AGARD-AG-221

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

AGARDograph No. 221

on

Advanced Techniques in Crash Impact Protection and Emergency Egress from Air Transport Aircraft

by

R.G.Snyder

NORTH ATLANTIC TREATY ORGANIZATION

DISTRIBUTION AND AVAILABILITY
ON BACK COVER

AD-A029375

AGARD-AG-221

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARDograph No.221

ADVANCED TECHNIQUES IN CRASH IMPACT PROTECTION AND EMERGENCY EGRESS FROM AIR TRANSPORT AIRCRAFT

by

Richard G. Snyder, Ph.D.
Head, Biomedical Department, and Research Scientist
Highway Safety Research Institute
Institute of Science and Technology
and Professor of Anthropology
Department of Anthropology
The University of Michigan
Ann Arbor, Michigan 48105
U.S.A.

This AGARDograph was prepared at the request of the
Aerospace Medical Panel of AGARD/NATO

THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

– Exchanging of scientific and technical information;

– Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

– Improving the co-operation among member nations in aerospace research and development;

– Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;

– Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;

– Providing assistance to member nations for the purpose of increasing their scientific and technical potential;

– Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Program and the Aerospace Applications Studies Program. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

Published June 1976

ISBN 92-835-1218-9

629.7.047:656.7.08

Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London, W1P 1HD

SUMMARY

Analysis of all NATO member air transport accidents, 1964-1975, revealed that injuries and fatalities, when such information could be determined, were primarily due to the post-crash effects of fire, smoke and toxic fumes, and secondarily to crash impact. Future air transport design trends were reviewed, and approximately 150 advanced crash-impact and emergency-egress concepts, devices, and state-of-the-art techniques were evaluated. These included occupant restraints, smoke hoods, aisle and egress emergency lighting, passenger warning systems, escape slides and devices, heat shields, high-energy emergency egress systems, and emergency inflight egress systems. It was concluded that rear-facing passenger seats, the NASA Ames ($21+G_x$ $45+G_z$) airline seat, and the production Sheldahl smoke hood can provide significantly improved occupant protection, while high-energy emergency egress systems appear promising for future aircraft. More research is needed to improve passenger warning and public address systems. Concepts of emergency inflight egress are not yet feasible, although technically within the state-of-the-art.

SOMMAIRE

Une analyse de tous les accidents aériens ayant eu lieu entre 1964 et 1975 et concernant les pays appartenant à l'OTAN a révélé que les blessures et les fatalités, lorsque ces renseignements ont pu être relevés, ont résulté principalement des effets d'incendie, de fumée, et de fumes toxiques après l'écrasement. Les tendances dans le dessin futur des transports aériens ont été évaluées ainsi qu'environ 150 conceptes comprenant des conceptes après-écrasement et des dispositifs avancés et techniques actuelles pour les sorties de secours. Cette évaluation comporte les contraintes de passagers, les capuchons anti-fumée, l'illumination des couloirs et des sorties de secours, l'avertissement des passagers, les toboggans et dispositifs de sauvetage, les protecteurs thermiques, les sorties de secours à haute énergie et les sorties de secours en vol. On a conclu que des sièges disposés dos contre dos, le siège NASA Ames ($+21G_x$ $45G_z$), et les capuchons anti-fumée Sheldahl peuvent fournir une meilleure protection au voyageur, tandis que les systèmes de sortie de secours à haute énergie semblent s'annoncer bien à l'avenir. Plus de recherches seront nécessaires pour améliorer les systèmes de communication publique. Les conceptes des sorties de secours en vol ne sont pas encore satisfaisants, quoique du point de vue technique ils sont dans les capacités de l'état-présent des recherches.

CONTENTS

SUMMARY.......... iii

LIST OF FIGURES.......... viii

LIST OF TABLES.......... xii

1. INTRODUCTION.......... 1

1.1 Background.......... 1

1.2 Scope and Objectives.......... 2

1.3 Future Trends.......... 2

1.3.1 Energy Effect Upon Design.......... 3
1.3.2 Next-Generation Transports.......... 3
1.3.3 Span-Loaded Flying Wing.......... 3
1.3.4 Very Wide Lifting Body Transports.......... 4
1.3.5 Liquid Hydrogen-Fueled Transports.......... 4
1.3.6 Very Large Transports.......... 5
1.3.7 STOL and V/STOL Air Transports.......... 5
1.3.8 Military Advanced Airborne Command Post.......... 7

2. AIR TRANSPORT ACCIDENT EXPERIENCE.......... 8

2.1 Sources and Limitations of Data.......... 8

2.2 Air Transport Fatality Data.......... 8

2.2.1 In-Flight Hazards.......... 12

2.2.1.1 Mid-Air Collision.......... 12
2.2.1.2 Turbulence.......... 12
2.2.1.3 Bird Strikes.......... 14
2.2.1.4 Explosion, Fire, Structural Failure.......... 14
2.2.1.5 Explosive Decompression.......... 15
2.2.1.6 Takeoff and Landings.......... 16

2.2.2 Ground Emergency Egress.......... 16

2.2.2.1 Review of 1973-1974 Accidents.......... 21
2.2.2.2 Summary of Emergency Egress Problems.......... 22

2.3 Military Air Transport Accident Experience.......... 24

2.3.1 USAF Boeing C-135 Low-Wing Transport.......... 24

2.3.2 USAF Lockheed C-141 High-Wing Transport.......... 24

2.4 Air Transport Ditchings.......... 27

2.4.1 Unintentional Ditchings of a Lockheed C-141A and Two McDonnell Douglas DC-8 Aircraft.......... 30

2.4.1.1 Military C-141A Ditching Experience.......... 30
2.4.1.2 1968 Japan Air Lines McDonnell Douglas DC-8 Ditching, San Francisco.......... 31
2.4.1.3 1969 Scandinavian Airlines McDonnell Douglas DC-8 Ditching, Santa Monica Bay, California.......... 32
2.4.1.4 Intentional Ditching of McDonnell Douglas DC-9.......... 33

3. PROTECTIVE DEVICES FOR PASSENGERS AND CABIN ATTENDANTS EXPOSED TO SMOKE, FLAME, AND TOXIC FUMES.......... 34

3.1 Background.......... 34

3.1.1 Governmental Activities: FAA, NTSB, NASA, NBS, Congress.......... 34

3.1.2 Boeing Smoke Tests.......... 36

3.1.3 Fire Tests and Flash Fire Effects.......... 36

3.1.4 Flight Deck Crew Smoke Mask Protection.......... 36

3.1.5 Toxic Gases.......... 37

3.1.5.1 Air Carrier Accident Findings.......... 37
3.1.5.2 Carbon Monoxide and Hydrogen Cyanide.......... 39

3.1.6 Military Studies.......... 41

3.2 Protective Devices 41

3.2.1 Background 41
3.2.2 FAA Civil Aeromedical Institute Tests 42

3.2.2.1 Leakage Evaluation 43
3.2.2.2 Toxic Environment Effectiveness 43
3.2.2.3 Vision 44
3.2.2.4 Acoustic Attenuation 44
3.2.2.5 Safety Briefing Effectiveness 45
3.2.2.6 Dense Smoke Evaluation 45
3.2.2.7 Conclusions of FAA/CAMI 1970 Tests 45

3.2.3 1967-68 AIA Smoke Hood Evaluation 45
3.2.4 1969 French Tests of Schjeldahl (Type D) Smoke Hood 47
3.2.5 1969 ATAA "Riley Report" 47
3.2.6 1970 NAS/NRC Space Science Board Report 47
3.2.7 Description of State-of-the-Art Devices 48
3.2.8 Discussion 60

4. ADVANCED OCCUPANT RESTRAINT SYSTEMS 61

4.1 Current Air Transport Restraint Systems 61

4.1.1 Passenger Lap Belt Systems 61
4.1.2 Current Aircrew Restraint Systems 63

4.2 Human Impact Tolerance Design Limits 63

4.3 Principles of Restraint 66

4.4 Rearward-Facing Seats 66

4.4.1 Rear-facing Passenger Accident Experience 68
4.4.2 Other Considerations 69

4.5 Advanced Active Systems 69

4.5.1 Integrated Upper Torso Restraint 70

4.5.1.1 NASA Ames Integrated System 71
4.5.1.2 Chrysler Corporate System 74

4.5.2 Y-Yoke Inertia Reel System 75
4.5.3 Seating Energy Absorbing Devices 77

4.6 Passive Restraint Systems 78

4.6.1 Passive Belt Systems 79
4.6.2 Passive Net Systems 81
4.6.3 Inflatable Belt Systems 82
4.6.4 Transparent Shields 84
4.6.5 Blankets 85
4.6.6 Cushions 85
4.6.7 Arms and Barriers 85
4.6.8 Static/Capsule Passive Restraint 86
4.6.9 Deployable Head Restraints 87
4.6.10 Integrated Passive Restraints 88
4.6.11 Inflatable (Air Bag) Passive Restraint Systems 89

4.6.11.1 History and Background of Development 89
4.6.11.2 Inflating Occupant Restraint System Components 91
4.6.11.3 Air Bag Design 92
4.6.11.4 Crash Sensors 94
4.6.11.5 Inflation Energy (Gas) Sources 101

4.6.11.5.1 Stored gas system 101
4.6.11.5.2 Stored gas system with modulated flow 101
4.6.11.5.3 Augmented air system 101
4.6.11.5.4 Augmented air system with staging 101
4.6.11.5.5 Liquid-cooled solid propellant gas generator system 101
4.6.11.5.6 Solid-cooled solid propellant gas generator system 102
4.6.11.5.7 Aspirator systems 102

4.6.11.6 Diffuser Design 103
4.6.11.7 Human Volunteer Tests 103
4.6.11.8 Noise 106
4.6.11.9 Toxicity 107
4.6.11.10 Accident Experience 108
4.6.11.11 Air Transport Application 108

5. AISLE AND EVACUATION MARKERS 110

5.1 Aisle Width 110

5.2 Chemo-Illuminescence 111

5.3 Electro-Illuminescence 112

5.4 Ultraviolet-Activated Pathway Systems 112

5.5 Self-Luminous Sources (Tritium) 113

5.6 Phosphorescent Markers 113

5.7 Incandescent Sources 113

5.8 Gaseous Discharge Systems 113

5.9 Floor-Level Lighting 113

5.10 Directional Aisle and Evacuation On-Off Lights 114

5.11 Tactile Aisle Markers 114

5.12 Other Considerations and Requirements 116

6. PASSENGER WARNING AND PUBLIC ADDRESS SYSTEMS 117

6.1 Background 117

6.2 Portable Solid-State Voice Amplification Devices 119

6.3 TWA Emergency Evacuation Signal System 119

6.4 Video Tape Presentation of Passenger Safety Information 119

6.5 Conclusions 119

7. ADVANCES IN EMERGENCY EGRESS CONCEPTS 119

7.1 Background 119

7.2 Slide Devices 120

7.2.1 Inflatable Escape Slides 120

7.2.1.1 Double-Lane Slides 120
7.2.1.2 Double Escape Slide with Center Divider 120
7.2.1.3 Combination Inflatable Slide and Life Raft 120
7.2.1.4 Inflatable Tubular Escape Slide/Raft 123
7.2.1.5 Exterior Platform Escape Slide Entry 124

7.2.2 Slide Inflation Devices 124

7.3 Mechanical Escape Devices 125

7.3.1 Seat Belt Escape Harness and Egress Conveyor System 125

7.3.2 Folding Escape Slide 126

7.3.3 Cargo Type Emergency Egress Techniques 126

7.3.4 Conveyor Belt Concept 126

7.3.5 Telescape System 127

7.4 Heat Shields 128

7.4.1 Exit Area Ablative Coating 128

7.4.2 Cabin Fire-Protective Shielding 129

7.5 High Energy Emergency Egress Systems 130

7.5.1 ELSIE 130

7.5.2 Liquid Explosive Emergency Exit System 132

7.6 Emergency Inflight Egress.. 132
7.6.1 Tail Evacuation.. 134
7.6.2 Paracone Concept.. 134
7.6.3 Rapidjet.. 136
7.6.4 Parachute Lowering of Fuselage.. 136

8. CONCLUSIONS.. 138

REFERENCES CITED.. 144

ACKNOWLEDGEMENTS.. 194

APPENDIX A.. 196

APPENDIX B.. 250

APPENDIX C.. 277

APPENDIX D.. 284

APPENDIX E.. 288

APPENDIX F.. 306

LIST OF FIGURES

Page No.

1. Future concept for air cargo. NASA Spanloader cargo flying wing, having 2.4 million lb takeoff weight, span of 375 feet [Aviation Week, 1974 (28)], and utilizing air cushion landing system. After Lange, 1975 (53) 3

2. Concept for air cushion landing system for Spanloader Transport Aircraft, showing enlarged section of air cushion. After Lange, 1975 (53) 4

3. International Husky Corporation/Boeing future concept lifting-body air freighter [Aviation Week, 1974 (32)] 4

4. Possible configuration of short-haul liquid hydrogen-fueled aircraft with external tanks [Automotive Engineering, 1975 (34)]. After Carline, 1975 (38) 5

5. Conception of long-range liquid hydrogen-fueled delta winged air transport and twin-fuselage configuration, featuring hydrogen tanks slung between two cabins [Automotive Engineering, 1975 (34)]. After Carline, 1975 (38) 5

6. Boeing concept of high wing air transport braced by struts. After Aviation Week, 1975 (29) 6

7. British Westland VTOL two-engine tilt-wing commercial air carrier design. After Cook, 1975 (39) 6

8. The Dornier Do 231 V/STOL air transport design for the 1980's in vertical takeoff and landing configuration with lift engine doors open [Courtesy Dornier AG, 1974 (40)] 7

9. USAF Boeing 747-E4A Advanced Airborne Command Post Design [Aviation Week, 1974 (32)] 8

10. U.S. Scheduled Air Carrier accidents and fatalities, 1964-1974 9

11. Fatal accident rate. All U.S. airline flying 10

12. An air carrier taking off at Tokyo International Airport on 13 November, 1975 in a flock of birds (Photo courtesy Wide World Photos) 14

13. Diagram of emergency egress hazards contributing to injuries in this Boeing 747 accident 18

14. Pan American Boeing 747 accident at San Francisco 30 July, 1971, resulting in nose-high attitude (Photo courtesy NTSB) 18

15. Evacuation slide failure in Pan American Boeing 747 accident 19

16. Obstacles to passenger egress in Icelandic Airlines McDonnell Douglas DC-8-61 "hard landing" 19

17. Tail-high attitude in this Miami Boeing 747 accident rendered the rear emergency evacuation slide unusable (Photo courtesy Wide World Photos) 20

18. Cabin layout, safety features, and emergency egress exits on the Concorde, as configured in production aircraft number 204, used in certification tests of February, 1975 (421) 20

19. Location of emergency egress exits and fatalities in Boeing KC-135 crash (Case #1) 26

20. Crew leaving the aircraft after inadvertent water landing of Japan Air Lines McDonnell Douglas DC-8 in San Francisco Bay, California (Photo courtesy J. Simpson, FAA, CAMI) 32

21. Passengers evacuated in life rafts (Photo courtesy J. Simpson, FAA, CAMI) 32

22. Fire and heavy smoke resulted in 45 fatalities of 62 passengers in this Trans World Airlines Boeing 707-331 accident at Fiumicino Airport, Rome, 23 November, 1964 (Photo courtesy FAA) 38

23. Dense smoke and fire following crash of Boeing 727 at St. Thomas, Virgin Islands 28 December, 1970 (203) (Photo courtesy NTSB) 39

24. Demonstration of passenger donning Schjeldahl "S" model "safety" hood in Chrysler Corporation Gulfstream. This smoke hood is presently in use in many corporate, FAA, and other aircraft and has been recommended in several studies for use in USAF air transport aircraft (Photo courtesy Chrysler Corporation) 46

25. Once smoke hood is donned it may protect the passenger against toxic fumes and smoke for 4 to 6 minutes, and protect the head and face against the effects of flames exceeding 800°C, providing additional emergency egress capability (Photo courtesy Chrysler Corporation) 46

26. Boeing Mask 48

27. John Hand Hood 49

Page No.

28. Racine Glove Company Hood.......... 49

29. Sierra Engineering Corporation Hood.......... 50

30. Life Support Systems Hoods.......... 50

31. Scott-O-Vista Mask.......... 51

32. Mine Safety Appliance Company Devices.......... 51

33. North American Rockwell Hood.......... 52

34. North American Rockwell Smoke Mask.......... 52

35. Sheldahl Hood - "D" (drawstring) Model.......... 53

36. Sheldahl Hood - "S" (Septal Neck Seal) Model.......... 53

37. Experimental FAA/Sheldahl Hood - Self-Contained Air Supply.......... 54

38. Westinghouse/Sheldahl PBA Hood.......... 54

39. Lear-Siegler Air Capsule.......... 55

40. Instructions for use of the Lear-Siegler Air Capsule.......... 55

41. Scott Aviation Emergency Smoke Hood and Breathing Device.......... 56

42. Experimental FAA/Schjeldahl protective hood of 2 mil Kapton which can provide 4 to 8 minutes of breathing time using a self-contained supply of compressed air.......... 57

43. An integrated harness system in which the upper torso restraint retracts into the seat back as designed for the Ford Techna future idea car (Photo courtesy Ford Motor Company).......... 70

44. Integrated bench seat-restraint system with 3-point harness [Robbins et al., 1971 (784)].......... 71

45. The NASA Ames seat reclining system [After Kubokawa, 1974 (8)].......... 72

46. NASA Ames integral aircraft passenger seat [After Kubokawa, 1974 (8)].......... 73

47. Unrestrained passenger seated with food tray in place (folds back into side) in final configuration of NASA seat (Photo courtesy C. Kubokawa, NASA Ames).......... 73

48. The restraint system shown in this mock-up seat features upper torso protection. Freedom of movement is allowed by inertia reels in the integrated seat (Photo courtesy C. Kubokawa, NASA Ames).......... 74

49. Details of NASA Ames integrated restraint system in mock-up seat (Photo courtesy C. Kubokawa, NASA Ames).......... 74

50. Integrated seat utilized operationally in Chrysler Corporation's Grumman Gulfstream G-2 jet corporate aircraft.......... 75

51. The upper torso belt is attached to an inertial reel, allowing freedom of motion, but restraint in +2G deceleration.......... 75

52. In this configuration the belt buckles at the center. This seat is also capable of rotating 180° and can be used in a rearward-facing orientation.......... 75

53. Integrated restraint system designed and developed by HSRI, The University of Michigan on NHTSA advanced concepts contract (Robbins et al., 1971).......... 75

54. Inverted Y-yoke harness system with inertia reel mounted in roll-bar, as used in specially modified Shelby American Ford G7-350 and GT-500 vehicles.......... 76

55. Prototype inverted-Y integrated 40 G seat designed and impact tested for NHTSA by HSRI, The University of Michigan [Robbins et al., 1971 (784)].......... 76

56. VW Automatic Restraint (VW-RA passive system as developed for automotive vehicles.......... 80

57. Schematic of a "full passive safety belt system" designed by Ford-werke AG, Cologne, Germany.......... 80

58. Schematic composite diagram of Nissan automatic falling occupant-protecting net as developed for automotive use.......... 81

59. Exploded view of Inflataband™ components.......... 82

Page No.
60. The inactive system is donned as a regular active restraint system............................ 83

61. Upon initiation, the Inflataband system inflates, providing additional passive protection to the occupant.. 83

62. Minicars Airbelt Restraint System developed under NHTSA contract............................. 84

63. Inertia switch flexible shield, stored overhead but swings into place during impact........... 85

64. Minicars Energy Absorbing Pylon Restraint configuration.. 86

65. Britax, Ltd. automatic cushion restraint.. 86

66. Concept of seating capsule with protective energy-absorbing forward panel..................... 87

67. HSRI/UniRoyal prototype deployable head restraint basic configuration.......................... 88

68. Instrumented dummy and prototype deployable head restraint.................................... 88

69. Integrated seat-restraint system with air bag designed in University of Michigan HSRI concepts study for NHTSA.. 89

70. Schematic of the basic driver and passenger air bag restraint system.......................... 92

71. General types of air bag configurations developed for automotive use.......................... 92

72. Mock-up of air bag system for light aircraft use... 93

73. Unbelted 50th percentile adult male dummy in HSRI sled deceleration........................... 95

74. Eaton Autoceptor first-generation crash sensor... 96

75. Crash sensor response tests... 97

76. Eaton wide angle crash active sensor.. 98

77. Solid-cooled solid propellant gas generator system... 102

78. Two types of aspirator systems.. 103

79. Prototype inflatable air bag restraint system stowed in passenger seat back, under development by F.L. Diamond Corporation, Granada Hills, California...................... 109

80. Cover removed, showing stowage of bag at top, CO_2 cylinder at right.......................... 109

81. Once the bag is inflated, it forms a protective cushion for head impact........................ 109

82. The inflatable bag, shown in deflated and inflated configurations.............................. 109

82a. Shapes of 1/8 and 1/4 inch tactile cues used in AIA tests...................................... 116

83. Typical bullhorn emergency public address system installation in civil air transport........... 118

84. Double escape slide with center divider... 121

85. Combination life raft escape slide recently certified for civil air carrier use................ 122

86. Concept of a combination inflatable escape slide/raft... 123

87. Exterior platform slide entry for overwing escape... 124

88. Cool gas generator system for inflatable escape devices... 124

89. In this system the passenger (1) attaches his seat belt to integrated seat-back straps, (2) hooks into an overhead hook, and (3) is automatically conveyed to an exit.................. 125

90. Mechanical folding escape slide/stairway.. 126

91. Cargo-type emergency egress technique... 126

92. Passenger egress from seat to emergency exit via conveyor belt.................................. 127

93. Post-crash view of Douglas DC-7 aircraft crash-tested by the FAA showing typical extreme buckling of the fuselage.. 128

94. Telescape swung into position for use at exit door.. 128

95. Evacuation using fully extended telescape device.. 128

96. Emergency exit area ablative coating... 129

		Page No.
97.	Cabin air temperature in NASA C-47 cabin shield fire test	129
98.	Installation of fire-protective materials in NASA aircraft cabin test	130
99.	ELSIE system for instantaneous egress as might be conceived for Lockheed C-141 aircraft	131
100.	Experimental high energy emergency exit configuration showing instantaneous deployment of slide/raft for subsequent emergency escape	131
101.	Total aircraft recovery concept for helicopters	133
102.	Capsule recovery concept for helicopters	134
103.	Paracone emergency inflight egress concept	135
104.	Pallet passenger packaging at initiation of inflight emergency escape by paracone concept	135
105.	Rapidjet emergency inflight egress system, deployment, and passenger cocoon container	136
106.	Inflight ejection of encapsulated compartments from disabled airliner	137
107.	Emergency inflight escape of passengers utilizing pod concept	137
108.	Concept of safe parachute lowering of passengers and crew in fuselage of air transport following major structural failure in flight	138

LIST OF TABLES

		Page No.
I.	World Wide Aircraft Accidents Involving Passenger Fatalities on Scheduled Air Services, 1950-1974	9
II.	U.S. Airline Fleet. Type of Aircraft, Number of Engines and Model	11
III.	Combined NATO Countries Civil Air Transport Accidents (Excluding U.S.)	11
IV.	Injuries Due to In-Flight Turbulence, 1975 (Incomplete)	13
V.	Injuries Attributed to Turbulence in U.S. Air Carriers, 1968-1971	13
VI.	Summary of USAF Lockheed C-141 Accidents. Jan., 1966 - Nov., 1971	24
VII.	Summary of USAF Boeing C-135 Accidents. Jan., 1964 - Nov., 1971	25
VIII.	Aircraft Lost in Water with No Survivors	28
IX.	Unintentional Ditchings Having Survivors	28
X.	Probable Survivors If Adequate Flotation Equipment Had Been Available	29
XI.	Carbon Monoxide and Cyanide Findings in Air Transport Accidents	39
XII.	Effects of Various Concentrations of Carbon Monoxide in Air at Sea Level	40
XIII.	Physiological Effects of Various Carbon Monoxide Hemoglobin Percentages	40
XIV.	Summary of Systems Analysis of Schjeldahl Smoke Hood System	58
XV.	Smoke Hood/Mask Functional Flow Fault Tree	59
XVI.	Human Subject Tests, Restrained by 3"-Wide Lap Belt	64
XVII.	Summary of Design Pulses Corresponding to the 95th Percentile Accident of Fixed-Wing Transport Aircraft	64
XVIII.	Passive Restraint System Concepts (Excluding Air Bags)	78
XIX.	Crash Sensor Performance Factors	95
XX.	Crash Sensor Characteristic Proficiency Evaluation	96
XXI.	Comparison of Crash Sensor Approaches	99
XXII.	Applicability of Basic Types of Radar to Automotive Radar	100
XXIII.	Summary Data Peak Values	105
XXIV.	Summary of Data From Tests With Human Subjects	106
XXV.	Civil Air Carrier Passenger Aisle Width Requirements Specified in F.A.R. Part 25.815	110

1. INTRODUCTION

1.1 Background

Crash impact experience in current civil and military air transport aircraft operations indicates that many injuries and fatalities occur that might have been prevented or reduced with improved occupant protection techniques. While considerable attention has been given to improving occupant escape and crash survival in military fighter and helicopter type aircraft, as well as the recent focus on improving occupant crash safety standards in automobiles and other ground vehicles, relatively little attention has been given to providing similar protection for the air transport occupant.

During the past few years there has been an increased emphasis on studies relating to crash impact protection, emergency egress, and survival, resulting in developments which have greatly advanced the state-of-the-art. Some of these advances have resulted in spin-offs from aerospace technology, others have been spurred by identification of specific deficiencies in analysis of current accident experience, and many have resulted from efforts of the Department of Transportation to improve occupant protection in ground vehicle accidents. However, no single published document has previously attempted to bring together and evaluate systematically those developments in the state-of-the-art which might have especial application to crew and passenger crash safety in air transport aircraft.

A basis for evaluating the particular areas where increased protection is necessary in air transport crashes can best be determined by analysis of previous accident experience. Unfortunately, these areas often receive little attention until a major air disaster emphasizes the problem and spurs research for a solution. An example is the serious deficiency of emergency warning systems and crew-passenger communication which was evident in the ditching of a McDonnell Douglas DC-9 jet transport near St. Croix, Virgin Islands in May, 1970. In this ditching the public address system was inoperative from flight deck to cabin and no ditching warning (after a 10-minute warning) was given to either passengers or some crew. This resulted in numerous injuries to unrestrained passengers standing in the aisles still donning life jackets at the time of impact [National Transportation Safety Board, 1970; 1971; 1972 (10-12)].

An analysis of civil air transport accidents from 1957 through 1967 resulted in the estimate by Caldara that 35 to 50% of the 794 non-survivors of survivable air carrier crashes could have been saved had adequate egress been available (4). Some three-fourths of the exits available were not used, due to jamming from fuselage distortion, blockage, fire, or other reasons. Studies of air transport evacuations during major crashes have shown that the primary cause for fatalities has been attributed to inhalation of smoke, toxic fumes, and fire. At present no protection at all is given crew or passengers under fire and smoke egress conditions, although work on improving flight-deck crew masks has been initiated. Thus, a major section of this report brings together the state-of-the-art of smoke hood devices. Previously such information has been unpublished, or scattered in technical reports, and difficult to locate.

Space technology has resulted in many concepts and techniques which might have application to increased air transport crash safety and passenger life support. An example of potential application of space technology to air transport crash-fire protection is illustrated by the Apollo spacecraft development of fire-retardant materials such as polyisocyanurate foam and an intumescent paint which acts on ablative principles to provide additional thermal protection. Recent work by the National Aeronautics and Space Administration (NASA) has taken the approach of heat shielding the passenger compartment by a fire-retardant shell using the above foam and paint to protect the occupants long enough for the fire to burn out or be extinguished.

The concept of providing a means of emergency in-flight egress in civil air transport aircraft has had very little attention. Several systems have been proposed, including one which would modify present operational techniques of aerial cargo delivery for human passenger and crew usage, but none has been evaluated thoroughly for this application. In a technology which has expended considerable effort in devising methods of astronaut space rescue, it would seem to be within the state-of-the-art to similarly seriously consider in-flight egress of air transport passengers in the event of presently non-survivable in-flight catastrophic structural failures. Current accident experience shows that in-flight structural failure as a result of extreme turbulence, mid-air collision, or other emergency such as fire, explosive decompression, bird strikes, or explosion is not an infrequent occurrence, as is shown by data presented in Section 2 and Appendices A-D. Certainly the potential for an increased incidence of such events should be balanced against prior experience.

Research and development of advanced restraint systems has had major emphasis during the past decade from many organizations, particularly in the United States. The U.S. Army has developed improved seating and restraint systems for helicopter and light aircraft aircrew. These offer increased impact protection to troops [Carr, 1972 (5)] and aircrew [Carr & Desjardins, 1975 (6)]. Studies by NASA, once focused on more exotic spacecraft systems, include design and development of the NASA Ames Integral Passenger Aircraft Seat, tested to impact levels of $21 + G_x$ $45 + G_z$ for air transports [Kubokawa, 1974 (8)]. U.S. Air Force studies have tested the air bag restraint system to 123 G ($-G_x$) with baboons [Clarke, et al., 1970 (7)]. Inflatable air bags have been combined with the U.K. Institute of Aviation Medicine version of the F-111 harness for providing increased protection in lateral capsule impacts [Shaffer & Brinkley, 1974 (17)]. The Federal Aviation Administration (FAA) has also explored the possibility of using passive air bag restraint in aircraft [Sommers, 1972 (18)]. A systems evaluation of air transport passive restraint has been reported in 1974 by Robbins and Snyder (14), while industry has considered inflatable air restraints for McDonnell Douglas DC-10 seat backs, and new developments in aircrew seating (The Concorde and IPECO Europe Ltd. aircrew seats).

Due to large-scale efforts of the automotive industry to comply with new federal requirements in the U.S. and other NATO countries, considerable effort has gone into design, development, and testing of "passive" restraint systems. These are presently required to be installed in all automotive vehicles manufactured for sale in the U.S. after August 14, 1976, for 1977 vehicles [National Highway Traffic Safety

Administration, 1975 (9)]. "Passive" restraint applies to any system which does not require occupant action for initiation. The most common of these devices are inflatable ("air bag") restraint systems. Examples of other methods of achieving this objective include deployable net restraint, "blanket," and head restraints. The requirement for a passive system has resulted from findings that too few automotive occupants wear present protective restraint systems and is based on a decision that a more automatic system is necessary to solve this problem. Although developed for automotive impact, which involves quite different crash profiles in respect to magnitude, vector directions, and time duration than in typical aircraft accidents, there has been interest in application to aircraft. Early tests of a pre-inflated air bag device in the FAA crash test of a DC-7 transport in 1964, and a series of ten decelerations at impact velocities up to 87 mph in 1965, indicated considerable protective capabilities, but it was also evident that a cabin full of air bags post-impact could create major evacuation problems. Since then such systems have been greatly refined, and must be re-examined in the air transport context.

Efforts at improving air transport crash impact survival and emergency egress have developed primarily during the past 10 years, although classic and pioneering crash fire tests were conducted in early National Advisory Committee for Aeronautics (NACA) tests [Black, 1952 (2)]. In 1967 three groups independently conducted overall assessments of the state-of-the-art of crash safety and crew and passenger life support for air transport aircraft. The USAF-Industry Life Support Conference (23) at Las Vegas considered a number of recommendations to responsible agencies for the immediate and long-range solution of many of the most pressing problems and requirements in the life support system. Within the industry, a Joint Crashworthiness Development Program was conducted by the Aerospace Industries Association of America, Inc. (1). This one-year study resulted in an industry evaluation of the state-of-the-art at that time of interior materials, fire suppression, smoke and fume protection, emergency lighting and exit awareness, and evacuation systems. Also in 1967 North American Rockwell Corporation [Roebuck, 1968 (15)] conducted an analysis of new concepts for emergency evacuation of air transport aircraft for the Aircraft Development Service of the Federal Aviation Administration.

Concurrent USAF studies related to military air transports have also been conducted by Sawyer [1967 (16)], Brown [1969 (3)], Reagin, et al. [1970 (13)], Snyder and Robbins [1971; 1972 (22, 21)], and Robbins and Snyder [1974 (14)]. The 1970 study by the Combat Egress Working Group [Reagin, et al., 1970 (13)] investigated passenger/cargo aircraft in the USAF inventory to identify equipment and procedural deficiencies. This represents the most complete analysis of crew and passenger crash safety, and provides many specific recommendations for areas where improvements are necessary. The Snyder and Robbins study conducted for the Air Force by the University of Michigan in 1971 represented the first major effort to evaluate military air transport safety from a point of view of state-of-the-art, using a systems engineering approach [Snyder, 1971; 1975; Snyder & Robbins, 1971; Robbins & Snyder, 1974 (14, 19-22)]. This has formed the nucleus for the current study, which attempts to update developments during the past four-year period.

1.2 Scope and Objectives

The purpose of this study was to bring together and evaluate new crash impact, escape, and survival devices and techniques applicable to aircrew and passengers in air transport aircraft. Advanced state-of-the-art technological developments were examined in the areas of advanced restraint systems, smoke hood protective devices, aisle and evacuation markers, passenger warning and public address systems, and other research programs, system developments and technology available or currently anticipated programs which might have application to current or future air transport aircraft. As one basis for establishing priorities of future requirements, current air transport accident experience is presented from NATO countries in Section 2.

In the 1971 Snyder and Robbins USAF study of military air transports (22) a complete systems approach was required to objectively evaluate the systems, devices, and concepts, and in the current study, use of military standards as a basis for assessment has been continued. In this regard, consideration was given to both the effects on the aircraft and crew members in accordance with MIL-STD-1472A (24). A preliminary analysis in accordance with MIL-STD-785A (25) was conducted on all concepts included in the study to determine which systems indicate the highest reliability. System components must be designed for minimum routine maintenance and servicing by technicians assigned to the using unit, field maintenance activities, and for major repairs by depot level maintenance, in accordance with MIL-STD-470 (26). In addition, a preliminary Hazard Analysis prepared in accordance with MIL-STD-882 (27) to evaluate system safety was included. In this respect overall systems analysis has been initiated with emphasis on the event-oriented nature of the problem of survival and escape from a crashed aircraft. A time-scaled flow chart of the crash and escape event has been developed to form a framework for the performance evaluation of each concept studied. This is supplemented by a detailed discussion of factors included in the analysis of system safety, reliability, maintainability, human engineering aspects, and technological feasibility. It is believed that this approach provides a reasonable basis for system evaluation, and is included in Appendix E.

While major consideration has been given to review of smoke hood protective devices, advanced restraint systems, and emergency egress, this also reflects the state-of-the-art. Less attention has been given in the past to the development of new (and feasible) concepts for aisle and path markers, emergency public address systems, emergency lighting requirements, and seating. This study has attempted to bring together and evaluate the state-of-the-art in the areas outlined as of 1975.

1.3 Future Trends

For planning purposes, the Federal Aviation Administration National Aviation System Plan of March, 1975, projects long-range goals through 1985 (44). An earlier FAA study projected through 1982 (43). The 1975 study indicates that the number of passengers carried by the U.S. scheduled air carriers may increase from 206.5 million in 1974 to 355.6 million by 1985. FAA also forecasts an increase in the U.S. commercial air carriers' fleet from 2,511 aircraft in 1974 to 3,383 aircraft by 1985. For comparison, the U.S. general aviation fleet is estimated to grow from 153,500 in 1974 to 262,000 in 1985.

A previous study took an even more extensive look at airline growth during the next decade. Goals and recommendations concerning what U.S. policy should be for Civil Aviation Research and Development (CARD) in 1985 were outlined in a U.S. Senate-sponsored joint Department of Transportation/National Aeronautics and Space Administration study published in 1971 (36, 37). This suggested priority be given to environment, congestion, low-density short-haul transport, and regulation reform. One prediction was that by 1985 there will be a need for larger air transports capable of carrying 800 to 1,000 passengers. It was estimated that the "free-world" air fleet would have grown from 5,100 to 8,300 (air carrier) aircraft. Such projections may well affect future living patterns [Ward, 1971 (67)], and may provide new medical and psychological areas of concern [Gerathewohl, et al., 1971; Mohler, 1966; Schaffer, 1969 (48, 55, 59)].

1.3.1 Energy Effect Upon Design. Trends in future transport designs may be significantly influenced by the recent concern for energy conservation. At the 1974 World Transport Conference, for example, Bouillioun, president of the Boeing Commercial Airplane Company, noted: "The need for greater fuel economy may drive future designs toward higher aspect ratios, reduced wing sweep, and greater thickness/cord ratios than aircraft currently in production. Design cruise speeds could be slightly less than today's designs. By the end of the 20th century, changes in the energy balance may well provide the impetus of more exotic transports such as hydrogen-fueled or laminarized-flow aircraft." (35) This forecast also pointed out that development of a new technological improvement or concept may still require 15 to 20 years for the present "commercial aviation system" to incorporate it.

1.3.2 Next-Generation Transports. Already many designs for the 1980's reflect concern for energy; the McDonnell Douglas Corporation's DC-X-200 wide-body transport designed for short-to-medium-haul traffic, anticipated to be available in 1980-81, may employ a smaller and lighter supercritical wing (Mach 0.82 cruise) featuring reduced wing sweep angle, increased thickness, a higher aspect ratio, and a small wing area [Fink, 1975a (45)]. The McDonnell Douglas DC-X-200, aimed toward 199-219 passengers, is a scaled-down twin-engine version of the DC-10-10 trijet for the 1980's short-haul market [Fink, 1975b; 1975c (46, 47)]. Boeing is currently designing an advanced medium-range 7X7 replacement for the Boeing 727 [Aviation Week, 1975a (28)].

The French are studying several next-generation commercial transports, including the Dassault-Breguet Mercure 200, a twin-engine 142-159 seat aircraft based upon the 135-seat Mercure 100 presently operated only in France by Air Inter; the Airbus Industrie A300B wide body transport in several versions, including a four-engine long-range air transport with 200-220 seats; and the Aerospatiale AS-200, a design encompassing two-, three-, and four-engine aircraft with seating capacities ranging from 120-170 passengers in the twin-engine version to 180-220 in the four-engine. Aerospatiale airbus versions under study include the A300C, a convertible passenger/cargo version; the A300B9, a stretched version seating 322 (compared to about 270 in the A300B2 and B4); the A300B10, a shortened derivative with 210-220 seats; and the A300B11, an alternative derivative shortened airbus using different engines [Ropelewski, 1975 (58)]. By 1985 some "30 to 40" Anglo-French Concorde supersonic transport aircraft may be in operation, as well as increased numbers of the Soviet Tupolev Tu-144 [Shumann, 1975 (63)].

1.3.3 Span-Loaded Flying Wing. Future aircraft trends may also be indicated by NASA studies of a large span-loaded flying wing design as a future fuel-efficient air freighter. Such aircraft would have a payload of up to six times that of the Boeing 747F freighter, the Lockheed C-5A, or the Douglas DC-10 tanker/cargo aircraft, and a minimum wing thickness of 3m(10') would accommodate intermodal containers and other outsized cargo (Fig. 1). Designers have considered use of 8 large overwing-mounted turbofans, allowing cargo to be carried inside the supercritical-type wing. Distributing cargo across the span to offset lift forces is expected to reduce structural weight and improve efficiency [Industry Observer, 1974 (52)].

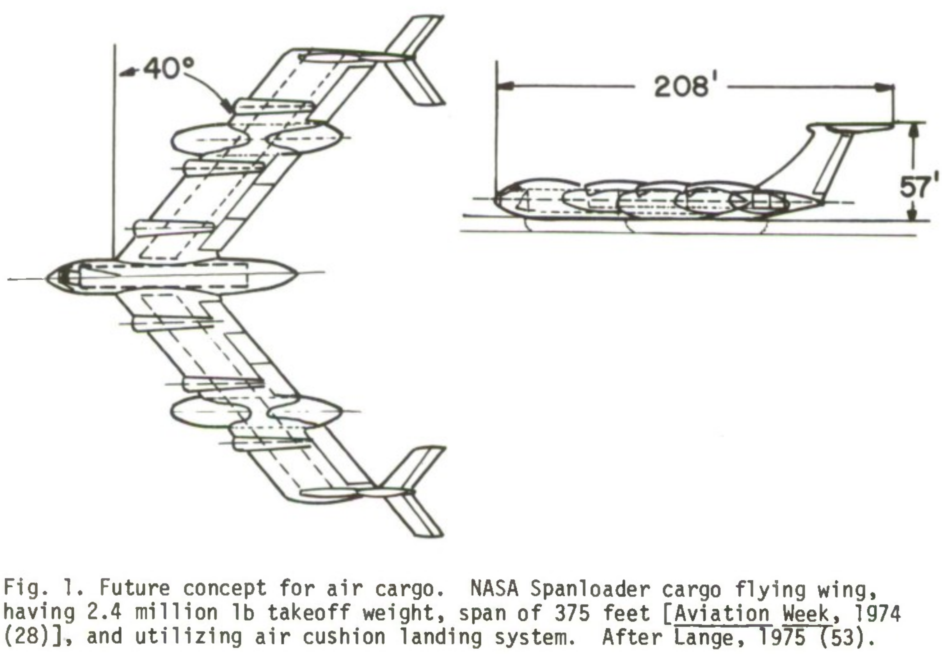


Fig. 1. Future concept for air cargo. NASA Spanloader cargo flying wing, having 2.4 million lb takeoff weight, span of 375 feet [Aviation Week, 1974 (28)], and utilizing air cushion landing system. After Lange, 1975 (53).

One unique proposed feature of the Spanloader is use of a three-element air-cushion landing system, permitting this air transport to be operated from unprepared terrain or water. The principal elements of the air cushion landing system are the trunks and ducting for air distribution. As illustrated in Fig. 2 the head-on profile shows an enlarged cross section through the center body, with the trunk inflated. The air supply duct is continuous from outboard body to outboard body, with air admitted to the trunks by valving. The air can be admitted to non-perforated inner liners and sealed off for parking. Such a system might also alter the crash impact pulse presently seen in air transport takeoff or landing accidents and increase potential occupant survivability.

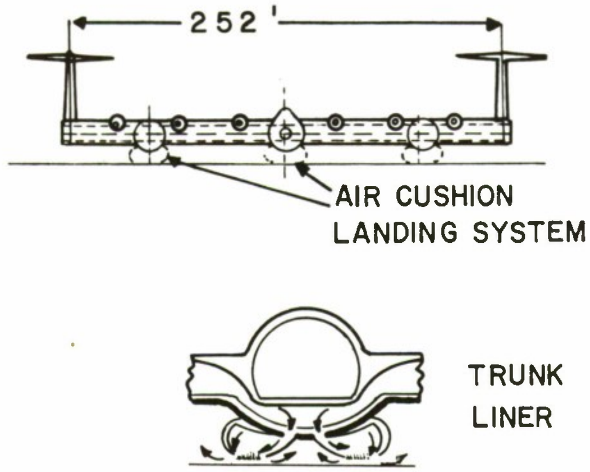


Fig. 2. Concept for air cushion landing system for Spanloader Transport Aircraft, showing enlarged section of air cushion. After Lange, 1975 (53).

1.3.4 Very Wide Lifting-Body Transports. For the past three years, Boeing has been studying a new freighter concept with Cole's International Husky Corporation, including extensive wind tunnel tests on an extremely wide fuselage in lifting-body shape housing five side-by-side cargo bays 27 m (90') long (Fig.3). The long-range version is intended to meet USAF's C-XX requirement for advanced cargo transport (57).

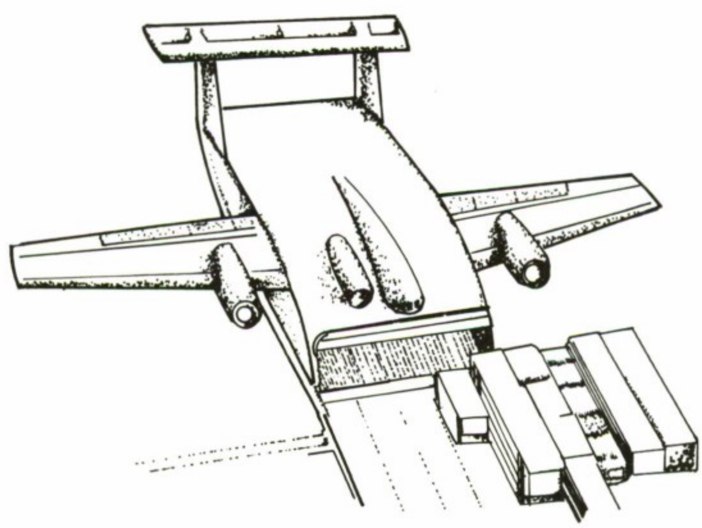


Fig. 3. International Husky Corporation/Boeing future concept lifting-body air freighter [Aviation Week, 1974 (32)].

1.3.5 Liquid Hydrogen-Fueled Transports. Some future air carrier aircraft may be fueled by liquid hydrogen as an alternative fuel. However, one of the design problems resulting from the use of low-density LH_2 fuel is the volume of tankage required when compared to conventionally-fueled aircraft. Wide-body aircraft employ high bypass ratio engines to reduce fuel volume required, while narrow-body transports utilize low bypass ratio engines. The LH_2-fueled aircraft would require approximately 4 times the volume for JP-fueled airplanes for a given gross weight, or 3.7 times when equal payload/range capability is considered [Carline, 1975 (38)]. Long-range large bodied aircraft might have LH_2 tanks located in the upper and rear fuselage. Short-haul smaller sized air transports of the McDonnell Douglas DC9-30 category might be designed with external tanks, as illustrated in Figs. 4 and 5.

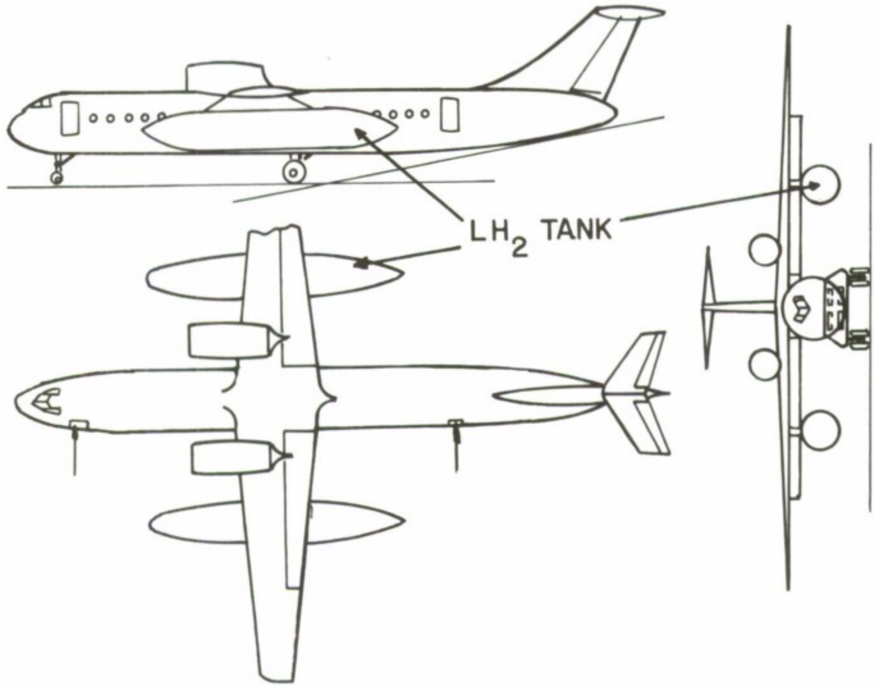


Fig. 4. Possible configuration of short-haul liquid hydrogen-fueled aircraft with external tanks [Automotive Engineering, 1975 (34)]. After Carline, 1975 (38).

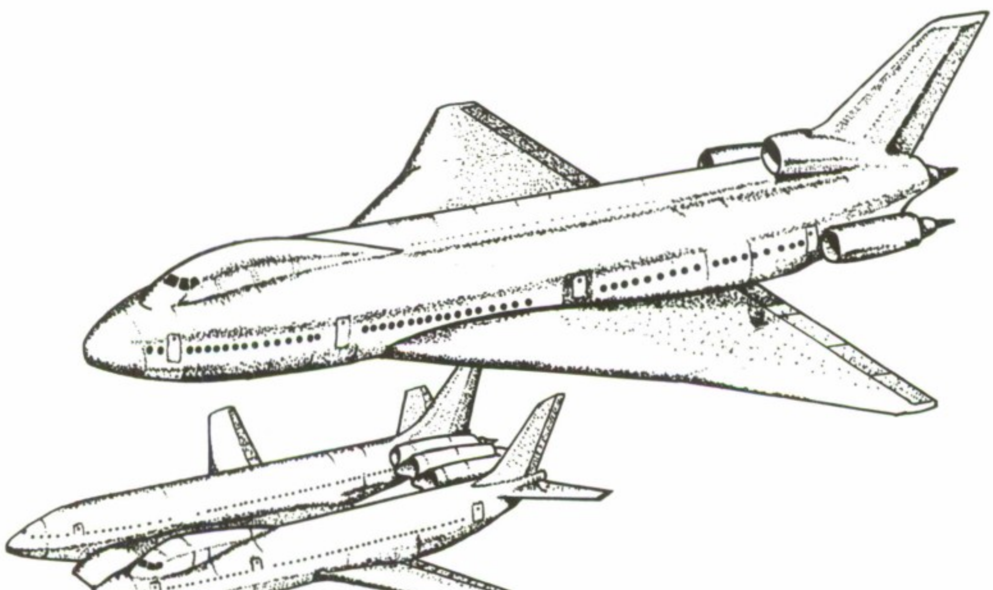


Fig. 5. Conception of long-range liquid hydrogen-fueled delta winged air transport and twin-fuselage configuration, featuring hydrogen tanks slung between two cabins [Automotive Engineering, 1975 (34)]. After Carline, 1975 (38).

1.3.6 Very Large Transports. A Boeing Company concept for a laminar flow control future air transport features a high wing braced by a strut as shown in Fig. 6. The European aircraft industry may be expected to build upon the knowledge acquired from the Concorde and Airbus to design new transportation needs outside the present subsonic domination of the U.S. Dornier cites very large cargo aircraft as one area of future interest with cargo aircraft exceeding 600 t payloads. A ten-engine advanced design having 1,000 t payload capacity has been suggested by Dornier GmbH [Dornier, 1975 (41)].

1.3.7 STOL and V/STOL Air Transports. Another direction of aircraft design is in the STOL (Short Takeoff and Landing) and V/STOL (Vertical/Short Takeoff and Landing) configurations. Current-generation aircraft, such as the Boeing YC-14 Advanced Medium Short Takeoff and Landing Transport (AMST) and the

Fig. 6. Boeing concept of high wing air transport braced by struts. After Aviation Week, 1975 (29).

McDonnell Douglas YC-15 AMST, are currently in prototype fly-off competition as a USAF replacement for the Lockheed C-130 Hercules transport aircraft [Boeing YC-14, 1975; Taylor, 1975 (33, 65)]. The Boeing YC-14 and McDonnell Douglas YC-15 advanced medium STOL transport AMST prototype programs are expected to provide technical fallout for new commercial transports. A 150-200 passenger airliner version could be in service by 1980, although a more realistic marketing date may be 1985 [Marks, 1976 (54)]. The AMST adaptability to future commercial versions is also being considered by NASA's Quiet Propulsive Lift Technology program for generating commercial transport innovation. However, the YC-15 military version with a high wing and Mach 0.75 cruise has resulted in negative airline reaction [Aviation Week, 1975 (28)]. Wind tunnel tests of other advanced short-haul designs for the 1980's are underway at Ames Research Center, NASA [Elson, 1975 (42)]. The major crashworthy hazards in slow approach military STOL aircraft involve fuselage crushing, flammable fluid ignition, crew, troop, and litter patient restraint failures, nose landing gear failure, and cargo restraint failure as described by Haley, 1976 (50). An early U.K. V/STOL design for a commercial airliner is shown in Fig. 7, illustrating a British Westland VTOL two-engine tilt-wing project [after Cook, 1975 (39)].

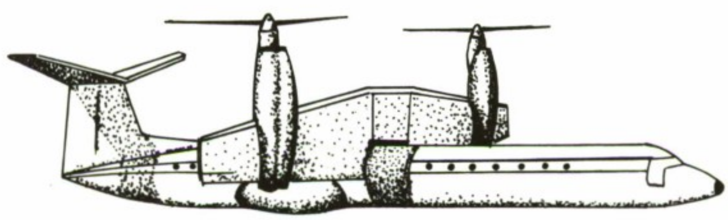


Fig. 7. British Westland VTOL two-engine tilt-wing commercial air carrier design. After Cook, 1975 (39).

In Canada, the Canadair Ltd CL-84 tilt-wing V/STOL, a utility 12-man or 16-troop seat aircraft, made its first flight in 1965. Tripartite instrument flight tests and transition in steep profiles were conducted at Pawtuxent Naval Air Station, Maryland in 1972-73, with continuing U.S. Naval evaluation (SCS-CL-84) in 1974 [Taylor, 1974 (64)]. The de Havilland Canada DHC-7 four-turboprop "Quiet STOL" airliner project was begun in late 1972, following a worldwide market survey of short-haul transport requirements. This new "Dash 7" aircraft has been designed for downtown STOL ports having 610 m (2,000 ft) runways, utilizing a quiet Pratt & Whitney (Canada) engine, propellor combination which is anticipated to limit external noise to 95 EPNdb at 152 m (500 ft) from the aircraft during takeoff and landing. This aircraft is intended to carry 50 passengers plus a crew of three or four. Emergency exits are located on each side at the front of the cabin and on the starboard side at the rear. Two pre-production flight test aircraft have been built to date, the first making its maiden flight at Downview on 27 March, 1975. A third airframe has undergone static testing and a fourth will be used for fatigue testing [Taylor, 1975 (65)]. In addition, six DHC-6-300S (MOT) aircraft have been used in tests. Certification is expected soon, and fifty orders have been taken to date [Newman, CATA/STOL, 1976 (56)]. However, these aircraft are designed to Federal Air Regulations (FAR) part 25, and appear not to include any advanced emergency egress or crashworthiness requirements beyond current standards.

In France the Armee de l'Air Breguet BR 941S STOL four-engined high-wing transport utilizes the deflected-slipstream technique. The design is sponsored in the U.S. as the McDonnell Douglas 188, with a 52 to 64 passenger capability. During March-May, 1969, the civil air carrier version was evaluated by American Airlines, and had previously been evaluated for air carrier consideration by Eastern Airlines [Tryckare, 1970; Newman, 1976 (66, 56)].

In Germany Lufthansa and the Federal Ministry of Defense prepared in 1973 skeleton requirements for a V/STOL transport aircraft for service in the 1980's. Dornier, in 1969, had reported considerable success with the Do 31 E experimental V/STOL aircraft, and had designed several STOL jet transports having high cruising speed and STOL or VTOL capability. In cooperation with NASA, a Dornier-NASA program included extensive flight testing at Oberpfaffenhofen with two Do 31 E-1 aircraft and one Do 31 E-3 aircraft, and NASA simulation studies at Ames Research Center, California. In 1969 Eastern Airlines became the first international airline to organize for V/STOL transport systems.

As a result of the experimental Do 31 E tests, Dornier designed the Do 231 V-jet, utilizing bypass jets for propulsion, supplemented by a large number of independent lift engines with very high bypass ratio for the V/STOL phase. This unique design (Fig. 8) is envisioned in two versions, one for military use with 800 km (500 mi) range including 400 km (250 mi) at low level with 10,000 kg (22,000 lb) military payload, and a civil transport version carrying 100 passengers, four stewardesses, and up to four crew on the flight deck. The engine system consists of two RB.220 bypass cruise engines mounted on pylons on the inboard wing sections, and 12 RB.202-25 lift engines. In the basic design the passenger cabin takes 16 rows of seats with 6 seats abreast. The evaluation committee of the German Ministry of Economic Affairs has selected the Dornier concept as the most promising line for future developments [Dornier, 1974 (41)].

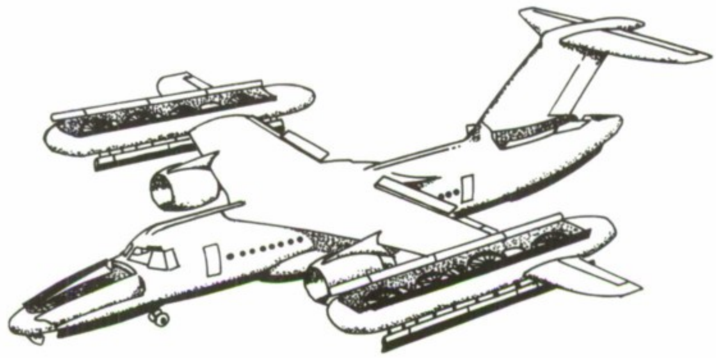


Fig. 8. The Dornier Do 231 V/STOL air transport design for the 1980's in vertical takeoff and landing configuration with lift engine doors open [Courtesy Dornier AG, 1974 (40)].

1.3.8 Military Advanced Airborne Command Post. Advanced aircraft such as those discussed in this section may also pose new human factors, crash impact, and emergency egress problems. Some military transports may present special emergency egress problems, such as the USAF Boeing 747-E4A Advanced Airborne Command Post [Taylor, 1975 (65)], which primarily utilizes conventional seating rather than state-of-the-art, as shown in Fig. 9.

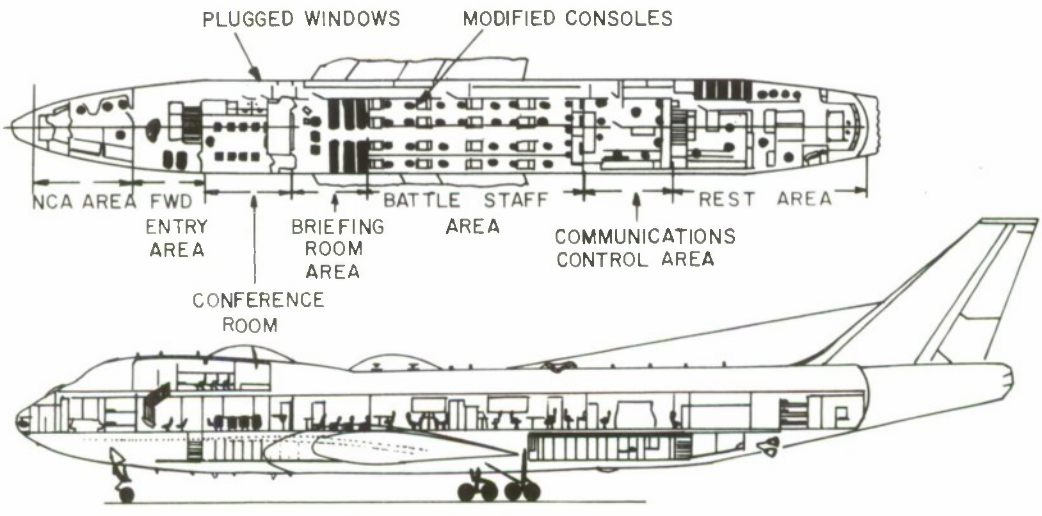


Fig. 9. USAF Boeing 747-E4A Advanced Airborne Command Post Design [Aviation Week, 1974 (32)].

Because the basic design state is the point at which "people packaging" and safety factors should be considered, one objective of this study has been to pull together and provide an assessment of the status of current relative technology. Some of the concepts, devices, or techniques discussed here should be considered for retrofit on current-generation aircraft (smoke hoods, improved seat restraint systems, emergency illumination, etc.). Others should be considered for future aircraft (such as heat shielding, advanced passive restraint systems, in-flight emergency escape systems, high-energy emergency egress systems, etc.). While this study has not attempted to include air transport helicopter or rotorcraft, many of the concepts considered would have equal applicability to such vehicles, although some different problems exist in crash impact as well as emergency egress.

2. AIR TRANSPORT ACCIDENT EXPERIENCE

The state-of-the-art of protection and survival technology is constantly changing as new materials, techniques, innovations, and requirements are developed. Nevertheless, the most valid data for determining future requirements and projecting most effective concepts in crash impact and emergency egress are derived from past and current field performance. Accident investigation often results in discovering egress problems, determining human factors considerations, and pointing out potential areas of future concern. However, not all accidents are investigated fully for human factors aspects. Emergency equipment and escape device performance under actual crash-fire conditions involving aircraft occupants in panic may differ considerably from predictions developed in non-stress laboratory environments. Similarly, concepts which appear feasible in theory may not be in fact.

2.1 Sources and Limitations of Data

This section reviews the accident experience of NATO* countries with respect to air transport accidents, as a basis for more clearly understanding past and current causes for occupant fatalities and determining priorities of greatest needs for technological improvements. While an attempt has been made to include all civil air carrier accidents of NATO countries for the period 1964-1974 (as well as preliminary reports for 1975), it has been found difficult to precisely determine every case with accuracy, since accidents occurring outside the country of registry may or may not be included. Even utilizing the computerized printouts of the NTSB for the U.S. has shown some apparent discrepancies (e.g., the U.S. registry DC-9 operated by Antilliaanse Luchtvaart Maatschappij N.V. [ALM] of Curacao, on lease to ALM from Overseas National Airways, Inc., a U.S. certified supplemental air carrier, which ditched in the ocean 30 miles (48 km) ENE of St. Croix, Virgin Islands, 2 May, 1970 [10-12], is apparently listed on U.S. records as a general aviation accident, rather than as an air carrier accident).

Listing of aircraft accident injury data can be deceptive in drawing conclusions if only the tabulated results are used and the environmental content is not clear. For this study an attempt was made to review each individual air carrier accident, and those reports available were reviewed, as well as the human factors group reports where they existed. However, particular difficulty was encountered in attempting to identify how fatalities and injuries occurred in individual accidents. In many cases there either was no human factors determination in the investigation, or else cause of trauma was not indicated. Thus an evaluation of occupant survival in many cases is not possible based upon the reports available. However, some cases, particularly in recent years, have sufficient information relative to injuries so that causes may be clearly identified. One objective, that of separating out and identifying occupant injury causation, was not found possible to attain in a large number of reported accidents, due to the lack of human factors documentation.

Basic sources included data from the International Civil Aviation Organization (ICAO), Aircraft Accident Digest [1975 (109, 299)], the World Airline Accident Summary of the United Kingdom Civil Aviation Authority (98-100), the U.S. National Transportation Safety Board and Civil Aeronautics Board (10-12; 85-97; 119-288; 310-329; 331-340; 344, 345; 355-363; 371-373; 409-420; 430-435), including a copy of the magnetic tape computer files of all accidents since 1964, the International Register of Civil Aircraft (72), the annual aircraft accident statistical summaries of the Ministry of Transport, Canada (110-118), and the multitude of individual aircraft accident investigation reports available.

A large number of supplementary sources were also utilized, including the Aircraft Accident Digest [ICAO (109; 299)], NTSB preliminary accident resume reports (for 1975 data), individual investigation reports provided in Aviation Week and Space Technology, The World Aviation Directory [Dean, 1975 (101)], Flight Safety Focus (London) (293), FAA reports (43, 44; 104-107; 306, 307), various annual reports of governmental agencies, and summary reports, special studies, and human factors reports made available by the NTSB. Additional general sources of precise technical information included Aerospace Facts and Figures 1975/76 (70), Commercial Aircraft of the World [Hofton, 1975 (51)], Jane's All the World's Aircraft [Taylor, 1959-1975/76 (64; 65; 291)], International Aerospace Specification Tables [1975 (76)], The Lore of Flight [Tryckare, 1970 (66)], Jane's Pocket Book of Commercial Transport Aircraft [Taylor & Munson, 1973 (292)], as well as the Air Force/NASA Design Handbook series [USAF, 1974 (298)], and other military and manufacturers' technical specifications and publications.

2.2 Air Transport Fatality Data

ICAO data indicate, as shown in Table I, that for the period 1950 to 1974 there have been 734 accidents involving scheduled air services on a world-wide basis, resulting in 18,377 fatalities [ICAO, 1975 (109)]. These figures include 119 countries but exclude People's Republic of China, and excluded USSR until November, 1970. This is an average of 735 deaths per year on scheduled airlines for this 24-year period, with the average increasing to 1,402 deaths per year in 1962, and to 1,382 (preliminary data) in 1974 (299). Note, however, that crew fatalities were excluded.

In operations of U.S. air carriers from 1964 through 1974 there were 684 accidents reported, of which 109 were fatal accidents, with 2,797 fatalities for this most recent 10-year period [National Transportation Safety Board, 1972 (213); 1975 (280)]. During 1974 U.S. scheduled air carriers were involved in 47 accidents, including 9 fatal accidents, and totaling 467 fatalities [National Transportation Safety Board, 1975 (280)]. This was more than double the 1973 total of 227 fatalities, and in the case of U.S. scheduled air carrier operations the death toll was the highest since the 499 recorded in 1960. Fig. 10 provides accident data from 1964 through 1974.

* Includes aircraft accidents of Belgium, Canada, Denmark, France, West Germany, Greece, Iceland, Italy, Luxembourg, Netherlands, Norway, Portugal, Turkey, United Kingdom, and United States.

TABLE I.

WORLD-WIDE AIRCRAFT ACCIDENTS INVOLVING PASSENGER FATALITIES ON SCHEDULED AIR SERVICES, 1950-1974

Year	Aircraft Accidents	Passengers Killed	Passenger Fatalities Per 100 million Pass.Km	Passenger Fatalities Per 100 million Pass.Mi	Fatal Accidents Per 100 million Km Flown	Fatal Accidents Per 100 million Mi Flown	Fatal Accidents Per 100,000 Aircraft Hrs	Fatal Accidents Per 100,000 Aircraft Ldgs
1950	27	551	1.97	3.15	1.88	3.02	0.54	
1951	20	443	1.27	2.01	1.23	1.99	0.35	
1952	21	386	0.97	1.54	1.18	1.90	0.34	
1953	28	356	0.77	1.25	1.44	2.32	0.43	
1954	28	443	0.85	1.36	1.36	2.19	0.42	
1955	26	407	0.67	1.07	1.14	1.82	0.36	
1956	27 (1)	552	0.78	1.25	1.06	1.71	0.34	
1957	31	507	0.62	0.99	1.09	1.76	0.36	
1958	30	609	0.72	1.15	1.02	1.65	0.34	
1959	28	613	0.63	1.00	0.91	1.46	0.31	
1960	34 (1)	873	0.80	1.29	1.09	1.76	0.40	0.52
1961	25	805	0.69	1.11	0.80	1.29	0.31	0.38
1962	29	778	0.60	0.97	0.90	1.44	0.37	0.44
1963	31	715	0.49	0.78	0.90	1.46	0.39	0.46
1964	25	616	0.36	0.58	0.68	1.09	0.30	0.35
1965	25	684	0.35	0.56	0.61	0.98	0.29	0.33
1966	32 (1)	1001	0.44	0.70	0.69	1.12	0.33	0.40
1967	30	678	0.25	0.40	0.57	0.91	0.29	0.35
1968	35	912	0.29	0.47	0.58	0.94	0.32	0.38
1969	32	946	0.27	0.43	0.48	0.77	0.27	0.34
1970	30	786	0.17	0.27	na	na	na	na
1971	33	975	0.20	0.32	na	na	na	na
1972	44 (2)	1402	0.25	0.41	na	na	na	na
1973	35	957	0.15	0.25	na	na	na	na
1974*	28	1382	0.21	0.34	na	na	na	na
Totals	734	18377						

Source: ICAO, 1975 (109) Does not include aircrew.
Data exclude People's Republic of China, includes USSR only from 1970.

* 1974 preliminary data.
(1) Includes a mid-air collision counted as one accident.
(2) Includes two mid-air collisions shown as one accident.
na Not available.

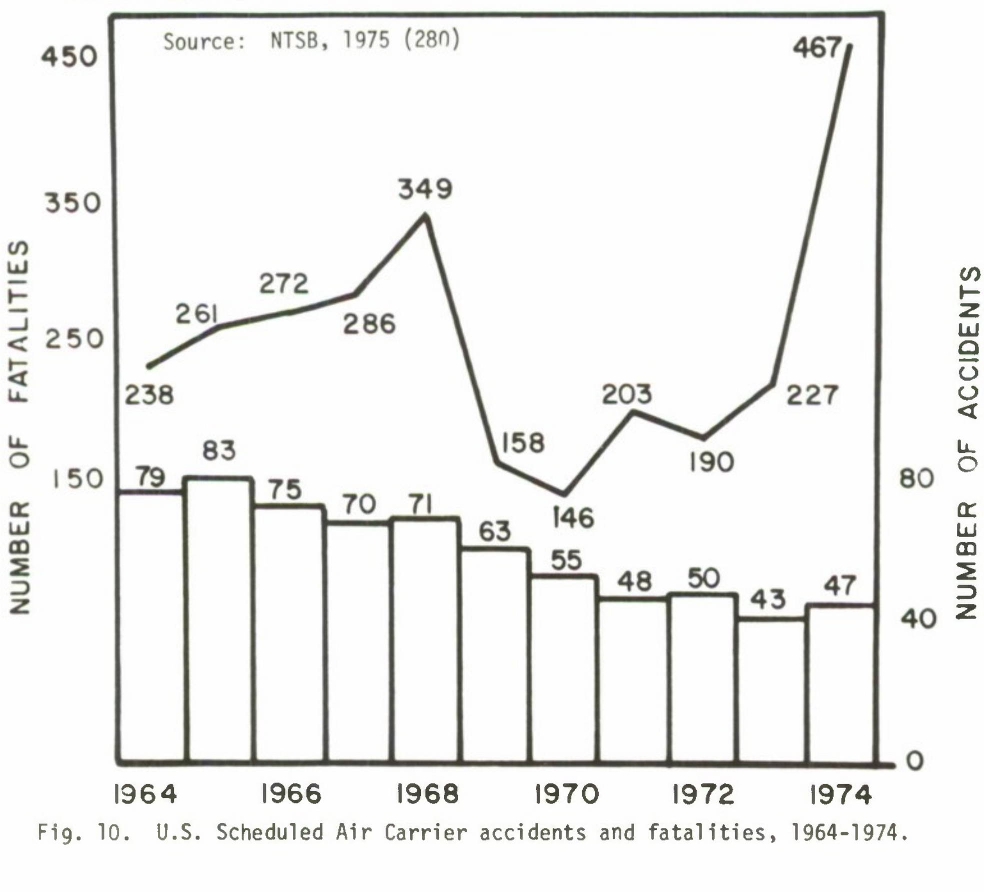


Fig. 10. U.S. Scheduled Air Carrier accidents and fatalities, 1964-1974.

Similarly, the fatal accident rate has increased in each of the last three years from the 0.94 per 100,000 hour rate achieved in 1971. The 1974 rate was the highest since 1968. The passenger fatality rate in certified route carriers' scheduled domestic and international passenger service has also shown an upward trend. The NTSB reports that from a record low of 0.001 passenger fatalities per 100 million passenger miles flown in 1970, this rate fluctuated to 0.119 in 1971 and 0.100 in 1972, rising to 0.115 in 1973 and 0.256 in 1974, the highest rate in ten years [National Transportation Safety Board Annual Report to Congress, 1975 (280)]. This is shown in Fig. 11.

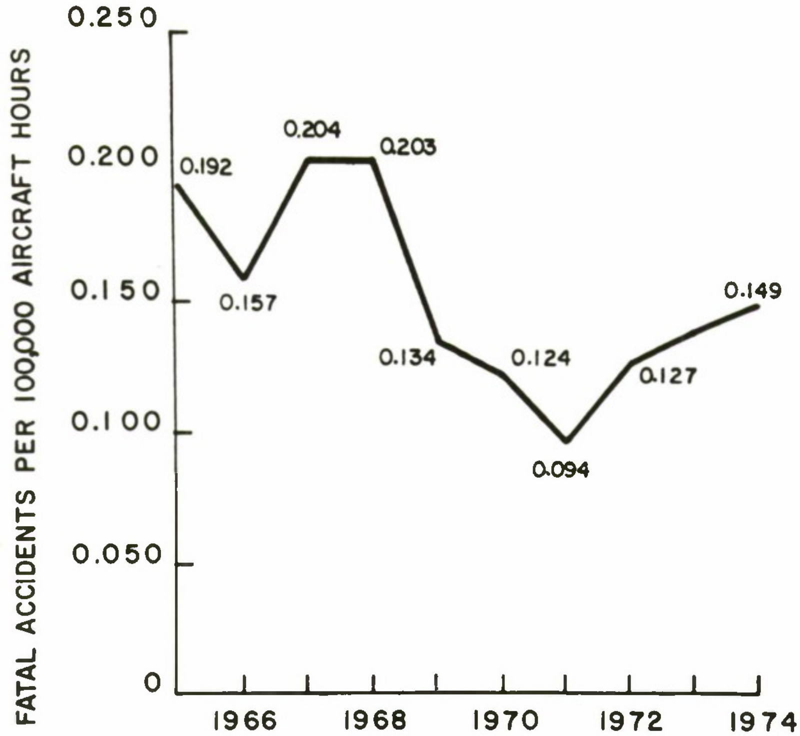


Fig. 11. Fatal accident rate. All U.S. airline flying. (Fatal accidents per 100,000 aircraft hours. Includes certified route and supplemental air carriers.) NTSB Annual Report, 1975, p. 6.

Air carrier fatality rates may be compared in various ways. The passenger fatality rate per 100,000,000 passenger miles has been tabulated by the FAA [Department of Transportation, 1970 (102)] for comparison among passenger automobiles (2.3), buses (.22), railroad passenger trains (.07), and domestic scheduled air carriers (.13). If fatality rates for U.S. general aviation are calculated on a basis of passenger fatalities (all occupants), the fatality rate (for 1973) was 15.1 per 10^8 miles of travel (excluding 3 suicides) [FAA, 1975 (103)] [Snyder, 1975 (289)]. Thus the U.S. domestic scheduled air carrier fatality rate is still on the order of 43.5 times less than that of the automobile (0.098 vs. 4.27), and 154 times less than that of general aviation (0.098 vs. 15.1).

The current U.S. air carrier fleet (1974) consists of 2,611 total aircraft. Table II lists the current U.S. civil air carrier inventory as an indication of aircraft presently in service (and thus those which will be principally involved in accidents over the coming decade).

During the past ten years an average of 414 crew and passengers per year have received fatal injuries in combined NATO countries (excluding U.S.) air carrier accidents. Of 372 accidents during this period, 96, or 25.8%, have been fatal accidents. Table III illustrates the summary data relative to fatalities, injuries, and accidents for both aircrew and passengers. Since these data have been compiled from several sources, they do not represent official data from the countries involved but are believed to be relatively accurate.

TABLE II.

U.S. AIRLINE FLEET
TYPE OF AIRCRAFT, NUMBER OF ENGINES AND MODEL
(Number of Aircraft as of 1 Jan., 1974)

Type of Aircraft, Number of Engines and Model	
TOTAL FIXED-WING	2,598
Turbine-Powered, Total	2,461
Four-Engine, Total	824
Turbojet, Total	750
Boeing 707	316
Boeing 720	45
Boeing 747	111
Convair 880	37
Convair 990	8
McDonnell Douglas DC-8	233
Lockheed L-1329	--
Turboprop, Total	74
Armstrong Whitworth AW-650	--
Boeing 377S	1
Canadair CL-44	--
Lockheed 188	53
Lockheed 382	20
Three-Engine Turbojet, Total	872
Boeing 727	733
Lockheed L-1011	48
McDonnell Douglas DC-10	91
Twin-Engine, Total	765
Turbojet, Total	535
Boeing 737	152
British Aircraft Corp. BAC-111	43
Dassault MD-20	--
McDonnell Douglas DC-9	340
Hamburger Flugzeugbau HF-320	--
Turboprop, Total	230
Aero Commander AC-680-V	1
Beech 99	--
Convair 580	105
Convair 600, 640	32
DeHavilland DHC-6	9
Fairchild F-27	25
Fairchild FH-227	31
Grumman G-159	1
Hawker Siddeley HS748	1
Nihon YS-11	23
Short SC-7	2
Piston-Powered, Total	137
Four-Engine, Total	42
Boeing 377	1
Douglas DC-4	4
Douglas DC-6	31
Douglas DC-7	5
Lockheed 749	--
Lockheed 1049/1649	1
Twin-Engine, Total	81
Aero Commander 500	1
Aero Commander 680E	--
Cessna 402	2
Convair 240	--
Convair 340/440	6
Curtiss CW-46	30
Douglas DC-3	12
Fairchild FC-82	2
Grumman G-21	6
Grumman G-44	1
Grumman G-73	1
Martin 202	--
Martin 404	18
Other	2
Single-Engine, Total	14
TOTAL ROTARY WING	13
Turbine-Powered, Total	10
Sikorsky S-61	7
Bell BL-206	3
Piston-Powered, Total	3
Sikorsky S-58C	3
TOTAL AIRCRAFT	2,611

Source: FAA (106); and Aerospace Facts and Figures, pp. 76-77, 1975 (71).

TABLE III.

COMBINED NATO COUNTRIES CIVIL AIR TRANSPORT ACCIDENTS (EXCLUDING U.S.)

Year	No. Acci-dents	Fatal Acci-dents	Total Occu-pants	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass
1964	36	7	(5) 1285+	2	0	26	23	11	234
1965	32	6	(4) 1227+	2	1	0	15	8	105
1966	29	9	(4) 1194+	2	0	30	30	23	408
1967	40	10	(6) 1481+	4	0	13	21	15	243
1968	31	10	(3) 1406+	6	7	136	17	16	221
1969	39	11	(6) 1445+	10	9	47	19	28	587
1970	41	10	(5) 2186+	0	7	98	14	11	249
1971	24	6	(2) 892+	11	2	118	9	11	99
1972	43	13	(4) 1830+	7	0	29	27	19	513
1973	29	7	1644	5	6	36	18	9	382
1974	28	7	2331	5	1	29	10	10	529
TOTALS	372	96	16921	54	34	562	203	371	3570
					650			4144	

(2),(3),(4),(5),(6)=Total occupants unknown for 2,3,4,5, or 6 number of accidents listed that year.

2.2.1 In-Flight Hazards. Although occupant crash impact protection and emergency egress aspects of air carrier accidents are usually considered in relation to a crash landing environment, there are a number of in-flight environments which also require occupant protection. The following sections briefly indicate the nature and extent of some of the more common in-flight hazards which may result in injuries to passengers or crew.

2.2.1.1 Mid-Air Collision. There have been a number of studies of mid-air collisions (300-330). However, unlike the first documented mid-air collision (on 2 October, 1910 at Milan, Italy, when a French Antoinette flown by Rene Thomas collided with U.K. Captain Dickson's Henri Forman [Gibbs-Smith, 1960 (308)], resulting in non-fatal injuries to both), the number of aircraft occupants per aircraft, and resulting chance of major disaster has greatly increased. One 1973 study conducted by the Mitre Corporation for the FAA Office of Systems Engineering Management, reviewed all mid-air collisions occurring over the continental United States during an eight-year period, 1964 through 1971 [Simpson et al., 1973 (330)]. During this period there were 12 mid-air collisions involving air carrier aircraft, with 239 fatalities. Despite constantly increasing annual levels of aviation activity, which doubled during the time of the Simpson study, the statistical risk of mid-air collision per flight hour did not significantly change. The authors did not indicate what trend would be shown if alternative units of risk were utilized in the statistical analysis. However, with forecasts of three- to five-fold increase in annual operations forecast over the next 10 to 20 years (305; 306), this risk may well increase. In 1968 there were 2,230 near-mid-air collisions (NMAC) reported to the FAA, 1,128 of which were classified as "hazardous," and 317 "critical" (i.e., the miss was "due to chance, with no time for evasive action")[FAA, 1969 (305)]. From 1969 through 1971 the FAA granted immunity from enforcement action to persons reporting near-mid-air collisions to encourage full reporting of such incidents [FAA, 1971 (307)].

During the first ten months of 1975 the Federal Aviation Administration has reported 207 "hazardous" near-collisions of U.S. aircraft, 125 of which involved a scheduled air carrier and a military or general aviation aircraft, and 61 of which involved only air carriers [McLucas, 1975 (309)]. However, interpretation of this report has been varied, with the United Press International reporting "158 near-collisions," and one technical publication stating that there were "210 reports of near-collisions, 40 involving air transport aircraft" (303).

On 5 March, 1974, a mid-air collision occurred between an Iberia McDonnell Douglas DC-9 and a Spantax Convair 990 near Nantes, France (both aircraft were of Spanish registry). Seven crew members and 61 passengers on the Iberia flight were killed, and the aircraft destroyed. Although the Spantax aircraft incurred substantial damage, there were no reported injuries to occupants. This accident was investigated by the Commission of Inquiry appointed by the French Secretariat of State for Transport (301). One of the most well-publicized was the recent near-collision on 26 November, 1975 between an American Airlines McDonnell Douglas DC-10 with 194 aboard, and a Trans World Airlines Lockheed L-1011 at 10,700 m (35,000 ft) over Michigan. A report of this near-collision and review of the mid-air problem is expected to be published by the NTSB in late February, 1976. At the time of the unplanned emergency descent of the American flight, the seat belt sign was on and a meal was being served. It was reported that all unsecured, or inadequately secured, occupants and objects floated to the ceiling and then fell to the floor. As a result, 24 individuals, including 10 cabin attendants, were injured. Three passengers received serious injuries (328). Nine days later, on 6 December, 1975, a Trans World Airlines air carrier with 77 persons aboard reportedly narrowly missed ("within 50 feet [15 m]," according to a passenger) colliding at 6,400 m (21,000 ft) with a United Airlines flight carrying 60 passengers [Associated Press, 1975 (302)].

Evasive action to avoid a mid-air collision also may cause injuries. Serious injury (fractured ankle) to a passenger resulted when an American Airlines Boeing 707 was descending to land at Phoenix, Arizona on 10 December, 1974. Although the seat belt sign was on at the time, this passenger was returning to her seat from the lavatory [NTSB, 1974 (324)]. A listing of other injuries as a result of evasive maneuvers may be found in a 1973 NTSB special study (331). Among the 1975 mid-air collisions, a Golden West Airlines de Havilland Twin Otter collided with a Cessna 150 near Whittier, California, with fatalities to all 14 occupants of both aircraft [NTSB, 1975 (327)].

2.2.1.2 Turbulence. Injuries due to in-flight turbulence are not infrequent. In most situations the injury could have been prevented had the injured passenger or aircrew been restrained. However, stewardesses are particularly vulnerable to unexpected encounters with violent turbulence since they often have to remain on their feet to conduct their duties.

In 1974 an Air France Boeing 707 B-328B enroute to Paris, France from Los Angeles encountered moderate to severe turbulence at 10,050 m (33,000 ft) near O'Neill, Nebraska, which lasted some 45 minutes. Two flight attendants and 13 passengers were injured, including serious injuries to two passengers and one flight attendant. An elderly lady received a fractured ankle and an elderly male passenger incurred a dislocated knee, a possible fracture, and other injuries. Twelve of the passengers had been standing at the rear of the aircraft making duty-free purchases or waiting to use the lavatories, and were thrown about when the turbulence was first encountered (282). During 1975 a number of injuries from this cause have already been reported. Several random U.S. cases including 17 injuries have been selected from preliminary NTSB investigations to illustrate this problem (see Table IV), although these do not represent the total cases for 1975. Each case involved sudden violent turbulence, and the last case was thought to be attributed to wake turbulence from a preceding wide-bodied air carrier.

In a special study, the NTSB has reported that during the period 1968-1971, 95 stewardesses and 241 passengers were injured due to turbulence in 70 air carrier accidents reported [NTSB, 1973 (331)]. This involved 116 individuals receiving injuries of a serious nature and 220 individuals reporting minor injuries, as listed in Table V.

TABLE IV.

INJURIES DUE TO IN-FLIGHT TURBULENCE, 1975
(Incomplete)

Date	Airline	Type of Aircraft	Injuries Stewardess	Injuries Passenger	Comments	Reference
21 March	Flying Tiger	McDonnell Douglas DC-8-63F	1	1	Serious injury (fractured kneecap) to stewardess; passenger wrenched neck.	(332)
20 May	Frontier	Convair 580	1	-	Stewardess thrown from feet and struck protrusion on passenger seat with back, knocked unconscious; serious injury.	(333)
12 July	Trans World	Boeing 707	-	1	Female passenger fractured ankle coming out of lavatory and thrown into air; serious injury.	(334)
28 July	Air France	Boeing 707	1	-	Stewardess sustained serious injury (fractured leg).	(335)
3 August	Delta	McDonnell Douglas DC-9	2	3	Minor injuries.	(336)
8 August	Delta	McDonnell Douglas DC-8-51	1	-	Serious injury (fractured vertebrae) to stewardess when thrown to floor from seat (in process of securing restraint).	(337)
15 September	Pan Am	Boeing 747	-	1	Female passenger received serious injury (compound fracture of leg) exiting from lavatory.	(338)
22 September	Delta	McDonnell Douglas DC-8-51	-	2	Two female passengers were in lavatories; one aged 78 received serious injury (fractured right ankle), the other received minor injuries to knee and finger.	(339)
3 November	Trans Intl.	McDonnell Douglas DC-10	1	2	Serious injuries to two passengers and minor injury to one stewardess.	(340)

TABLE V.

INJURIES ATTRIBUTED TO TURBULENCE IN
U.S. AIR CARRIERS, 1968-1971

Year	Reported Accidents	Occupants	Injuries Serious	Injuries Minor
1968	20	Flight Attendants	14	12
		Passengers	18	44
1969	19	Flight Attendants	11	24
		Passengers	24	59
1970	16	Flight Attendants	16	7
		Passengers	11	40
1971	15	Flight Attendants	7	4
		Passengers	15	30
Totals	70		116	220

Source: NTSB, 1973 (331)

2.2.1.3 Bird Strikes. An example of another in-flight hazard which may disable an air carrier involves bird strikes. Van Messel (350) in a 1960 study noted 117 reported bird strikes on aircraft the first ten months of that year in Holland alone. Between 1964 and 1973, 63 accidents were attributed to birds in the U.S., 17 involving air carriers (348). During 1975 Tokyo International Airport reported 19 cases of bird strikes on air carriers (341) (see Fig. 12). Several tragic consequences have occurred.

Fig. 12. An air carrier taking off at Tokyo International Airport on 13 November, 1975 in a flock of birds (Photo courtesy Wide World Photos).

In 1960 an Eastern Airlines Lockheed L-188 Electra was disabled on takeoff by a flock of starlings at Boston's Logan International Airport, resulting in 62 fatalities (349). In 1962 a United Airlines Vickers Viscount struck birds over Maryland that damaged the horizontal stabilizer, resulting in 13 fatalities (348). More recently, on 12 November, 1975, the crash of an Overseas National Airways McDonnell Douglas DC-10-30CF was attributed to ingestion of large seagulls. The aircraft was destroyed on takeoff at J.F. Kennedy International Airport in New York [(342); NTSB, 1975 (346)]. The main landing gears collapsed as the captain attempted to turn off the runway, and the aircraft settled to the ground enveloped in flames, destroying the aircraft and resulting in injuries to the flight deck crew. On 20 November, 1975, Federal Aviation Administration Lockheed L-1329 (N1) incurred bird strike damage to number four engine while landing at North Philadelphia Airport [NTSB, 1975 (347)].

A 1969 accident illustrates several of the problems which may be encountered during emergency evacuation when an aircraft lands or aborts a takeoff after striking birds, even when smoke or fire is not involved. On 1 December, 1969, a Pan American Airways Boeing 707 aborted takeoff at Sydney, Australia after running into a flock of birds. The aisle by the galley was blocked by the in-flight oven being dislodged into the aisle. There was confusion in evacuation instructions, with no announcement or warning made from the flight deck, yet while the forward cabin attendants were evacuating passengers, the person in the rear used the public address megaphone to instruct the passengers to stay in their seats. The rear galley exit was blocked by a 95-year-old woman seated next to the exit who refused to move; she was accompanied by her 78-year-old son, neither of whom spoke English. They were eventually forced down a slide [Australian Air Safety Investigation Branch, 1969 (343)].

As a result of the 1960 Lockheed Electra accident and another incident in which starling ingestion caused an aborted takeoff, an FAA/CAMI study was conducted by Swearingen and Mohler [1962 (349)] to determine why starlings appeared to be attracted to the Lockheed Electra. It was found that the Electra sound spectrum contains an audible chirp identical in frequency and wave form to the chirp of field crickets, indicating that "the starlings are attracted to the Electra by being misled into the belief that there is a field of crickets at the source of the Electra noise" [1962 (349)].

An incident has been reported of a bird strike at 2,440 m (8,000 ft) in which a vulture penetrated the windshield and caused fatal injuries to the copilot, while in another incident a vulture broke through the captain's windshield on takeoff and caused serious injuries, although in both cases the aircraft landed safely [Khan, 1966 (345)]. Dodds, in New Zealand, has proposed a number of measures to remove the bird hazard on airfields, primarily by removing sources of food, letting grass grow 15 to 23 cm (6 to 9 in) high, providing alternative roosting areas, and using scaring devices in a random sequence (distress calls, mechanical hawks, shooting and pyrotechnics, real or artificial carcasses, and dogs) [Dodds, 1966 (344)].

2.2.1.4 In-Flight Explosion, Fire, or Structural Failure. Unexpected in-flight explosions may impair controls or damage the structure irreversibly, resulting in a fatal crash, or may, with luck, be survived without injury. The hazard from explosive devices purposefully placed in civil air transport aircraft remains with us despite the effectiveness of NATO airport security boarding controls. A number of air carrier disasters have been attributed to in-flight explosions in recent years. One which occurred in May of 1962 involved the explosion of a dynamite device in the right rear lavatory of a Continental Airlines Boeing 707 cruising at 11,900 m (39,000 ft) over Iowa, causing a violent explosive decompression. Two minutes later, at 11,200 m (36,800 ft) and an airspeed of 508 km/hr (315 mph) (IAS) the empennage and a 11.6 m (38 ft) portion of the rear fuselage separated, the subsequent crash resulting in 45 fatalities. Since one passenger was found alive 7 1/2 hours post-impact lying across a "triple" forward-facing seat, although he died 9 hrs, 20 min post-impact from injuries received, this accident received unusually comprehensive human factors, medical, and bio-engineering analysis as reported in Aerospace Medicine [Dille & Hasbrook, 1966 (356)]. A similar incident, but with a stewardess surviving a 9,450 m (31,000 ft) fall, occurred on 26 January, 1972. This in-flight explosion was attributed to a terrorist-planted bomb, which fatally disabled a Yugoslav Airlines McDonnell Douglas DC-9 bound from Sweden to Yugoslavia, with 27 fatalities [Vulovic, 1972 (367)]. On 8 September, 1974 a Trans World Airlines Boeing 707-331B enroute from Tel Aviv to New York crashed into the Ionian Sea with 88 fatalities as a result of "the detonation of an explosive device within the aft cargo compartment of the aircraft, which rendered the aircraft uncontrollable" [NTSB, 1975 (357; 351; 352, 353)]. An explosive decompression at 8,540 m (28,000 ft) coincided with the explosion. The NTSB indicated that the "explosion took place below the cabin floor, which shielded the cabin occupants," thus had the flight not been disabled, it is possible that this accident might have been survivable. More recently, a Middle East Airline Boeing 720B crashed 1 January, 1976 in a remote region of Saudi Arabia, killing all 82 persons on board [Aviation Week, 1976 (355)]. While this accident is still under investigation and no cause has been determined, the aircraft reportedly disappeared from Beirut's surveillance radar while cruising at 11,000 m (36,000 ft), and an explosion must be considered. While a number of other in-flight explosions have occurred, these cases illustrate the high fatality rate presently associated with such accidents.

When in-flight fires occasionally occur, they are usually readily controlled. However, such occurrences can result in a fatal crash or lead to injuries. For example, a Pan American Boeing 747 flight, enroute from Honolulu to Guam on 17 November, 1974 at an altitude of 610 m (2,000 ft) after takeoff, experienced a fire warning in number three engine. Although the engine was shut down and one extinguisher bottle fired, the fire persisted. The second extinguisher bottle was fired but the engine fire still continued. The aircraft returned to Honolulu and landed, and the fire was finally put out by the ground crash rescue team. Had this fire occurred later in the flight the results might have been different. Incidentally, although the 172 aboard deplaned successfully, five of the emergency evacuation slides "failed to function either partly or totally" [NTSB, 1974 (358)]. Earlier that same month (5 November) an Allegheny Airlines McDonnell Douglas DC-9-31 experienced an electrical fire and intense smoke in flight, 16km (10mi) out on approach to Logan International Airport, Boston, and was able to land successfully. In this instance the flight deck crew and cabin attendants were unable to open the exit doors because of cabin pressurization and some two minutes elapsed before rescue personnel were able to break open the overwing exits from the outside. Emergency egress was accomplished primarily through the overwing exits without injury [NTSB, 1974 (359)].

Structural failures in air carrier aircraft may occur when the vertical induced velocities exceed the design gust limits during violent maneuvers incident to evasive action, loss of control, overload conditions, wake turbulence, extreme up and down drafts (wind shear), clear air turbulence, or combinations of these and other causes. A study of such failures over a 10-year period in general aviation aircraft has been published by Snyder [1972 (366)]. While explosion, bird strikes, explosive decompression, midair collision, and fire also may all result in structural failure, there is still another category involving failure of structure in the absence of any of these factors. This most commonly occurs when a portion of the engine, gear, or wing control surface fails, and often does not result in an accident. Despite the relatively excellent safety record of NATO air carriers, such failures are not uncommon. Since many cases of structural failure of an aircraft component do not result in an accident, the accident briefs do not provide an accurate indication of the incidence of such failures.

Some recent examples of in-flight structural failures include the National Airlines McDonnell Douglas DC-10-10 accident near Albuquerque on 3 November, 1973 when the fan section of a General Electric CF6-6D turbofan engine failed, resulting in an explosive decompression and passenger fatality when he was sucked out of the aircraft after the fuselage was pierced by debris [Aviation Week, 1975 (354)]. Some random incidents during June through September of 1975 further illustrate this hazard. An American Airlines Boeing 727 flight from Los Angeles International aborted takeoff on 24 July with subsequent evacuation when the right MLG sway brace became separated from its attachment at the shock strut, according to preliminary investigation [NTSB, 1975 (360)]. On 25 July one engine on a Continental Airlines McDonnell Douglas DC-10-10 was shut down on approach to Seattle due to high vibration. Preliminary investigation subsequently indicates this was attributed to deformation and separation of turbine blades [NTSB, 1975 (361)]. On 24 August a United Airlines Boeing 747 enroute from San Francisco to Honolulu incurred an in-flight fire to number three engine at 10,670 m (35,000 ft), and after landing at Honolulu without incident it was found in preliminary inspection that a seventh-stage compressor rim failure had occurred [NTSB, 1975 (362)]. On 8 September an American Airlines Boeing 747-123 was on final approach to the San Juan International Airport, Puerto Rico, "when the outboard section of the left inboard trailing edge foreflap separated from its attachment, struck the left side of the fuselage, and fell to the ground," according to preliminary investigation. However, although one passenger reportedly sustained minor head contusions, the aircraft was landed with no apparent difficulty [NTSB, 1975 (363)]. A Trans World Airlines Boeing 747, taking off from London on 11 September, experienced failure of the tire and part of the wheel assembly which separated and struck both left and right body gear wheel well doors and gouged the fuselage, according to preliminary investigation, although this flight continued to Chicago and landed without incident [NTSB, 1975 (364)]. On 14 September the number four engine forward thrust reverse panel separated from the engine ten minutes after takeoff of a Trans World Airlines Boeing 707-131B from Edwardsville, Illinois [NTSB, 1975 (365)]. These examples from a three-month period during 1975 indicate the nature of such failures; those which attributed to accidents can be found by referring to the Appendices.

2.2.1.5 Explosive Decompression. Another in-flight hazard which occurs frequently on scheduled airlines involves rapid or explosive decompression. However, such incidents are usually reported to the FAA only in the form of a "Mechanical Reliability Report" (MRR), so neither the actual number of occurrences nor their potential consequences are often publicly recorded. Study of this problem is currently underway as of January, 1976, by the Human Factors Branch of the Bureau of Safety, National Transportation Safety Board. An idea of the number of decompressions is seen in the 253 which occurred in the 26-month period between May, 1968 and June, 1970 [FAA, 1971 (368)]. "In house" studies by the Federal Aviation Administration indicate that at least 27 decompressions occurred on U.S. scheduled air carriers during 1972, of which at least 4 were explosive, and 34 decompressions, of which 7 were explosive, occurred in 1973 [FAA, 1974 (369); see also Mohler et al., 1969 (370)]. The National Airlines McDonnell Douglas DC-10 explosive decompression, which resulted in a fatality when a passenger was sucked out the fractured fuselage window at 11,900 m (39,000 ft) near Albuquerque in November, 1973 [NTSB, 1975 (372)], and the McDonnell Douglas DC-10 explosive decompression near Detroit on 12 June, 1972 [NTSB, 1973 (371)], are good examples of near-disasters. One of the most recent incidents occurred on 27 December, 1975 when a Capitol Airways International McDonnell Douglas DC-10, approaching Oakland from Honolulu at 9,750 m (32,000 ft), experienced a decompression resulting in the hospitalization of 10 of 183 passengers and crew [NTSB, 1976 (373)]. Fatalities to 175 of 330 occupants in a USAF Lockheed C-5A transport crash occurred 4 April, 1975 in Saigon, when aft cargo door lock failure displaced 1,846 cu m (65,000 cu ft) of air in less than 1 second, severing empennage controls. A decompression was probably responsible for the worst crash in history when on 5 March, 1974 a Turkish Turk Hava Yollari McDonnell Douglas DC-10, climbing through 3,962 m (13,000 ft) after takeoff from Paris blew out the left rear freight door, resulting in 345 fatalities (100). Injury to passengers (and cabin crew) can occur not only as a result of the rapid or explosive decompression event or subsequent structural consequences, but also in any resulting emergency descent.

Examination of current decompression experience should be considered also in light of projected requirements, and for those aircraft already having service ceilings of 13,720 m (45,000 ft) (such as the Gates Learjet 23/24/25 business jet transport series) to the 18,000-18,290 m (59,000-60,000 ft) service ceilings of the USSR Tupolev Tu-144 or Aerospatiale/British Aircraft Corporation Concorde supersonic transports. For passenger flights above the 12,200-15,250 m (40,000-50,000 ft) levels, as has been pointed out by Mohler (1970), careful precautions are required with respect to (1) preventing pressurization malfunctions and (2) providing appropriate occupant protection in the event of pressurization loss (370). Significant factors are oxygen mask features, donning times, passenger and cabin attendants' response, descent procedures, the cabin environmental compressor capabilities, and the aircraft descent limitations. Mohler has provided a series of "critical cabin altitude" curves for passengers which have been tested in the Civil Aeromedical Institute (FAA) altitude chamber. Proposed changes in the FAR's are presently under discussion (1975).

2.2.1.6 Takeoff and Landings. A very high proportion of all accidents occur during the takeoff and landing phase of flight. The most recent and comprehensive study of takeoff and climb accidents has been conducted by Newman for the Canadian Air Transportation Administration STOL Project survey [1975 (374)]. This report found that an aborted takeoff resulting from an equipment failure occurred in approximately 15 air carrier flights per million departures, with some 66% attributed to failure of a single engine and about 16% to problems related to the landing gear. However, of these, Newman found that fewer than 1% of engine failure-caused aborts resulted in an accident, while about 12% of the gear-related incidents ended up as an accident. Overall, about one incident in 30 becomes an accident, with over 50% of the aborts resulting in the aircraft veering off to the side of the runway. This study also found a "surprising" number of multiple-engine-failure accidents occurring during both ground roll and initial climb, with most attributed to bird ingestion. There have been a number of earlier studies. Among these, Foxworth and Marthinsen [1969 (375)] in an Air Line Pilots Association (ALPA) study reviewed 18 rejected takeoff accidents of air carrier aircraft through 1968, an ICAO study reviewed world-wide runway overrun reports [1967 (378)], Kennard [1962 (376)] reviewed approach accidents, and an Air Force study reviewed military accidents [USAF, 1965 (379)]. The Newman CATA/STOL study reviews 101 accidents/incidents (for takeoff and climb phase only) where serious injury occurred, the aircraft inadvertently left the runway, and/or substantial damage occurred (374). Approach and landing accidents in air carriers, representing 25% of all air carrier accidents during the period 1948 through 1958, were reviewed in a cooperative Flight Safety Foundation/Boeing Airplane Company/Air Line Pilots Association study of 437 accidents [1960 (377)]. The Newman study, or the NTSB Annual Reviews of Aircraft Accident Data, U.S. Carrier Operations, provide further references and data.

2.2.2 Ground Emergency Egress. In recent years there has been more widespread awareness of air transport safety failures, and to some extent emergency egress problems, due to television documentaries [Bergman, 1974; 1975 (381)] and publication of books in the general literature [Halacy, 1961 (394); McClement, 1966 (405); Lowell, 1967 (404); Serling, 1969 (422); and Godson, 1974 (393)]. One of these, Runway: Anatomy of a Major Crash [Godson, 1974 (393)], examines in great detail a single accident, that of the crash of the Capitol International Airways McDonnell Douglas DC-8-63 at Anchorage, Alaska on 27 November, 1970. At present neither the NTSB nor FAA formally keep records of successful evacuations since there is no requirement for this, although the Emergency Evacuation Laboratory at the FAA Civil Aeromedical Institute in Oklahoma City attempts to keep track of these through cooperation of the air carriers. This makes it difficult to assess the overall reliability or effectiveness of current systems, since only the failures attract notice. However, these occur frequently enough so that problems have been well documented.

There have been a large number of accident reports (399; 410-418; etc.) and some human factors studies (382; 385; 388; 400-402; 406-409) which have recorded current experience and these should be referred to for more detailed information. In addition, several special reports and reviews related to civil air carrier accidents are available [Carroll, 1962 (385); Dougherty, 1966 (387); Doyle, 1967 (388); Flight Safety Foundation, 1968 (389); Haley, 1967 (395); Hasbrook, 1958 (396); Henneberger et al., 1964 (398); Hoffman et al., 1976 (399); Shuckburgh, 1975 (423); Snow et al., 1970 (424); Snyder, 1976 (425); and Tillman, 1956 (426)]. Studies of military air transport evacuations are found in Reagin et al. [1969 (13)], Sawyer [1957 (16)], Snyder and Robbins [1971 (21); 1972 (22)], USAF Industry Life Support Conference [1967 (23)], and Haley [1967 appendix II (395)]. Emergency evacuation tests from the Lockheed C-141 have been conducted by McIntire [1967 (406)], of the Lockheed (Galaxy) C-5A by the USAF [1970 (427)], of the McDonnell Douglas (Nightingale)C-9A by Chesterfield [1969 (384)], of the Lockheed 1649 by Garner and Blethrow [1966 (390)], and of the SST by Garner and Blethrow [1970 (391)]. Many other evacuation compliance tests have been conducted by the airfoam manufacturers and the air carriers; some of the most interesting being tests conducted in the Concorde supersonic transport certification program [Anstey & Brownbill, 1975 (421)].

Undoubtedly the model professional study in the field is the Snow, Carroll, and Allgood FAA/CAMI report of three air carrier accidents (United Airlines McDonnell Douglas DC-8, Denver, 11 July, 1961; United Airlines Boeing 727, Salt Lake City, 11 November, 1965; and Trans World Airlines Boeing 707-331, Rome, 23 November, 1964) in which a total of 105 of the 261 passengers aboard the three aircraft died in the lethal thermotoxic environment within the cabin one to three minutes post-impact, despite "mild" crash deceleration forces and "minimal" cabin destruction [Snow et al., 1970 (424)]. Other earlier major studies have been conducted by Bruggink [1961 (382)] of three reciprocating engine transport accidents. Pioneering air transport studies were published by Cornell University Medical School of a 1952 Northeast Airlines Convair 240 crash at LaGuardia (386), and by Hasbrook of gross pattern of injury of 109 survivors of five reciprocating engine transport accidents [1958 (396)]. Typical of the trend toward attempting to relate medical and human factors to the crash environment is the study by Joensen and Joensen of the crash of a Scandinavian Airlines Fokker F-27 into a mountain in the Faroe Islands (Sweden) on 26 September, 1970 (401). More recent human factors studies conducted by the NTSB Human Factors Branch have resulted in excellent in-depth reports. A few examples include the Capitol International Airways McDonnell Douglas DC-8-63F at Anchorage, Alaska which crashed on 27 November, 1970 [Leroy, 1971 (402, 403)], the Pan American World Airways Boeing 707 crash at Pago Pago, American Samoa [Burgin, 1974 (383)], or the Continental Airlines Boeing 727 crash on takeoff at Denver on 7 August, 1975, resulting in injuries to 55 occupants [McCormick, 1976 (433, final report not yet released)].

The United Airlines McDonnell Douglas DC-8 accident at Denver in 1961 also resulted in a separate FAA/CAMI analysis of the evacuation pattern by Hasbrook, Garner, and Snow [1963 (397)]. In this accident 16 of 122 occupants died of carbon monoxide poisoning, even though the impact was of low force and the cabin area was virtually intact. A post-crash fire outside the aircraft generated a large volume of dense smoke and noxious fumes which funneled through the passenger cabin as soon as the exits were opened. It was found that the 16 fatally overcome passengers, along with 65 other passengers, occupied a cabin area in which aisle width was minimal and only one door exit was available for emergency escape at the extreme rear of the compartment. In addition, there was no placard or other sign in the compartment indicating the existence of emergency exits in the forward (first class) section. It was also determined to be "virtually impossible" for cabin attendants in the tourist section to go forward and accelerate the passengers toward the rear exit due to the narrow aisle width. Ironically, in contrast, the first class cabin had three emergency exits available for only 41 occupants, and aisle width was 40% greater than that in the tourist section. Prior to this incident no emergency evacuation instruction was given to the passengers. Available fire-fighting equipment was unable to contain or control the post-crash fire in time to prevent smoke from entering the cabin.

Due to the increased use of wide body air transports a brief review of the emergency evacuation problems encountered in two accidents involving such aircraft may provide a typical illustration of current problems. In the first case, a Pan American Boeing 747 struck the Approach Light System (ALS) structure at the departure end of the runway while taking off from San Francisco International Airport on 30 July, 1971 (191). The flight had 199 passengers and a crew of 19 aboard. At contact with ALS, which penetrated the passenger compartment, two passengers (seats 47G and 48G) were seriously injured. A section of angle iron nearly severed the left leg below the knee of the passenger in seat 47G, and severely lacerated and crushed the left upper arm of the passenger in seat 48G. A second piece of angle iron penetrated the floor of the cabin and impaled seats 45F, 46F, 47F, and 48F, but as the seats were unoccupied, there were no injuries. A third section of angle iron passed through other unoccupied seats and lavatories. At this time this resulted in three sections of the ceiling panels falling to seat-top level, causing no injury but effectively blocking access to and egress from this area of the forward economy section. In addition, several overhead baggage compartment doors came open, the movie screen near the right No. 1 exit fell to the "down" position, blocking the view and movement from the aisle to the exit, and the complete passenger escape slide rack fell from the left No. 4 door (See Fig. 13). Passenger shoes were put in the lavatory.

The aircraft continued in flight for 1 hour and 42 minutes while the flight crew assessed the structural damage and dumped fuel over the ocean. After returning and landing, the aircraft veered off the right side of the runway and came to a stop in the dirt approximately 1,600 m (5,300 ft) from the approach end of the runway. Fire was observed on and around the left wing main landing gear as the aircraft was veering off the runway, but extinguished itself. Passengers were briefed concerning the emergency landing and impending evacuation; there was no announcement over the public address system to evacuate the aircraft. The first officer inadvertently transmitted the order to evacuate on the tower frequency rather than on the public address system. Overhead luggage racks opened during the landing and dumped their contents into the cabin. The second officer and second flight engineer came down from the flight deck, shouted to the cabin crew to start the evacuation, and opened the No. 1 right and left exits and the right No. 2 exit. Although they did not hear the verbal command to start the evacuation, cabin attendants toward the rear of the cabin opened their assigned exits when they saw the evacuation activities in the front of the cabin. The available self-powered "bullhorns" were not used.

Motion pictures taken of the landing showed that right and left exits No. 1 were opened 30 seconds after the aircraft came to a stop. The right No. 2 exit was opened in 38 seconds, right exit No. 3 opened in 48 seconds, left and right exits No. 5 opened 1 minute 10 seconds after the aircraft stopped. The first occupant evacuated (right No. 1 exit slide) 43 seconds after the aircraft stopped, and the first occupant to use the left No. 1 exit slide did so 56 seconds after stopping. The evacuation of approximately eight passengers from the forward section of the aircraft, in addition to the movement of passengers to the rear of the passenger cabin because of failure or partial failure of emergency egress slides at five of the ten exits (L-2, L-3, L-4, R-4, L-5) resulted in a shift of weight which caused the aircraft to tilt back on the rear fuselages. This occurred as the right No. 5 door was opened (Fig. 14), and resulted in slide L-1 slanting aft. This slide was not used until someone on the ground pulled the slide to a more normal position. Slide L-2 was blown back across the wing and parallel to the fuselage, and was not usable. Slide R-2 extended in a horizontal position until a passenger entered the slide. The left-over-the-wing slide L-3 was not used because the slide portion over the wing flap to the ground did not inflate. The gas generator for this slide was in the left body gear wheel well and the trigger mechanism had sustained impact damage. The L-4 slide had fallen to the floor during the takeoff and was not usable. The R-4 slide did not inflate. The gas generator bottle, mounted in the upper portion of the door structure, had shifted toward the center of the aircraft and misaligned the trigger mechanism and the bottle. Slide L-5 was jammed under the fuselage as the aircraft tilted to the tail-down position. The exit floor was then about 1.5 m (5 ft) above the ground and some passengers utilized the exit by jumping to the ground. The forward exit slides became almost vertical as the aircraft settled back on its tail. At least four persons were observed using slide L-1 and others used R-1 after the aircraft tilted. Eight passengers were hospitalized with serious back injuries after they used the No. 1 slides. Nineteen other persons received minor cuts, abrasions, contusions and sprains during the evacuation. There was no record of the total elapsed time required to complete the evacuation. Fortunately there was no smoke or fire to affect evacuation.

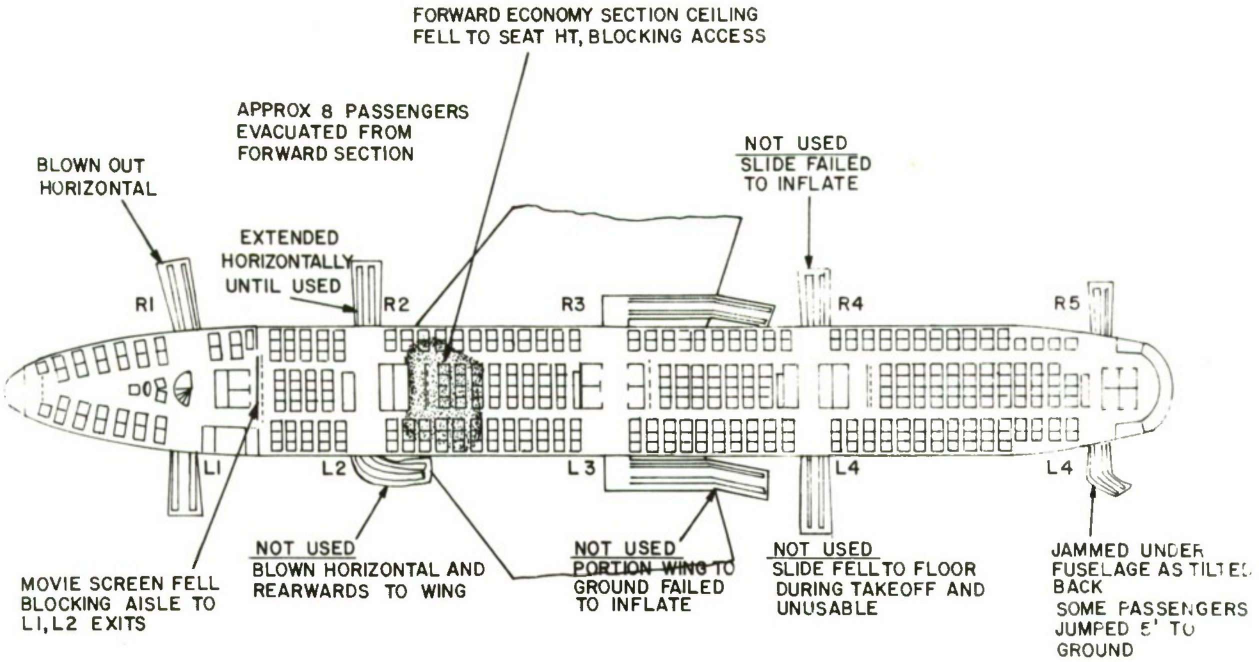


Fig. 13. Diagram of emergency egress hazards contributing to injuries in this Boeing 747 accident.

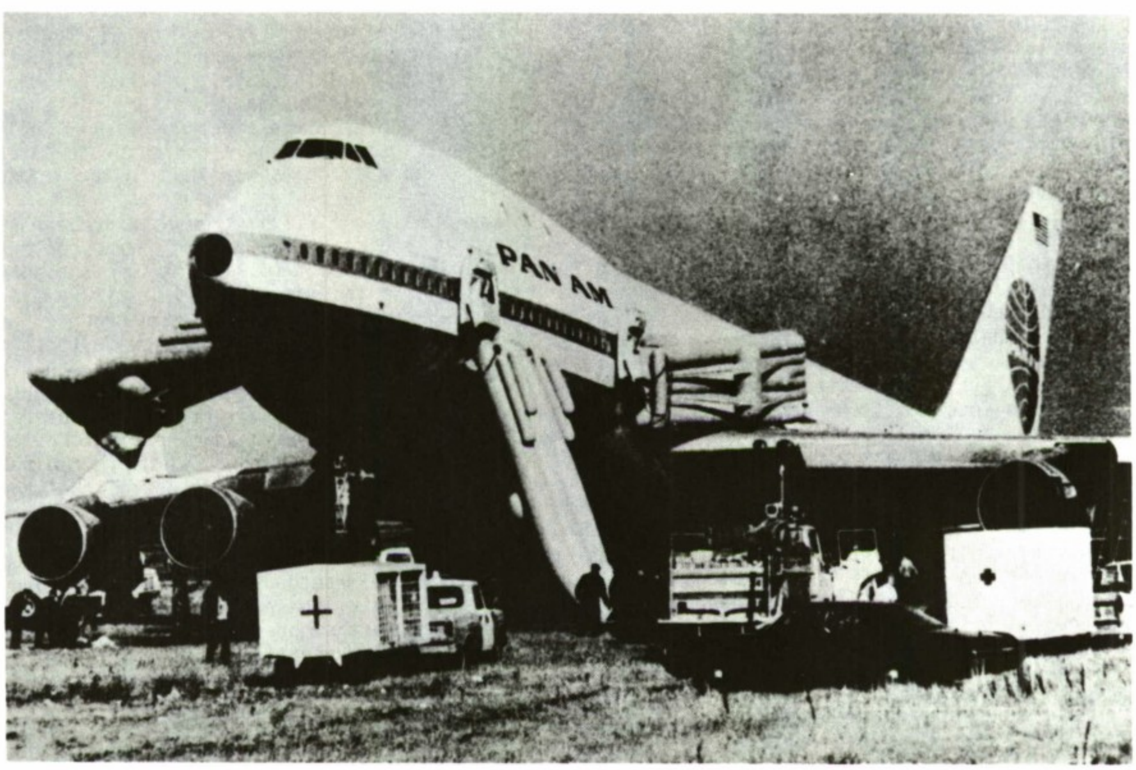


Fig. 14. Pan American Boeing 747 accident at San Francisco 30 July, 1971, resulting in nose-high attitude. 27 injuries were suffered in the subsequent evacuation. Note wind effect on left (L-2) slide, blown aft almost parallel to the wing, and right side (R-1) escape slides. The vertical deployment of left L-1 escape slide resulted in an almost vertical drop of approximately 27 feet (or a 3-story drop). (Photo courtesy NTSB. See ref. 191.)

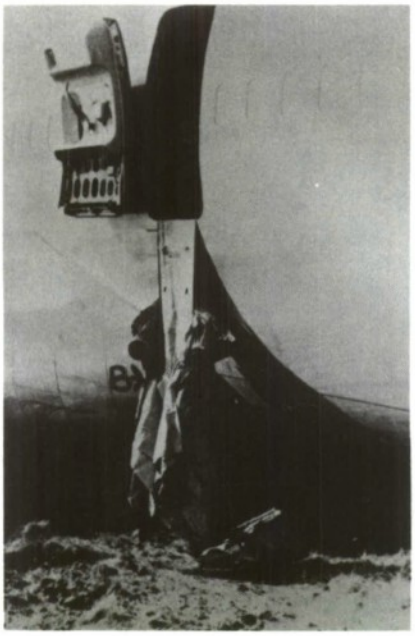


Fig. 15. Evacuation slide failure in Pan American Boeing 747 accident.

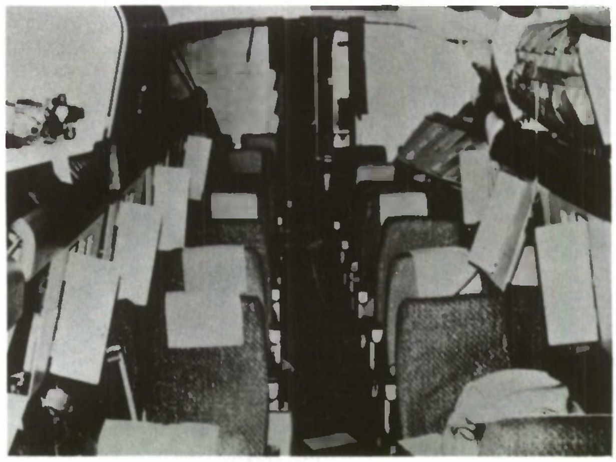


Fig. 16. Obstacles to passenger egress in Icelandic Airlines McDonnell Douglas DC-8-61 "hard landing" included failure of hat racks, injuring passengers, and failure of overhead compartments, spilling life rafts and an emergency escape slide pack into the aisle.

Typical obstacles which may impede passenger evacuation in an accident are shown in Fig. 16. In this case an Icelandic Airlines McDonnell Douglas DC-8-61 experienced a "hard landing" on 23 June, 1973 at John F. Kennedy International Airport, New York. Subsequent to impact the No. 1 engine broke off and a fire erupted in the engine pylon. Of 119 occupants, 30 received minor injuries and 8, including two stewardesses, were seriously injured due to the "hard landing." However, factors influencing this night evacuation included failure of the hatracks in the cabin, injuring passengers and creating egress obstructions; the overhead compartments spilled life rafts into the cabin aisleway; and the emergency escape slide pack on the right rear service door broke loose from its mounts.

Evacuation can be hampered by other final orientations of the aircraft fuselage, which may render some emergency exits hazardous or unusable. For example, in a Northwest Orient Airlines Boeing 747 accident at Miami on 15 December, 1972 (244; 411), birds were ingested on takeoff, the nosegear collapsed after striking a concrete abutment, and the aircraft came to rest in a tail-high attitude (Fig. 17). No one was injured in the crash; however, four occupants received minor injuries in the evacuation, which was accomplished in about 2 minutes. In this case the 2 rear exits were unusable, and one evacuation slide failed to inflate, rendering that exit also unusable.

In a fourth case, a Trans World Airlines Boeing 747 was involved in an evacuation accident on 1 September, 1972, at the John F. Kennedy International Airport, New York, during which 8 passengers were injured seriously and 72 received minor injuries (409). During taxi out for takeoff, a fire and smoke from the left body landing gear precipitated the night evacuation. An evacuation alarm was used to initiate the evacuation and all but about 70 of the 335 passengers aboard evacuated the aircraft via emergency evacuation slides. The evacuation continued while the aircraft engines were still running, and most of the 80 injuries resulted when passengers were blown down by exhaust blast from the engines. Other injuries were attributed by investigators to passengers deplaning with carry-on baggage and to passengers piling up at the bottom of the evacuation slides. The slides were not illuminated by emergency exterior lighting, and passengers landed on a hard surface (taxiway). Three of the evacuation slides were deployed near the fire, and poor coordination and communication between crew members was found (411).

The Aerospatiale/British Aircraft Corporation Concorde represents the newest NATO air carrier aircraft. Due to its increased performance over other types, of a maximum cruising speed of 2,179 km/h (1,354 mph) TAS or Mach 2.05 at 15,635 m (51,300 ft), it has presented a number of new problems related to safety. On 10-11 February, 1975 emergency evacuation certification demonstrations were carried out to demonstrate to the Franco-British airworthiness authorities that the Concorde met requirements of TSS Standard 5-2 (issue 5, paragraph 9.2) [Anstey & Brownbill, 1975 (421)]. In such certification tests, regulations require that the manufacturer demonstrate that the maximum number of passengers which can be carried can be evacuated within 90 seconds to the ground or ramp steps using only the exits on one side of the aircraft. (For U.S. certification this is specified in FAR 25.803[c].) In these tests 134 persons (3 flight deck crew, 3 cabin attendants, and 128 passengers) successfully evacuated in 85 seconds average time, using three (right side) of the six slides available in this aircraft. In two of the three trials, each of the three slides used operated normally and a rate of 50 persons a minute was achieved on the front right slide on one evacuation test.

It is interesting to note that during the second of the three trials, the forward right slide unit deployed but failed to inflate, the threshold emergency light was inoperative, and the manual inflation handle was not pulled. In addition, the right center slide was punctured on the underside of the inflated walkway, making the slide portion unstable at its upper end. This center unit continued to be used in the

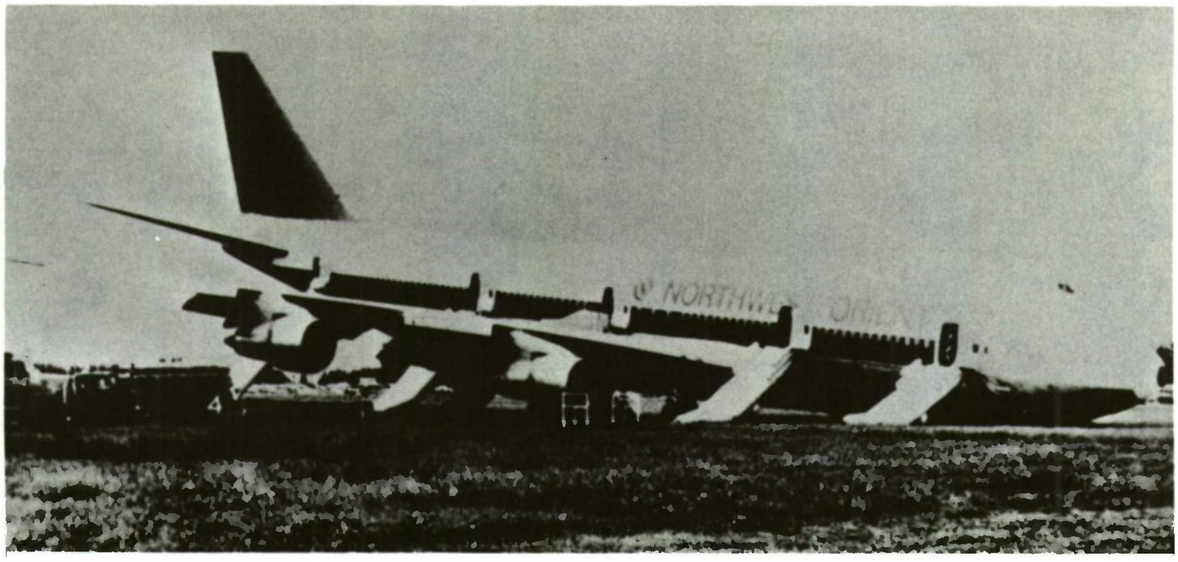
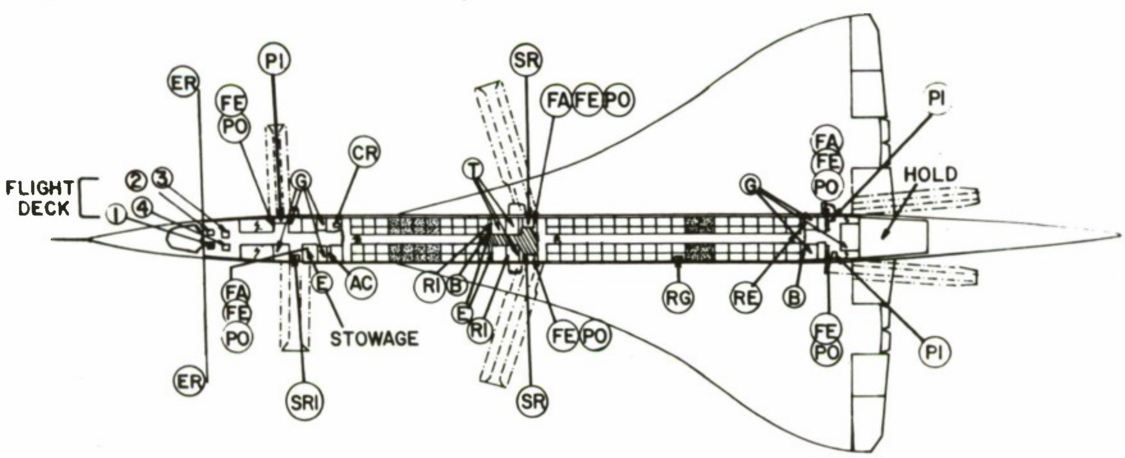


Fig. 17. Tail-high attitude in this Miami Boeing 747 accident rendered the rear emergency evacuation slide unusable (Photo courtesy Wide World Photos).

test but the sliding rate decreased to 35 persons per minute (compared to 40 in the first trial, and 46 in the third). The second trial was abandoned after 90 seconds. Analysis of the second evacuation trial indicated that the unusability of the forward exit, uncertainty concerning safety of the center slide, and absence of cabin attendants in other than the exit doorways to redirect evacuees, all contributed to the slower (and possibly more realistic) evacuation test. A total of eight evacuees, all females, were injured in these three tests, and this suggests that emergency evacuation injuries may also be of concern with this new aircraft. As with other current wide body air carriers, the height above the ground of the exit doors when the gear is down is impressive, being 4.95 m (16 ft, 3 in) to the sill of the forward exit [Taylor, 1975 (65)]. However, as was noted in previous accidents, evacuations of wide-bodied air carriers such as the 8oeing 747, can present hazardous situations when the sill height results in a high vertical drop of evacuees. Fig. 18 illustrates the various safety features and emergency exit locations of the Concorde aircraft, as positioned on production aircraft number 204, used in the certification tests of February, 1975.



KEY

T TOILET
AISLE CURTAINS (LEFT OPEN DURING EVACUATION TRIAL)
E EMERGENCY PACK (WITH CANOPY FOR SLIDE RAFT)
G GALLEY
A AMENITY STOWAGE
B RAOIO BEACON
AC ACCELEROMETER
ELECTRICS & ELECTRONICS

SMI SLIOE RAFT WITH INTEGRAL INFLATION
SM SLIDE RAFT WITH REMOTE INFLATION
PI SLIDE WITH INTEGRAL INFLATION
RI REMOTE INFLATION AIR BOTTLE
RE LIFERAFT WITH EMERGENCY PACK
ER ESCAPE ROPE
FA FIRST AID KIT
FE FIRE EXTINGUISHER
PO PORTABLE OXYGEN BOTTLE
IS STOWAGE (INSTRUMENTATION)

RG RATE GYRO
AIRCRAFT SEAT UNITS
RAISEO FLOOR IN CENTRE VESTIBULE AREA
TERMINAL AISLE WIOTHS 15" MINIMUM BELOW 25" FROM FLOOR 20" MINIMUM ABOVE 25" FROM FLOOR

FLIGHT DECK
1st-1st PILOTS SEAT
2nd-2nd PILOTS SEAT
3rd-3rd CREW MEMBER'S SEAT
4th-1st SUPERNUMERARY'S SEAT (NOT USEO)

Fig. 18. Cabin layout, safety features, and emergency egress exits on the Concorde, as configured in production aircraft number 204, used in certification tests of February, 1975 (421).

2.2.2.1 Review of 1973-74 Accidents. All reported air carrier accidents for NATO countries during the period 1964-1974 have been tabulated in Appendices A and B and should be referred to for additional information. In addition, preliminary accident data for 1975, obtained from the U.K. Civil Aviation Authority [World Airline Accident Summary supplements 25 and 26 (99, 100) to 30 September, 1975], and from Preliminary Accident/Incident Resume Reports of the NTSB for 1975, are tabulated in Appen. C, D. However, to illustrate the current problems in crash impact and emergency evacuation, 22 accidents occurring during 1973-1974, the most recent period for which final reports are currently available, have been summarized in the following.

1974

(1) On 30 January, a Pan American Boeing 707 collided with runway lights in landing at Pago Pago, American Samoa, with subsequent gear collapse. Of 101 occupants, 96 were fatally injured. Although the cabin structure remained intact and occupant restraint systems were adequate for the impact forces, primary emergency exits were not opened by crew. Passengers also crowded to the front and rear exits, ignoring the window exits. All survivors were seated in the middle of the cabin and had observed the preflight briefing. The only fatal impact injury reported was to the copilot, and 5 survivors received injuries. All other deaths were attributed to the post-crash fire, in what should have been a survivable crash (276).

(2) A TWA Boeing 707 with 65 aboard was involved on 16 January in an excessively hard landing at Los Angeles, resulting in collapse of the nosegear. In the subsequent fire the aircraft was destroyed, but injuries to 8 passengers were attributed to the emergency evacuation and none to flames. The aircraft was evacuated in 30-45 seconds (270).

(3) On 6 January a Beechcraft 99 operated by Air East crashed at Johnstown, Pennsylvania, while descending below published minimum descent altitude (MDA). Due to the high vertical loads, this accident was judged not survivable, although one of the 17 occupants survived. The occupiable space was substantially reduced in the impact. While seat belts remained buckled, their floor anchorages and seat tracks failed. There was no post-crash fire, and all injuries and fatalities were due to impact (430).

(4) On 4 January a United Boeing 727 lost an engine on takeoff at Tampa, Florida, and one of 118 occupants aboard was injured in emergency evacuation (431).

(5) On 11 September an Eastern McDonnell Douglas DC-9 crashed during an instrument approach at Charlotte, North Carolina, and 72 of the 82 occupants were fatally injured. This accident was judged to be partially survivable. The fuselage fractured on impact, and the tail section, including the last 5 rows of seats, was the only part to retain any structural integrity. Fire erupted in the cabin during the crash sequence. The crash forces were estimated to be within human tolerability, but most passengers were found outside the two main cabin wreckage areas,indicating restraint failures. Restraints in the last 5 rows remained intact, but most occupants who survived the crash there died due to post-crash fire. The auxiliary exit through the tail was usable, but the attendant was probably unable to open it because of her injuries. All survivors in the rear of the aircraft were either thrown out of the wreckage or crawled through holes in the fuselage. Three survivors in the forward section, including the copilot and a stewwardess, egressed through the cockpit window. Thirty-one passengers and one crew member died from impact. Twenty-five passengers died from burns and smoke inhalation, and the death of one passenger was attributed to smoke inhalation only. Five passengers in the aft area of the cabin died from a combination of factors. It was noted that survivors wearing double-knit clothing received more severe burns (432).

(6) On 20 November a Lufthansa Boeing 747 crashed at Nairobi Airport when the pilot failed to extend the leading edge slats on takeoff. In the subsequent crash which occurred shortly after the aircraft became airborne, 59 of 157 occupants aboard died, and 20 were injured. No information is available on the evacuation, human factors, or cause of fatalities and injuries (99).

(7) On 29 October a Panarctic Oils Lockheed L-188 mixed cargo freighter crashed on 20 cm (8 in) sea ice short of the runway during an instrument approach to Rea Point, Northwest Territories, Canada. Of 34 aboard, only two survived. The fuselage separated behind the cockpit, and all seats (behind the cargo section) were torn out. Fire broke out, and the aircraft sank in the sea. It was determined by Canadian authorities that 16 of the 32 killed had potentially survivable impact injuries, 5 surviving longer than 15 minutes, 4 between 10 and 15 minutes, and 7 surviving less than 10 minutes, of which 6 had drowned. Some belts may have had inadvertent impact release, as chafing on some of the cams on fabric-type belts showed that the passenger had worn the belt, although thrown out of the seat in the impact. None of the crew wore the upper torso restraint. Seats failed at floor tracks. All passengers were thrown to the front of the aircraft in the impact, although the aft door T-handle was found up and the door opened. Vertical loads of 16-20 G were estimated; the captain (who drowned) and copilot receiving lumbar vertebral compression fractures (110).

(8) On 28 February an Aer Turas Douglas DC-7 overran the runway during landing at Luton, England. Injuries to a crew member and one passenger, of 11 aboard, were attributed to not having restraints secured (99).

(9) On 8 February a Union de Transports Aeriens (UTA) McDonnell Douglas DC-8 aborted takeoff at Los Angeles due to fire in the landing gear area. Of 162 occupants aboard, one passenger broke an ankle during evacuation. (See Appendix B.)

(10) On 26 January a Turk Hava Yollari (THY) Fokker 28 crashed on takeoff at Cumaouasi, Turkey with 72 aboard, with fatalities to 7 and injuries to 65. No information is available concerning emergency egress or injury causation (99).

(11) On 1 January an Itavia Fokker 28 crashed during approach near Turin, Italy, with 42 aboard. In the post-crash fire 4 were injured and 38 killed. No information concerning emergency egress or injury causation is available (99).

1973

(12) On 27 November an Eastern McDonnell Douglas DC-9 overran the runway at North Canton, Ohio, plunging down an 11.6 m (38 ft) embankment. There was no post-crash fire, and high vertical impact forces accounted for all injuries. The cabin and cockpit remained intact, but some head injuries were caused by the collapse of overhead racks onto seat backs during final impact, which also interfered with use of over-wing exits. Evacuation was orderly and effective; however, all 26 occupants were injured in the crash impact (273).

(13) On 17 December an Iberian McDonnell Douglas DC-10 struck approach lights during an instrument landing system (ILS) approach into Boston's Logan Airport. Of 167 occupants, 16 received injuries from evacuation. After the first impact the captain's seat became loose and slid to its aft limits of travel. The post-crash fire was extinguished before spreading. Cabin attendants could not open three of the exit doors. Aft cabin floor buckling caused failures of some restraint components, but no seats became completely detached. Aisle blockage trapped 5 persons in the aft cabin. Four escaped through a fracture in the top of the fuselage, and three of these were hospitalized when they slid off the fuselage (275).

(14) On 28 October a Piedmont Boeing 737 overran the runway on landing at Greensboro, North Carolina. Five of 96 occupants were injured. Cabin evacuation was orderly. Small post-crash fire outside of the fuselage caused no injury (266).

(15) On 3 November, after number three engine disintegrated in flight near Albuquerque, a National McDonnell Douglas DC-10 with 128 aboard experienced an explosive decompression, fatally extracting one passenger out a window. Smoke filled the aft part of the cabin following decompression. The deployment of passenger oxygen masks was unsuccessful in some parts of the cabin, and took as long as three minutes in others. Twenty-four injuries were due to decompression and smoke inhalation (255).

(16) During an ILS approach to Chattanooga, Tennessee, a Delta McDonnell Douglas DC-9, with 79 aboard, crashed on 27 November. The impact was survivable, with the fuselage retaining its structural integrity. Scattered fires occurred around the fuselage, but died out or were extinguished. A flash fire occurred in the rear of the cabin but caused no serious injuries. Emergency lighting was either inoperative or obscured by heavy smoke from fire in the baggage compartment, making visibility very poor and hampering evacuation. Debris in the aisle from the galley also interfered with movement. The evacuation was completed in two to three minutes. All 42 injuries were reported to be as a result of impact (274).

(17) An Overseas National Airways (ONA) McDonnell Douglas DC-8 aborted takeoff after tire failure at Bangor, Maine on 20 June. Fire occurred in the landing gear area. Evacuation of the 261 occupants did not begin until three minutes after the aircraft came to a stop. There was confusion as to the location of the fire. The left engines were left idling for more than three minutes after the aircraft stopped and for nearly two minutes after the door light came on. Not all of the attendants were at stations, and they did not use megaphones, so no clear instructions were given to the passengers. Three injuries were sustained during evacuation (257).

(18) On 23 June an Icelandic McDonnell Douglas DC-8 deployed full spoilers inadvertently just before landing at New York with 128 aboard. Severe vertical loads on the subsequent crash landing caused 8 impact injuries. Post-crash fire was quickly extinguished. Evacuation was orderly (253).

(19) On 22 July a Pan American Boeing 707 crashed after takeoff at Papeete, Tahiti, killing 78 of 79 occupants. The investigation was conducted by the French government.

(20) An Ozark Fairchild 227B with 44 occupants crashed at St. Louis on 23 July while shooting an ILS during thunderstorm activity. Although this could be classed as non-survivable due to high impact loads and severe damage, the two pilots were the only survivors. All but one passenger seats were torn loose from the floor. Three seat belts failed. The cockpit remained relatively intact, but the pilots' injuries could have been greatly reduced had they been wearing shoulder harnesses. A cabin attendant was killed by cargo after the cargo net failed (263).

(21) On 10 April an International Vanguard Invicta crashed into mountainous terrain while executing a missed approach near Basle, Switzerland. Of 145 occupants, 108 were killed and 36 received injuries. However, details of the evacuation and crash are not available (99).

(22) On 11 July a Varig Boeing 707 with 134 occupants aboard had heavy smoke come into the cabin from a lavatory during descent to Orly, Paris. Attempts to distinguish the source of the smoke were unsuccessful. The flight crew were unable to see their instruments due to the smoke, so a forced landing was made in a level area 6.4 km (4 mi) from the airport. The resulting crash landing was survivable. Seven occupants escaped through cockpit windows, two attendants through the left forward door, and one through the right galley forward door. All 116 deaths were due to CO_2 or toxic gas inhalation, and there were no survivors aft of the galley. Only the flight crew used oxygen masks through the period. The aircraft was destroyed by post-crash fire

2.2.2.2 Summary of Emergency Egress Problems. As can be seen from the summaries of 1973-1974 accidents, as well as the preceding cases noted, the cause of the injuries or fatalities is not always clear from the accident investigations. The crash impact is identified as having resulted in 81 injuries during this period and at least 107 deaths, not counting fatalities in non-survivable accidents. But since many of these fatalities from impact probably also involved cabin areas which were non-survivable, injuries from this cause are difficult to assess without more precise factual reports. In the Ozark crash (No. 20) (263), note that the pilots received injuries due to not using their shoulder harnesses, while in the McDonnell Douglas DC-10 explosive decompression (No. 15) (255), the passenger sucked out a window was wearing a lap belt loosely. A large number of seat track and restraint failures are observed in the accidents involving higher impact loads.

It is important to note the 112 deaths and 81 injuries attributed to smoke inhalation and toxic fumes.

As is discussed in greater detail in Section 3 (relative to smoke hoods), smoke, fire, and toxic gases have been shown to be a major cause of fatalities in survivable accidents. Of particular note is an earlier accident which occurred 27 November, 1970. In this instance, a Capitol International Airways Military Air Command (MAC) charter McDonnell Douglas DC-8-63F aircraft crashed during an attempted takeoff in freezing rain at Anchorage, Alaska [Leroy, 1971 (402, 403)]. Fire occurred before the aircraft came to rest, followed by several explosions. Forty-five passengers and one cabin attendant did not survive because they failed to evacuate the aircraft--a 46th passenger died the following day. One hundred seventy-three passengers and 9 crew members survived this accident.

This aircraft is normally configured to carry 250 passengers with 45 rows of seats and a 46th row single seat on the right side. However, when used for military charter, the configuration is changed to 219 passengers to allow more space between rows. There were 219 passengers and a crew of ten aboard for a total of 229 occupants. Passengers included two women, three young females, and a two-week-old infant.

The crash occurred without prior warning. While the aircraft was still moving, the left overwing exit was opened and fire came into the cabin. Upon a second impact, major structural damage occurred. At this time, with fire evident on the right side, a number of military passengers unfastened their lap belts and reportedly attempted to get away from the fire area, but were caught by the third impact, which threw them forward and injured several of them. Some seats failed; some persons found themselves outside the aircraft still strapped in their burning seats.

Five of the 12 cabin exits were not utilized because they were either jammed, blocked, or not opened. Of the two main left entry doors, one was jammed and inoperative. There were two galley service doors; one was blocked and inoperative and the other partially blocked. Of the four jet escape exits, the two forward exits operated effectively, but the two aft exits were not opened. Three of the 4 overwing exits were opened. The cockpit/cabin door was blocked by 1.2 m (4 ft) of debris. One of the left-hand forward escape slides ended in a pool of fire.

There was a failure of the emergency exit lights, which might have contributed to some failures to evacuate. Since survivors had been seated in all parts of the aircraft, it has been termed a survivable accident. All deaths were attributed to fire and smoke inhalation, although cyanide was also found in the smoke. Eighteen of 19 blood samples taken at random from survivors exhibited carbon monoxide saturations of from 17.3% to 68.6%. An interesting finding, similar to that found in the Salt Lake City Boeing 727 crash, was mechanical obstruction of the trachea, bronchi, and bronchioles by a black carbonaceous material evidently produced in the cabin fire. Human factors study of this crash is not yet complete; however, the pattern of fatalities due to fire and smoke inhalation is similar to that of previous major survivable accidents and emphasizes the need for an emergency protective smoke hood and adequate emergency exit lighting, and suggests the need for improved egress exits.

Numerous airline non-crash evacuations have occurred. Further, the possibility of emergency evacuation occurring which is not initiated by flight crew, or one which progresses without the flight crew's awareness, should be considered on the basis of two such occurrences in 1971. In April, a TWA Boeing 727 had landed at O'Hare International Airport, but because a gate was not yet ready, had to hold on the ramp. The flight engineer attempted to start the auxiliary power unit (APU) but unbeknownst to the crew, flame from the APU start was observed on the right side of the aircraft by some passengers and a TWA supervisory stewardess riding as a non-revenue passenger. As a result, an emergency evacuation was initiated through the two left window exits and subsequently through the rear stairs. The three scheduled stewardesses were not aware that an evacuation was in progress until they saw passengers leaving by these exits. The flight deck crew was completely unaware than an evacuation was in progress (opening overwing does not activate any cockpit warning lights). They were about to continue taxiing when the forward stewardess knocked on the cockpit door, and concurrently a warning light went on as the rear door was opened. The flight deck crew then shut down and advised passengers to exit through the rear stairs. No emergency evacuation alarm was sounded. Four serious and 7 minor passenger injuries occurred in jumping from the left wing landing edge 2.7 m (9 ft) to the concrete ramp (435).

The second case occurred on 15 May, 1971, involving a United Airlines McDonnell Douglas DC-8 with 45 passengers and 7 crew aboard. Prior to boarding at San Francisco, the crew had been alerted to a bomb threat. As the first engine was being started, a pneumatic air hose broke loose and began to flail about, knocking down the ramp crewman and disconnecting his interphone. The explosive noise of the hose parting and subsequent unidentified noise of the flailing against the aircraft caused the nervous stewardess to commence evacuation. Overwing exits, rear exit slide, and an aft exit slide were employed, and the aircraft was evacuated in 40 seconds. Six passengers received serious injuries when they jumped to the ramp from the wings (433). The subsequent evacuation of a Pan American World Airways Boeing 747 at San Francisco on 30 July, 1971, as noted in Section 2.2.2, also has pointed up problems with emergency evacuation equipment and shown that a new generation of escape devices will require new techniques (434).

During this 1973-1974 period 29 individuals were reported to have received injuries during evacuation from the aircraft post-accident. This would clearly indicate that attention should be given to improving egress techniques to provide greater safety in slide and exit design. Among other problems noted in these cases were failure of the emergency lighting system, non-use or failure of the emergency public address system, and failure of the emergency oxygen mask system. Heavy smoke in the cockpit caused the emergency crash landing of the Varig Boeing 707 near Paris and caused the fatal crash of a Pan American Boeing 707 freighter at Boston. Post-crash fire occurred in most instances, although was often extinguished early.

The recent special study by the National Transportation Safety Board examined 10 recent U.S. air carrier accidents in which an emergency evacuation occurred [1974 (411)], and should be referred to for further details. The factors which most commonly were identified as influencing emergency egress were: weather, terrain, aircraft attitude, fire and smoke, evacuation slides, emergency lighting, emergency communications equipment, obstructions to egress, passenger preparedness, crew member training, and crew member procedures. This resulted in 10 safety recommendations concerning needed improvements in evacuation slides, megaphones, public address systems, passenger briefings, emergency lighting, and crew member training.

The full tabulation of accidents (Appendices A-D) also indicates a surprising number of serious in-flight injuries occurring as a result of non-restrained passengers during encounters with turbulence. While this discussion of current accident performance has been brief, examination of summary data shows that impact, fire, smoke, and toxic hazards, and emergency egress remain major problems requiring better occupant protection techniques.

2.3 Military Air Transport Experience

Air transports designed or modified for military operations may present some different problems than those in civil use relative to emergency egress and occupant protection. Factors may include alternative seating configurations for each model, which may include side-facing troops or mixed cargo, different requirements and procedures for emergency aisle or exit identification and usage, and other operational procedures.

Since aircraft configuration relative to high- or low-wing may play a role in the problem of occupant protection and egress, a comparison of a typical high-wing transport, the Lockheed C-141, with the low-wing Boeing C-135 was reported in a 1971 University of Michigan study conducted for the U.S. Air Force [Snyder & Robbins, 1971 (22)].

2.3.1 USAF Lockheed C-141 High-Wing Transport. In this study a total of 14 Lockheed C-141 accidents were reported as of November, 1971, and these are summarized in Table VI. Only two accidents involved crash environments, and in both cases the aircraft were destroyed. Both must be classed as non-survivable accidents, although one involved a crash into the sea in which two survivors escaped through the open fuselage. From a crash protection or emergency egress viewpoint, these cases provide little additional accident performance information.

TABLE VI.

SUMMARY OF USAF LOCKHEED C-141 ACCIDENTS
Jan., 1966 - Nov., 1971

Day/Night	Total Occup	Survivability	Injuries Pilot	Injuries Crew	Injuries Passengers	Circumstances and Egress Comments
1. Day	7	No crash	2 none	5 none		Ldg and go-around damage.
2. Day	7	No crash	2 none	5 none		Minor damage.
3. Day	7	No crash	2 none	5 none		In-flight explosive decompression.
4. Day	7	No crash	2 none	5 none		In-flight hail damage.
5. Day	5	No crash	2 none	1 serious 2 none		In-flight evasion to avoid mid-air collision - engineer unrestrained.
6. Day	68	No crash	2 none	11 none	1 major 1 minor 53 none	Air evacuation. In-flight turbulence. 2 nurses unrestrained.
7. Dusk	32	No crash	2 none	5 none	1 fatal	Night drop. Paratrooper fatality.
8. Day	8	No crash	2 none	6 none		In-flight hail damage.
9. Day	8	No crash	2 none	6 none		Precautionary ldg.
10. Night	8	No crash	2 none	1 major 5 none		In-flight explosive decompression.
11. Day	7	No crash	3 none	4 none		In-flight explosive decompression.
12. Day	29	Survivable	2 none	9 none	18 none	In-flight rapid decompression and hydraulic failure. Loss of communication system, use of aft and crew entrance exits. Hand fire extinguisher. Flight deck.
13. Night	9	Non-survivable*	1 fatal	6 fatal		Takeoff crash in sea. Two survivors.
14. Night	5	Non-survivable	2 fatal	3 fatal		Aircraft destroyed in runway collision.

Source: Snyder and Robbins, 1971 (22)

* Two crew survived, but crash destroyed aircraft.

2.3.2 USAF Boeing C-135 Low-Wing Transport. A total of 30 low-wing Boeing C-135 accidents occurred involving 194 crew members and 214 passengers. Of these, 15 accidents involved no injury to crew or passengers, 11 accidents were non-survivable and fatal to all occupants, one accident could probably be classed as non-survivable (fatal to 81 of 83 occupants), and 3 accidents involved minor to major injuries. Of the 30 Boeing C-135 accidents listed in Table VII, 9 accidents provide crash evacuation performance

TABLE VII.

SUMMARY OF USAF BOEING C-135 ACCIDENTS
Jan., 1964 - Nov., 1971

Configuration	Day/Night	Total Occup	Survivability	Injuries Pilot	Crew	Passengers	Circumstances and Egress Comments
1. KC-135A	Day	5	Non-survivable	3 fatal	2 fatal		Crash into ground, catastrophic destruction. IFR approach. Material failure.
2. KC-135A	Night	8	Survivable	3 none	4 none		Overran F4C on night T.O. Emergency exits used by crew. Rope used on left pilot side but unable to use on right side. Alarm bell used.
3. KC-135Q	Night	5	Survivable	3 none	2 none		Normal ldg and wing damage. No emergency egress.
4. RC-135S	Night	18	Survivable	2 none	16 none		Ran off icy runway on ldg. Alarm bell used. Pilot and copilot windows jammed. Change pilot inertial reel lock to rt. side.
5. KC-135A	Night	6	Survivable	2 none	4 none		Aborted T.O. ran off runway. Normal exit. No crew briefing. Alarm bell used. Only 5 sets survival gear for 6 crew; no helmets worn.
6. KC-135A	Day	6	Survivable	3 none	3 none		Minor accident. 3 engine ldg. Normal exit.
7. KC-135A	Day	4	Survivable	1 none	1 none	2 none	Ldg go-around. Normal exit.
8. WC-135B	Day	9	Survivable	2 none	7 none		Ldg roll off runway. Emergency exits used. Evacuation in 45 secs.
9. KC-135A	Night	7	Survivable	2 none	2 none	3 none	Blew tires on T.O. Gear collapse on ldg. Alarm bell used. Crew evacuation through crew entry chute using escape rope.
10. KC-135	Night	6	Non-survivable	2 fatal	4 fatal		WX approach into mt. Total destruction.
11. KC-135	Day	4	Non-survivable	2 fatal	2 fatal		Crash on T.O. Total destruction. None of crew wearing restraints nor helmets.
12. KC-135A	Day	56	Survivable	2 minor	1 major 1 none	11 fatal 6 major 3 minor 32 none	Ldg short of runway. Aircraft destroyed. Emergency evacuation in 45 secs. All fatalities due to smoke inhalation; poor emergency lighting; 5 crew injuries due to improper lock on shoulder restraint.
13. KC-135	Day	9	Non-survivable	3 fatal	6 fatal		In-flight accident. Total destruction.
14. KC-135	Day	4	Survivable	1 none	3 none		Air refueling damage in flight.
15. KC-135A	Day	5	Survivable	3 none	2 none		T.O. crash. Emergency evacuation. Rope used tangled.
16. KC-135	Day	4	Survivable	2 none	2 none		Hail damage in-flight.
17. KC-135	Day	6	Survivable	2 none	4 none		Hail damage in-flight.
18. KC-135	Day	4	Survivable	2 none	2 none		F4 boom collision in-flight.
19. KC-135	Day	13	Non-survivable	8 fatal	5 fatal		T.O. crash, total destruction.
20. KC-135	Day	3	Survivable	1 none	2 none		Air refuel damage in-flight.
21. KC-135A	Dusk	14	Survivable	2 none	5 none	7 none	T.O. abort. Alarm bell used. Unable to use rear exit.
22. KC-135R	Day	5	Survivable	3 major	1 fatal 1 major		T.O. crash fire. Aircraft destroyed. Fatality due to not wearing seat belt or helmet.
23. KC-135	Night	9	Non-survivable	4 fatal	5 fatal		IFR ldg approach. Hit mt. Aircraft destroyed.
24. KC-135	Day	7	Non-survivable	2 fatal	5 fatal		T.O. crash. Aircraft destroyed.
25. KC-135	Night	5	Non-survivable	2 fatal	1 fatal	1 fatal	Ldg crash/fire. Aircraft destroyed.
26. KC-135	Night	84	Non-survivable	3 fatal	8 fatal	73 fatal	IFR T.O. crash. Aircraft destroyed.
27. KC-135	Night	5	Non-survivable	2 fatal	3 fatal		IFR ldg crash. Aircraft destroyed.
28. KC-135	Day	4	Non-survivable	2 fatal	2 fatal		T.O. dutch roll. Aircraft destroyed.
29. KC-135	Night	8	Survivable	3 none	4 none	1 none	Ldg short of runway.
30. KC-135B	Night	83	Non-survivable(?)	3 major	3 fatal 2 major	75 fatal	IFR ldg. Crashed short of runway coming to rest inverted in 3 sections. Destroyed in fire and explosions. Copilot's window jammed. Difficulty in locating crash axe.

Source: Snyder and Robbins, 1971 (22)

information of particular pertinence to this study and are summarized as follows.

Case No. 1 (these numbers do not correspond with numbers in table). A Boeing KC-135A making a 3-engine approach crashed short of the runway with 56 crew and passengers aboard. The aircraft was destroyed by post-impact fire. All 11 passenger fatalities were attributed to asphyxiation secondary to hypoxia and inhalation of smoke. This was attributed to their inability to locate or egress through emergency escape exits in the confusion resulting from fire, smoke, and inadequate warning of the emergency landing. Thirty-two passengers received no injury, 3 minor injury, 6 major injury; one crew member received major injury, one none, and the two pilots minor injuries.

In this case, investigation revealed that passengers were not briefed and the pilot did not know how many passengers were aboard. There was no announcement to passengers to prepare for landing. The crash was unexpected by the pilots, and no alarm bell was used prior to crash. Life preservers (LPV's) were not worn by the pilot or some crew members, and only 31 LPV's were worn during egress. Had this crash occurred in the ocean, some 305 m (1,000 ft) from the runway, egress from this aircraft could have resulted in more lives lost. Fire broke out in the aft section and the cargo compartment, and the flight deck filled with black smoke and apparently ammonia gas, causing panic among some passengers. Surviving passengers escaped through the crew entry door, the emergency hatch over the right wing, and the emergency hatch over the left wing.

The pilot, copilot, and boom operator received vertebral compression fractures in the impact due to either not having the shoulder harness on or not locking it prior to landing impact. The navigator noted all the equipment in the compartment above his station came down on his head on impact. Egress problems were noted on the flight deck, with both the pilot and copilot getting stuck in their respective window exits, blocking exit for other crew, and not having time to locate or use the escape rope. Evacuation was completed in 45 seconds. The location of exits and fatalities is shown in Fig. 19. Note the pile-up of four fatalities which occurred aft of the left overwing exit due to aisle blockage from small cargo, and the apparent inability of those passengers in the aft compartment to egress through the right or left aft escape windows, even though one individual was identified as sitting in the aisle seat adjoining the left aft window. In this configuration, 26 individuals used rear-facing seats, but six passengers sitting over the boom pod area would have had great difficulty in assuming the recommended ditching and crash landing position as found in T01C-135KA-1 [pp. 3-52 (436)], even if they had been pre-warned of the crash. Survivors reported that they had a great problem in attempting to evacuate through the available emergency exits from any seated position.

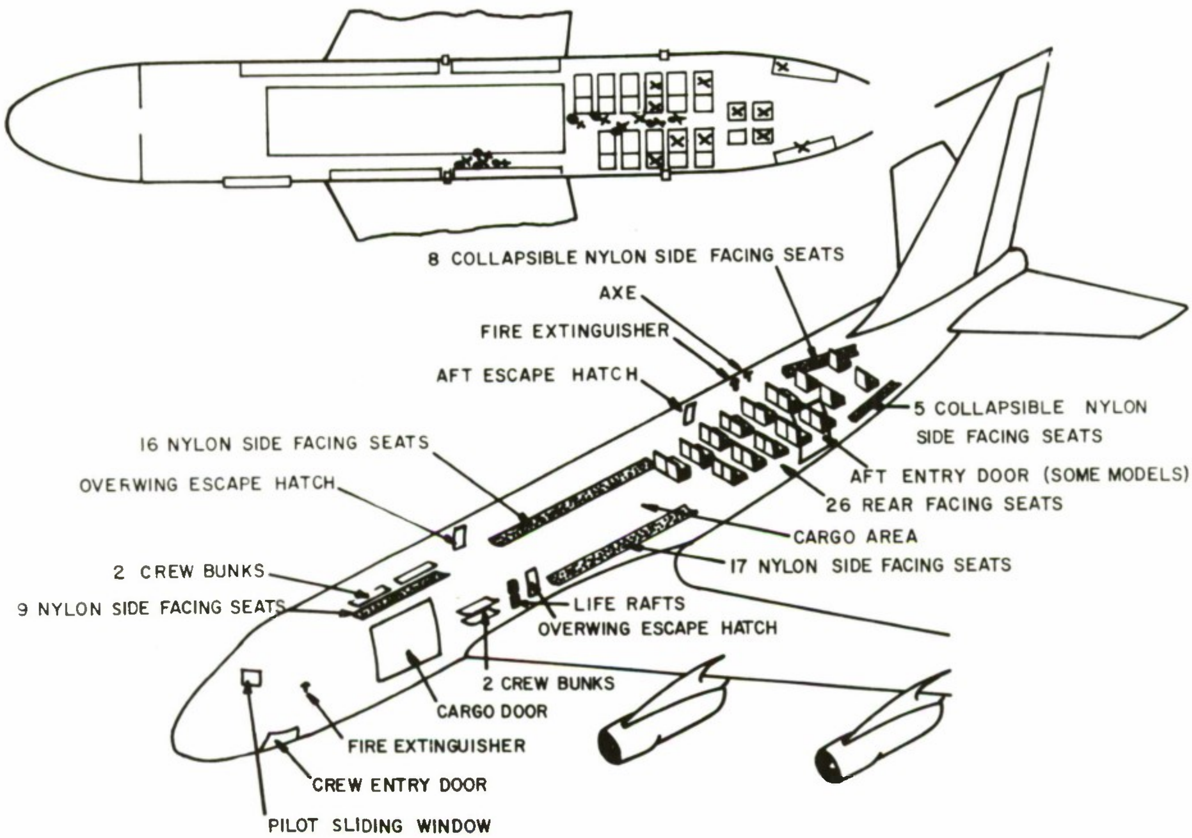


Fig. 19. Location of emergency egress exits and fatalities in Boeing KC-135 crash (Case #1).

It was concluded by the investigators that the military Boeing KC-135 aircraft was not properly configured to perform passenger service with safe emergency egress, and that emergency escape was impossible under conditions of no emergency lighting, inadequate emergency exits for the number of passengers carried, and lack of briefing. As a result it was recommended that the number of passengers on KC-135 aircraft be limited to the number that can safely egress under simulated emergency conditions in one minute, using only the three escape hatches in the passenger compartment; that the loudspeaker system be modified to ensure positive communication between crew and passengers; that additional emergency exits or enlargement of existing escape hatches be considered; and that installing impact-activated emergency lighting systems for emergency exits also be considered.

Case No. 2. This Boeing KC-135A aircraft ran off the runway during an aborted takeoff. There was no fire or smoke. Impact forces were low and all of the crew used the restraints provided. The crew had HGV-2A/P helmets but none were worn; there were only five sets of survival gear, including life jackets, for six crew members. There was no preflight crew briefing given. The boom operator was unable to use the rear escape hatch due to aircraft altitude, and exited through the left overwing escape hatch. The alarm bell was activated prior to going off the runway. Need of impact-activated lights was reiterated by investigators.

Case No. 3. This accident involved an emergency abort crash landing of a Boeing KC-135A on the runway on takeoff. A fire in the left wing area was extinguished and all crew evacuated without injury. However, the pilot experienced difficulty with the emergency rope which became entangled around his right foot, and it was released by the I.P. (instructor pilot). Difficulty in identifying and reaching the pilot's emergency rope storage compartments was reported, and it was recommended that the crew wear gloves to prevent rope burns, and that an additional emergency escape rope be installed at the crew entry chute. No alarm bell was used.

Case No. 4. An emergency abort was initiated on takeoff, and the Boeing KC-135A aircraft was stopped off the runway with a brake assembly fire. The alarm bell was used and the I.P. instructed the crew on interphone to evacuate as soon as the aircraft stopped, but passengers had no interphone communication. Passengers opened the rear exit hatch but closed it due to smoke and flames, and ran forward to the left wing exit hatch, noting jam-up of people at front entrance exit ladder.

Case No. 5. After takeoff, this Boeing KC-135A aircraft lost altitude, crashed, burned, and was destroyed with major injuries resulting to four crew members. A fatal head injury was received by a navigator, riding in the boom operator's seat, who was not wearing a seat belt. Evacuation was accomplished in less than one minute using left and right cockpit windows. Distance was 1.5-1.8 m (5-6 ft) above ground level and escape ropes were not used. The I.P. got stuck in the right cockpit window. Although none of the crew were wearing helmets or parachutes, the flight medical officer recommended that parachutes not be worn on takeoff or landing because of interference with emergency escape.

Case No. 6. This Boeing KC-135A aircraft hydroplaned on an icy runway and went off the runway on landing roll. The pilot activated the alarm bell prior to stopping, and no fire occurred. Both the pilot's and copilot's windows jammed and could not be used. The pilot escaped through the aft emergency escape hatch, using the escape rope. The copilot and navigator evacuated through the crew entry door. Eleven other crew members were facing aft and four were facing forward. Of these, nine egressed through the aft emergency door, five through the crew emergency door, and one went out the wing emergency exit. The pilot's shoulder harness inertial reel failed to lock, and because his left hand was busy with nose wheel steering during the landing roll, it was recommended that the pilot's inertial reel lock switch be changed from the left to right side so it can be more easily locked in emergency situations.

Case No. 7. On night formation takeoff, the Boeing KC-135A aircraft overran a McDonnell Douglas F-4 on the runway ahead, impacting at 148 km/h (92 mph), and swerving to the right off the runway, on fire. There was no briefing whatever of the crew prior to takeoff; the tower supervisor had overslept and was not on duty. The alarm system was activated after impact. Three crew chiefs and a boom operator exited through the overwing escape hatch, with the latter receiving knee and scalp injuries in exiting. The remaining four crew members evacuated through the cockpit side windows. Although the escape rope was used on the pilot's side, the I.P. was unsuccessful in getting it out the copilot's window.

Case No. 8. During an IFR (instrument flight rules) approach in a rainstorm, this Boeing KC-135B impacted short of the runway. The airframe came to rest inverted in three main sections and was destroyed in the subsequent fire and explosion. There were 78 fatalities; the three pilots and two of the three flight deck crew receiving major injuries. Heat from fire, and smoke inhalation resulted in 95% of the fatalities, and it was estimated by the flight medical officer that in the absence of fire, 70 of the 78 fatalities would have survived. All of the surviving crew received major injuries from acute chemical smoke inhalation. Due to the inverted position of the aircraft, the surviving navigator was unable to find an escape exit, and exited from an emergency exit cut aft of the copilot's seat by the rescue crew. Three pilots and one engineer escaped out the copilot's side window, although it had jammed and had to be broken out with a crash axe. The crew experienced considerable difficulty in locating the flight deck crash axe, and it was recommended that it be relocated near windows and a canopy-shattering tool be installed. Except for a single tier of three seats thrown clear when the fuselage broke up, all seats remained intact in the impact. No alarm was given, and the report did not state whether any briefing was given to passengers by the crew.

Case No. 9. A Boeing WC-135B encountered control problems on takeoff and crashed on the right side of the runway. The nine crew members evacuated within 45 seconds and were uninjured. A small nose section fire was extinguished. The pilot used the pilot's escape window without using a rope as the nose was on the ground, and the copilot and flight engineer went out the copilot's window. The navigator exited over the left wing from the aft compartment. The navigator received strain due to the side-facing position of his seat. It was recommended that T01C-135A-1 [Figs. 3-11, pp. 3-46 (436], be changed to show the navigator seated facing aft in any emergency landing (297).

Details of the various Boeing C-135 and Lockheed C-141 Military Air Transport Operational Configurations, emergency escape routes, crew positions, and emergency equipment storage are found in the respective T.O.'s (technical orders) (436, 437), or are provided in Snyder and Robbins [1971 (22)]. The latter reference also includes detailed crash impact and egress deficiencies found in inspection of operational aircraft, and in addition to confirming the observation and recommendation of the Combat Egress Working Group Report [Reagin et al., 1970 (13)], points up other areas of concern. The accident experience summarized in the foregoing sampling of operational high- and low-wing military transports indicates that there are a number of areas in which occupant crash protection or emergency egress can be improved.

2.4 Ditchings

Since air carrier aircraft must fly over large expanses of water, even on some domestic flights, protection of occupants exposed to water ditchings must be considered. An emergency ditching should not be confused with an uncontrolled crash. The National Transportation Safety Board defines a water ditching as "a forced landing of aircraft in water" [NTSB, 1970 (473)]. Such cases exclude instances where an aircraft collided with land or water in uncontrolled flight. The U.K. definition of ditching is "a premeditated maneuver which, in the large majority of transport aircraft, has been proved capable of execution with reasonable hope of escape and survival. It is deliberately executed by the pilot, under full control, with the specific intention of abandoning the aircraft" [Townshend, 1963 (483)]. NASA defines ditching as "to set an aircraft down upon water deliberately under emergency conditions, an act or instance of making a forced landing on water with subsequent abandonment of the aircraft" [Adams, 1959 (439)].

Civil or military water ditchings of jet air carrier aircraft have rarely occurred, with only one intentional case involving an Overseas National Airways McDonnell Douglas DC-9 turbojet reported to date [NTSB, 1970; 1971; 1972 (10-12)]. In this 1970 accident 40 occupants survived (35 passengers and five crew members); however, there were 23 occupant fatalities (including a stewardess and two infants). One unintentional ditching of a McDonnell Douglas OC-8-62 occurred in 1968, when a Japan Air Lines flight "landed" 5,791.2 m (19,000 ft) short of the runway in San Francisco Bay [NTSB, 1969 (472); Simpson, 1969 (475)]. In three other instances involving a McDonnell Oouglas DC-8, and two Boeing 707's, water contact was not defined as a ditching. In addition, one Lockheed C-141 USAF military transport has crashed into the sea on takeoff, and one McDonnell Oouglas OC-8 crash-ditched during an attempted landing; however, there was no attempt to ditch in either of these cases.

Air carrier ditchings have been studied both experimentally and as a result of accidents. King and Richardson (469) examined 18 U.S. air carrier ditchings occurring between 1946-1956 and conducted Civil Aeronautical Administration (CAA)/U.S. Navy ditching trials with a modified Martin 404 fuselage. Fisher and Hoffman (458) studied Douglas DC-4 and OC-6 ditching characteristics in 1950 by use of NACA models. Oitchings between 1952 and 1962 were evaluated in detail by Townshend (483) who found that of 102 incidents, 53 were premeditated ditchings, of which more than half were 100% successful. In studying 11 inadvertent ditchings and 22 incidents in which there were no survivors ("400-500 fatalities"), he concluded that a substantial number could have been saved if life rafts had been available. In a third general study, 22 U.S. air carrier water ditchings were reported in detail for the period July, 1954 through June, 1964 by Doyle and Roepe (457), who found that 647 of 720 fatalities were attributed to impact forces, while only 71 died as a result of drowning, exposure, or other causes. Doyle updated this experience in a 1967 paper (456).

In the Ooyle and Roepe [1965 (457)] study, the air carrier ditchings were identified by three groups; those involving aircraft lost with no survivors, unintentional ditchings having survivors, and premeditated ditchings having survivors. Five jet transport aircraft "ditchings" were reported for this period as summarized in Tables VIII and IX. Note that none of these involved an intentional ditching and it is doubtful that the three accidents listed in Table VIII can be classified as ditchings under the NTSB classification.

TABLE VIII.

AIRCRAFT LOST IN WATER WITH NO SURVIVORS

Date	Air Carrier Type	Fatalities	Survivors	Remarks
1/28/61	American Airlines/Boeing 707	6	0	"Pilot training flight. Severe impact. Possible structural failure after loss of control. Fire and smoke." 1.6 km (1 mi) from shore. (Long Island Sound, N.Y.)
3/1/62	American Airlines/Boeing 707	95	0	"Control failure. Crashed after takeoff. Debris and fuel burned at impact." 1.6 km (1 mi) from shore. (Jamaica Bay, N.Y.)
2/25/64	Eastern Airlines/McDonnell Douglas DC-8	58	0	"Occupants died at impact. Unused flotation gear recovered." 6.4 km (4 mi) from shore. (Lake Ponchartrain, La.)

Source of Tables VIII and IX: Doyle and Roepe, 1965 (457)

TABLE IX.

UNINTENTIONAL DITCHINGS HAVING SURVIVORS

Date	Air Carrier Type	Fatalities	Survivors	Remarks
9/24/61	American Airlines/Boeing 720B	0	71	"Overshot landing. Occupants picked up by small boats. Evacuation completed in 10 min." .16 km (0.1 mi) from shore. (Boston Harbor, Mass.)
4/7/64	Pan American/Boeing 707	0	145	"Overshot landing. Occupants eventually walked to shore; very confused evacuation." .16 km (0.1 mi) from shore.

Although no current-generation aircraft designs are involved, Table X shows an estimate of survivors in ditchings had adequate flotation gear been available. This indicates that 48 of the 49 fatalities should have survived the ditching.

TABLE X.

PROBABLE SURVIVORS IF ADEQUATE FLOTATION EQUIPMENT HAD BEEN AVAILABLE

Date	Air Carrier	Type Aircraft	Fatalities C	Fatalities P	Probable Survivors C	Probable Survivors P	Means by Which Additional Lives Could Have Been Saved
12/22/54	JOHF	DC-3C	1	9	1	9	Survivors swam 22.9 m (75 ft) to shore. Ample time to evacuate sinking aircraft. Life rafts and/or vests would have saved all 10 fatalities.
9/24/55	FLTX	DC-4	3	0	2	0	Life raft accessible from cockpit would have saved 2 of 3 fatalities. One trapped c/m could not be saved. One c/m killed by shark attack and the other c/m by drowning/exposure.
4/2/56	NWA	B-377	1	4	1	4	Buoyant cushions saved survivors. Life rafts would have saved all 5 fatalities, as ample time was available to evacuate and the proximity of rescue craft was such that everyone should have survived.
9/23/62	FLTX	L-1049H	5	23	5	23	Only 1 of 5 25-man rafts available for use. Relocation of wing-stowed life rafts to interior of aircraft and better crew and passenger discipline would have saved all 28 lives, provided all occupants were able to evacuate the aircraft successfully.
1/17/63	WCA	F-27	3	0	3	0	Crew died of exposure and drowning in extremely cold water. Life rafts would most likely have assured their survival.
TOTALS			13	36	12	36	
			49		48		

Source: Doyle and Roepe, 1965, Table VIII (457)

Several conclusions resulted from this study. It was observed that "all factors being equal, premeditated ditchings should have an equal or greater number of survivors than a forced landing on land, if adequate survival and rescue facilities are provided." It was also noted that "most present-day aircraft are capable of withstanding ditching impact forces and remain afloat for a sufficient length of time to complete a successful evacuation. High-wing aircraft are possible exceptions to this conclusion. The addition of top hatches on such aircraft would provide a means of egress for occupants in the case of water landings" [p. 657 (457)].

The findings that 647 of 720 fatalities in the above study were attributed to impact injury appear to contrast with the case for general aviation aircraft. Snyder [1974 (476); 1975a (477); 1975b (478)] and Snyder and Gibbons [1974 (479)] studied 306 light aircraft ditchings, involving 633 occupants, which occurred in the United States between 1964 and 1974, finding 88.5% survivability, and reporting that at least 50% of the fatalities occurred subsequent to a successful ditching, and were due to drowning after egress. This study reported finding that occupants of high-wing multi-engine light aircraft have a significantly less chance (>0.005), with 37.9% occupant fatality rate, of surviving a ditching when compared to other configurations (477), agreeing with conclusions expressed previously by Townshend [1963 (483)], and Doyle and Roepe [1965 (457)]. If these indications are correct, the ditching capability of air carriers such as the Airbus Industrie A300 series probably involves some greater risk than would be expected in low-wing configuration ditchings. In this regard, ditching experience in military jet high-wing transports (Lockheed C-141) has been evaluated by McIntire (406) and Snyder and Robbins [1971 (21); 1972 (22)]. The USAF Lockheed C5A has also been evaluated for ditching egress [1970 (427)]. A comprehensive discussion of the factors in ditching an air bus, including considerations of high- vs. low-wing design, has been published by Townshend [1968 (484)]. Air carrier aircraft ditchings have resulted in a number of additional studies through the years, but no attempt has been made here to include a comprehensive listing (440-446; 449-450; 452-454; 459; 471; 481-482; 487); it is suggested that Snyder, 1975 (477) be referred to for a more complete bibliography.

Military aircraft have been ditched with overall greater frequency than civil aircraft [1965 (450)], and there is an extensive literature. Rotorcraft often ditch [1969 (440)], and Bruggink has summarized ditching techniques for helicopters [1968 (447)]. White et al. have studied ditching egress [1952 (486)]; Keating, 40 G ditching seats [1954 (468)]; and Dodd, the rate of cockpit flooding in a sinking aircraft [1963 (455)]. Considerable work has been done, mostly by the U.S. Navy, relative to underwater escape from aircraft, and a comprehensive listing can be found in Woerden [1961 (487)], Snyder et al. [1963 (480)], and Ice et al. [1966 (467)].

General survival principles have been examined in other studies. One of the most comprehensive discussions of general ditching procedures was published by Kysor, a former Eastern Airlines captain, in 1961 (470). The most complete manual on aircraft ditching is a combined publication of the Army, Navy, Air Force, and Department of Transportation [1968 (451)], which includes detailed instructions on basic ditching techniques as well as ditching under adverse environmental conditions. Design priorities of low-wing and adequate flotation have been proposed by Hardingham [1948 (465)], who found that "drowning occurs in far too many ditchings" (p. 480). In the United Kingdom, under project "Walrus" (Wrecked Aircraft Location and Recovery Under the Sea), Hunt has analyzed some 43 aircraft which ditched and sank between 1961 and 1970, 32 of which sank in under 182.9 m (600 ft) of water, and 3 in depths over 1,828.8 m (6,000 ft) [1974 (466)]. Bruggink [1972 (448)], in a special NTSB report, has outlined emergency ditching techniques. More recently, several issues of the FAA Aviation News [1974 (462-464)] have included pointers for pilots concerning ditching techniques, primarily for those flying light aircraft. Recent ditchings have included a Douglas DC-3 non-scheduled passenger flight 25 July, 1975 in Lake Mistassini, Quebec, Canada, when the pilot became lost and "made a perfect ditching in the lake approximately 20 feet [6.1 m] from the shore" (100). On 14 January, 1976 an FAA crew, ferrying a North American Rockwell Sabreliner 40 flight inspection aircraft from Frankfort, Germany to Oklahoma City, ditched in the Atlantic 106 km (66 mi) off Recife, Brazil. Two of the crew were injured and an electronics technician killed; however, at this time it is not known whether the injuries were due to drowning, impact, or other causes [1976 (441)]. In December, 1975 a Britten Norman BN2-8 ditched near St. Thomas, Virgin Islands [NTSB, 1975 (474)]. Meanwhile, light aircraft continue to ditch in the United States at an average rate of about 29 per year [Snyder, 1975 (477)], and ditchings are reported for other NATO countries as well [Dept. of Trade, 1974 (452-454)].

Due to the rarity of intentional ditchings by jet air carrier aircraft, one intentional and three unintentional recent ditchings are summarized in the following relative to environmental conditions and human factors aspects.

2.4.1 Unintentional Ditchings of a Lockheed C-141A and Two McDonnell Douglas DC-8 Aircraft.

2.4.1.1 Military C-141A Ditching Experience. A crash occurred 13 April, 1967 in Cam Ran Bay during takeoff of a C-141A aircraft. After the pilot noted the controls felt "mushy" on takeoff, the aircraft struck the water at about 259 km/h (161 mph), and was destroyed. Water contact was in a flat left-wing-low attitude, with wing flaps extended to 75%, landing gear full down, and the spoilers in the ground position. Seven crew members were fatally injured or drowned, one (the loadmaster) received major injuries, and one (the pilot, seated in the left seat) received minor injuries of the face and limbs. The two survivors were transferred to the hospital 1 hour 9 minutes post-impact.

Insufficient information is available to evaluate the C-141 ditching characteristics from this crash, since the aircraft was not in recommended ditching configuration--the gear was down, flaps in approach position, spoilers deployed, and air speed excessive. All cockpit seats were found with the seat belts unfastened and inertial reels automatically locked (except for the copilot's seat). Both seat belt assemblies (side-facing) that the loadmasters were using in the aft compartment failed, coming loose from the rings.

Although the probable cause of fatalities was drowning, the investigation noted that the aircraft commander and one flight engineer had head injuries which might have rendered them unconscious post-impact. Similarly, another engineer reportedly had a crushed left chest which could be attributed to impact. Although the surviving pilot was wearing an upper torso restraint, the accident report does not indicate whether the fatally injured crew members were wearing upper torso restraints.

The flight deck interior was submerged within seconds after water impact. The pilot (I.P. was in the right seat) attempted to stand up but found his seat belt was still on. After releasing it he started swimming up, was pounded back by a wing section, and finally climbed on a wooden pallet. The surviving loadmaster was slammed into the bulkhead between the galley and flight deck entrance when his seat belt failed. As the aircraft was immediately filled with water, he got tangled up trying to swim out, and finally found a hole, either the open troop door or a gaping hole inside. He did not open any escape hatch. He did not think anyone was killed by impact but rather trapped and drowned.

The crew had no warning prior to the ditching, although the surviving loadmaster, who was on interphone, could tell there was some sort of emergency from the cockpit conversation. The crash circumstances of this accident preclude any conclusions concerning evacuation under normal ditching, except to indicate that there may be little egress time post-impact. However, failure of the side-facing seat belt assemblies, and the possibility that two of the flight deck crew were not wearing upper torso restraint could have contributed to the fatalities.

The experience represented by this single C-141A crash/ditching to date had been previously predicted in a study by McIntire [1967 (406)]. Using Army paratrooper subjects, emergency evacuation time in the C-141A was investigated under simulated ditching conditions. McIntire's review of prior ditching and water-crash cargo/transport accidents showed that high-wing aircraft either head up and sink immediately, or they are heavily damaged and quickly sink to the wing level; in both cases flooding the passenger compartment within 5 to 30 seconds. The most rapid ditching evacuation time reported in the C-141 tests was 230 seconds when life rafts were not deployed, and 337 seconds (5.6 min) when the life rafts were deployed. The average time found required to evacuate 114 passengers and 6 crew members and to deploy life rafts and survival equipment was 480 seconds. McIntire concluded that "if a high-wing transport like the C-141 goes into the water, and if the cabin remains level and does not fill with water, and if there are no injuries, 114 passengers and 6 crew members will require approximately 450 seconds to escape the aircraft and deploy their survival equipment. In an actual emergency, it is reasonable to expect that the escape time will be longer" [1967 (406)]. Since a maximum time of 30 seconds is available prior to the aircraft sinking, the probability of passenger escape in this situation is poor. Note that these simulated tests did not involve fire or smoke hazards, which could considerably increase these evacuation times. The USAF Industry Life Support Conference of 1967 found the following "inadequate ditching provision deficiencies...hatch opening deficiencies, poor escape ladder placement and deployment methods, and poor location of internal survival equipment" [1967, p. 17 (23)].

2.4.1.2 1968 Japan Air Lines McDonnell Douglas DC-8 Ditching, San Francisco. On 22 November, 1968, at about 0920 PST, a Japan Air Lines McDonnell Douglas DC-8-62 aircraft bound from Tokyo, Japan to San Francisco landed (in the ocean) 5,791.2 m (19,000 ft) short of Runway 28L. Aboard were 11 crew members and 96 passengers for a total of 107 occupants [NTSB, 1969 (472)]. A human factors study was reported by Simpson [1969 (475)] as abridged:

On final approach the aircraft struck the water with the right main landing gear. The left main landing gear subsequently contacted the water, and the aircraft made a slow turn to the left. Upon initial contact with the water, the captain stated that his indicated airspeed was approximately 254 km/h (158 mph). Some of the experienced travelers aboard described the aircraft deceleration as merely a hard landing, and many of the passengers thought they were on the runway until they looked out and saw the water. During the deceleration some of the carry-on baggage slid forward one to two rows; however, it was reported in other instances that carry-on baggage remained in place.

Many of the translucent plastic covers over the so-called "cove" lights under the overhead rack came off at impact and were propelled at a high velocity through the passenger cabin. Apparently, no one was injured by these missiles. Blankets and pillows thrown from their stowage in the overhead racks cluttered the aisleways. The heavy metal rod across the fuselage to which the class divider curtain in front of the aft cabin is attached came loose on deceleration and was propelled into the forward cabin. No one was struck by this object. With the exception of one steward in the aft cabin jump seat, all occupants were positioned in their seats with seat belts fastened. This steward was seated and in the process of fastening his seat belt when the first impact occurred. He stated that he was able to hold onto his seat belt and remain in his seat during the first impact; however, on the second impact he was thrown forward approximately 2.4 m (8 ft), but was not injured.

The aircraft came to rest on the bottom of the bay in an approximate four-degree, nose-up attitude, supported by its intact landing gear. The water level was reported to have been about 1.8 m (6 ft) below the door sills of the forward Type I exits, .6 m (2 ft) below the leading edge of the wing, and .9 m (3 ft) above the door sills of the aft Type I exits. Two Type I exits were located in the forward compartment, one on each side of the fuselage. Two Type I exits were located in the aft cabin section. Also located in the aft passenger cabin were four Type III exits, each measuring 50.8 cm x 121.9 cm (20 x 48 in), situated over the wings, two on each side of the aircraft fuselage. Two 25-man life rafts were stored overhead in the center of the aisleway of the forward cabin immediately behind the cockpit entry door. Four 25-man life rafts were stored overhead in the center of the aisleway across from the overwing exits at seat rows 12 and 15 (no seat row 13). In addition, two 25-man life rafts were stowed overhead in tandem at seat row 31 (last passenger seat row), making a total of 6 life rafts in the aft cabin section and two rafts in the forward cabin section. An adult life jacket, stored in a yellow container under each seat, was available for each passenger. On the back of each passenger seat were printed the words: "Life vest under front of your seat."

Immediately after the aircraft came to rest the purser reassured the passengers that the aircraft was resting on the bottom of the bay and would not sink. The passengers were advised to remain calm and to don their life jackets. There was some difficulty in obtaining life jackets because of displacement of carry-on baggage which became forcibly jammed under the seats at impact. All passengers were briefed as to procedures for donning life jackets; however, some passengers nevertheless experienced considerable difficulty. Child life jackets were not immediately available for each of the six infants aboard as the child vests were stored in the aft galley area, inaccessible to the cabin attendants due to heavy congestion in the aisleways which included both occupants and miscellaneous litter.

One of the stewards was reported to have had difficulty opening the main cabin entry door. Upon discovery that the cabin pressurization system was maintaining a slight positive pressure and correction of this condition, no further difficulty was experienced in opening the door. The pressurization system was bled and the electric power system to the aircraft turned off simultaneously. Discontinuation of electric power resulted in failure of the aircraft public address system. Since no portable systems, i.e., bullhorns, were present on this aircraft, the crew was forced to conduct the evacuation by shouting the necessary commands.

Two life rafts were removed from their stowage in the forward cabin section and launched, one from the main cabin entry door on the left side of the fuselage, and the other from the forward galley service door. Only two of the four life rafts stored in the aft cabin section across from the overwing exits were utilized. These two life rafts were launched from the leading edges of the wings, one from the left and the other from the right wing. One of the two life rafts stowed in the extreme rear of the aft cabin section was launched from the forward galley service door. The stewardesses reported that it was almost impossible for them to remove any of the life rafts from their overhead stowage areas without the rafts, each weighing approximately 65 kg (143 lb), falling to the floor and perhaps being damaged. Therefore, male crew members had to perform all handling of the life rafts, from removal at stowage areas to launching.

The actual evacuation of the aircraft was not initiated until the aircraft had been on the water approximately 5 minutes. Since there appeared to be no imminent danger of the aircraft sinking, evacuation was not completed until about 12 minutes later. It was extremely difficult to determine the passenger flow and exits used during the evacuation due to the language barrier and the unavailability of passengers following their rescue and release by U.S. Customs and Japan Air Lines. Although no one was injured in this accident, Simpson noted a number of hazards which could have been more serious problems had rapid emergency evacuation been required. These included:

(a) A serious injury potential was created when the cove light covers were detached at impact and became flying missiles throughout the cabin.

(b) Failure of the public address system at a critical moment in the evacuation resulted in difficulties experienced by crew members in communicating with passengers.

(c) Children's life vests were not immediately available to every child and, therefore, some small children were without a personal flotation device of any kind.

(d) Difficulties and delays were imposed by small female crew members attempting to remove the heavy life rafts from their overhead stowage areas, and by inexperienced persons, with a variety of language backgrounds, attempting to don life vests.

(e) The placard "Life vest under front of your seat" tended to confuse a number of passengers, many of whom interpreted this as an indication that their life vests were located under the backs of the seats directly in front of them. In addition, carry-on baggage served as an impediment to removal of life vests from their under-seat stowage locations.

Fig. 20. Crew leaving the aircraft after inadvertent water landing of Japan Air Lines McDonnell Douglas DC-8 in San Francisco Bay, California (Photo courtesy J. Simpson, FAA, CAMI).

Fig. 21. Passengers evacuated in life rafts (Photo courtesy J. Simpson, FAA, CAMI).

2.4.1.3 1969 Scandinavian Airlines McDonnell Douglas DC-8 Ditching, Santa Monica Bay, Calif. A Scandinavian Airlines Systems McDonnell Douglas DC-8-62 crashed on 13 January, 1969 in Santa Monica Bay approximately 9.7 km (6 mi) off Los Angeles International Airport [NTSB, 1970 (161)]. This aircraft was attempting an instrument approach to Runway 07R which resulted in "an unplanned descent into the water." The aircraft was destroyed by impact, with the fuselage breaking into three pieces, two of which sank in 107 m (350 ft) of water. The third section, including the wings, the forward cabin, and the cockpit, floated for about 20 hours before being towed into shallow water where it sank (and was later recovered). Of the 45 persons aboard the aircraft, three passengers and one cabin attendant drowned; 9 passengers and two cabin attendants are missing and presumed dead; 11 passengers and 6 crew members (including the captain, the second pilot, and the systems operator) were injured in varying degrees; and 13 passengers escaped without reported injury. There was no fire. The flight recorder was recovered and indicated water impact had occurred at 287 km/h (178 mph) airspeed and 1.5 +G vertical acceleration at the C.G., taildown.

The six crew member survivors were located in the forward portion of the aircraft, with 18 passenger survivors from the forward tourist cabin that remained afloat, and 6 passenger survivors from the aft cabin section. The cockpit filled with water to one-third depth. Passenger survivors reported only one impact which they described as a very hard landing. The impact was followed by rapid deceleration. Quantities of water were forced up through the cabin floor, and the center aisle between seat rows 2-11 was disrupted, with portions missing entirely and leaving openings down to the baggage compartment. This condition made evacuation difficult. The surviving crew members, assisted by a non-revenue captain and stewardess, evacuated passengers from the cabin onto the wings through the overwing exits. and into life rafts. From impact to rescue was estimated as from 45 minutes to 1 hour.

The survivors reported several egress problems, mainly associated with the panic conditions following the impact. A major problem that could have affected survivability following this accident was the reported rapid collapse of two life rafts when they were punctured by the jagged wreckage (despite double tube construction). It was suggested that an improvement would be to compartmentalize the tubes and connect them with one-way flow valves to increase life raft reliability. The "Fasten Seat Belt" sign was on but the "No Smoking" sign had not yet been turned on. All occupants apparently had seat belts on, but the nature and cause of occupant injuries, as to whether received at impact or during evaucation, was not reported. Failure of life jacket lights was reported. Difficulty was noted in finding the life raft cover release pull string. In the darkness on the wing life rafts had to be turned over several times to locate the string, and it was suggested that life raft covers should have a ball handle and/or luminous paint to facilitate finding the lanyard for the life raft inflation. The emergency cabin lights operated, although it was reported they did not remain lighted long. Some of the survivors reported that the standard seat belts had extra long free ends which delayed their release, since they had to interpret what the problem was during a time of panic, as well as having to use both hands to release the belt.

2.4.1.4 Intentional Ditching of McDonnell Douglas DC-9. On 2 May, 1970 an Overseas National Airways DC-9-33F operating as ALM (Antilliannse Luchtvaart Maatschappij) Dutch Antillian Airlines, ran out of fuel and was ditched 46.6 km (29 mi) E.N.E. of St. Croix, Virgin Islands VOR (very high frequency omni-range station) in the Carribean Sea. This is the only known intentional ditching of a scheduled jet air transport aircraft to date. Detailed information can be found in NTSB accident reports [1970 (10); 1971 (11)], NTSB special study [1972 (12)], and in Walhout (Human Factors Group Chairman's Factual Report [1970 (485)]. Of 63 aboard, there were fatalities to 23, including a stewardess and two infants.

This flight departed J.F. Kennedy International Airport, New York, for St. Maartens, Netherland Antilles, with 55 adult passengers, two infants, and a crew of 6 aboard. At St. Maartens, after aborting one ADF approach and three circling approaches, they diverted to St. Thomas. They then changed course to St. Croix due to fuel shortage. The captain instructed the purser to brief the passengers for a possible ditching, and to have the passengers don life jackets as a precautionary measure. No further instructions were given. The navigator, with the help of the purser and a male passenger, repositioned the life raft from the coat closet into the galley area, with some difficulty. Passengers reported difficulty in removing life vests from the storage pockets under the seats. The steward put life vests on the two infants aboard.

There was no "prepare to ditch" warning given by the crew prior to water impact, nor was a "brace for impact" warning given. Neither the navigator nor the purser had time to fasten his seat belt before impact. The steward was seated on the life raft package, facing aft. The stewardess's position at impact is uncertain. Some passengers were seated upright; some had assumed a brace position; others were standing, donning their life vests, when impact occurred. There were reports of seat failures. Some passengers did not have their seat belts fastened at impact. Other passengers reported being thrown from their seats despite having fastened seat belts (although the report does not provide this information, similar instances have previously occurred when long belt ends whipped and released buckles in the metal-to-webbing type seat belts). One couple reported that they had unfastened their belts prior to impact in order to be able to evacuate faster. Evacuating passengers observed unconscious or apparently lifeless passengers subsequent to impact. The pilot had a life vest on as well as shoulder harness and seat belt. The copilot wore his shoulder harness but no life vest. The impact deceleration was reported to be severe, longitudinal, with a minor left lateral component.

Post-impact, the copilot, navigator, purser, and steward evacuated through the galley door after having difficulty with the life raft, which inflated in the galley area. The captain exited through the left sliding cockpit window and opened the left overwing exits from the outside. A passenger seated next to the right aft overwing exit opened this exit as soon as the aircraft came to rest and exited, followed by at least 22 other passengers. Two passengers from the first row exited through the cockpit window, swam to the left side of the fuselage and opened the left overwing exits from the outside, and helped a man and woman passenger egress. None of 5 life rafts aboard was deployed. The navigator found the emergency escape slide from the galley service area floating in the water and inflated it. Many passengers and the copilot congregated around this flotation device. Life rafts subsequently dropped were not located or could not be returned to the passenger area due to rough seas with 1.8-2.4 m (6-8 ft) swells. Survivors were rescued by helicopters. The aircraft sank in over 1,524 m (5,000 ft) of water.

This ditching resulted in a NTSB special study (12) which included in the detailed analysis the aircraft and occupant impact dynamics, equipment failure, and post-ditching emergency egress problems. The magnitude of the deceleration was estimated to be 8-12 G's applied over 0.5-1.0 seconds, with the aircraft stopping in 15.2-24.4 m (50-80 ft). In this instance the pre-ditching briefing was incomplete and the stewardess and at least five passengers were unrestrained at impact, at least seven restrained passengers were thrown from their seats, and three double-seats failed, which contributed to the fatalities. It was estimated that this aircraft floated for five to six minutes and most survivors were evacuated within two to three minutes. Since this ditching experience is unique the conclusions and recommendations of the NTSB are important in considering technology which might provide additional protection in future air carrier ditchings, and are as follows [NTSB, 1972, pp. 13-14 (12)]:

CONCLUSIONS: 1. The pre-takeoff briefing, which is required to acquaint passengers with the emergency provisions of the aircraft, was inordinately short, a statement of facts rather than a briefing, and it left the initiation of action to the passengers.

2. The pre-ditching briefing was incomplete in that the passengers were not informed about the various emergency provisions on the aircraft. This was as a direct result of the failure of the cockpit crew to inform the cabin crew adequately about the urgency of the situation.

3. The briefing outline regarding the life vests was inadequate; despite two recent demonstrations, the passengers were unfamiliar with the location, the storage method, and the packaging of the life vests, and considerable difficulty was experienced in donning the life vests. This reduced the effective use of the available time for passenger preparation.

4. The entire crew had received standard training; despite this fact, the cockpit crew exhibited inadequate knowledge of the critical actions necessary in the preparation for a water landing, and did not exert its command responsibility. The cabin crew exhibited less than efficient management in the cabin preparation as a result of dissimilar training and experience.

5. Unfamiliarity of the entire crew with each other and the use of dissimilar safety procedures and methods resulted in conflicting actions.

6. The aircraft went through the ditching sequence without significant structural compromise to the occupiable areas. The forces generated were estimated to have been on the order of 8 to 12 G's applied over a time period of 0.5 to 1.0 seconds.

7. Analysis of the dynamics of occupants indicates that the high proportion of fatalities in this accident was due to disabling injuries which were caused by a combination of unrestrained passengers being

thrown forward, by failures of seats, and by slippage of a number of seat belts.

8. Adequately stressed aft-facing seats probably would have greatly diminished the injuries sustained in this accident by virtue of the increased body support offered through such an arrangement.

9. The forces generated during the water impact approached the 9 G design strength of the seats and were a factor in their failure. Since impact tolerance of the human body, when restrained by a seat belt only, has been established on the order of 15 to 20 G's, the failure of seats at the 9 G value exposes occupants to serious and unnecessary injuries.

10. At least seven instances were reported wherein the seat belt failed to restrain its user. Slippage of the "fabric-to-metal" belt has been found in other accidents and this condition is indicated in this accident. The demonstrated inadequacy of the locking device raises serious doubt as to its suitability as a restraining device.

11. The contents of the galley were spilled during the deceleration of the aircraft, and blocked ready access to the raft package as well as the emergency exit at that location. Spillage of drawers and bins has been observed in many other accidents, indicating that the locking devices on these items are unreliable.

12. Through analysis of the movements of the captain, it is estimated that the aircraft floated for approximately 5 to 6 minutes after landing on the water and that most survivors had evacuated the aircraft within 2 to 3 minutes.

13. The value of seating knowledgeable persons next to emergency exits was demonstrated when a passenger, who made it a practice to prepare himself for any eventuality, promptly opened the aft overwing emergency exit. This opening served as a focal point for other passengers and allowed at least 31 persons to evacuate the cabin through this exit.

14. The navigator and the two male cabin crew members were unable to move the life raft package after the aircraft came to a stop. Weight of the package is not considered a likely factor to explain this difficulty. The only other plausible explanation is that the galley structure shifted during impact and impinged on the raft container, thus retaining it in its original position.

15. The navigator and the steward should have proceeded to the overwing exit area and directed passenger evacuation after the aircraft came to a stop. Inadequacy of training is cited for their failure to do so in that no evacuation drills were given as part of their training, and neither of them was intimately familiar with the survival equipment because wet ditching drills had not been a part of their training curriculum.

16. Additional lives could possibly have been saved if crew leadership had been exhibited within the aircraft to the degree such leadership was shown while the survivors were awaiting rescue.

17. The loss of all life rafts on board the aircraft probably affected the survival of several passengers. If the evacuation slide had not been deployed and used as a rallying point, additional lives might have been lost because of dispersion of the survivors.

18. If a slide-raft combination had been installed in this aircraft, at least one raft might have been available without the necessity of dealing with the cumbersome and time-consuming method of launching and boarding the raft. The slide-raft combination offers a measure of automation which should facilitate the tasks of the cabin attendants.

19. Life vests were found to be restrictive around the neck and gave the passengers a low level of confidence regarding retention. In addition to the difficulties in donning the vests, the passengers had considerable problems finding inflation and adjustment controls.

As noted by the NTSB [p. 13 (12)], "faulty judgement on the part of the cockpit crew, inadequate training of the entire crew, and functional failure of the equipment" combined to influence the fatal outcome.

To date these cases appear to represent the state of experience in jet air transport ditchings, and point out a number of problem areas which will require improvement for increasing the prospects of survivability in future ditchings.

3. PROTECTIVE DEVICES FOR PASSENGERS AND CABIN ATTENDANTS EXPOSED TO SMOKE, FLAME, AND TOXIC FUMES

3.1 Background

The need for better protection of passengers and crew from the effects of toxic fumes and inhalation of smoke or flame is evident from investigations of both civil and military jet transport accidents. Smoke inhalation has been shown to be a significant factor in the incapacitation of passengers, resulting in their inability to evacuate the aircraft prior to its destruction by fire.

It has been found that the collapse through smoke inhalation of only one passenger can have a direct and very deleterious effect upon passenger evacuation flow, particularly when the affected individual is located at a critical point, such as in the aisle, or blocking an overwing emergency exit. In the typical jet transport accidents which have been investigated to date, decelerative forces are often found to be relatively low and structural deformation impeding escape minimal. Injuries are generally minor and sustained during escape rather than at impact, yet it is not unusual for those deaths and major injuries which occur to be caused by smoke and fire. While there is a variation in the heat fluxes generated in post-crash fires (e.g., .54-1.35 gm-cal/cm2/min [2-5 btu/ft^2/min]), a fuselage has burned through in as little as 7 seconds [Peterson, 1970 (553)]. In tests by the Flight Safety Foundation the cabin temperature reached 948.8°C (1,740°F) in 40 seconds, and in ALPA tests conducted at Cleveland, a 1,093.3°C (2,000°F) cabin temperature was recorded in less than 2 minutes. More recent studies are being conducted by NASA. While the scope of this paper does not include a detailed analysis of materials flammability, toxic gas emission, smoke emission, or flash fire hazards in post-crash fire, a brief description of major work and findings in this area may be useful background. The major review of the state-of-the-art to date has been by Simpson [1973 (563)].

3.1.1 Governmental Activities: FAA, NTSB, NASA, NBS, Congress. Civil air carriers are required by Federal Air Regulation to demonstrate that all passengers (maximum passenger capacity) can be evacuated within 90 seconds to the ground or ramp steps using only the exits on one side of the aircraft (FAR

25.803 [c]) [1967 (505)]. Yet in actual emergencies even this short time span required for evacuation may be insufficient. Military recommendations as a result of one C-135A accident included a recommendation that the number of passengers should be limited to those able to evacuate in one minute from three exits.

In recognition of the problem of toxic gas and smoke emission from the pyrolysis (chemical decomposition of a substance by heat) of interior materials, the Federal Aviation Administration has proposed several new standards relative to transport category airplanes. An Advance Notice of Proposed Rule Making (ANPRM) was published 30 July, 1969 [Notice 69-30; 34 F.R. 12450 (507)], soliciting views on four questions upon which a Notice of Proposed Rule Making (NPRM) would be issued. This resulted, six years later, in a proposal to amend Parts 25 and 121 of the Federal Air Regulations as published in the Federal Register [F.R. 6506, 12 February, 1975 (510)]. It was based upon FAA findings at that time that aircraft interior materials were available which emitted appreciably less smoke than the currently used materials, and that test methods could correctly and consistently measure the smoke emission characteristics of aircraft interior materials [NBS, 1971 (543)]. What was not fully recognized at that time and has since been established is that chemicals which suppress flame or smoke, when pyrolyzed, may emit toxic gases in lethal quantities. More recent evidence indicates that smoke chamber results may not be consistent, and one of the current basic problems is lack of an accepted, proven test protocol which is consistent

As a result of the Capitol International Airways DC-8-63F crash at Anchorage, Alaska, on 27 November, 1970 (402; 403; 544), the National Transportation Safety Board recommended that FAA cooperate with NASA to develop and implement major improvements in the design of transport aircraft interiors including "the flammability of cabin interior materials" (NTSB, 1971, Status of Board Safety Recommendations). On 16 August, 1973 NTSB staff met with FAA relative to planned ANPRM on cabin materials toxicity and on revised standards for materials flammability testing. In an ANPRM published in the Federal Register [39 F.R. 45044, 30 Dec., 1974 (509)], the FAA solicited comments related to compartment interior materials toxic gas emission; however, no immediate standards may be expected to result from an ANPRM. Subsequently in February, 1975 the FAA issued an NPRM [40 F.R. 6506 (510)] related to smoke emission from compartment interior materials. On 13 March, the FAA issued the first ANPRM soliciting comments relative to flammability standards for flight attendant clothing [40 F.R. 11737 (511)]. Such a need has been cited as a result of many accidents [Peterson, 1970 (553)].

Relative to materials flammability the approach after World War II was to limit the flammability of cabin materials as a primary means of reducing the effects of post-crash fire. This resulted in standards established in 1947 limiting the horizontal burn rate of materials. In 1962 tests conducted by the FAA at National Aviation Facilities Experimental Center (NAFEC) indicated that many materials in operational use could pass this standard but still could cause fatal fires [Marcy et al., 1964 (531)], due to breakdown of test protocol between laboratory and full-scale tests. These standards were subsequently stiffened in 1967 for certain cabin materials and they were required to demonstrate self-extinguishing characteristics after the flame was removed. In 1972 these standards were expanded to all cabin materials and apply to all U.S. certified air transports certified before 1967 to be retrofitted to current standards [Simpson, 1973 (563)]. NASA has research programs related to the development of more fire resistant cabin interior and cabin insulation materials [Kourtides & Parker, 1972 (526)], which should result in further state-of-the-art standards relative to air transport aircraft in the future. The advanced space research activity of NASA has produced materials, test techniques, and data which must be considered by federal regulatory agencies.

Smoke emission tests from burning materials at NAFEC showed a problem for emergency egress [Marcy, 1965 (532)]. But with the adoption of flammability standards it was found that the flame retardant additives used increased smoke emissions [Aerospace Industries Association, CDP-2, 1968 (488)]. Subsequently the National Bureau of Standards and FAA jointly studied smoke and gas emission from 141 aircraft interior materials. This work developed the NBS Smoke Chamber, proposed as a compliance test apparatus in NPRM on smoke emission from compartment interior materials as of 12 February, 1975 [FAA (510)]. Since the NBS apparatus deals with small smoke samples, FAA contracted with Lockheed Aircraft Corporation to correlate the NBS Smoke Chamber data with full scale fire tests in a Lockheed L-1011 wide body jet transport fuselage section [Lopez, 1973 (529)]. NASA has investigated new classes of polymers which are non-flammable and produce little or no smoke or toxic gas when exposed to fire [Simpson, 1973 (563)].

The FAA's proposed program approach to cabin interior flammability, and smoke and toxic gas emission involves three elements. The FAA general airworthiness review program, initiated in December, 1974, includes raising cabin flammability standards for older aircraft (as one of more than 600 changes being considered). As detailed in Part 8 of a NPRM published 20 June, 1975, all jet transports would be required to have cabin interiors that meet 1972 flammability standards within three years after the regulation is adopted. The current flammability standards for older jet transports were issued in 1967 and required compliance only when the aircraft was next overhauled or had its cabin interior refurbished. In 1972 new flammability standards were adopted for new type certified aircraft, such as the Boeing, McDonnell Douglas, and Lockheed wide body jets. The main difference between the 1967 and 1972 standards were the more rigorous requirements for seat cushion, upholstery, and carpet materials. The latter NPRM was issued in time for materials meeting the new standards to be used in the Boeing 737 and for McDonnell Douglas to meet some, but not all, of the 1972 standards in its DC-9 aircraft [Klass, 1975 (525)].

The 12 February, 1974 NPRM for industry and user comments proposes a new standard for smoke emission of cabin interior materials, requiring retrofit of interiors to meet the new specifications during the first major overhaul or refurbishment that occurred after five years from the effective date of the amendment of Parts 25 and 121 of the FAR's. There would be a five-year period of grace if the standard is adopted as proposed, but any major overhaul or cabin interior change after this period would require the use of low smoke emission materials.

In the ANPRM published 30 December, 1974, comments were requested for possible standards for toxic gas emission from cabin interior materials. Due to the limited knowledge of the relative toxicity of different materials and how to measure and specify acceptable levels, it has been estimated "that the FAA will not be in a position to propose a specific set of standards for at least a couple of years. Any requirement for retrofit would necessarily be at least several years in the future, delaying it until at least the early 1980's" [Klass, 1975 (525)]. In the Aerospace Industries Association response to the FAA, a number of cabin interior materials and items were cited for which there are no substitute materials or construction available which can still perform the intended functions. Their list included acoustic ceiling panels, material for window reveals, Tedlar acoustic sandwich panels for partitions and bulkheads, urethane, vinyl and natural rubber seat cushions, as well as cabin windows and cockpit side windows. Many items currently meeting the FAA flammability standard would not meet a toxicity standard. From a group of some 140 different cabin interior materials, the FAA has narrowed the number down to about 75 for toxicity tests to be conducted during 1976-1977.

An investigation in early 1974 by the Special Subcommittee on Investigations, House Interstate and Foreign Commerce Committee centered on concern for air carrier passenger safety. One area of interest included the smoke hood as a device to protect passengers and crew from the effects of toxic fumes, smoke, and flame. However, it was decided not to hold hearings but rather to take direct action with the FAA to determine why such devices have not been adopted for use in commercial air carriers (512). Further Congressional interest in air safety has been shown in more recent hearings [February, 1976 (572)].

3.1.2 Boeing Smoke Tests. Smoke evacuation tests were conducted by Boeing in March and April, 1963, to certify the Boeing Commercial Transport Model 707-321C. Tests were conducted by Pan American personnel using two 707 aircraft. Early tests were made to evaluate smoke evacuation and smoke penetration characteristics of a Boeing 707-321C convertible model and those of a 707-321C "stripped freighter." These tests were primarily related to in-flight smoke air flow characteristics and, as a result of the crash of a Pan American World Airways Boeing 707 (a non-passenger cargo flight) landing at Boston's Logan Airport on 3 November, 1973 [NTSB, 1974 (546)], further tests were made by Boeing in March, 1974. Both of these series of flight tests are described in some detail in the 10 March, 1975 issue of Aviation Week and Space Technology (540). In the Logan crash the presence in the cockpit of dense smoke, which was continuously generated and uncontrollable, was determined by the NTSB to be the probable cause of the accident. Vision was also impaired. Although the source of the smoke could not be established conclusively, the NTSB (546) believed that the spontaneous chemical reaction between leaking nitric acid, improperly packaged and stored, and the improper sawdust packing surrounding the acid's package initiated the accident sequence. One by-product may have been nitrogen dioxide (NO_2), formed when colorless nitric oxide (NO) reacts with oxygen in the absence of ultraviolet light. Orange nitrogen dioxide in sunlight has a half-life of less than 30 seconds. Immediate effects of inhaling colored nitrogen dioxide are mild irritation, headache, and weakness [Maxey, 1975 (540)]. Cases such as this indicate a need for adequate crew smoke masks as well as those for the passenger.

3.1.3 Fire Tests and Flash Fire Effects. Experimental fire tests of instrumented aircraft outfitted with then-representative interior materials were conducted by the Airline Pilots Association (ALPA) and indicate that smoke density approaches saturation in two to two and one-half minutes [Heine, 1966 (522)]. Detrimental effects to both vision and respiration would occur much sooner. In these experiments temperature rise approaching intolerable levels (248.5°C [480°F]) occurred at the fifth and sixth minutes, followed characteristically by a flash fire with temperatures rising in excess of 871°C (1,600°F) in one or two minutes. Smoke density and temperature measurements in other tests indicate stratification and localization, with flash fires reported to travel through the fuselage at a rate of 20.7 m/min (68 ft/min) [Marcy, 1965 (532)].

In order that evacuation may be accomplished before the cabin or flight deck areas become uninhabitable due to elevated temperatures, the protection of the human respiratory system is of critical importance. The occupant must remain mobile and in a conscious state post-crash in order to effectively evacuate. Clinical investigations have shown that shock may not be an important factor, accounting for a low (20%) fatality in burn cases [Phillips, 1960 (554)], while respiratory tract trauma, with or without superimposed respiratory tract infection, may account for nearly 50%. Yet where facial burns are incurred, more than three-fourths of the victims may develop respiratory difficulties due to inhalation of flame. It has been reported that if the lower respiratory tract, consisting of the trachea, main bronchi, and secondary bronchi, is burned, a fatality is usually inevitable [Connell, 1960 (498)].

In cabin fires injuries to the skin and respiratory system are the primary concern. Occupants exposed to heat have widely varied tolerances. Survival is dependent upon one's tolerance to pain and the thermal level at which his exposed skin will suffer second degree burning. Normal individuals experience pain when human skin is heated to 45°C (113°F). At 40°C (120°F) the rate of cellular destruction is more rapid than cellular repair [USAF, 1974 (298)]. Inhalation of hot gases produced by a crash fire creates the possibility of respiratory system injuries, but information concerning human tolerances is very limited. The highest known ambient temperature to which a human respiratory system has been exposed without damage is 198.8°C (390°F) [USAF, AFSC DHI-6 39.4, 1974 (298)].

Flash fires occur when the combined mixture of smoke, gases and oxygen in the burning cabin environment reaches a temperature at which ignition occurs, and all of the oxygen in the cabin is consumed, precluding survival. Temperatures may reach in excess of 815.5°C (1,500°F) in less than a second and ignite the entire cabin. Although no new NASA studies related to investigation of this phenomenon have been reported at this date, the National Bureau of Standards and NAFEC are continuing research on flash fires. This continues work reported in 1973 concerning burning polyurethane foam cushions [Paabo et al., 1973 (549)].

3.1.4 Flight Deck Crew Smoke Mask Protection. The FAA in recent tests conducted at the Civil Aeromedical Institute, has evaluated 137 devices intended to provide flight deck/crew smoke protection [1975 (535)]. These included 124 devices previously approved by the FAA on a basis of static fit, as well as 13 experimental prototypes provided by the manufacturers. Of these, 14 mask/goggle combinations, 6 full face masks, and 2 hood devices passed the test criteria. The criteria established involved: (1) no more than 5% contaminant leakage into the respiratory portion of the device, and (2) no more than 10% contaminant leakage into the visual portion of the device. If the mask happened to be designed so that the respiratory and visual portions were combined, as in full face masks or hoods, the 5% contaminant criteria applied. All of the equipment which passed this test was designed for and tested with "safety" or "emergency pressure." Since adequate performance wearing corrective glasses is a requirement of the applicable FAR, all subjects in these tests wore standardized corrective glasses.

The results of these tests indicated that the most significant problem was the effect on leakage, fit, and displacement of the equipment induced by glasses. On the other hand, the respiratory protection of oral-nasal masks was generally good. It was found that in many of those devices which passed this test the "safety" pressure required to compensate for large leakage areas induced such a leakage and waste of oxygen that the aircraft crew supply would be depleted in a very short time. It was concluded that eye protection remained a principal problem. Since few of those flight deck/crew smoke protection devices presently approved by the FAA were found to offer protection at the levels established in the tests, results and proposed regulatory changes were discussed in a meeting between FAA, equipment and airframe manufacturers, air carriers, and pilot groups, which was held at the FAA Aeronautical Center, Oklahoma City, 11-12 December, 1975. Since the emphasis in this chapter is upon passenger and cabin attendant protection, rather than crew/flight deck protection, it should be noted that some quite different objectives and criteria are involved, and crew smoke masks utilizing the aircraft oxygen system should not be confused with passenger and cabin attendant smoke protective devices intended for emergency egress.

3.1.5 Toxic Gases. The National Bureau of Standards tests for FAA in 1968 [Higgins et al., 1971 (524)] and the Aerospace Industries Association full scale tests in 1968 (488, 489) measured toxic gas concentrations, although emphasis was on fire control and suppression techniques. More recently, attempts to reduce the toxic gas emissions of burning cabin interior materials by tests of improved materials has been underway by FAA at NAFEC, and at Ames Research Center at Mountain View and Johnson Space Center at Houston. This work is reported to be successful in regard to flammability, but incomplete in terms of smoke, toxicity, and practical use considerations [Simpson, 1973 (563)]. Simpson also reports work underway by the Society of the Plastics Industry to study plastic material toxic gas emission, under funding to the National Bureau of Standards and the Southwest Research Institute to conduct tests in coordination with the FAA's work at NAFEC.

A concise review of the physiological and toxicological aspects of smoke during fire exposure was conducted by the University of Utah for NAFEC [Einhorn, 1973 (501, 502)] and should be consulted for more detailed evaluation and critique of laboratory test procedures and human tolerances. In a subsequent study, rigid- and flexible-urethane foams were evaluated at the University of Utah's Flammability Research Center for flammability characteristics and thermal degradation of urethane cellular plastics used in air transport cabin interiors [Einhorn et al., 1973 (501, 502)].

3.1.5.1 Air Carrier Accident Findings. In the AIA study of 1968 (488), industry, CAB, and FAA accident files were searched for detailed information on air carrier jet accidents prior to 1967. Of 170 accidents, fires were known to have occurred in 74 and there were significant fuel spills in 50. Six were interior fires. In 48 accidents the aircraft fuselage was ruptured, with fuel spillage occurring in 34 of these. In the total of 170 accidents (world-wide) applicable to the AIA study, it was concluded that 35 accidents with 1,881 fatalities were unsurvivable, 16 accidents with 539 fatalities were impact-survivable with fatalities, and 119 involved accidents or incidents having no fatalities.

However, toxic gas emission from burning cabin materials has only recently had serious attention as a result of findings in several major accidents occurring within the past decade. Accidents which have been of particular note in this regard include:

(1) Before noon on 11 July, 1961, a United Airlines McDonnell Douglas DC-8 crashed during a landing at Stapleton Field, Denver, Colorado. Soon after the aircraft stopped two major fires broke out; however, 98 passengers escaped prior to cabin fire. There were 17 fatalities with no signs of impact trauma. Smoke, from the chimney effect when the aft galley door was opened, was the major egress hazard, and 17 passengers were fatally overcome. Blood carboxyhemoglobin concentrations were determined from heart blood samples of all victims and ranged between 30 and 85% [Hasbrook et al., 1962 (397); Snow et al., 1971 (424)].

(2) After dark on 11 November, 1965, a United Airlines Boeing 727 crashed during a landing at Salt Lake City Municipal Airport. The rate of descent on final approach was 914.4 m/min (3,000 ft/min), touchdown was at 228 km/h (141.6 mph), and as the gears sheared, the aircraft skidded for 853 m (2,800 ft)in about 27 seconds, with a mean deceleration of 0.25 G, and came to rest engulfed in flame to an area forward of the wing. Of 85 passengers aboard the aircraft there were 41 fatalities, and of the 44 survivors only 11 were uninjured. Carboxyhemoglobin determinations from heart blood samples of 35 victims ranged from 13 to 82% with a mean value of 36.9% (10% is ordinarily considered the top limits of normal). Blood ethanol determinations from 35 victims resulted in 17 displaying positive values between 0.1 and 1.0 mg/ml, although one, at 1.5 mg/ml, fell in the range of intoxication where judgement may be considered impaired. These values could be associated with post-mortem changes, and were not considered a significant factor in emergency egress. Fatalities were attributed to smoke inhalation and cabin fire [Snow et al., 1971 (424)].

(3) On the afternoon of 23 November, 1964 a Trans World Airlines Boeing 707-331 with a crew of 11 and 62 passengers aboard, crashed in an attempted aborted takeoff at Fiumicino Airport, Rome, Italy. While still traveling at an estimated velocity of 64 km/h (40 mph) it struck a steam roller, continuing some 243.8 m (800 ft) in the next 22 seconds. Twenty seconds after stopping, a center fuselage tank exploded and fire rapidly spread. The fire equipment arrived 3 minutes, 45 seconds after the accident (Fig. 22). This accident was fatal to 45 passengers (72.5%). Of the 17 survivors, 10 received minor injuries and 7 were hospitalized. Carboxyhemoglobin (COHgb) elevations of the 24 fatalities found in the cabin were from 13.8% to 49.0%, although two were only 3.0% and 10.4%. In general, death was attributed to thermal burns or asphyxia, whether the victims were found inside the cabin or were among the 17 whose bodies were found outside the cabin. In those outside the cabin, COHgb values were generally below 10%, but were as high as 35.8%. Four victims died later, primarily of thermal burns [Snow et al., 1971 (424)].

Fig. 22. Fire and heavy smoke resulted in 45 fatalities of 62 passengers in this Trans World Airlines Boeing 707-331 accident at Fiumicino Airport, Rome, 23 November, 1964 (Photo courtesy FAA).

(4) On 27 November, 1970 (1705 AST) following an unsuccessful takeoff attempt, a Capitol International Airways, Inc., McDonnell Douglas DC-8-63F crashed and burned. The flight was being operated as a Military Airlift Command (MAC) contract flight and there were 219 passengers and a crew of 10 aboard. 46 passengers and 1 flight attendant were fatally injured as a result of the post-crash fire [Leroy, 1971 (402, 403); NTSB (209)].

(5) An Allegheny Airlines Allison Prop Jet Convair 340/440 crashed into cottages while making an instrument approach to the Tweed-New Haven Airport, Connecticut at 0949 EDT on 7 June, 1971. The aircraft was destroyed and 28 passengers and two crew members were fatally injured; only two passengers and the 1st officer survived. Autopsy and toxicological examination of 26 of the fatalities indicated that all had died of chemical asphyxiation and/or thermal injury [NTSB, 1972 (216)].

(6) At 1428 CST on 8 December, 1972, a United Airlines Boeing 737-222 crashed and burned in a residential area about 2.4 km (1.5 mi) short of the runway while on instrument approach to Chicago-Midway Airport. Of 55 passengers and 6 crew members aboard, 40 passengers and 3 crew members were killed, and 2 persons on the ground also received fatal injuries. Since there were allegations of foul play related to this accident, the trauma of non-survivors was closely examined. Elevated hydrogen cyanide levels were found in the captain and six coach passenger fatalities [NTSB, 1973 (247)].

(7) On 20 December, 1972 at 1800 CST a North Central Airlines McDonnell Douglas DC-9-31 and a Delta Air Lines Convair 880 collided at an intersection at the O'Hare International Airport, Chicago. The DC-9 was taking off and the CV-880 was taxiing at the time of the collision. The DC-9, with 41 passengers and a crew of 4, was destroyed by impact and fire. Nine of the 10 fatally injured passengers failed to escape from the aircraft, and smoke was reported to have been dense within the cabin [NTSB, 1973 (545)].

(8) On 3 November, 1973 a Pan American World Airways Boeing 707-321C crashed on final approach to Logan International Airport, Boston, Massachusetts. The crew of three reported excessive smoke in the cockpit which reached such severity that the aircraft could not be controlled. The in-flight smoke was caused by improper packaging of hazardous nitric acid cargo, and caused the subsequent non-survivable crash [NTSB, 1974 (546)].

(9) A Varig Boeing 707 approaching Paris on 11 July, 1973 also incurred an in-flight fire, possibly originating in a lavatory, and forced an emergency crash landing near Paris. A reported 120 deaths resulted from in-flight toxic gas inhalation; the only occupants surviving were the flight deck crew who had masks.

The majority of the 356 fatalities in these nine air carrier accidents have been attributed to the toxic effects of smoke and fumes or the thermal effects of fire. In the three crashes (1)-(3) cited above, 105 of 261 passengers aboard died in attempts to escape during the one to three minutes prior to the build-up of a lethal thermo-toxic environment within the cabin. Fig. 23 shows the dense smoke and flames typical of post-crash fires. This crash of a Boeing 727 at St. Thomas, Virgin Islands [NTSB, 1971 (203)] involved 46 passengers, 2 infants, and a crew of 7, with 2 fatalities. If passengers in this type of accident can be protected from the immobilizing and incapacitating effects of inhalation of smoke, toxic gases, and flame for only one to two minutes of additional evacuation time prior to the build-up of intolerable temperatures within the cabin, it seems that a significant increase in passenger survival can be attained. In some situations, however, additional evacuation time may be required.

Fig. 23. Dense smoke and fire following crash of Boeing 727 at St. Thomas, Virgin Islands 28 December, 1970 (203) (Photo courtesy NTSB).

3.1.5.2 Carbon Monoxide and Hydrogen Cyanide. The accidents noted above were investigated for carbon monoxide and/or hydrogen cyanide in victim blood levels. Results of these studies are shown in Table XI.

TABLE XI.

CARBON MONOXIDE AND CYANIDE FINDINGS IN AIR TRANSPORT ACCIDENTS

A. CARBON MONOXIDE IN AIR TRANSPORT ACCIDENTS

Accident	Total Passengers	Fatal Passengers	Passengers Tested For Carbon Monoxide	Carbon Monoxide (as Blood Carboxyhemoglobin)
Denver DC-8	114	17	17	30-85% range (mean = 62%)
Rome 707	62	45	24	3-49% range (mean = 23%)
Salt Lake City 727	85	43	35	13-82% range (mean = 37%)
		105	76	

B. CARBON MONOXIDE AND CYANIDE IN AIR TRANSPORT ACCIDENTS

Accident	Carbon Monoxide (as Blood Carboxyhemoglobin) in Fatal Victims	Cyanide in Blood Sample
Anchorage DC-8	19 positive (5-69% range)	18 positive (0.01 μg/ml to 2.26 μg/ml range)
New Haven 580	23 positive (9-49% range)	23 positive (0.007 μg/ml to 3.38 μg/ml range)
Chicago 737	Pilot 40%	Pilot 3.9 μg/ml
Chicago DC-9	9 positive (26-64% range)	9 positive (1.10 μg/ml to 2.65 μg/ml range)

Source: Mohler, 1975 (542)

Although many toxic gas products are generated during a crash fire, carbon monoxide (CO) may be the most significant because small percentages of CO can produce serious consequences. The effects of various concentrations of CO are illustrated in Tables XII and XIII.

TABLE XII.

EFFECTS OF VARIOUS CONCENTRATIONS OF CARBON MONOXIDE IN AIR AT SEA LEVEL

% of CO in Air	Effects
1.28	Immediate effect, unconsciousness and danger of death in 1-3 min
0.64	Headache and dizziness in 1-2 min; unconsciousness and danger of death in 10-15 min
0.32	Headache and dizziness in 5-10 min; unconsciousness and danger of death in 30 min
0.16	Headache, dizziness and nausea in 20 min; collapse, unconsciousness, possibly death in 2 hr
0.08	Headache, dizziness and nausea in 3/4 hr; collapse possibly unconsciousness in 2 hr
0.04	Frontal headache and nausea after 1-2 hr; occipital after 2-1/2 to 3-1/2 hr
0.02	Possible mild frontal headache in 2-3 hr

Source: HIAD, USAF, AFSC DHI-6 DN 395, p. 4, 20 July, 1974 (298)

TABLE XIII.

PHYSIOLOGICAL EFFECTS OF VARIOUS CARBON MONOXIDE HEMOGLOBIN PERCENTAGES

Carboxyhemoglobin Percentage	Symptoms
100	
90	Immediate death
80	
70	Unconsciousness, respiratory failure, death in long exposure
60	
50	Headache, disorientation, collapse, fainting
40	Pronounced headache, fatigue, irritability, judgment impaired
30	
20	Shortness of breath during moderate exertion, minor headache
10	No major effect except shortness of breath on extreme physical activity
0	No effect

Source: HIAD, USAF, AFSC DHI-6 DN 395, p. 4, 20 July, 1974 (298)

A rapid estimation of carboxyhemoglobin from expired breath after carbon monoxide exposure has been developed by Stewart et al. [1976 (566)], utilizing a portable electrochemical cell.

Mohler [1975 (542)] has discussed the causation of the production of toxic products from cabin fires and provided some alternative solutions. Carbon monoxide levels have been shown to rapidly exceed physiological tolerances in post-crash fire tests [Einhorn, 1972 (501, 502); Gross et al., 1968 (518); Heine and Brenneman, 1966 (522); AIA, 1968 (488)]. In full scale tests cabin carbon monoxide levels of 10,000 parts per million were reached in 90 seconds, and in another test 26,000 ppm in 180 seconds. Mohler notes this is above the fatal level for a 2.5 minute exposure but that incapacitation may occur at lower levels.

Hydrogen cyanide and carbon monoxide result from the thermal decomposition of most organic materials such as wood, cotton, paper and plastics, or human hair. In addition, many specific cabin interior fixtures and materials, including polyurethane used in seat cushions, carpet pads and hat racks; acrylonitrile-butadiene-styrene used in passenger service unit window structures; modacrylics used in dust panes; and wool used in seat upholstery. Similar materials may be carried into the cabin by passengers. In the tests referenced above cyanide (hydrogen cyanide) exceeded 4,000 ppm in 90 seconds, above a fatal level for this time exposure. Mohler [1975 (542)] points out that incapacitation may occur "perhaps at half the fatal concentration." Thus while coma and death begin to occur at the 60-70% blood level range, 30% blood carboxyhemoglobin produces severe headache, weakness, dizziness, dimness of vision, nausea, vomiting, and collapse. Similarly, while cyanide causes death at about the 5 μg/ml blood level, incapacitation can occur at half that. Combined, lethal effects could be expected with a blood carbon monoxide of 20% plus a blood cyanide of approximately 2 μg/ml. Of all the plastic polymers, polyvinyl chloride has been implicated primarily in causing the most serious problem among fire fighters because it releases hydrogen chloride gas when burning. Dyer and Esch [1976 (500)] have reported on 175 fire fighters who experienced symptoms from its toxicity from 1970 to 1975.

Higgins et al. [1971 (524)] in tests of the combined inhalation toxicity of carbon monoxide, hydrogen cyanide, and other toxic gases have found that these toxic substances, when inhaled in combination, can be more lethal than when inhaled separately. Mohler [1975 (542)] has suggested the use of new materials for possible retrofitting of existing aircraft and use in future aircraft; however, more recent NASA studies have suggested that even materials such as Nomex, Tedlar, or fiberglass are not as satisfactory as first thought. (Tedlar is the duPont trade name for polyvinyl fluoride decorative panel surface and Teflon is the duPont trade name for fluorocarbon polymer. Kynar is the Raychem Corporation's trade name for polyvinylidene fluoride plastic material, and Nomex is the duPont trade name for its high-temperature-resistant nylon, formed in fabric or paper.) Current NASA investigations indicate that a polyimide foam may be acceptable as a substitute cushion.

Both the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration

(OSHA) have set air pollution and exposure limits to vinyl chloride (VC), a colorless gas derived from chlorine and petrochemicals, which is the major ingredient in polyvinyl chloride (PVC), used in some interior materials [Time, 1974 (567)]. While these long-term standards relate primarily to workers in the manufacturing process, they indicate the mounting concern and emphasis for short-term exposure in future aircraft for non-toxic and non-flammable materials. Unfortunately, while there is much known about long-term exposure toxicity data, little is understood by toxicologists about acute short-term exposure typified by an aircraft crash fire.

In 1973 the Committee of the French Aerial Transport (CFAT), VTA, Air France, and Air Inter formed a commission to study the problem of on-board fires. This included a group to study materials, an inquiry group, and a medical group. Dr. Fourn, Medicine Chief of VTA in Paris presented the toxicological findings resulting from the medical portion of this study at the XXII International Meeting on Aviation and Space Medicine in Beirut in October, 1974 [Fourn, 1974 (517)]. Six materials from cabin interiors of the McDonnell Douglas DC-9 and DC-10 were found to yield combustion products of carbon monoxide, as well as some hydrochloric acid. In addition, certain cyanhydric (hydrocyanic) acids were detected. Papago Harmonic and Polyplastex produced sulfuric acid; Papago Harmonic, Moquette RK, Mousse Tramico, and the Taraflex RK produced some nitrogen oxides.

Plastic interior materials from the Boeing 707, when burned, were found to emit carbon monoxide, carbon dioxide, hydrochloric acid, hydrofluoric acid (Fluorhydrigue), hydrogen fluoride, and hydrogen sulfide. Since each airline specifies its own particular interiors, however, there may be some difference between them.

In addition to the above aircraft, tests were also performed on the combustible products of six plastic materials from the Caravelle aircraft. Results of combustion showed that carbon monoxide, carbon dioxide, and hydrocarbons were common to all. Specific to certain materials were hydrochloric acid (with Royalite [ABS],Makrolon, Panneau sandwich, and traces with Nomex), hydrogen fluoride (with wool and Royalite [ABS]), sulfuric acid and hydrocyanic acid (with wool and linings). In reference to the Varig 1973 accident near Paris, Fourn stated that 108 passengers had died of carbon monoxide inhalation, and 12 others, after histological studies, were found to have died of suffocation resulting from the reflex inhibition of respiration under the action of the chlorinated by-products and fluorides affecting the mucous membranes of the nose and pharynx.

3.1.6 Military Studies. Military as well as civil air transport accidents have indicated the major influence of post-crash fire on survival. A review of survivable USAF passenger-carrying aircraft accidents resulted in the conclusion that fire was a prime factor in limiting the successful egress of the passengers [Reagin et al., 1969 (13)]. Studies by Sawyer [1967 (16)] of 196 cargo/transport accidents involving 1,899 occupants occurring from 1962 to June, 1967 indicate the overall incidence of fire was 35%. Of these, 69 USAF cargo/transport accidents involved fire during this period, and 16 resulted in major or fatal fire injuries. 74% (or 139) of the 189 fatalities were attributed to fire, resulting in the observation that "the risk for aircrew was 34%, whereas 93% of all passenger fatalities were due to fire" [Sawyer, 1967 (16)]. Reviewing 40 selected USAF passenger-carrying accidents from 1964 through 1968, Brown (1969) found that many fatalities occurred even though the crash itself was survivable. This was confirmed by recent review by the author of 30 Boeing C-135 accidents occurring from 1964 to date, and 14 Lockheed C-141 accidents from 1968 to date. In one case involving a C-135 accident, a small on-board auxiliary power unit caught fire upon impact, and 11 passengers died from smoke (asphyxiation secondary to hypoxia and inhalation of smoke) when they failed to evacuate in time. In this accident 30 passengers were uninjured. One recommendation resulting from the investigation was "that commercially available safety hoods be obtained and tests conducted" [Solt, 1969 (565)].

A 1970 USAF study of emergency escape and survival from transport aircraft concluded that "a simple lightweight bag-shaped smoke hood...would lengthen the survival time by providing three to four minutes of clean air to breathe inside the hood. In addition, the hood would provide adequate visibility enabling the passenger to see escape hatches and allow mobility to complete the evacuation of the aircraft. By providing additional survival time and visibility, the evacuation and survival would be enhanced. Individual smoke hoods can be made available by attaching a hood to each seat in the aircraft" [Reagin et al., 1969 (13)].

3.2 Protective Devices

3.2.1 Background. Research and development of passenger smoke hoods have continued sporadically during the past ten years as a result of the initial work of E.B. McFadden at the FAA Civil Aeromedical Institute which started in the fall of 1965. A number of smoke mask devices have been proposed or tested, and 16 versions of these are considered in this section. However, emphasis is on the Schjeldahl (now "Sheldahl") smoke hood since this has had the most extensive testing and is a currently available protective device. As a result of investigation of the Salt Lake City Boeing 727 crash evacuation on 11 November, 1965, McFadden constructed several working models of polyethylene (non-flame resistant) hoods to test feasibility of the concept. Learning that duPont Chemical Company had a polyimide flame-resistant and transparent plastic film, he contacted the Schjeldahl Company in December, 1965 to fabricate five polyimide hoods. However, in these experimental hoods the adhesive was of insufficient strength. By May, 1966, the defective adhesive hoods were replaced by five more using a Schjeldahl proprietary adhesive, and were followed in September, 1966 by Schjeldahl-fabricated hoods with metallic coatings [Reynolds, 1966 (557)].

The results of the initial study [McFadden et al., 1967 (538)] and subsequent comprehensive multidisciplinary investigations [McFadden et al., 1968 (537); McFadden and Smith, 1970 (539); McFadden, 1970 (534); McFadden and Gibbons, 1970 (536); Lewis, 1970 (528); Tobias, 1970 (568); and Smith, 1970 (564)] represent the most exhaustive studies published to date of this protective device. Two versions of the Schjeldahl smoke hoods were used in the FAA/CAMI tests but the subsequent NPRM in 1969 was primarily based upon results of investigations with the earlier version. Several other research studies have also evaluated smoke hood protective devices. In 1967-68 the Aerospace Industries Association (AIA) evaluated a number of prototype devices, which were subjectively tested (488). In October, 1969 the Aeroport de Paris carried out two tests by three volunteers of an early Schjeldahl Type D (drawstring) smoke hood furnished by the FAA [Mouton and Armand, 1969 (583)]. Subjective evaluation was also made by consultants to the Air Transport Association of America (ATAA) (560), and in 1970 by three members of the Space Science Board, National Academy of Science/National Research Council upon request of the FAA. The background and results of these investigations are provided in some detail in the following subsections.

In January, 1969, a Notice of Proposed Rule Making was published in the Federal Register which would amend Part 121 of the Federal Air Regulations to require that protective smoke hoods be carried on all civil air carriers. Citing results of earlier studies, the "FAA concludes that, if protective smoke hoods were provided in large transport airplanes, the probability of occupant survival in airplane crashes would be significantly increased; that the economic burden of fitting airplanes with such hoods is reasonable in relation to expected benefits; and that prototype hoods have been tested and evaluated to a sufficient extent to justify a requirement (with a reasonable implementation period) at the present time" [F.R. 34, p. 466, 1969 (507)].

The FAA received 23 comments as a result of this NPRM. Of the major aviation associations which commented, the Airline Pilots Association supported the proposal; however, the Air Transport Association, Aerospace Industries Association, Airline Stewards and Stewardesses Association and the Airline Dispatchers Association were strongly opposed. The Flight Safety Foundation opposed the rule on the basis of a medical evaluation submitted by consultants of the Air Transport Association of America, a supporter of the FSF. The National Transportation Safety Board concurred in the FAA intent, but expressed concern over a possible increase in evacuation time and limitation of available oxygen with use. The major comments involved questions of hood safety, practicality, concern over whether it would slow down evacuation time, and whether the specifications listed were justifiable. As a result of analysis of the comments received related to this proposed rule, the FAA withdrew Notice 69-2 in September, 1969, despite the strong objections of the FAA Office of Aviation Medicine. In view of the difference of opinion expressed between the medical and regulatory arms of the Federal Aviation Administration concerning the value of the smoke hood concept in post-crash emergency evacuation, the basis for rejection of the 1969 FAA proposed smoke hood requirement for civil air carrier aircraft should be reexamined both in relation to air transport aircraft requirements, and with consideration for subsequent advances in the state-of-the-art. In this regard, the results of the reports and studies bearing upon the questions posed seem particularly pertinent and are summarized in the following sections.

3.2.2 FAA Civil Aeromedical Institute Tests. Initial development and testing of the smoke hood were conducted at the FAA Civil Aeromedical Institute (CAMI) laboratories at Oklahoma City under the direction of E.B. McFadden in 1966, and the following summarizes this work [McFadden et al., 1967 (538)]. Experimental transparent hoods were fabricated under contract by the G.T. Schjeldahl Company. Primary design criteria involved:

(1) Design and operation simplicity.
(2) Smoke inhalation protection for a limited (2-1/2 - 8 min) duration.
(3) Omnidirectional visibility and donning.
(4) Lightweight and compact in size.
(5) Device should not melt or burst into flame when worn on the head or face.

Secondary design considerations were determined to be:

(6) To prevent inhalation of flames and respiratory damage.
(7) To protect the face and hair from direct contact with flames.
(8) To provide protection from convective and radiant heat.
(9) To extend passenger escape time by maintaining passenger mobility and continuation of evacuation.
(10) Esthetic considerations involving prevention of disfiguring facial burns.

These hoods were constructed of "Kapton," (tradename of E.I. duPont de Nemours Corporation, Wilmington, Delaware), a high-temperature polyimide film, selected because of its characteristics of non-melting when exposed to extreme heat, non-flammability, and transparency. Char levels for Kapton are stated to exceed 800°C (1,472°F). Kapton also exhibits a high tensile strength, folding endurance, low shrinkage, insolubility in organic solvents, and inertness to fungi. Conventional heat-sealing techniques could not be used in fabrication since polyimide film has no melting point. One initial series was fabricated utilizing high temperature adhesives. A second series was fabricated with a transparent reflective metalizing coating. Some 21 samples of polyimide film were successively coated with varying thicknesses of gold, silver, and aluminum, with and without a protective coating over the metal. Evaluation was made for infrared emissivity and reflectance, heat, and optical transmission.

The normal volume of the hood was calculated to be about 18.5 liters (1,129 cu in) exclusive of the volume occupied by the wearer's head. Human testing was conducted with subjects wearing the clear, uncoated, amber-colored, polyimide hoods and the coated silver polyimide hoods for eight minutes of infrared radiation exposure with the filament of the lamps located 55.9 cm (22 in) from the front surfaces of the hood. The metalized polyimide film was shown to develop up to 90% infra-red reflectance. When the clear hood was used, skin temperatures of 46.1-47.2°C (115-117°F) approached the limits of voluntary heat tolerance. A maximum skin temperature of 37.7°C (100°F) resulted under the same conditions while subjects wore the coated silver hood. When the heat sources were moved to a point 16.5 cm (6.5 in) from the front surface of the hood (lamp lens within 2.5-5.0 cm [1-2 in] of contact) forehead skin temperature averaged 41.1°C (106°F). Some reduction in visibility with both clear and metalized hoods was found. It was cautiously concluded from this investigation that the Schjeldahl smoke hood had potential usage for short-term emergency protection, however additional tests and development were required "prior to any specification for operational use in aircraft" [McFadden et al., 1967 (538)].

However, the initial tests reported in 1967 [McFadden et al. (537, 538)] as well as the FAA Flight Standards full scale evacuation tests [Federal Aviation Administration, 1968 (506)], and studies carried out by the Aerospace Industries Association Crashworthiness Development Program Technical group [1968

(488)], had revealed specific design deficiencies in the original prototype. The primary deficiencies noted were:

(1) Neck Seal. Passengers and crew evacuating from jet aircraft could not be relied upon to consistently tighten the drawstring neck seal.

(2) Vision. While polyimide surface aluminization was shown to provide excellent radiant heat reflectance and sufficient transparency for adequate vision under normal illumination levels, it was found that evacuation test subjects experienced vision difficulties when exposed to the .05 foot-candle emergency illumination as provided in jet transport aircraft.

(3) Useful air supply. Limitations in time duration of hood effectiveness in rebreathing (partially due to neck seal).

In a subsequent study by the Civil Aeromedical Institute, FAA [edited by McFadden and Smith, 1970 (539)], specific items were evaluated as suggested by the results of the initial tests. This combined multi-disciplinary physiological, medical, and psychological investigation examined leakage, toxic effectiveness, vision, acoustic characteristics, effects of safety briefings, and simulated evacuation tests through dense smoke.

The current state-of-the-art of the Schjeldahl smoke hood is still represented in these areas by this 1970 evaluation, which was designed to investigate: (1) the degree of protection against incapacitating agents provided by the hood; (2) the hood limitations in terms of useful air supply, vision, and audition; and (3) the utility of the hood. The specific findings of these studies are summarized as follows:

3.2.2.1 Leakage Evaluation. As a result of the earlier findings concerning poor neck seal with the drawstring hood ("Type D"), a new neck seal consisting of a septal (membrane) of heat-resistant urethane was developed ("Type S") which fits closely about the neck upon donning. The objective was twofold; to determine life-support capabilities with respect to both the quality of the contained air supply and to the metabolic rate of the wearer [McFadden et al., 1970 (539)].

Ten hoods of each type were tested utilizing ten male and ten female naive subjects. Temperature exposure was limited to 60°C (140°F). Respiratory rate was continuously monitored with an impedence pneumograph which also provided estimates of relative tidal volume. Oxygen consumption, carbon dioxide production, heart rate (ECG), hydrocarbon concentration, and loss of air were measured.

The most marked difference between the septal and drawstring hoods was the observation that CO_2 accumulation and O_2 reduction in the septal type (S) tended to progress in a relatively uniform linear fashion, while with the drawstring (D) hood this tendency was interrupted when the CO_2 concentration reached a level which induced hyperventilation. This increase in depth of breathing (pumping action) characteristically resulted in a gross leakage and leveling off of CO_2 concentrations with the earlier drawstring (D) hood. Overall leakage of the D drawstring version was markedly greater than with the S Septal hood. However, it was noted that repeated usage of the septal seal (S) hood resulted in a trend toward greater leakage (fatigue of the elastic polyurethane seal) which could be a factor if hoods were to be donned repeatedly during drills or precautionary evacuations, and it was recommended for this reason that seals be replaced after each usage.

These investigators point out that the results of these tests illustrate that no hood which is designed to meet the criteria of accessibility and economy of storage can be expected to provide absolute protection and life support for indefinite periods. A CO_2 concentration of 5% was reached in septal seal (S) hoods within 1.4 to 4.0 minutes, depending on the temperature and degree of physical exertion. A projection to 8%, the generally accepted minimum allowable concentration, is reached in 3 minutes under exercise conditions and 6.4 minutes under rest "cool" conditions; in 2.2 minutes under exercise and 4.9 minutes under rest "heat" conditions.

Information concerning metabolic rates of semi-hysterical people attempting to escape a burning aircraft are not known. However, these authors believe this should not exceed the O_2 consumption of the exercising subjects. They conclude that the 8% tolerance time of approximately 120 seconds obtained for this group seems a conservative estimate of the time during which the average evacuee could benefit from the hood, and that the newer septal seal (S) type hood provides excellent fume protection.

Some cautions were also expressed. Pentane gas was selected as the single model agent as a compromise between gases of higher and lower molecular weight, fat solubility, and other chemical properties, as well as because of safety up to the flammability limit of 1.4% concentration. But toxic gases with greater diffusion potentials than pentane may occur in aircraft fires and include HCN, CO, HCL, and aldehydes. Failure of a particular device can occur even under the best of manufacturing controls, as was pointed up by an incident reported by these investigators. "An experienced investigator, wearing approved (Bureau of Mines) full-face regalia with air supply, became incapacitated by a leakage of lacrimator gas while serving as a safety man for another investigator who was wearing a Type S septal seal smoke hood. The man equipped with the hood discovered the accident and led the visually incapacitated 'safety man' from the chamber" [McFadden et al., 1970, p. 15 (539)]. Another possible risk is that an individual who is abnormally insensitive to CO_2 may suffer from insidious hypoxia when the O_2 is consumed. Normal individuals would be forced to remove the hood by the sensation of suffocation.

3.2.2.2 Toxic Environment Effectiveness. The objective of this study was to determine the effectiveness of the newer septal seal (S) protective smoke hood in preventing inhalation of toxic substances similar to those produced in the combustion of aircraft fuel and cabin interior materials. Test subjects were exposed to a heavy black smoke environment consisting of significant quantities of carbon monoxide (CO concentration from 450 to 950 ppm) and soot particles resulting from combustion of JP-4 fuel and water-soluble oils. Seven adult (4 male, 3 female) subjects were tested in an octagonal maze smoke chamber in a clockwise direction while conducting a switching task until they had been exposed to at least 90 seconds of test [McFadden and Gibbons, 1970 (536)].

This study was based on the well-established affinity of blood for carbon monoxide, which is several hundred times greater for CO than O_2. Since it is more easily passed through membranes due to its small molecular size, it is particularly important that the smoke hood prevent inhalation of this gas. During the chamber exposure subjects traversed linear distances of 33 to 67 m (108 to 220 ft), which were considered to exceed those required in the movement to emergency exits in aircraft, and were able to perform a relatively large number (11 to 25) discrete switching operations under these conditions. This study confirmed the effectiveness of the septal seal (S) smoke hood in a toxic environment under evacuation conditions requiring both movement to exit areas and ability to perform manipulation operations.

3.2.2.3 Vision. Since the earlier FAA tests examined optical transmissions of the Schjeldahl smoke hood by spectrophotometric measurement and found deficiencies in vision under emergency lighting (.05 foot-candles) conditions, the purpose of this study was to evaluate the optical transmission of the hood by visual photometry and determine the effect on visual acuity [Lewis, 1970 (528)].

Nine male and three female subjects were tested, utilizing both the hood without aluminization (from Type S) and the aluminized with a clear band (from Type D). The visual acuity tests were designed to represent a worst-case situation. Thus subjects were adapted to an illumination in excess of that provided by normal aircraft interior lighting; the illumination was therefore set at 30-foot-candles measured at seat level. This exceeds the usual 15- to 25-foot-candles provided by aircraft reading lights and the 5- to 15-foot-candles general illumination at armrest height. Simulated emergency illumination was obtained by adjusting the voltage of a tungsten lamp to provide .05-foot-candle illumination. Test procedure involved the subject seated 3 m (10 ft) from the test target and adapted to normal illumination for 1 minute. Basal acuity was measured, after which subjects were instructed to don the smoke hood after lights were turned off and read each test card as rapidly as possible. Matched tests were conducted without the smoke hood, and each subject made eight runs, four in each condition.

Results showed that visual acuity in these tests was reduced under emergency illumination to 0.68 without the smoke hood, compared to a further reduction to 0.55 while wearing clear smoke hoods (Type S). With aluminized hoods (Type D), visual acuity was reduced to a level below the measurement capacity. It was reported that clear smoke hoods (Type S) have optical transmissions of about 75-80% (similar to transmission of optical glass sunglasses). A difference of 5% between the uncoated patch test samples and the clear areas from aluminized samples was considered to be due to the coating used to protect the aluminized surface. While visual capacity was reported to be significantly affected by wearing clear hoods under emergency illumination, a 20 to 30% increase in the level of emergency illumination would compensate for the transmission loss through the non-aluminized hoods [Lewis, 1970 (528)].

3.2.2.4 Acoustic Attenuation. The purpose of this study was to determine the extent to which the smoke hood may act as a barrier to the transmission of sound. This is of especial importance in an emergency evacuation if passengers are to hear crew instructions.

Thirty male and female subjects were each tested twice, once with and once without wearing the hood. Each subject wore the hood for two periods of 100 seconds each. It was concluded that the Schjeldahl (Type S) smoke hood does not interfere with the transmission of sound waves. A barely discriminable maximum threshold shift of 3dB at 5,000 Hz was reported [Tobias, 1970 (568)].

3.2.2.5 Safety Briefing Effectiveness. The utility of the smoke hood during an actual evacuation primarily depends upon the passengers' or crew's success in using it, and it was considered that this is probably a function of the effectiveness of the preflight safety briefing. This psychological study was therefore designed to determine to what extent increasing the amount of information presented during safety briefings influences the degree of hood-donning success (as measured by both ease and speed of donning), the extent of hood inflation, the incidence of positive and negative feelings about hoods, and the willingness to use them. In addition it was considered important to ascertain: (1) how much of the information presented during briefings is retained, as a function of the amount presented; (2) the importance of the use of demonstrations, (3) whether hood-donning ability is affected by the passenger's sex; and (4) whether practice will result in a significant performance improvement. This study was conducted by Smith [1970 (564)].

Naive subjects consisted of 35 females and 68 males between the ages of 17 and 31; 22 observers were pretrained for behavioral observations. The study was conducted in an aircraft cabin with seating modified to allow observers to directly observe subjects. A pocket containing a compactly folded Type S smoke hood (15.2 x 17.8 x 3.8 cm [6 x 7 x 1-1/2 in]) was firmly taped on the seat back in front of each subject, and positioned so that the upper portion would tear off when a subject pulled on either of two red tabs located at the upper corners of the pocket. A tape recording presenting six variations in briefings provided a greeting, statement of emergency exit locations, description of the use of oxygen, and statement of the location and purpose of the safety hood. Each subsequent briefing (with a different group of subjects) increased the amount of information given about the smoke hood, although the stewardess gave the same demonstration during all briefings. At the conclusion of each briefing the subjects were told that on a signal they were to don the smoke hoods located on the backs of the seats in front of them as quickly as possible.

Results of the hood-donning efficiency indicated that subjects (95.2%) felt that the instructions were clear. Observers noted, however, that 90.3% of the subjects encountered some sort of a problem in donning the hoods, although all were reported to have gotten the hood on both quickly and satisfactorily. Finding and spreading the neck seal and completely inflating the hood so that it would contain a maximum amount of air seemed to present the biggest difficulties. It was judged that giving instructions about getting the hood over glasses could be helpful.

Some 73.4% demonstrated satisfactory retention of safety information, with no difference in retention rates between demonstrated and non-demonstrated items. However, it was also reported that subjects in 5 of the 6 groups did better on non-demonstrated than demonstrated items. Subjects did poorest in retention of information related to exits, and on how long to wear the hood. Previous hood-donning experience was found to significantly reduce the time of donning as well as problems encountered. It was suggested that passengers seated next to windows may have more difficulty in hood donning than aisle passengers due to space limitations. Nothing was noted about the middle passenger in a triple seat.

It was concluded by Smith that increasing the amount of information presented during briefings about the use of protective smoke hoods had little effect on donning time but resulted in fewer problems in donning over glasses, better inflated hoods, and more positive feelings about the hood use. All subjects stated they would use the hood in an emergency although some expressed reservations about a shortage of air in the hoods.

Recommendations resulting from this investigation were reported as follows [Smith, 1970 (564)]:

(1) General safety briefings should probably contain more information about the use of safety devices.
(2) The portion of the briefings dealing with safety hoods should include mention of the adequacy of air supply.
(3) The opening in the S type hood's septal seal neck should be modified to make it easier to find (perhaps by outlining in a contrasting color).
(4) Consideration should be given to using a larger, less compact hood package, with possible enclosure of self-distending devices.

3.2.2.6 Dense Smoke Evacuation. This final investigation in the 1970 FAA study of the smoke hood was designed to determine the reactions of a naive group of subjects to smoke hood use during simulated evacuation in the presence of heavy smoke. This work was conducted by McFadden [1970 (534)].

The test evacuations were conducted in a Lockheed L-749 Constellation cabin, with motion picture analysis (smoke completely obscured visibility), sound recordings by means of a tape recorder, and with one slide inflated and in place at the exit door (at left rear cabin), partly open prior to tests. The smoke hood packet was inserted in the seat back pocket. The Type D drawstring hood was used in these tests. One group of 64 subjects evacuated without smoke and without using the hoods, then in a second test used hoods in dense smoke to evacuate upon activation of an audio alarm. A second group of 64 subjects made their initial evacuation under smoke conditions while wearing smoke hoods, and a second test without the presence of smoke and without wearing hoods. Smoke was produced by means of a theatrical smoke generator to an extent that visual cues were virtually eliminated. This series of tests was intended to measure the flow of a maximum number of passengers through only one exit.

It was found that the presence of smoke was the primary variable influencing speed of evacuation, although the use of hoods alone was reported to have had little significant effect on evacuation rate. Subjective questionnaire results indicated the experience gained in evacuating without smoke was beneficial when subjects subsequently evacuated under smoke conditions.

3.2.2.7 Conclusions of FAA/CAMI 1970 Tests. The six studies summarized in the foregoing indicated that the currently available smoke hood devices tested did protect the individual from the respiratory effects of smoke and provided him with an air sample which was relatively uncontaminated and adequate for evacuation from current civil jet transports. However, there still remained some limitations, primarily that the hood did not increase visibility in smoke other than preventing eye irritation, and the air supply was limited. The septal seal neck of the new Schjeldahl Type S hood had been shown to be a distinct improvement over the older drawstring D type in preventing the penetration of noxious substances into the hood air sample. Several problems pointed out relating to the passenger locating the seal for donning, and the decrement of the seal through repeated usage, were felt to be solvable. Results from these briefing tests indicated that even with a minimal briefing most passengers should be able to use the hood adequately. The major improvement, which was explored in subsequent experimental developments, evaluated the incorporation of a self-contained oxygen supply and carbon dioxide removal agent. In view of the foregoing studies the FAA medical investigators felt that development of a safe "get-me-out" smoke protective device had progressed to the point where its use in civil air carriers should be mandatory. Figs. 24 and 25 illustrate the use of this particular device in the Chrysler Corporation G-2 Gulfstream.

3.2.3 1967-68 AIA Smoke Hood Evaluation. As part of the Crashworthiness Development Program of the Aerospace Industries Association of America, evaluation and testing of aircraft crash-egress smoke masks were conducted in 1967-68 and a limited distribution of results prepared in July, 1968 [AIA, 1968 (488)]. A Boeing-McDonnell Douglas team evaluated prototype "masks" at the McDonnell Douglas laboratories at Long Beach and the Boeing Company laboratories at Renton, Washington. These are the only comparative tests known for a number of prototype devices. In September, 1967, 28 companies were sent an invitation to participate which described suggested requirements for smoke and fume protective devices that could be used for escape from an aircraft fire. As a result, 8 companies submitted 10 prototype devices. These consisted of the Schjeldahl hood (drawstring version, "D"), Boeing Mask, John Hand Hood, Racine Glove Company Hood, Sierra Engineering Corporation Hood, two Life Support Systems Hoods, Scott-O-Vista Mask, and two Mine Safety Appliance Company devices, as illustrated and described in Figs. 26-32. Tests included subjective smoke tests, in which a volunteer subject entered a 9.6 cu m (340 cu ft) smoke chamber wearing a previously donned and adjusted hood, and remained until breathing became intolerable for that individual. White irritant smoke was initiated from a smoke bomb device. These tests were reported as indicating that small amounts of leakage had a significant effect on the wearer, making the subject want to remove the mask. One test was conducted in a noxious environment produced with a .09 m sq (1 ft sq) pan burning in a 4.5 m (15 ft) mock-up utilizing a Boeing Mask with a modified mouthpiece and nose seal. (Rebreathing of less than 2 liters (122 cu in) of previously exhaled air used to inflate the device would appear to be an inadequate rebreathing volume.)

Three exposures of increasing but unspecified duration were reported as successfully tolerated, but in a fourth exposure planned for 150 sec, the subject lost consciousness at 130-140 sec. It was concluded that this resulted from a lack of oxygen. No information is available as to the number of subjects, number of tests, or number of each hood type tested. Apparently no objective testing was conducted.

Fig. 24. Demonstration of passenger donning Schjeldahl "S" model "safety" hood in Chrylser Corporation Gulfstream. This smoke hood is presently in use in many corporate, FAA, and other aircraft and has been recommended in several studies for use in USAF air transport aircraft (Photo courtesy Chrysler Corporation).

Fig. 25. Once smoke hood is donned it may protect the passenger against toxic fumes and smoke for 4 to 6 minutes, and protect the head and face against the effects of flames exceeding 800°C (1,472°F), providing additional emergency egress capability (Photo courtesy Chrysler Corporation).

It was reported that eight evacuation tests were conducted in an abbreviated Boeing 727-200 mock-up, using only Schjeldahl (Type D), John Hand, and Boeing masks due to limited availability of other devices. Illumination conditions and instructions were varied during the smoke tests. Information was reportedly obtained by use of motion picture photography, questionnaires, and voice recorders. Results indicated that donning time ranged from 8 to 14 seconds. Hoods were frequently not zipped up or properly tightened and the Boeing Mask mouthpiece often was not gripped in the mouth. Subjects were reported to have lifted the devices above their eyes to improve visibility. Devices used in light smoke and with 0.1-foot-candle average cabin illumination resulted in a 30% decrease in evacuation rate (but this report does not indicate over what). Devices used in a dark cabin with smoke were reported to be 33 to 52% slower when compared to evacuation in dark conditions with no masks or hoods. Device usage increased when clearer instructions were given in briefing. This study concluded that use of the devices tested was not satisfactory; that visibility was decreased and evacuation slowed about 30%. Although these conclusions are not objectively documented by in-depth tests of the devices examined, they represent a major attempt to survey the state-of-the-art at that time.

3.2.4 1969 French Tests of Schjeldahl (Type D) Smoke Hood. In October, 1969, the Aeroport de Paris carried out two tests by three volunteers of the early Type D (drawstring) smoke hood loaned by the FAA (Mouton and Armand, 1969, unpublished). Volunteers were all pilots and tests were carried out in a smoke-filled cabin of an obsolete Starliner transport at Orly. Although these tests were limited and of a subjective nature, the conclusions and comments resulting should be noted.

They observed that the smoke hood was easily donned, there was no smoke penetration, there was effective protection of the face from flame (but the plastic neck collar burned when placed by itself directly in flame), hearing appeared normal, visibility was 360°, and the hood design allowed it to be donned in anv position. However, they also noted a problem with moisture condensation from respiration within approximately one minute after donning which lowered visibility. In this regard, this observation was made at close to normal temperature and it was postulated that such moisture might not occur in the heat of an actual fire. Another critical comment involved a lack of air experienced at about 75 seconds, and a maximum usage limit of 2 to 2.5 minutes. The lack of visibility in a smoke-filled cabin was also noted, as well as the fact that one of the three masks tested tore "rather easily," although the report did not state where the tear occurred or under what conditions.

Thev proposed (through the SNPL Technical Committee) the combined use of the oxygen mask and smoke hood to increase the breathing time, although noting the fire danger from use of O_2. This report concludes that the smoke hood represents considerable progress in fire protection and contributes to preventing passenger panic. They suggested improvements consisting of: (1) reinforcing plastic collar; (2) using improved heat-resistant plastic in collar; (3) extending hood below collar to protect it; (4) providing chest shielding; and (5) consider combining with an oxygen mask to provide prolonged survival time.

3.2.5 1969 ATAA "Riley Report." Appended to the Air Transport Assocation of America comments on the protective smoke hoods for emergency use by passengers and crew members (Docket No. 9344, Notice 69-2) were opinions expressed by Dr. Richard L. Riley, Professor and Chairman, Department of Environmental Medicine, The Johns Hopkins School of Hygiene and Public Health, and Dr. Solbert Permutt, Professor of Environmental Medicine in the same department, consultants to the ATAA. They were of the opinion that the early CAMI study failed to give adequate consideration to the hazard of hypoxia created by the smoke hood itself, and therefore that the smoke hood "does create a significant hazard in itself." They were especially concerned with the possibility of fatal accidents occurring as a result of prolonged breath-holding, and cited an investigation by Craig [1961 (499)] of eight near-drownings and five drownings in which it was believed that hvperventilation before breath-holding and exercise may delay the onset of the urge to breathe ("white-drowning"). In this case, before the partial pressure of CO_2 increases significantly, the O_2 may decrease to a degree incompatible with high-level cerebral function. In other words, when the individual hyperventilates he drives out the CO_2 and soon uses the O_2 faster than he builds up CO_2. They also disputed that everyone will remove the smoke hood once the CO_2 reaches a certain level. The arguments presented in this report were based upon critical review of the early CAMI report [McFadden et al., 1967 (538)], aircraft evacuation movies, evacuation evaluation of the Aerospace Industries Association [AIA Report CDP-2, 1968 (488)], and inspection and donning of Type D and Type S hoods.

Their views were subsequently concurred in by Dr. Fenn of the University of Rochester, Flight Safety Foundation consultant, who read their report and concluded that there is a danger in the use of a gas-proof bag of that type because it can lead to suffocation and unconsciousness when the oxygen is sufficiently depleted.

At the time of these opinions, the more extensive FAA/CAMI smoke hood research reported in 1970 (539), utilizing the more advanced Schjeldahl septal seal, was not available.

3.2.6 1970 NAS/NRC Space Science Board Report. In 1970, at the request of the Office of Aviation Medicine, FAA, to the National Academy of Science/National Research Council (NAS/NRC), critical evaluations of the smoke hood device, apparently based primarily on the most recent FAA studies [McFadden et al., 1970 (539)], were conducted by three members of the Space Science Board. In the comments received, several potential hazards were pointed out. The narcotic effect of higher CO_2 concentrations have led to sudden unconsciousness, without warning (at 9.2% level CO_2) [White et al., 1952 (571)], and when asphyxiation to the point of respiratory failure is brought about by inhaling pure CO_2, resuscitation has not been successful. Hypoxia was also felt to be a serious hazard due to the limited supply of oxygen. Another point brought up concerned the legal problem which an airline might find itself in, in the case of a lethally injured individual found wearing a smoke hood following a fire. Cause of death may be difficult to determine in this instance. Hood material deterioration characteristics were questioned, as well as reusability. The tolerance of hood-wearing on people with cardiac disease or pulmonary dysfunction is unknown, and the wearing time in egress at higher elevations was questioned. What are the problems in fitting infants, children, and people with abnormal neck size into the D or S type hood?

While one reviewer, experienced in CO_2 toxicity, stated that he doubted he would wear the smoke hood as an alternative to evacuating a smoke-filled cabin, other evaluators, while cautious, appeared to indicate in general that progress had been made. The necessity for ease in donning, a minimum amount of instruction, good vision, and a self-contained oxygen supply and CO_2 removal agent was emphasized. This report undoubtedly represents the most thorough medical critique of the smoke hood development of the D and S types. The more advanced self-contained air supply type of hood presently under development appears to meet the most serious criticisms; however, other factors pointed out such as deterioration characteristics, legal problems, effect upon cardiac or pulmonary patients, and special problems related to infants, apparently remain unknown.

3.2.7 Description of State-of-the-Art Devices. The following figures provide basic illustration and data on the 16 smoke hood systems evaluated in this study. Most are experimental or prototypes, but several are commercially available.

Fig. 26. Boeing Mask

Physical Description. 2 liter (.07 cu ft) polyimide (Kapton) rebreather bag mouthpiece mounted on polyurethane nose-blocking pad accordion-folded polyimide heat shield. Weight 184 grams (6.5 oz). Designed to install on seat back with only handle showing.

How Used. Grasp handle, blow up rebreather bag, hold mouthpiece with teeth. Pull thermal shield over head, rebreathe air in bag.

Availability. Experimental. Prototype used in 1967 AIA tests.

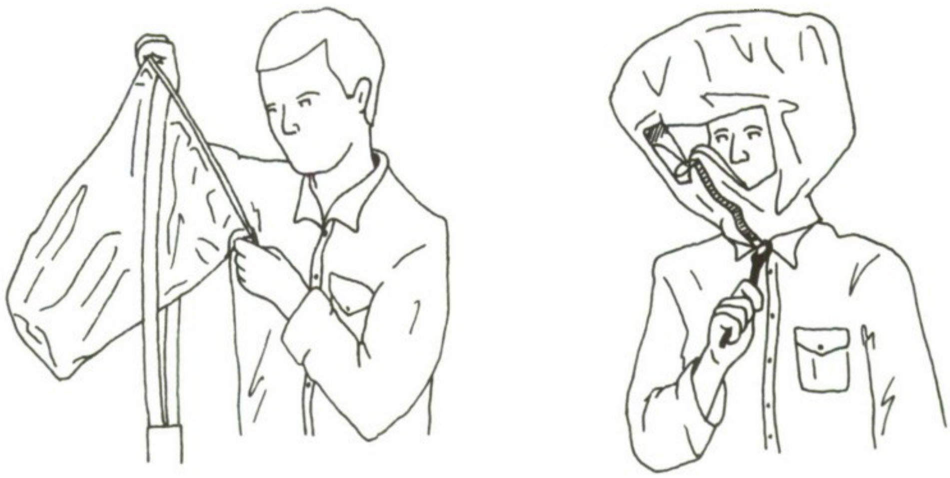


Fig. 27. John Hand Hood

Physical Description. Vinyl-coated fiberglass hood, clear fluorocarbon (Aklar) film view window, open-cell foam neck seal, with zipper closure. Weight 170 grams (6 oz).

How Used. Unfold hood and don over head. Position viewing window. Pull zipper down to join neck seal.

Availability. Experimental. Prototypes used in 1967 AIA tests.

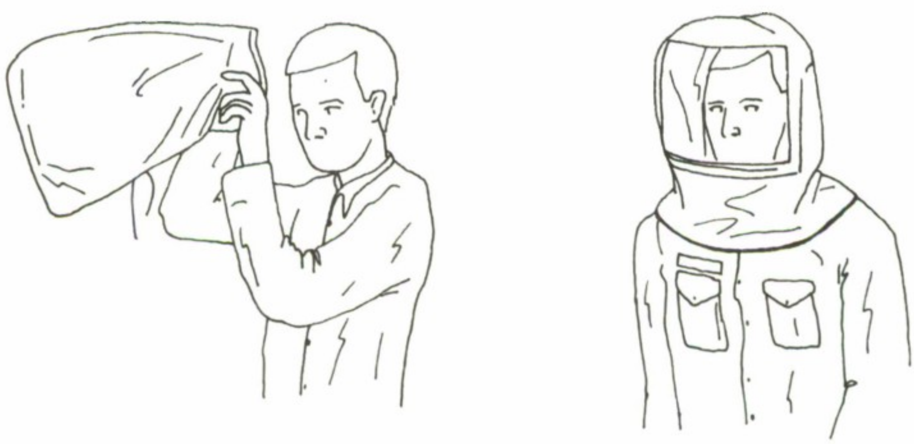


Fig. 28. Racine Glove Company Hood

Physical Description. Aluminized rayon hood, polyimide (Kapton) film view window. Coil-spring holddown in hood, lower rim stainless steel, vent screen on hood back. Velcro tab ends on straps hold hood down on body. Weight 340 grams (12 oz).

How Used. Remove from container. Automatically unfolds by coil spring action. Place hood over head and position view window. Place hold straps under arms and fasten about chest with Velcro tape.

Availability. Experimental. Prototypes used in 1967 AIA tests.

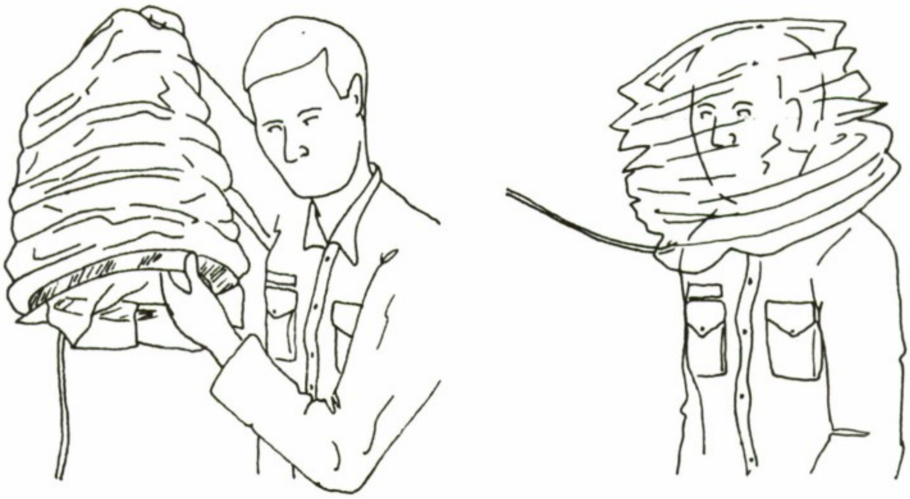


Fig. 29. Sierra Engineering Corporation Hood

Physical Description. Accordion polyimide (Kapton) cylinder with flat top. Supplemental air is vented into top, which inflates a toroidal neck seal (air supply, not yet designed). Weight 235 grams (8.3 oz) (without air supply).

How Used. Place hood over head. Activate supplemental air supply.

Availability. Experimental. Prototypes used in 1967 AIA tests.

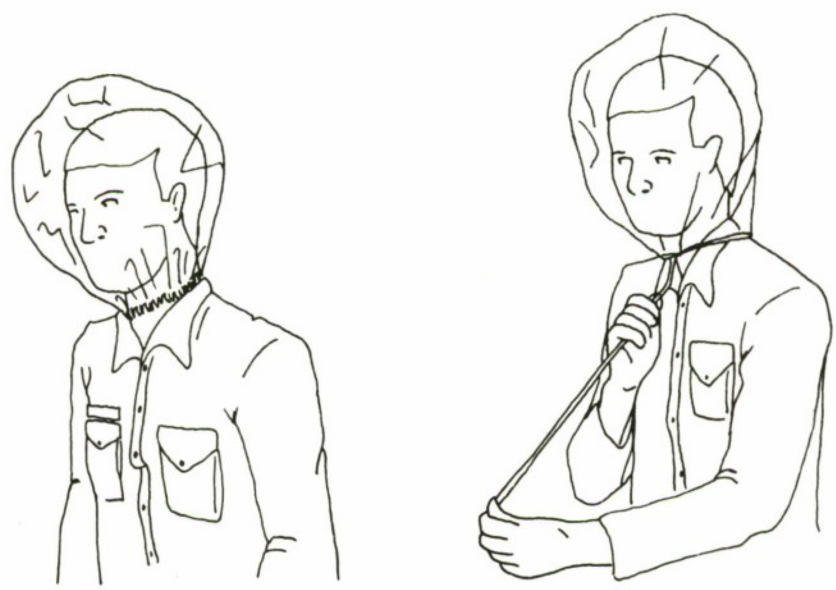


Fig. 30. Life Support Systems Hoods.

A. Elastic Neck Seal Type

Physical Description. 1-mil polyimide film (Kapton) hood, elastic neck seal. Weight 19.8 grams (0.7 oz).

How Used. Unfold and pull over head.

B. Lanyard Neck Seal Type

Physical Description. 1-mil polyimide film (Kapton) hood, sliding ball and lanyard seal. Weight 36.8 grams (1.3 oz).

How Used. Unfold and pull over head, push elastic ball up lanyard to form tight neck seal.

Availability. Experimental. Prototypes used in 1967 AIA tests.

Fig. 31. Scott-O-Vista Mask

Physical Description. Polycarbonate plastic (Lexan) "bubble" face-piece, set in high-temperature-resistant rubber frame. Sealed filter canister for removal of smoke, fumes, CO, from inhaled air. Mask held to face by elasticized head-band, voice amplification by a vibrating resonator. Weight 260 grams (9.2 oz).

How Used. Pull seal from canister air inlet. Place mask over face and pull band over head.

Manufacturer. Scott Aviation, 225 Erie St., Lancaster, N.Y., 14086.

Availability. Production item.

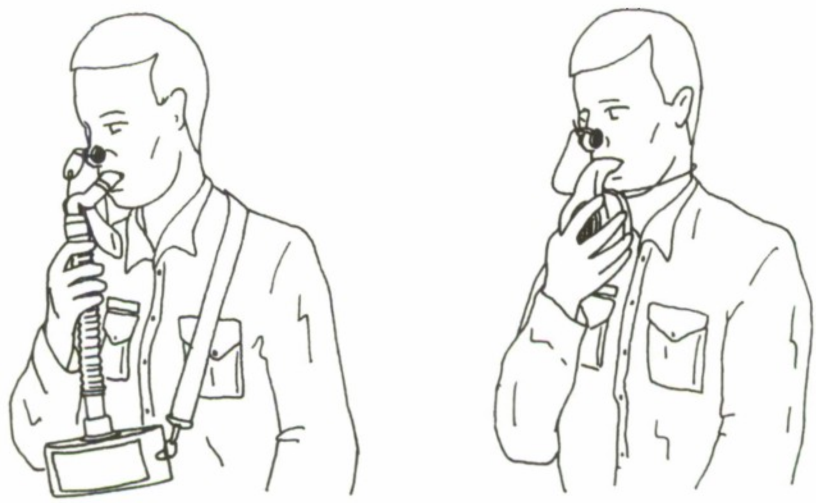


Fig. 32. Mine Safety Appliance Company Devices

A. Canister Device (88480)
Ultra Filter Respirator (457117)

Physical Description. Protects against dust, gases, smoke particles .9 microns or larger, vapors, but no CO removal. Weight 680 grams (24 oz).

How Used. Remove or break seal. Place mouthpiece firmly in mouth. Put clip on nose.

B. W-65 Self-Rescuer (455299)

Physical Description. Removes large smoke particles and CO_2. Designed primarily for escape from CO_2 environment. Can only use once and must replace entire unit. Weight 510 grams (18 oz).

How Used. Remove or break seal. Place mouthpiece firmly in mouth. Put clip on nose.

Manufacturer. Mine Safety Appliances Co., 400 Penn Center Blvd., Pittsburgh, Pa., 15235.

Availability. Production items. Cost: A. Filter ($5.80) and canister ($64.85) B. $47.50.

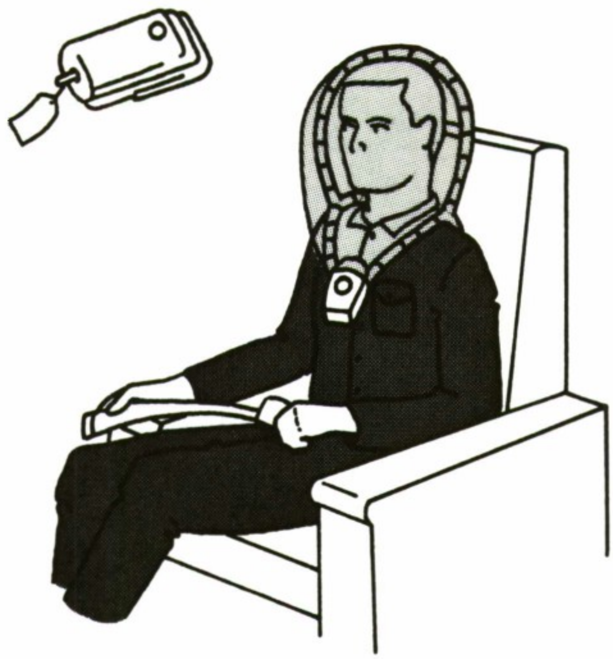


Fig. 33. North American Rockwell Hood

Physical Description. This smoke/flame hood concept would include three components: transparent hood, neck closure system, and compressed air supply. A short-range radio receiver could be incorporated for instructions from the crew.

How Used. Would be designed to fold into packet on seat back. Pull hood out of packet, don over head, and pull down into position.

Availability. Experimental. Prototype used in 1967 AIA tests.

Fig. 34. North American Rockwell Smoke Mask

Physical Description. This concept consists of a moist cloth of several layers and large enough to cover the mouth and nose. An elastic band fits around the head.

How Used. Sealed in a plastic bag, the moist cloth would be held to the mouth and nose by hand, and by an elastic band over the head.

Availability. Experimental. Prototype used in 1967 AIA tests.

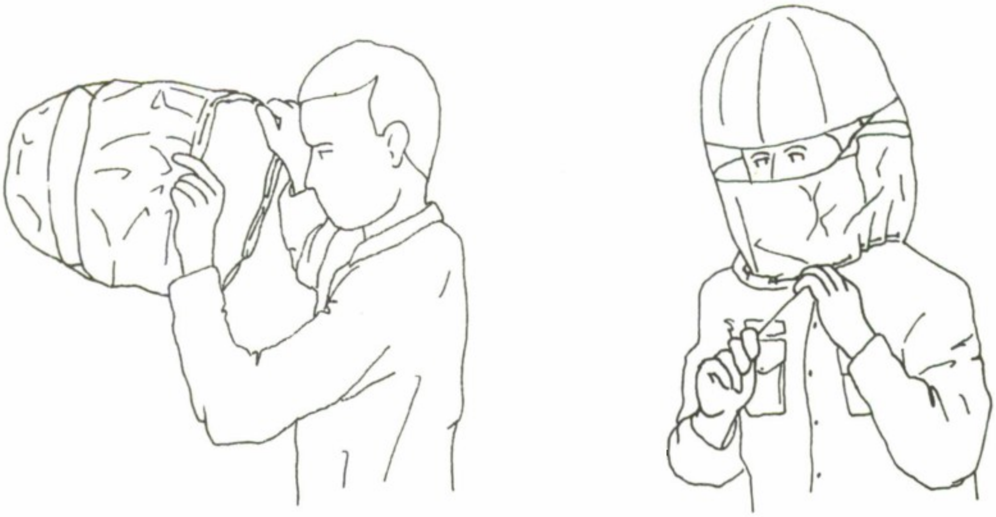


Fig. 35. Sheldahl Hood - "D" (drawstring) Model

Physical Description. Metalized polyimide (Kapton) hood. Volume 26.5 liters (0.9 cu ft). Cylindrical with domed top. Elastic fiberglass neck drawstring. 5 cm (2 in) vision band.

How Used. Unfold from container, take breath of air, slip over head, draw neckband snug.

Manufacturer. G.T. Sheldahl Company, Advanced Products Division, Northfield, Minnesota, 55057.

Availability. Prototype experimental device. Superceded by modified production "S" model.

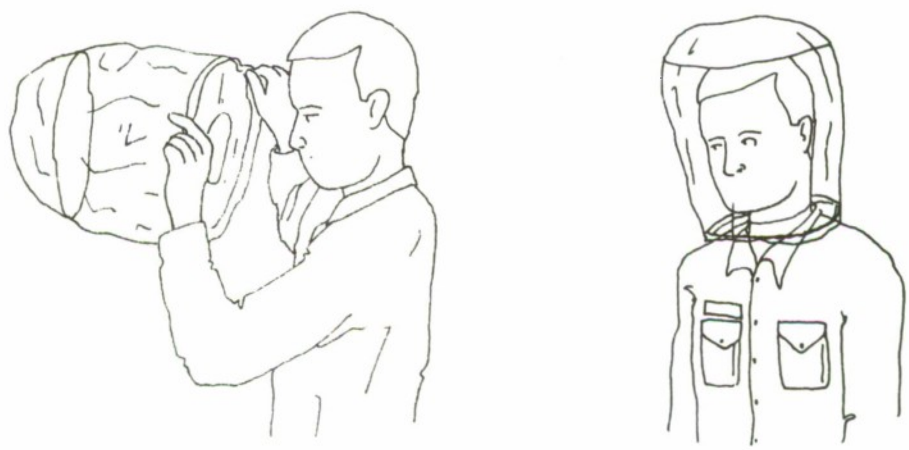


Fig. 36. Sheldahl Hood - "S" (Septal Neck Seal) Model

Background. The Schjeldahl (or Sheldahl) smoke hood is the most prominent of the protective devices developed to offer respiratory protection. Although patents (Nos. 3,562,813 and 3,521,629) are held by the G.T. Sheldahl Co., Northfield, Minn., 55057 [Reynolds, 1970 (557,558); Origer, 1971 (548)], initial research and development were as a result of cooperative effort with E.B. McFadden, Chief of the Survival Equipment Research Protection and Survival Laboratories, Civil Aeromedical Institute, FAA, in studies reported 1965-1970. This has had the most extensive testing and development of any smoke hood device. About 600 have been sold for use to date.

Physical Description. Cylindrical with domed top. Volume 26.5 liters (0.9 cu ft). Annular neck ring of elastomeric film. Clear hood, except for metalized polyimide domed top. Rebreathing device providing 4-6 minutes air, protection exceeding 800°C (1,472°F) temperature.

How Used. Unfold from container, take breath of air, slip over head.

Manufacturer. G.T. Sheldahl Company, Advanced Products Division, Northfield, Minn., 55057.

Availability. Production item since 1969. Currently available from the manufacturer at $49.95 each (Feb., 1976), or less for volume orders.

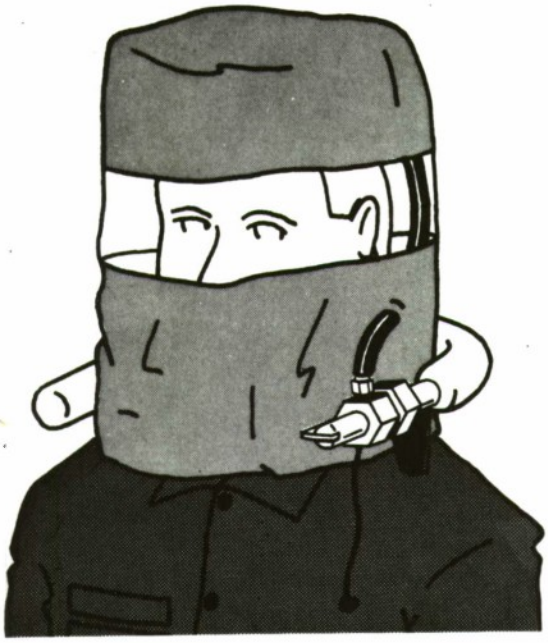


Fig. 37. Experimental FAA/Sheldahl Hood - Self-Contained Air Supply

Physical Description. Clear cylindrical hood with metalized polyimide domed top (2 mil Kapton). Annular neck ring of elastomeric film. V-shaped compressed air cylinder with rubber tube into hood; lanyard mechanical initiation. Compressed air unit snaps to hood, stabilized by two shoulder tabs. Air supply duration can be varied, 4-15 min.

How Used. Draw over head, pull lanyard.

Manufacturer. G.T. Sheldahl Company, Advanced Products Division, Northfield, Minnesota, 55057.

Availability. Prototype experimental device developed for FAA/CAMI testing.

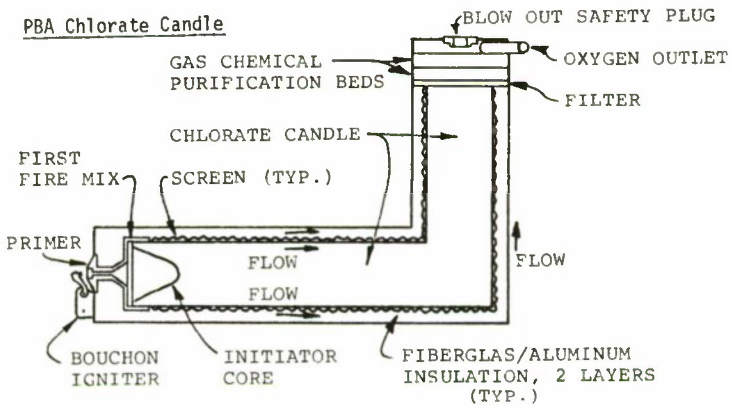


Fig. 38. Westinghouse/Sheldahl PBA Hood

Physical Description. Mylar plastic hood with rubber neck seal and celluloid non-fogging lense eyepiece. 20.3 x 19 x 7.6 cm (8 x 7.5 x 3 in) carrying case with chlorate candle mouthpiece with dual scuba type air hose polycarbonate heat shroud.

How Used. Place hood and heat shield over head. Bite mouthpiece, adjust carrying case with strap. Don helmet (designed for mine rescue).

Manufacturer. G.T. Sheldahl Company, Advanced Products Division, Northfield, Minnesota, 55057.

Availability. Experimental. Approximately 10 units designed and fabricated under U.S. Bureau of Mines contract to Westinghouse Ocean Research, Annapolis, Maryland, 1971.

Fig. 39. Lear-Siegler Air Capsule

Physical Description. 5-minute duration. Breathing air (21% oxygen, 74% nitrogen, 5% helium) is stored at 351.8 kg/sq cm (5,000 psi) in a corrosion-resistant stainless steel tubing coiled into a compact reservoir. Transparent hood with drawstring. Carried in either binocular-size case or soft sock. Shelf-life 3 years (Model 5000).

Manufacturer. Lear Siegler, Inc., Electronic Instrumentation Division, 714 North Brookhurst Street, Anaheim, California, 92803.

Availability. Production item. Cost: about $122.00.

1. Open hard case or soft pack.

2. Pull out Air Capsule. (a) hard carrying case: pull out both hood and attached air reservoir. (b) soft pack: pull out hood only (a clear air hose supplies you with fresh air from the reservoir.

3. Unfold hood.

4. Pull start ring. It's located at the end of the air reservoir. A slight tug will start the air flow.

5. Slip hood over your head. The elastic hood opening stretches to 28 in. It easily accommodates glasses and beards. In donning an Air Capsule with air reservoir attached (hard case only), start by pulling the hood over the back of your head. With the hood fully in place, the air reservoir will rest at the back of your neck.

6. Pull drawstring tight and adjust elastic neck band. This elastic band should touch your skin all around your neck to form a comfortable seal. Now breathe easy. You can breathe and speak normally.

Fig. 40. Instructions for use of the Lear-Siegler Air Capsule.

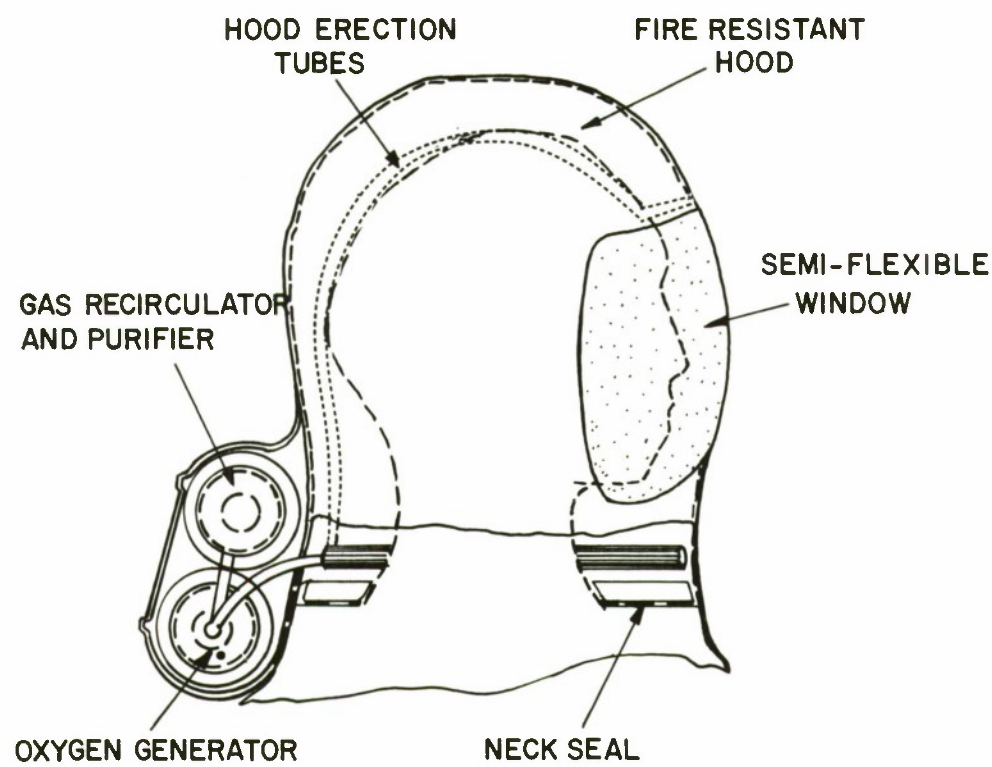


Fig. 41. Scott Aviation Emergency Smoke Hood and Breathing Device

Physical Description. This system consists of four major components: an oxygen supply source, a chemical carbon dioxide and water vapor "scrubber," a loose fitting hood, and a venturi pump, supplying 4 liters (244 cu in) per minute O_2. 15-minute recirculation system. Solid-state oxygen generator with ten-year shelf life.

How Used. Remove from case, activate oxygen supply (which erects the hood by pressuring inflater tubes), pull unit over head.

Manufacturer. Scott Aviation, 225 Erie St., Lancaster, New York, 14086.

Availability. In final stages of development (Dec., 1975). Not yet in production. No test results or details of specifications released.

Fig. 42. Exp-rimental FAA/Schjeldahl protective hood of 2 mil Kapton which can provide 4 to 8 minutes of breathing time using a self-contained supply of compressed air.

The logical follow-up development will involve overcoming these disadvantages while retaining the advantages of a longer duration air supply. This means that instead of manual operation the device should become passive, with automatic actuation of the air supply when the device is donned. Experimental development of a smoke hood with self-contained automatic air supply is being considered by the Civil Aeromedical Institute of the FAA at Oklahoma City. However, to date this is still in a concept stage.

Adaptation of the emergency oxygen mask for inflight fires and smoke emergencies has generally not been successful because the dilution value allows in outside air (smoke and toxic fumes). Attaining a cabin pressure of 4,267 m (14,000 ft) (during loss of cabin pressure) automatically trips the emergency oxygen system; however, the automatic oxygen regulator only provides a minimum of oxygen flow at this altitude--approximately 0.5 liter NTPD (normal temperature/pressure/dry or 21.1°C/760 mm), expanding to only a liter or so in terms of BTPS (body temperature/pressure/saturated or 37°C/ambient/saturated). At rest an individual breathes approximately 7 liters per minute; therefore the difference between approximately one liter and seven must be composed of air which may contain smoke and toxic gases.

There has been a general desire to increase the breathing time of the smoke hood protective device from its present 3-6 minute (FAA tests) rebreathing capability (AIA found Boeing system provided only 50 seconds, Schjeldahl "D" hood 1-1/2 minutes) to 15 minutes or more. However, it appears questionable whether accident experience will substantiate such a time requirement. The civil airlines are required to demonstrate that their air transport aircraft can be evacuated in 90 seconds or less. FAA burn tests have demonstrated that after three minutes current aircraft interiors are no longer habitable due to heat. If a chemical generator is employed in the smoke hood to increase breathing time, it also increases complexity of actions necessary by the user, and would require more instruction. Thus, there may be a reasonable argument to dispute a requirement for a longer air supply than currently provided in the Schjeldahl "safety" hood, which appears to be the only currently available smoke hood which has had extensive testing.

Table XIV provides a summary analysis of the Schjeldahl septal neck seal (Type S) smoke hood, which has been evaluated as the best available device within the current state-of-the-art, and is a production item (see Figs. 24 and 25). Among the factors which tests to date have indicated may be problems are deterioration characteristics, durability, reusability, fit on passengers other than adults, ability to don the hood over glasses, hood fogging, vision, effect upon passengers with cardiac or pulmonary dysfunction, CO_2 buildup, hypoxia, and legal implications. Most of these problems appear solvable or insignificant for civil or military transport emergency use.

A detailed analysis of the system safety, maintenance, hazards, reliability, and human factors of the various smoke hood/masks available within the state-of-the-art have been made and a smoke hood functional flow fault tree is shown in Table XV.

It is concluded that the currently available Schjeldahl rebreathing smoke hood with septal neck seal (Type S) can provide significant protection from smoke, toxic fumes, and flame in post-crash fire emergency egress and its demonstrated merits far outweigh any potential risks or problems.

For additional selected references related to effects of fire, heat, and CO_2 on man, see references 586-619, and for material flammability, references 620-666.

TABLE XIV.

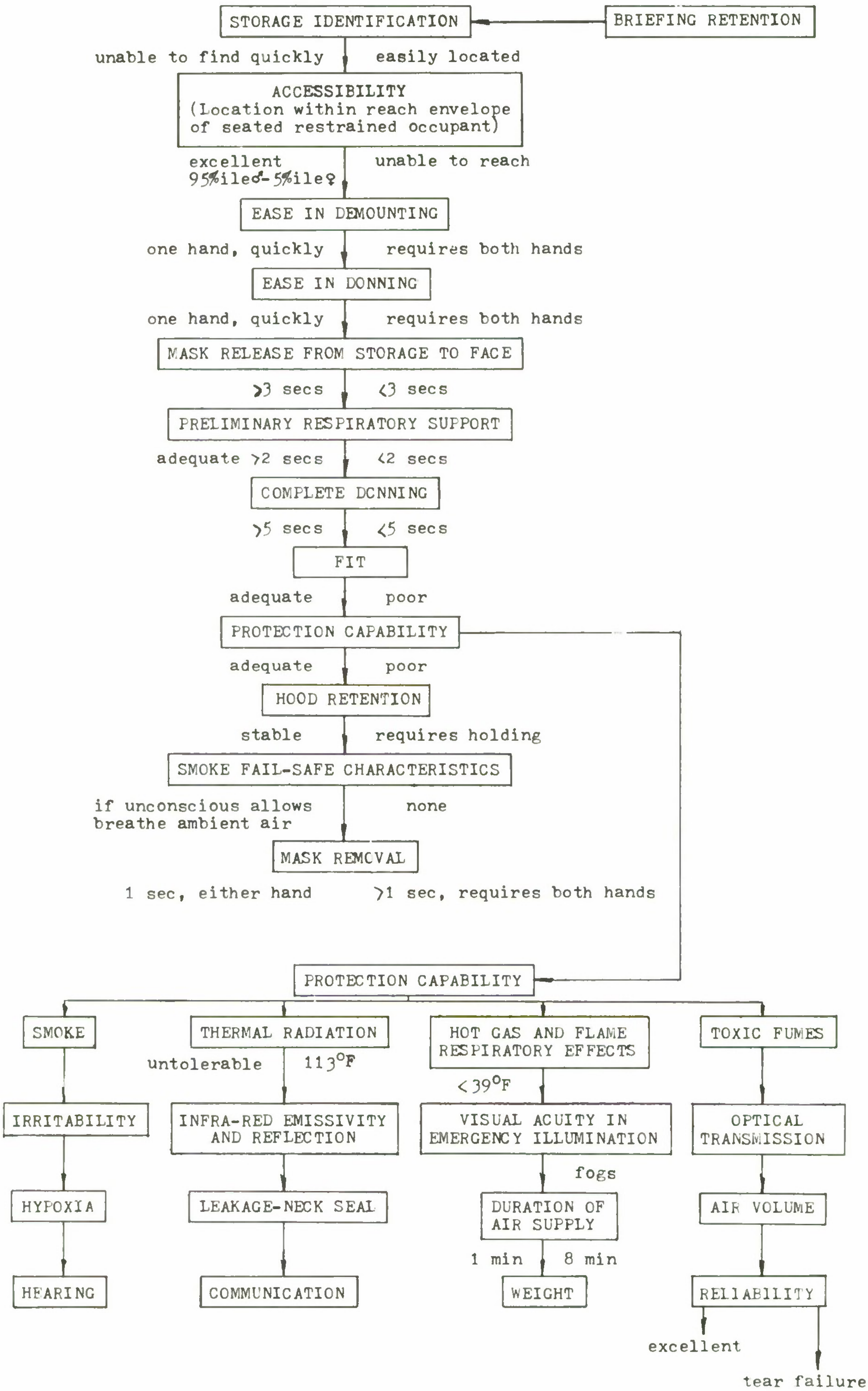
SUMMARY OF SYSTEMS ANALYSIS OF SCHJELDAHL SMOKE HOOD SYSTEM

AMBIENT ENVIRONMENT	MENTAL DEMANDS	HAZARD EXPOSURE	PHYSICAL DEMANDS
.Polyimide (amide) films capable of protecting in excess of 1400°F. .3-6 min O_2 supply. .Visual acuity not impaired at low .05-foot-candles levels of illumination (models). .Infra-red emissivity and reflectance excellent. .Optical transmission - not satisfactory with model D - excellent with model S.	.Simple to don. .Tests show simple verbal briefing adequate. .Requires no mechanical aptitude or skill. .Requires little training, little judgement, ability to follow relatively simple written or oral instructions. .Requires moderate recall.	.Available O_2 - when CO_2 critical level of about 8% reached sensation of choking will cause subject to remove hood. .Flammability protection - excellent. .Toxic hazards - excellent with model S, fair with model D. .Irritability protection - excellent with model S, fair to poor with model D. .Hazard level category II - marginal (can be counteracted or controlled without injury to personnel or major system damage (MIL-STD-282).	.Simple to don. with normal use of hands. .Can be donned with one hand with some difficulty. .Requires little expenditure of energy. .Readily learned by demonstration.

	HUMAN FACTORS (MIL-STD-1472A)	SYSTEM SAFETY (MIL-STD-882)	TASK EXPOSURE
	.Some difficulty in quickly locating neck seal (needs color outline). .Instructions adequate. .Can increase donning time and decrease problems in donning with prior experience.	.Present hood cannot remain in use beyond 3-6 min. .Hazard Level II.	.Potential effect of improper task performance on system operation critical.

EQUIPMENT CHARACTERISTICS	RELIABILITY (MIL-STD-785)	MAINTENANCE (MIL-STD-470)	POTENTIAL VALUE
.Material:metalized polyimide (Kapton). .Weight. Not signif. .Size (stored) - packet (in use) 16" high 12" diameter. .Volume - 26.5 liters. .Shape - cylindrical, with domed top. .Closing (model D) - Elastic fiberglass neck drawstring. (model S) - Annular ring of elastomeric film (3"). .Heat resistance - Polyimide film with reflective coating. .Vision (model D) - 2" vision band. (model S) - clear hood.	.General - excellent (only failure determined to date occurred when one mask ripped in coal mine test). .Life cycle decrement undetermined.	.Accessibility - excellent. .May be problem with decrement with repeated usage (seal breakdown). .Periodic inspection and replacement would probably be necessary. .Effect on depth and frequency of maintenance requirements at each level. .Facilities, support equipment, skill levels and number of individuals required to be determined.	.Tests to date indicate offers excellent protection to head and face in flammability. .Advanced model S septal neck seal model offers greater protection from toxic fumes, smoke, and eye irritability than earlier neck drawstring D model. .Tests of S model clear hood indicate no signif. vision acuity decrement under conditions of low illumination. .Limitation of 3-6 min breathing time can be increased by modification with self-contained O_2 generator or compressed air source.

TABLE XV. SMOKE HOOD/MASK FUNCTIONAL FLOW FAULT TREE



3.2.8 Discussion. The main objective of this portion of the study is to evaluate the practical usefulness of the smoke hood/mask with particular attention to psychological and physiological effects on the wearer in a flame, toxic fume, and smoke post-crash environment. Studies have been reviewed relating to considerations of visibility, acoustics, ease of donning, time of use, and optimum neck seal devices, as well as effectiveness under various smoke, toxic fume, and flame environments. Various smoke hood/mask concepts as applied to passenger and crew member emergency evacuation needs have been reviewed. The majority of the information and testing has been specifically related to civil air carrier application. Thus, some of the objections outlined in the preceding summary of test results may not be valid in the military environment.

To date civil air carrier organizations appear to have opposed FAA-proposed smoke hood requirements primarily on the grounds of cost, pilferage, and the hazards of too long use. Some support for the latter opinion has been expressed in both the ATAA Riley report and in FAA-solicited comments from NAS/NRC scientists. It has been noted that the narcotic effect of higher (9.2% level CO_2) concentrations of CO_2 can lead to sudden unconsciousness, and after asphyxiation, to unsuccessful resuscitation. Similarly, it has been suggested that there is a danger of hypoxia due to a limited supply of oxygen. Further, the legal implications of potential liability remain unresolved, and are outside the scope of this evaluation.

However, concern about potential hazards of hypoxia and insufficient air supply appear to be overcome by new devices designed with their own self-contained compressed air supply. Attempts to increase the time of usefulness have involved addition of a self-contained oxygen generator (fire hazard), and consideration of a chlorate candle (as in C-5A pallet seating system). The Westinghouse/Schjeldahl smoke hood developed under the "Coal Mine Rescue and Survival Program," has a J-shaped canister containing a chlorate candle and 15.2 x 7.6 cm (6 x 3 in) lithium hydroxide CO_2 absorbent, which has apparently enabled subjects to breathe for a period of one hour. The hood itself was not rigidly tested in this program, nor was it designed for aircraft fire protection.

Several other smoke hood protective devices have been developed for non-aviation related purposes which might have potential application for aircraft passengers. Lear-Siegler, Inc. markets an "Air Capsule" which provides a 5-minute air flow. This consists of a transparent hood with breathing air at 351.8 kg/sq cm (5,000 psi) (21% O_2, 74% N, 5% He) contained in a double coil of stainless steel tubing in a cylinder held behind the neck. Some 150,000 units have been supplied to the U.S. Navy for emergency use. Robert-Shaw Controls and Scott have also developed emergency breathing devices for marine or industrial use. Bendix has proposed a system to the USAF for escape from missile silos which contains a 10-minute air supply in a cylinder, weighs approximately 3.6 kg (8 lb), and uses a concept of venturi recycling. A Bendix program in cooperation with Schjeldahl, designed a hood for a Navy proposal. This hood has an air supply canister attached to it to provide 5-8 minutes of air. A special breather bag is also attached to the front of the hood. The National Institute for Occupational Safety and Health (NIOSH) is presently testing a Lear-Siegler hood for potential industrial use which incorporates compressed gas, a venturi aspirator and CO_2 scrubber, and which may provide 15 minutes of breathing time.

The most advanced modification of the Schjeldahl smoke hood for air transport passenger egress also involves the addition of a self-contained compressed air supply. Prototype units have been fabricated by Schjeldahl under contract to FAA, with cylinders fabricated under contract to U.S. Divers. As shown in Fig. , this consists of a 77.4 kg/sq cm (1,100 psi) cylinder clipped to the hood at neck level. Activation is by pulling a cord which initiates a mechanical puncture of the cylinder, allowing compressed air to flow directly into the hood. The flow rate can be adjusted by changing orifice flow control fittings to provide various flows and durations. Experimental durations of four to eight minutes have been tested to date at the FAA's Civil Aeromedical Research Institute, Oklahoma City. Tests of an orifice providing a four-minute, forty-seven second duration flow calibration has been found to provide the following flow rates:

Start	-	8.5 lpm
1 minute	-	5.8 lpm
2 minutes	-	3.5 lpm
3 minutes	-	1.8 lpm
4 minutes	-	0.7 lpm
5 minutes	-	0.1 lpm

In addition, this modification of the smoke hood has been improved in other respects. The hood is constructed of extra heavy Kapton (.051 mm [2 mil]) instead of the standard .025 mm (1 mil) polyimide film (Kapton) used in the standard rebreathing hood. This provides improved aging characteristics (shelf life). However, little is known of the aging characteristics of the elastic polyurethane film of the neck seal. The hood has been completely metalized, except for a 5.1 cm (2 in) visibility band.

Although tests of this development are still unpublished some results available to date show the following characteristics when the hood is donned and activated:

(1) After activation the hood begins to inflate somewhat like a balloon. Once inflated, the cylinder is lifted up off the shoulders. With the hood distended vision is improved.

(2) The neck seal acts as a relief valve, and CAMI measurements indicate only 1 to 2 mm Hg of positive pressure can be built up inside the hood. A slight eardrum pressure may be experienced, similar to diving 1.2 to 1.5 m (4 to 5 ft) under water.

This experimental modification of the Schjeldahl smoke hood, as well as the Lear-Siegler "Air Capsule" and other developments discussed, appears to offer one solution to several concerns to smoke hood usage in current civil air transport aircraft by providing a self-contained air supply. The compressed air cylinder offers a means of increasing the air supply to allow greater egress time duration capability, and thus improved occupant protection. However, this also increases the complexity of the device and ironically degrades the simplicity of the original hood. For successful use, briefing or training becomes more important, since a manual action is required by the passenger after donning in order to initiate the air supply. On the other hand, even if the wearer neglects to pull the cord to initiate the air supply at all, he still has the same protection as the rebreather hood.

4. ADVANCED OCCUPANT RESTRAINT SYSTEMS

In recent years several new restraint systems have undergone development and testing, primarily due to the impetus of recent federal standards for automotive vehicles. While considerable emphasis has been placed upon the development of inflatable (air bag) passive restraint systems, other systems, both active and passive, have also been developed for occupant protection. However, not all restraint systems are applicable to the air transport environment.

This section is prefaced by a general discussion of current operating practice and federal standards relative to occupant (crew and passenger) restraint protection in air transport aircraft, as compared to relative human whole body impact tolerances and capabilities of various configurations of restraint. Subsequently, seat/restraint design principles are considered from a systems viewpoint. Particular attention is given to the developmental background of the inflatable passive restraint, and the various features of present systems and components are described. Relative evaluation of sensors, bag and diffuser design, tolerable sound levels, human volunteer performance tests, operating temperature ranges, and other aspects vital to operation are considered. Review of other active and passive state-of-the-art systems includes webbing belt restraints which automatically are locked in place when the individual sits in the seat, deployable net restraints, integrated harnesses, and inflatable belt systems. The NASA Ames integral aircraft passenger seat has been designed specifically for future air transports with design objectives of attenuation of 21 G_z and 45 G_z impacts (8). Rearward-facing seating is also considered, with an evaluation of test data and current crash experience relative to rearward seating. Currently RAF VC-10 (9 G_x) and USAF Lockheed C-141 (16 G_x) or Lockheed C-5A utilize rearward-facing seats, but few civil transports are so equipped except for attendant stations on some aircraft (McDonnell Douglas DC-10, Boeing B-747, and Lockheed L-1011).

4.1 Current Air Transport Restraint Systems

4.1.1 Passenger Lap Belt Systems. Present civil air carrier passengers receive minimal crash impact protection in comparison to either state-of-the-art design capabilities or human deceleration tolerances. Most current jet transport aircraft utilize 1,224.7 kg (2,700 lb) webbing metal-to-metal buckle lap belt restraints for passengers, although some aircraft are still found operating with older fabric-to-metal 793.8 kg (1,750 lb) webbing (792).

Part 25, Federal Air Regulations [Airworthiness Standards: Transport Category Airplanes, 25:561[b], June, 1974 (670)] states that "The structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when...(2) the occupant experiences the following ultimate inertia forces acting separately relative to the surrounding structure:

(i) Upward - 2.0 G
(ii) Forward - 9.0 G
(iii) Sideward - 1.5 G
(iv) Downward - 4.5 G, or any lesser force that will not be exceeded when the airplane absorbs the landing loads resulting from impact with an ultimate descent velocity of five f.p.s. [1.5 m.p.s.] at design landing weight."

British Civil Airworthiness Requirements for ultimate inertia forces are not substantially different from U.S. requirements (667). However, aft-facing seats are recommended under their Acceptable Practices and for foward-facing seats, the radius of the arcs of travel of the occupant's head, and seat back specifications are detailed.

Current values for occupant protection in air transport impacts specified in the U.S. FAR's have not changed significantly since the CAA first issued such requirements for certification. Both the NTSB (674) and the FAA Office of Aviation Medicine have strongly recommended increased occupant impact protection design criteria and especially seat/belt strength requirements on a number of occasions over the past decade.

In response to the NPRM 69-33 issued by FAA Flight Standards Service (669), the Office of Aviation Medicine transmitted considerable documentation in 1969. The Office of Aviation Medicine recommendations were (673, 675):

Upward	20.0 G
Forward	20.0 G
Sideward	10.0 G
Downward	20.0 G
Rearward	20.0 G

It was further recommended that the inertial loads related to a 77.1 kg (170 lb) occupant be established at 102.1 kg (225 lb), since many passengers today exceed 77.1 kg and therefore compromise the safety of the current seat design. In support of these values, the NASA development of a lightweight 15.9 kg (35 lb) seat designed to protect a 102.1-kg occupant against 20 G forward, 20 G vertical and 10 G lateral accelerations was cited [Yost, 1969 (682)]. It was also noted that the Federal Register of 25 December, 1968 contained a definition of the 95th percentile U.S. adult male as 101.2 kg (223 lb) partially clad, in the 25-34 year age bracket, making a fully clothed 95th percentile male at least 102.1 kg (225 lb). In comparison, U.S. Air Force transport seat design specifies a 113.4 kg (250 lb) design occupant weight (MIL-S-26688) (298).

Research conducted by the Civil Aeromedical Institute of FAA also indicated that seat failure had occurred in a number of otherwise survivable accidents. CAMI investigations of five air transport crashes during the preceding six-month period from August, 1968 to January, 1969 were cited. Relative to inadequate seat restraint protection of occupants, these accidents included: (1) the Piedmont FH-227B crash on 10 August, 1968 at Charlestown, W. Va., fatal to 35 of 37 aboard (141); (2) the Northeast Fairchild FH-227 crash on 25 October, 1968 near Hanover, New Hampshire, fatal to 32 of 42 occupants (153); (3) the Allegheny Convair 580 crash on 24 December, 1968 at Bradford, Pa., fatal to 20 of 47 occupants (152); (4) the North Central Convair 580 crash at Chicago on 27 December, 1968, fatal to 27 of 45 occupants (213); and (5) the

Allegheny Convair 440 which crashed near Bradford, Pa., fatal to 11 of 28 occupants (157).

A March, 1968 staff study (673) conducted by the Office of Aviation Medicine stressed the following findings: "Data on human tolerance limits to deceleration (threshold of injury), when properly restrained, far exceed the ultimate inertia forces for a minor crash landing as specified in Part 25.561. Conferees at the December, 1967 USAF-Industry Life Support Conference recommended revising load factor for passenger seats from the present 16 G to 20 G and that aft-facing seats be used whenever possible.

"Experience has shown that survival can be expected and has occurred repeatedly at crash force levels far in excess of the minor crash landing criteria in Part 25.561. This experience confirms the experimental data accumulated over the last two decades. In addition, survivable conditions relative to the occupiable area have been found to persist at increasingly higher crash force levels. Survivable crash force conditions in today's modern airplane are approaching the threshold limits of human tolerance to accelerative forces.

"Conclusions: There are no standards dealing with occupant protection in moderate to severe survivable accidents. It is concluded that human tolerance to accelerative forces is much greater than the forces generated during some of today's 'nonsurvivable' accidents. We have 40 G people riding in 20 G airplanes, and sitting in 9 G seats and restraint systems" (23; 673).

Similar conclusions have been repeatedly expressed in a number of other documents. Analysis of 61 survivable aircraft crashes by the Flight Safety Foundation in 1967 indicated that nearly half of the 1,037 fatalities and serious injuries probably could have been prevented by the use of improved restraint systems (4). In 1967 Turnbow (681) recommended design loads for seats and lap belt restraint systems for fixed-wing transport aircraft of:

	Forward-Facing	Rearward-Facing
Longitudinal	20-25 G	35-40 G
Vertical	15-20 G	15-20 G
Lateral	10-15 G	20-25 G
Time duration, sec	0.2-0.3	0.2-0.3

More recently, after a number of years of discussion, a committee of the Society of Automotive Engineers has proposed a new Aerospace Recommended Practice 1226 (ARP) for General Aviation Seat Design (forward-facing) for 25 G applied 20 degrees to either side of the longitudinal axis, an aft load of 5 G, an upward load of 15 G, and a downward load of 15 G (677). This ARP still requires council approval before final issue, and pertains to light aircraft only. However, civil air transport ARP 682A (Safety Lap Belts) (678) is also currently under review.

Society of Automotive Engineers ARP 767 (Impact Protective Design of Occupant Environment--Transport Aircraft) (679) provides information for the design engineer. Part 6.1.11 indicates that forward deceleration of the healthy young male restrained only by a seat belt of 5-cm (2-in) width which is properly positioned on the hips may be tolerated up to 33 G for 0.035-0.065 second at 2,300 G/sec onset rate with minor complaints, with human tolerance limits for non-reversible injury to 50 G peaks at 500 G/sec rate of onset for 0.025 second duration with both shoulder and lap belt restraint (issued 10-31-67).

SAE ARP 750A (Passenger Seat Design--Commercial Transport Aircraft), 15 January, 1974 (676) notes that FAR's and technical standards order (TSO's) requirements are minimum requirements only, but does not suggest any particular dynamic seat load requirements.

In accordance with Resolution No. 162 adopted at the meeting of ISO/TC in June, 1967 (672), the USSR prepared a proposal for passenger seats in aircraft, which also exceeded the United States Federal Air Regulations Part 25.561:

vertical force - from 4 G downward to 4.5 G upward
horizontal force - from 9 G forward to 1.5 G backward
side force - from 0 to 2.25 G

The passenger weight was assumed to be 77 kg (169.8 lb). This standard is the same as British Civil Airworthiness Requirements as far as forces are concerned (667).

Flight deck crew seats have different functions than those for the passengers. Most have a greater range of adjustment for comfort. The 20.5 kg (45 lb) IPECO aircrew seat (IPECO Europe Ltd.), for example, used in the Fokker F-27, F-28, BAC-111, Mercury, and BW614 has a special lumbar pad which can be adjusted 3.2 cm (1.25 in) back or forward, and the height of both the shoulder pad and lumbar pad can be adjusted some 7.6 cm (3 in) relative to the seat pan. The most complex of the Concorde crew seats is that of the third crew member, since his workload is such that the seat must be capable of moving fore and aft at a controlled speed the full length of the flight deck, stopping or starting in any position. In addition, the seat must be able to move laterally. This seat is probably one of the most complex yet devised for air transport use, since the unusual workload necessitates this crew member to be forward at the center console to monitor throttles during takeoff, to move aft and face outboard to monitor the engineer's instrumentation panel (when the flight deck floor is at maximum angle of attack and acceleration), and to move to the extreme aft end of the flight deck to monitor circuit breakers. The very large changes in pitch, attitude and acceleration require a 12° change in back angle of this seat for different crew functions. The seat pan is mounted on a tubular telescopic pedestal, and to prevent head jerk at initiation of seat movement, an electrically-operated slugging device automatically reduces the rate of seat acceleration.

A unique feature of the prototype Boeing B-2707-100 SST, due to its length of 93.3 m (306 ft) and resulting bending moment, was that some seats were designed to comply with load factors of 9 G forward, 7.5 G downward, 4.5 G upward, and 3 G sideward (times a factor of 1.33). This was because seats toward the ends of the cabin would be subjected to greater bending moment and greater load factors than at stations toward the center. Crew stations would require ultimate seat load factors of 16 G forward, acting within 20 degrees to either side, compared to 12 G for passengers.

As an attempt to relieve some of the circulation problems often presented in sitting for long periods, the Circutone Company of North Hollywood, California, has developed a crew seat which features a series of plastic channels built into the seat, which are inflated pneumatically in sequence to provide a continuous massage effect, which may improve comfort on long-range flights. McDonnell Douglas has also been developing crew seat design as on the DC-8 and DC-9, and has developed an adjustable lumbar seat back support consisting of a foam-filled air cushion, which is integral with the seat back cushion and can be inflated or deflated, conforming to the individual body contours. A recent comprehensive discussion of both design hardware developments and medical functional aspects of transport crew seats is found in Hawkins, 1974 (671).

In high performance air transport aircraft, the consequences of not wearing restraint on the flight deck during flight can be tragic. The spectacular crash of the Russian Tupolev Tu-144 supersonic transport at the 1973 Paris Air Show has been hypothesized as due to the unrestrained flight test engineer being in the cockpit with a movie camera when the pilot made a sudden evasive maneuver, perhaps fearing collision with a nearby French Air Force Dassault-Breguet Mirage 3R. The crew member may have fallen against the pilot or the controls during this critical time, precluding recovery. Four bodies and a movie camera were found upon investigation, where only three should have been (680).

4.1.2 Current Aircrew Restraint Systems. Each crew member seat at flight deck stations must have provisions for a shoulder harness (FAR 25.785g) which must be worn during takeoff and landing unless the wearing interferes with crew member function (Part 121.31). Investigation of the United Boeing 727 crash at Chicago O'Hare on 21 March, 1968 revealed that the "crewmembers' cuts, bruises, and back injuries were received as a result of their being violently tossed around inside the cockpit by the crash impact" and prompted the NTSB to recommend (28 January, 1969, Not. 187, 69-27) to the FAA that shoulder harnesses be required for aircrew during takeoff and landings (674).

Responding to the NTSB on 17 March, 1969, the FAA issued NPRM 69-33, amending Part 121.311(e) to propose that shoulder harnesses be worn during takeoff and landing. On 12 August, 1969 this requirement was subsequently adopted. However, as a result of lack of shoulder harnesses being worn during the United Boeing 737 crash at Midway on 8 December, 1972 (247); in the North Central McDonnell Douglas DC-9 crash at O'Hare on 20 December, 1972 (261); and in the Eastern Lockheed L-1011 crash at Miami on 29 December, 1972 (227), the NTSB again recommended to the FAA (674) that all air carrier checklists contain a "fasten shoulder harness" item. The FAA responded (A-73-39) on 16 July, 1973 by revising Air Carrier Operations Bulletin No. 69-21 to suggest that "fasten shoulder harnesses" be made a standard item.

At that time it was also recommended by NTSB that FAA amend 14 CFR (Code of Federal Regulations) 25.785(h) to require provisions for a shoulder harness at each cabin attendant seat, and amend 14 CFR 121.321 to require that shoulder harnesses be installed at each cabin attendant seat. Some 30 years had elapsed from the first NTSB/CAB recommendation (No. 32-0-38) for FAA to require crew upper torso restraints [Carroll, 1963 (668)]. On 29 January, 1973 (674) NTSB pointed out to FAA further inconsistencies relative to shoulder harnesses: "Under part 121, the degree of protection afforded crewmembers flying aircraft certified before January 1, 1958, is less than that provided in more recently certified aircraft, where shoulder harnesses are required to be installed. FAA statistics show that as many as 269 of the 2,797 registered multi-engine air carrier airplanes still in service were certificated prior to January 1, 1958. One of the airplanes in this category, a Mohawk FH-227, crashed at Albany, New York, on March 3, 1972 killing 14 passengers and the two crewmembers on the flight deck (238). This aircraft, although manufactured in 1967, was type certified prior to 1958 and thus exempted from the shoulder harness requirement. Investigation disclosed that the Captain and the copilot might have survived the accident had they worn shoulder harnesses" [NTSB Not. 407, CY 70-42, 1/29/70 (674; 238)].

4.2 Human Impact Tolerance Design Limits

In contrast to the current FAR requirements discussed in regard to forces on the lap-belted air transport passenger (Part 25.561), field data from aircraft crash investigations and research data related to human impact testing have long documented that current requirements provide less occupant protection than has been the state-of-the-art. In this respect the following summary and discussion of restrained occupant impact tolerances may be useful.

Several recent state-of-the-art evaluations and comprehensive compendiums are available related to human impact tolerances, and should be referred to for detailed information. These include "Whole Body Tolerance to Impact" [Stapp, 1966 (718)], "Forces on the Human Body in Simulated Crashes" [Patrick et al., 1966 (701)], "Occupant Injury Tolerances for Aircraft Crashworthiness Design" [Snyder, 1971 (706)], State-of-the-Art--Human Impact Data [Snyder, 1972 (705)], "Impact" in NASA Bioastronautics Data Book [Snyder 1973 (707)], and most recently, "Survey of the State of the Art of Human Biodynamic Response" in Aircraft Crashworthiness [King, 1975 (696)]. Selected research studies are also listed in the Section 4.2 references 683-730. Engineering Design Guides (684, 688, 690, 693, 702, 727, 728) also present current data.

Test results reported for human subjects restrained only by a 7.6-cm (3-in) wide nylon lap belt are shown in Table XVI for forward, rearward, and sideward-facing decelerations.

The USAF design guide specifies human tolerance limits as (298; 683):

.Upward (headward, eyeballs down, $+G_z$)		25.0 G (for 0.1 sec)
.Forward (backward, eyeballs out, $-G_x$)		45.0 G (for 0.1 sec)
	or,	25.0 G (for 0.2 sec)
.Sideward (lateral, $\pm G_y$, lap belt alone)		9.0 G (for 0.1 sec)
(lateral, $\pm G_y$, lap belt and shoulder harness)		11.5 G (for 0.1 sec)
.Downward (footward, eyeballs up, $-G_z$)		15.0 G (for 0.1 sec)
.Rearward (forward, eyeballs in, $+G_x$)	from	45.0 G (for 0.1 sec)
	to	83.0 G (for 0.004 sec)

TABLE XVI.

HUMAN SUBJECT TESTS, RESTRAINEO BY 3"-WIOE LAP BELT

Force, lb	Peak G	Onset Rate, G/sec	Time Ouration sec	Response	Oata Source
.Forward-facing ($-G_x$):					
	15	300	0.002	Subjective pain threshold	Lewis & Stapp 1957 (700)
4290	11.4-32.0	280-1,600	0.002	limit with no significant	Stapp 1970 (721)
	26	850	0.002	injury highest voluntary	Lewis & Stapp 1957 (700)
	~30	~1,500		level tested; transient injury, minor reversible injury.	Stapp 1970 (721)
.Rearward-facing ($+G_x$):					
	30	1,065	0.110	No injury.	Stapp 1949 (711)
	40	2,000		Severe but transient response.	Stapp 1949 (711)
	82.6(chest) 40.4(sled)	3,800	0.040	Highest voluntary measured test, transient injury.	Beeding & Mosely 1960 (687)
	>45		0.100	Estimated injury threshold Air Force design limit.	HIAD (683)
.Lateral ($\pm G_y$):					
	9 (average)		0.100	Subjective pain threshold.	Zaborowski 1966; Zaborowski et al. 1965 (729; 730)
	14.1	600	0.122	Maximum voluntary pain level.	Sonntag 1968 (710)

The U.S. Army design guide provides the following table of design pulses corresponding to the 95th percentile accident of fixed-wing transport aircraft (727; 690):

TABLE XVII.

SUMMARY OF OESIGN PULSES CORRESPONDING TO THE 95TH PERCENTILE ACCIDENT OF FIXEO-WING TRANSPORT AIRCRAFT

Impact Direction	Velocity Change (fps)	Peak G	Average G	Pulse Duration "T" Second
Longitudinal (Cockpit)	64	26	13	0.153
Longitudinal (Cabin)	64	20	10	0.200
Vertical	35	36	18	0.060
Lateral (Cockpit)	30	20	10	0.093
Lateral (Cabin)	30	16	8	0.116

Source: U.S. Army Aviation Material Laboratories (727; 690)

The chapter on Impact in NASA's Bioastronautics Data Book [Snyder, 1973 (707)] presents a wide range of tolerances related to restraint system used, body orientation, magnitude, direction, distribution, duration, and pulse shape of the force resulting from the impact, as well as biological factors of age, sex, and physical condition. However, human tolerances for voluntary decelerations have been measured on humans to the following values without injury, in young healthy male subjects under full body restraint:

.Upward ($+G_z$) 220 G at 0.12 sec (shoulder harness)

.Forward ($-G_x$) 35 G for 0.061 sec (seat belt only)
58 G for 0.017 sec

.Sideward ($\pm G_y$) 33.6 G at 710 ft/sec R.O. (standard aircraft shoulder harness)
21.6 G at .210 sec

.Downward ($-G_z$) 69.5 G at 0.01 sec (shoulder harness)

.Rearward ($+G_x$) 82.6 G for 0.052 sec

While such maximum peak values may be high for some segments of the population such as children, elderly, or females, these voluntary subjects did not reach the injury level, and the survival level (non-reversible injury) would have been considerably higher.

In the forward-facing ($-G_x$) seated position, protected only by the lap belt restraint still found in most current civil aircraft, human subjects have been voluntarily tested to 26 G. In a series of tests, Lewis and Stapp [1957 (700)] concluded that minimum contusions would result when decelerative force exceeded 10 G, at 300 G/sec rate of onset, for 0.002 sec duration. By 13 G, at the same onset rate and time duration, soreness and muscle strain would be expected. At the highest level studied--26 G (at 850 G/sec for 0.02 sec)--although the subject complained of severe epigastric pain lasting for 30 sec post-impact, and thoracic back strain for two days, no lasting injury was reported. In this case, a 7.6-cm (3-in) nylon military lap belt was used; impingement pressure was calculated to be 6.3 kg/sq cm (89.5 psi), and belt loads were measured at 1,946 kg (4,290 lb). Up to 15 G, these levels of time duration and onset rate have subsequently been considered safe for human volunteer subjects (for subjective pain threshold and transient injury only).

For the forward-facing position, with lap belt restraint only, Stapp [1970 (721)] concluded that "rates of onset between 250-1,600 G/sec and 11.4-32.0 peak G can be sustained against a lap belt restraint up to approximately 90 psi [6.3 kg/sq cm] average load, with no significant injuries resulting." Effects of higher loads have been investigated with animal subjects, but even in tests where the lap belt was purposely positioned high and loose, 30 G peak impact (22.6 m/sec [74.2 ft/sec] entrance velocity, 3,000 G/sec onset rate, 20 deg seat pan pitch, 0.055 sec plateau time, 0.094 sec total impact duration) produced no significant injury [Snyder et al., 1967 (708)]. It has been found that seated human occupants restrained by a 7.6 cm (3 in) lap belt only and subjected to aircraft crash forces can survive 30 peak G at rates of onset below 1,500 G/sec with only minor reversible injurious effects. When this is increased to more than 38 G at 1,300 G/sec, the immediate effects of deceleration are greater than at 45 G peak at 500 G/sec.

However, as has been pointed out by Swearingen et al. [1962 (726)], the arcing trajectory as the body goes forward to the limits of the belt and then jackknifes over the lap belt is sufficiently great, so that if the torso is not also restrained, the lap-belted occupant will almost certainly strike any forward structure. And even though whole-body loads of a 30 G deceleration are survivable with no more than minor injury, fatal injuries at far lower levels can result from the head striking the sharp forward structure. Thus, upper torso body restraint is necessary for most effective crash protection of the seated forward-facing aircraft occupant.

Use of upper torso restraint increases whole-body human tolerance limits to approximately 50 G peak (at 500 G/sec rate of onset for 0.25 sec duration) [Stapp, 1951 (712)]. Changes in the rate of onset have been found to have direct effects upon human response for various impulse durations [Snyder, 1971 (706)]. Peak acceleration of approximately 45 G (0.09 sec at 500 G/sec) resulted in no sign of human voluntary shock, yet 38 G for 0.16 sec above 1,300 G/sec was found to produce signs of severe shock [Stapp, 1951 (712); 1970 (721)], and 45 G for 0.23 sec at 413 G/sec produced severe delayed effects (run 215) [Stapp, 1951 (712)]. Air Force design recommendations have been given as 45 G for a duration of 0.1 sec or 25 G for a duration of 0.2 sec (298; 683). Restraint in the experiments establishing these limits was by means of a double shoulder harness of 7.6-cm (3-in) width, a seat belt with thigh straps, and a chest belt. Even greater tolerance has been found in tests with more optimum protection. Chimpanzee tests collaborate findings from human free-falls that forward-facing whole-body tolerance with optimum full-body restraint may be about 237 G (at 11,250 G/sec for 0.35 sec), and about 247 G (at 16,800 G/sec over 0.35 sec) [Stapp, 1961 (717)]. Persistent injury was found above 135 G (at 5,000 G/sec for 0.35 sec), although transient injury effects were observed at 60 G (at greater than 5,000 G/sec) [Stapp, 1955 (716)]. It is clear that there is a considerable range between the region of human voluntary exposure tested and the known region of injury.

Rearward-facing ($+G_x$) tolerances are considerably higher than for either forward- or side-facing positions, primarily due to the greater distribution of loading throughout the entire back area of the seated occupant, and thus the lower kg/sq cm (psi) per unit area. This results in greater stress on the seat back which must be constructed to fail at higher levels than a forward-facing seat. While human tolerance for rearward-facing body orientation has not been clearly established, the occupant so protected can be expected to withstand 40 G peaks at 30 G for 0.11 sec duration when calculated rate of onset is 1,065 G/sec [Stapp, 1949 (711)], and 40 G peaks at 2,000 G/sec with severe but transient responses [Stapp, 1961 (717)]. To date, a level of 83 G (chest acceleration), at 3,800 G/sec for 0.04 sec duration, has been tolerated with only transient injuries reported [Beeding and Mosely, 1960 (687)]. The current Air Force design limit falls between this and 45 G for 0.1 sec endpoint [AFSC, 1969 (298); 1974 (683)].

Knowledge of human response to lateral deceleration forces ($\pm G_y$) is very limited, but tests to date strongly indicate that tolerances are lower for this position than for either forward- or rearward-facing body orientations. This is reflected in a change in SAE Aeronautical Recommended Practice 767 , omitting side-facing seating recommendations. Human subjects have found the subjective pain threshold to be only 9 G (average) for a duration of approximately 0.1 sec [Zaborowski, 1965 (729); 1966 (730)]. Even when body restraint consisting of both lap belt and upper torso harness is worn, Sonntag [1968 (710)] found the maximum voluntary subjective tolerance to be 14.1 peak sled G at 600 G/sec for 0.122 sec duration.

Injuries to the lower extremities are statistically the second most frequent type of trauma found to occur in aircraft accidents. They are seldom life threatening in themselves, unless extensive loss of blood occurs. But unlike such injuries in ground vehicles, upper or lower leg, knee, ankle, or foot debilitation in an aircraft accident may have far more severe consequences in cases where they prevent the individual's post-impact evacuation. In case of fire or other hazards, where such evacuation must be completed immediately, even relatively minor injury may result in fatal consequences.

To determine crash loads on the backs of aircraft seats caused by the legs of passengers striking the seat ahead, in 1962 Snyder tested four embalmed male cadaver legs on the FAA bungee decelerator (705). Fracture of the tibia occurred at about 453.6 kg (1,000 lb) peak load on each; these tests were also of interest in that they indicated a seat back could be subjected to at least 907.2 kg (2,000 lb) load by the legs alone, and that in three-abreast airline configuration, 2,721.5 kg (6,000 lb) loads could occur during impact from the legs alone.

4.3 Principles of Restraint

Through high-speed photographic techniques the kinematics of the seated occupant exposed to collision forces have been well documented, particularly in automotive impacts. If the passenger is not wearing a restraint system and the aircraft is involved in a collision, the following sequence of events is observed to take place. First, he slides forward in the seat until the knees contact the seat or instrument panel structure ahead. Second, his torso pitches forward and the head contacts the panel or seat back. Extremely high G-loadings can be registered in the head during this portion of the event, particularly if the head contacts a food service tray stored in the seat back. Third, the neck and upper torso are stopped by the upper seat or panel structure. Fourth, the lower portion of the upper torso continues its downward motion causing the head to be bent to the rear (hyperextension) relative to the torso. The occupant will then rebound back into the seat or be ejected depending on the direction of impact and seat position.

The three basic problems in providing occupant protection are demonstrated by this example. The first of these is to restrict the motions of the occupant from contact with structures causing injury. In the case of crew members, the structures would consist of the myriad of equipment and controls present in the cockpit of the aircraft. Occupants of troop seats must be restrained from contact with their neighbors. Passengers of rear-facing seats appear to be in the best position to avoid this problem provided seat structural strength is sufficient to resist crash impact loads.

The second problem in providing impact protection is limiting the acceleration G-loadings and forces applied to the body based on human tolerance data. The problem faced in designing aircraft seating has one factor not often found in automotive crashes--vertical G-loading as the aircraft impacts. This indicates that seat cushion design for aircraft application has greater importance than in the automotive case. This problem has additional importance in that the tolerable loadings in the spineward direction are lower than for front-to-rear loading. In designing an impact protection system for aircraft use, it is thus as necessary to consider the energy-absorbing properties of the seat cushion as it is to consider the properties of an upper torso restraint, whether it be an airbag or an Air Force harness. Therefore, in developing specifications for impact protection, the relevant life support system can be defined to consist of both the seat and the restraint system.

The third problem in providing impact protection is limiting extensive motions between adjacent body elements. This factor was also illustrated in the example as the head was bent to the rear relative to the torso.

A lap belt is effective in avoiding complete ejection from a seat but is not capable of avoiding all potentially injurious contacts with other aircraft structures. This is particularly the case with crew seating positions where the occupant faces forward. In those cases the upper torso must be restrained. This is accomplished successfully by a variety of active belt restraint systems and can also be accomplished by passive restraint systems such as the airbag. The lap belt may be eliminated to yield a purely passive restraint system provided provision is made to catch the knees and lower part of the torso by suitable energy-absorbing structures. This can be accomplished either by additional passive bag deployment or by crushable panels.

Current-generation airbag and upper torso belt systems do not provide the solution to the restraint problem in side G-loadings. Dummy test subjects in side impact, restrained by standard lap belts and single diagonal harnesses, have been observed to slide under the belts and end up almost entirely off the seat [Robbins et al., 1970 (731)]. The lap belt is insufficient to restraint the pelvic region and the shoulder harness does not prevent the upper torso and head from contact with structures adjacent to the seat if they are present. It seems likely that this problem could be experienced with the troop seats observed in some military air transport aircraft.

Some insight into techniques for preventing motions to the side are found in studying the protective potential of children's restraint systems [Robbins et al., 1970 (732)]. In this case side impact tests were conducted on a Volvo child seat which provided padded structures at the side of the user. This effectively reduced side motions and distributed the loadings over the body. This concept of side impact protection was also incorporated effectively in a prototype integrated seat/restraint system built and tested at the Highway Safety Research Institute of the University of Michigan [Robbins and Roberts, 1971 (733)], and more recently in inflatable side protection in the General Dynamics F-111 fighter [Shaffer and Brinkley, 1974 (17)].

The major problems in rear impact protection are load distribution and provision for head restraint. These features have been effectively included in rear-facing seats. A supplemental lap belt is necessary, however, to prevent ramping up the seat back and rebound after impact.

In summary, the three basic problems in occupant protection during crash impact are: (1) ejection from the seating position, (2) application of excessive forces to the body; and (3) the occurrence of large relative motions between adjacent body segments. In the case of wake or other forms of turbulence encountered in flight, the seat belt also serves to prevent ejection and possible injury.

4.4 Rearward-Facing Seats

During the past three decades a considerable number of studies have been conducted related to the occupant body orientation relative to the direction of the impact force. These have been recently tabulated and summarized in the NASA Bioastronautics Data Book (707). As indicated in the preceding discussion of impact tolerances, the tolerances for rearward-facing ($+G_x$) body orientation are higher than in either forward-facing or sideward-facing occupant positions. Chest accelerations as high as 83 G (at 3,800 G/sec onset rate for 0.04 sec duration) have been recorded in rearward-facing tests conducted on the Daisy Track at Holloman Air Force Base, New Mexico [Beeding and Mosely, 1960 (687)]. However, this did not represent a non-reversible injury limit for this subject and other evidence from free-falls and sub-human primate tests have indicated that survival tolerances may be more than three times higher [Stapp, 1955 (716); 1966 (718); Snyder, 1972 (705); 1973 (707)]. On the other hand, human tolerance tests have to date been limited to young healthy male volunteers, with tests conducted under maximum restraint and closely controlled medical conditions, and information relative to tolerances for other segments of the population has not yet been developed. The accepted U.S. Air Force design limit is 45 $-G_x$ for a duration of 0.1 second or 25 $-G_x$ for a duration of 0.2 second in rear-facing impact (278; 683).

The research data appear to overwhelmingly substantiate that the seated occupant can tolerate much higher crash forces when oriented in the rearward-facing ($+G_x$) position. There has been a great deal of controversy concerning rearward-facing seating in the past. Experimental deceleration studies using animals and human volunteer subjects have demonstrated that the occupant is able to tolerate greater forces in this orientation. However, comparison of the protective advantages of rearward-facing seating in operational conditions has been difficult to objectively determine since few accidents have occurred in which passengers were facing rearward and, of these, most have involved propellor-driven aircraft [Wilson and Helmholtz, 1947 (779); USAF staff study, 1947 (774, 767, 764); Gronow, 1954 (747)]. NACA analyses resulting from experimental Curtiss C-46 and Fairchild C-82 crashes in the 1950's resulted in objective considerations in support of the need for improved seating,wwith indications that properly installed rearward-facing seating could be advantageous [Preston and Pesman, 1958 (760); Pinkel, 1960 (758); Pinkel and Rosenberg, 1956 (759)]. Early studies by the Royal Air Force, particularly Fryer [1958 (744); 1959 (745); 1962 (746)] had strongly recommended the increased protection for passengers in rearward-facing seats.

Fryer [1962 (746)] notes that "...it was soon realized during the second World War that those seated in aft-facing positions with adequate head support could tolerate higher crash forces than their forward-facing colleagues. This can be attributed to the distribution of the decelerating force over a much larger and more suitable surface than that covered by the conventional harness." The RAF Transport Command conducted tests by Pekarek [1941 (756)] and Dudgeon [1960 (741, 742)], subsequently introduced 25 G backward-facing seats for passengers into two of the RAF's post-war transport aircraft, and found beneficial results in several accidents. Fryer found that in many minor accidents the differences between rearward- and forward-facing passengers were "...slight but in major crashes the advantages of the rearward-facing position are both theoretically and practically proved to be considerable" [Fryer, 1958 (744)].

Arguments against the adoption of aft-facing seats appear to have centered about concerns for additional weight which might be necessitated by increased strength and anchorage requirements, possible added cost, and the subjective feeling that people don't like to ride backward.

Since 1946 rearward-facing seats for passengers have been installed in all Royal Air Force transport aircraft brought into service [Gronow, 1954 (747)], and 16 G rearward-facing passenger seats have been specified for USAF transport aircraft since 1951 (298; 740; 774). U.S. Navy passenger aircraft which are carrier qualified must carry passengers rearward-facing, but otherwise forward-facing seats are utilized. During the early 1950's some European airlines had begun to provide rearward-facing passenger seating. While some seats in many air carrier configurations through the years have been rear-facing, the first flight by a commercial airline in the United States in which all of the passengers sat facing the rear was a North American Airlines Douglas DC-6 flight into LaGuardia, New York, in May, 1953 [Hawthorne, 1953 (750)].

In 1947 the U.S. Army Air Force Air Transport Command modified two aircraft for transcontinental flights with all passenger seating rearward-facing (767). Questionnaires from 1,020 passengers were analyzed and it was found that the subjective results were overwhelmingly in favor of the change and indicated no discomfort or adverse reaction to this type of seating. It was recommended that an adequately stressed aft-facing seat be designed, all operational air transport aircraft be modified for rear-facing passenger seating, and a recommendation made to "...include in specifications for future transport aircraft the principle of rearward-facing seats." It is also interesting to note that this military staff study summarized its findings in rather direct language: "If the rearward seating principle is disregarded, these passengers will die. It may well be economically unfeasible to modify present aircraft, but when lives are balanced against dollars, there can be no excuse to continue designing new aircraft without embodying the safety factor" (p. 3). Appended to the staff report in a letter of transmittal of 5 May, 1947 (754) were results of the questionnaires.

In 1955 the U.S. Navy Bureau of Aeronautics established a study "which would support the selection of either the forward or aft seating arrangement for passenger type aircraft based on a comparative evaluation under crash load conditions" [Noble and Domzalski, 1961 (755)]. In this series of tests, eight experiments utilized two male volunteers of approximately the 5th and 95th percentile stature dimensions, exposed to 2 to 5 G (.25 to .37 sec at 1,100 G/sec) while seated in two type MIL-S-7877B Weber transport seats. The tests were intended to go to 8 G; the reaction at 5 G in the forward-facing seat precluded lap belt only forward-facing decelerations above 5 G, although dummy tests subsequently went to 9.2 G.

On the basis of this comparison it was concluded that "a passenger seated in the aft-facing position can better withstand the effects of rapid deceleration because his body and head receive support from the entire back of the seat" [Noble, p. iii, 1961 (755)]. It was recommended that the aft-facing passenger seat be retained in military passenger type aircraft with four modifications. The modifications included adding an adjustable back mechanism to the right armrest, adding a 2.5 cm (1 in) ensolite padding across the lower back cross member to eliminate bottoming, reanalyzing the seat design to see if additional bracing was needed, and providing a stop plate under the seat to prevent "jackknifing"of the passenger's legs.

A 1966 series of tests conducted by the FAA (CAMI) also support the 1961 Navy study recommending rearward-facing seating, although for different reasons. Dynamic impact tests of instrumented anthropomorphic dummy heads into the backs of current models of forward-facing air transport seats showed that portions of some seats have good deformation characteristics. However, Swearingen [1966 (724)] considered "lethal design" features to include tubular construction, rigid serving trays, rigid seat arms protruding rearward between seats, and excessive break-over forces. In impact tests against the backs of 8 different airline seats at 9.1 m/sec (30 ft/sec) impact velocity, Swearingen concluded that 30% would have been fatal, 80% would have produced facial fractures, and 97% would have rendered the passenger unconscious, with only 3% of these head impacts considered to show that the passengers would have survived without unconsciousness or injury.

The USAF 16 "g" passenger seat requirement including shoulder harness or rearward-facing seats was adopted in 1951 (Technical Instruction 2140, Installation of Seats and Shoulder Harness in USAF Aircraft), and G factor was based upon a 113.4 kg (250 lb) occupant (thus 1,814.4 kg [4,000 lb] ultimate load in a 16 G seat). (Note that the FAA T50-C39 provides only for a 694 kg [1,530 lb] ultimate load for a 77.1 kg [170 lb] occupant in a 9 G seat.) In 1951 the first 660 rearward-facing seats were delivered, and the first were installed in a Military Air Transport Service Boeing C-97 aircraft by Lockheed Engineering Company. This aircraft made its first flight on 11 June, 1951. Subsequently all MATS Boeing C-97 aircraft were modified with 16 G rearward-facing seats as they received 1,000-hour inspections.

The Air Force Systems Command Handbook of Instructions for Aircraft Design (AFSCM 80-1) section 2.1 related to passenger seats states: "Install all passenger seats to face rearward and locate them to the rear of any cargo carried. Comply with the 16 'g' strength requirements of MIL-S-26688 (740) for passenger seats on transport aircraft which are used alternately for carrying cargo and passengers and install them to meet the requirements in MIL-A-8865..." The most recent USAF/NASA design handbook (AFSC DH1-6 System Safety, fourth edition, 20 July, 1974) specifies: "The maximum protection from impact forces on the body is provided by rearward-facing seats. Use these seats for all passengers and for crew members whose duties do not require them to face forward" [3Q2.1. Seat Orientation (773; 298)]. Currently the USAF Military Airlift Command (MAC) primarily utilizes rearward-facing seating in its Lockheed C-141A Starlifter and Boeing C-135 troop transport, however, not all seats are rear-facing. In the C-141 a standard seating arrangement is 46 three-place rear-facing seats (138 occupants) without a comfort pallet, or 120 troops in three-place rear-facing seats when a comfort pallet is available. Such seats have either 5.1 cm (2 in) or 7.6 cm (3 in) lap belts with no shoulder harness, and are stressed for 16 G impact loads. However, other passenger configurations include litter arrangement (head-first body orientation) and in cases where paratroops are carried, the rear-facing seats may be replaced by four sections of side-facing net seats. There is also a modification of this arrangement (C-141A Kit #1) consisting of one row of inboard-facing canvas seats positioned along each side of the cargo compartment (T.O. 1-C-141A-1).

The USAF Boeing C-135 cargo carrier or troop transport and KC-135 tanker is primarily used with the Strategic Air Command, and has provisions for up to 135 passengers. Military Airlift Command also operates five Boeing VC-137B and Boeing VC-137C models, modified from the Boeing 707 civil air carrier version, with a crew of seven or eight and 50 passengers which is used for the President and government officials. Although USAF aircraft are not required to operate under FAA airworthiness bulletins, the 89th Military Airlift Wing at Andrews AFB, Maryland, which operates the VC aircraft, is the only military unit in the USAF operating under FAA standards as well as USAF standards, and operates its own FAA certified repair station [Covault, 1974 (65; 736)]. A typical SAC configuration includes both cargo and passengers with 10 rear-facing seats aft of the cargo area, equipped with either 5.1-cm- or 7.6-cm-wide (2 or 3 in) lap belts. There are also provisions for carrying 55 troops in folding nylon side-facing seats positioned along each side of the fuselage and in the tail section. When no cargo is carried, the USAF Boeing C-135 passenger configuration consists of 42 aft-facing track-mounted triple seat units mounted on either side of the fuselage for six-abreast seating, for 126 rear-facing passengers (436). When the aircraft is utilized for aero-medical evacuation, 44 litters and eighteen triple aft-facing seat units for 54 passengers can be mounted.

Thus, while not all USAF passengers, even in the Lockheed C-141 or Boeing C-135, travel in aft-facing seats, this is the predominant passenger orientation for most operations. The Royal Air Force presently utilizes rearward-facing seating for passengers in the VC-10 transport, Comets, Brittanias, Belfasts, and some Hercules transports; however, the RAF has no experience to date with these aircraft where passengers have been subjected to impact deceleration in rearward-facing seats.

4.4.1 Rear-Facing Passenger Accident Experience. The accident data for Lockheed C-141 and Boeing C-135 aircraft have been previously presented in summary form but information was not available from the Air Force to compare rear- versus forward-facing passenger survivability. Although there has reportedly been a C-141 accident in Australia involving rear-facing passengers, and isolated air carrier accidents where some occupants have been seated in rear-facing seats, unfortunately information is limited relative to operational accident experience in current jet air carriers.

Accident comparisons between rear- and forward-facing occupants has now extended over two decades. Investigation of casualties and fatalities in a study of 20 crash landings in Consolidated B-24 type aircraft indicated that persons in the rear were seven times less likely to be fatally injured, three times less likely to have serious injury, and three times more likely to have no injury as passengers or crew forward of the leading edge [Wilson and Helmholtz, 1947 (779)]. In 1954 the Royal Air Force reported results of eight years' experience with rear-facing seats in all RAF military transports required since the end of World War II. Comparisons were made between four types of RAF Transport Command two-engined Dakotas and four-engined Yorks (both having mainly forward-facing seating) and two-engined Valettas and four-engined Hastings (primarily aft-facing seating) for the years 1946-1953. For this period 21.6% of passengers involved in forward-facing seating (substantial damage or destroyed Dakota or York aircraft) were fatally or seriously injured, while in comparison, only 6.4% of the rearward-facing passengers (Valettas and Hastings) were fatally or seriously injured [Gronow, 1954 (747)].

Subsequently, a USAF study of accident data from all USAF Transport accidents over a 2-1/2 year period (1955-57) resulted in finding that injuries to those passengers facing forward were seven times greater than received by those facing to the rear [Moseley, 1957 (753); Stanfield, 1957 (764)]. Of 3,108 occupants in survivable military transport accidents during this period, 2,990 received no injuries, including almost 100% of those facing to the rear. Four percent of those forward-facing received major injuries and 1.3% of those forward-facing were fatally injured. Data for both high impact and "survivable" air transport accidents showed that 98.3% of passengers facing rearward received no injuries. In comparison, 11.1% of those in forward-facing seats were killed and 4.5% received major injuries. Predominant injuries to aft-facing passengers involved the extremities. At that date the USAF reportedly used rearward-facing seats for all aircraft used strictly for air carrier use.

An Air Force Convair C-131, equipped with rear-facing passenger seats, crashed short of the runway at Tinker AFB, Oklahoma after fuel starvation in 1962. Investigation revealed that injuries to several occupants, including a general officer aboard, were attributed to incorrect installation of several sets of armrests on rearward-facing seats which permitted failure of the seat back in a moderate force accident (748, 749). One previously described accident involved a Boeing KC-135A which made a 3-engine approach and crashed short of the runway with 56 crew and passengers aboard, destroying the aircraft in the post-crash fire. This aircraft had 26 rear-facing seats aft of the cargo section (refer to Fig. 19). Although evacuation was accomplished in 45 seconds, 11 passenger fatalities were attributed to effects of fire and smoke. Of the 12 occupants injured, no rearward-seated passengers were reported to have received impact injuries. In a more recent crash on 5 April, 1975 in Vietnam, a USAF Lockheed C-5A crashed near Saigon when the aft cargo door and ramp blew off in decompression and severed the flight controls as a result of the locks on the rear cargo door and ramp coming unlatched in flight. Of 330 persons aboard there were reported to be 155 survivors; however, the Air Force has released no information to date related to those occupying rearward-facing seats on this aircraft.

4.4.2 Other Considerations. In 1968 as a result of an FAA Office of Aviation Medicine staff review of accident experience and adequacy of the existing air transport, and proposed V/STOL tentative airworthiness Standards for Transport category, one major recommendation was to "require, where practicable, aft-facing seats" [Staff report, 1968 (768)]. It has been shown that current air transport cabin structures can remain reasonably intact at crash force levels of 20 G (for 23 msec at rate of onset of approximately 1,500 G/sec), which is considerably less than the rear-facing human occupant can tolerate. It is of interest to note that the 16 G seat, originally designed by the Aeromedical Laboratory of the USAF Air Material Command, contained aluminum sheet structure 6.8 kg (15 lb) lighter than the 6 G seat it replaced. The 1967 USAF Industry Life Support Conference concluded that human tolerance to $+G_z$ probably exceeds 50 G. This conference recommended revising the load factor to 25 G for crew seats and 20 G for passenger seats, and that aft-facing seats be used wherever possible (23).

More recent studies by von Beckh [1969 (776,777)] have reported that during the post-decompression emergency descent of multi-mach high-altitude aircraft the occupants will be subjected to deceleration-induced inertial loads in the direction of the flight path which will reach or exceed 0.5 G. In such a situation he reports that forward-facing passengers who have not been able to don the oxygen mask may lose consciousness for various periods of time and will assume positions which are not favorable for the recovery from hypoxic stress. On the other hand, von Beckh recommends a reassessment of the value of aft-facing seats since aft-facing passengers, even if unconscious, would still be supported by their seat back and would be forced into an advantageous (for recovery) semisupine position by the combined effect of the aircraft's negative altitude angle and the decelerative load. This work points up a new advantage of aft-facing passenger seats particularly pertinent in today's high altitude passenger flights.

The major advantage of rearward-facing impact protection is that the crash loads are distributed over a larger portion of the body. This results in less load per unit area, and increases the capability of the occupant to withstand greater crash forces than were he seated in a forward-facing lap-belted position. However, this raises the center of gravity and loads the seat back higher, thereby stressing the seat back and tie-down anchorages greater than in a forward-facing position. This requires a stronger seat and stronger attachments due to the higher loading. A passenger seat cannot simply be turned around and perform adequately in a crash. The requirement for greater seating strength for rearward-facing seats does not, however, necessarily mean that it will be more costly or weigh more. Tests conducted by the Air Force and previously mentioned in this paper, have shown that the 16 G rearward-facing seat was 6.8 kg (15 lb) lighter than the 6 G forward-facing seat it replaced, while studies by Stapp [1963 (766)] for air transports, by Swearingen [1958 (769)] for general aviation aircraft seats, and by NASA (8) for 20 $+G_x$ forward-facing commercial passenger seating, have also indicated that stronger, lighter seats can be built with today's technology. Time motion studies were made by Stapp and Lewis [1956 (778)] of 20 subjects exposed to 6 G and 12 G in aft-facing and forward-facing seating, and resulted in recommendations regarding rearward seating of transport passengers in relation to escape from survivable crashes.

The concerns expressed by some individuals that people do not like to ride rearward in an aircraft have not been substantiated in past studies [USAF Staff Study, 1947 (767); FAA Staff Study, 1968 (768); Kubokawa, 1974 (8)]. In the 1971 evaluation of USAF transport aircraft seating, the rearward-facing Boeing C-135 and Lockheed C-141 16 G seats were found to offer substantially better occupant crash protection over any other civil airline passenger seats in use [Snyder and Robbins, 1971 (21); Snyder, 1975 (20)]. There seems to be ample evidence that current technology can provide rearward-facing seats with even lighter weight, greater strength, and at relatively less cost per unit than current rearward-facing seats. Review of all pertinent impact test data strongly supports the considerably increased crash protection offered to the occupant seated in a rearward-facing seat.

4.5 Advanced Active Systems

Any restraint system which requires the user to "actively" adjust or get into is known as an active system, and this includes most restraint systems currently in use, ranging from those used in racing cars to configurations used by astronauts. To date, there are at least 100 different configurations of restraint systems, many of which are reviewed in references 792, 784, and 786. Belt restraint systems are often referred to as 2, 3, 4, or 5-point systems, which refers to the number of attachment or anchorage tie-down points used. A single lap belt, therefore, is a 2-point system, being attached to a structure at either end, and is also known as a type 1 belt under FMVSS 208. However, if a single upper torso belt is added, (type 2 belt system) it can be a 3-point system (if the upper end is anchored separately, but the lower end attaches directly to the lap belt, as at the buckle), or a 4-point system (if the upper end is anchored separately, and the lower end is also separately anchored to the floor structure). Many European motor vehicles use a continuous lap belt/upper torso belt slip-through system, employing one buckle and three attachment points. Almost all current air carrier passenger seats use a single lap belt arrangement, with the tie-downs usually to the seat structure itself, rather than to the floor structure (as is often the case for flight deck crew positions).

As noted in Section 4.2, restraint of the upper torso prevents the seated occupant from jackknifing forward and striking structures during impact, and has been required for all front seat outboard positions in motor vehicles manufactured for sale in the United States since 1 January, 1968 [FMVSS 208 (782)].

In February of 1973 the FAA issued an NPRM which would make the installation of shoulder harnesses mandatory in newly certified general aviation aircraft (manufactured one year from the effective date of the proposed amendment), through amendment of Part 23.785(g) and addition of a new Part 23.785(h) (781). However, to date few air carrier type aircraft are equipped with upper torso restraints for passengers. One exception is the Grumman G-2 Gulfstream Corporate jet flown by Chrysler Corporation, which employs an integrated diagonal upper torso restraint for passengers. This is probably the most advanced system, except for rearward-facing military systems, currently in operation for air transport passengers. U.S. FAR Part 25 (Airworthiness Standards: Transport Category Airplanes) (780) specifies that each seated occupant must be protected by a safety belt and "as appropriate to the type, location, and angle of facing of each seat, by one or more of the following: (1) A shoulder harness that will prevent the head from contacting an injurious object..." (780). Since there is such a variety of active restraint systems available and there is a very extensive literature dealing with development and testing, this paper will only review selected advanced state-of-the-art devices and concepts. Other systems have been previously covered in some detail in references 785 and 792.

4.5.1 Integrated Upper Torso Restraint. Integrated restraints are those in which the restraint is attached to (and retracts into) the seat itself. This concept was proposed in 1909 (783), and has been proposed in almost all recent automotive experimental vehicles, such as the Ford "Aurora" and "Techna," General Motors "Astro I," "Runabout," and "Mako Shark" and Chrysler Corporation's "300X" futuristic concept vehicles. Such systems have also been proposed for the Liberty Mutual capsule seat design, the Republic Aviation Division, Fairchild Hiller, New York Safety Sedan, the Cox seat (Cox of Watford, Ltd.), the Irvin Safety seat, and the Winebrenner concept, as detailed in reference 792. Fig. 43 illustrates one type of integrated harness, developed by Ford Motor Company, but never used in production vehicles. This can utilize either a single diagonal harness, as shown, or a double upper torso harness as proposed in 1909 (783).

Fig. 43. An integrated harness system in which the upper torso restraint retracts into the seat back as designed for the Ford Techna future idea car (Photo courtesy Ford Motor Company).

In a 1971 study conducted for the National Highway Traffic Safety Administration by the Highway Safety Research Institute, the University of Michigan, design concepts of integrated restraint systems were developed and tested [Robbins et al., 1971 (784)]. These tests were preceded by a series of analytical studies utilizing two- and three-dimensional mathematical models of an automobile crash victim. Impact tests were conducted in frontal, oblique, side, and rear tests using anthropomorphic dummies for one of these systems (described in Section 4.5.2). As shown in Fig. 44, one triple bench/bucket seat system (as could be utilized in an air transport aircraft) was developed which consists of an upper torso restraint which retracts by inertia reel into the seat belt, side protection, and an automatically adjusting lap belt. The other three systems included a (1) bucket seat with airbag torso restraint and energy absorbing lower panel (pure passive system), (2) bucket seat with inverted Y-yoke harness, and (3) bucket seat with 3-point harness system.

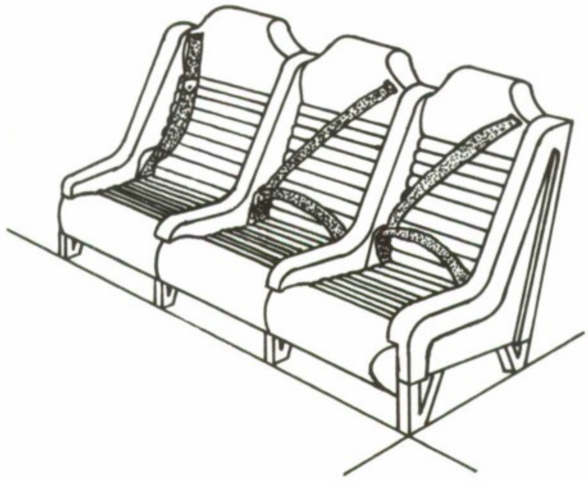


Fig. 44. Integrated bench seat-restraint system with 3-point harness [Robbins et al., 1971 (784)].

Advantages of the integrated seat system are that it would allow for optimum belt angles on the occupant since the system would be independent of seat movement. In addition, there would be no loose belts, because when not in use they would retract into the seat, making them easier to don. Balanced against these advantages, however, are a number of disadvantages. Such seats must be constructed to contain and provide maintenance access for interior reels, retractors or other devices, yet be built strong enough to protect against high G loads. Since the shoulder harness would retract into the seat back above the shoulder level, the higher center of gravity during forward deceleration would require considerable structural strengthening beyond that for current airline seats. Nevertheless, this system offers some distinct packaging advantages for ease in passenger use.

4.5.1.1 NASA Ames Integrated System. The National Aeronautics and Space Administration initiated studies in 1966 to analyze and propose modifications to existing commercial transsonic aircraft to provide improved passenger protection. This was funded under the Life Support and Protective Systems subprogram of the Human Factors System Program, a line item of the 1966 Congressional Authorization to NASA. An initial conceptual study was conducted by Stencel Aero Engineering Corporation of Asheville, North Carolina (NASA contract NASw-1530) for the "improvement of human survival in civilian aircraft emergencies" [Yost and Oates, 1969 (682)]. Examining FAA data, a definition of the boundary between a survivable and non-survivable accident as a function of flight velocity and impact angle was determined. Crash data available indicated to them that 70 to 80% of all aircraft injuries were as a result of face or head impacts to passengers as the upper torso flailed forward in a crash. Following lap belt dynamic tests of 5th and 95th percentile dummies, it was concluded that allowing excess seating clearance for unrestrained torso motion was neither economically feasible nor safe for the passenger, and that head and torso restraint of the airline passenger was a safe and practical way to protect against flail injuries. Interior survival for the passenger was focused on energy absorbing seat designs [Yost et al., 1970 (789)].

The integrated restraint concept has been a basis for the air carrier passenger seat under development by NASA since 1968. This system features a double upper torso harness and lap belt with inertial reels, although the upper torso harness does not retract into the seat as in the systems discussed in the preceding (4.5.1) section. The NASA Ames design effort arose from an attempt to provide maximum safety, comfort, and protective features for the airline passenger into a single seat design, and to demonstrate that "steps can be taken to prevent future airline crash fatalities or passenger injuries which can be attributable directly to inadequate seat design" [Kubokawa, 1974 (8)]. An in-depth design, fabrication, and impact analysis was conducted to design passenger protection in high G impacts (20 $-G_x$ horizontal, 36 $+G_z$ vertical, and 16 $\pm G_y$ lateral). The method for absorbing impact energy was accomplished by a combination of stretching stainless steel cables, breaking of stitch threads, and use of a hydraulic mechanism and special Temper Foam cushions. Since this seat/restraint development undoubtedly represents the most advanced passenger seat available for future air carriers it is recommended that Kubokawa's report (8) be examined in greater detail than is summarized here. The report by Ball et al. [1972 (786)] also provides background relating to the development from 1966 to 1972.

The constraints which went into this seat were as follows:

(1) Not to exceed the dimensions of the new generation aircraft seats (B-747, L-1011, DC-10, B-2707 SST).
(2) Not weigh over 2.3 kg (5 lb) more than the new generation aircraft seats--present single seats weigh 28.6, 22.7, and 19.5 kg (63, 50, and 43 lb) first class, to 13.6 kg (30 lb) economy class.
(3) Be able to attenuate 20 G in the horizontal direction ($-G_x$) (it was tested to 21 $-G_x$ successfully).
(4) Be able to attenuate 36 G in the vertical direction ($+G_z$) (it was successfully tested at 45 $+G_z$).

(5) Be able to withstand at least 3 G in the lateral direction ($\pm G_y$).
(6) Not exceed 106.7 cm (42 in) pitch (normally allowed for present overseas flights). Pitch being the distance from the back of one seat to the back of the seat directly in the front or the rear.
(7) Incorporate all the safety and human engineering features as recommended by NASA, Ames Research Center.
(8) Be comfortable when seated for long periods.
(9) Be constructed with nonflammable material (i.e., cushion, upholstery, etc.), and
(10) Incorporate the new NASA Ames restraint system.

A list of 21 negative safety features of current airline seats, and 11 additional safety hazards associated with present seats in aircraft crashes was noted. The unsafe features of currently used airline seats were made a basis for studying improvements which resulted in the NASA Ames seat. At the same time, NASA also proceeded to explore fire retardant paint and chemicals, jellied aircraft fuel, emergency escape systems, and other advanced concepts which might have applicability to increasing survivability in aircraft emergencies.

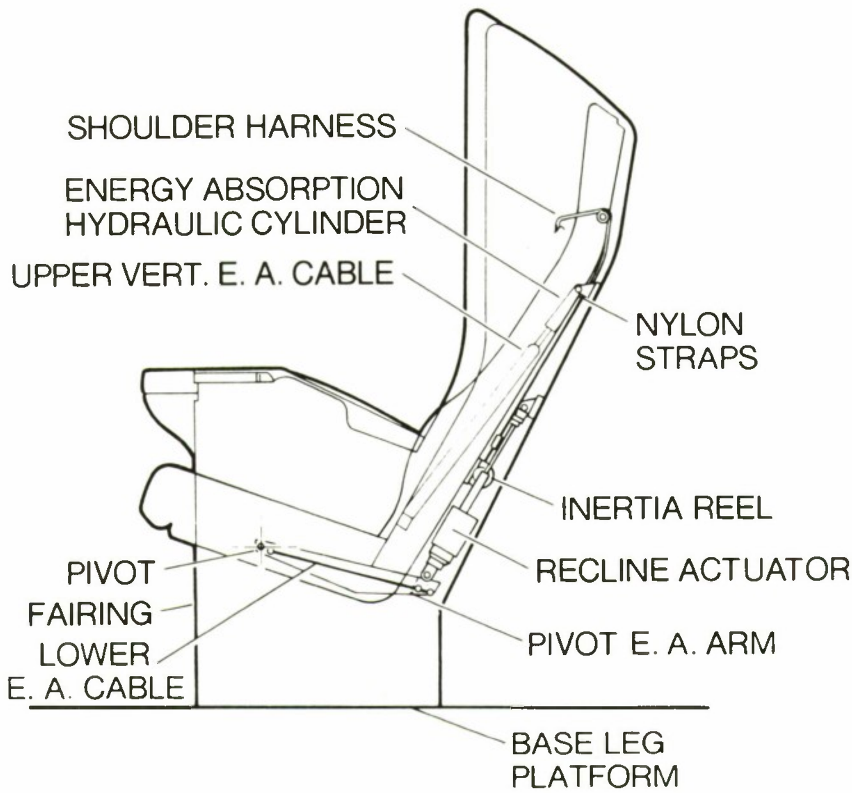


Fig. 45. The NASA Ames seat reclining system [After Kubokawa, 1974 (8)].

The NASA Ames airline seat is composed of two major elements, as well as special impact attenuating and passenger comfort equipment. An inner seat consists of an aluminum structure with a fixed seat angle of 105° between the seat pan and seat back. The seat pan is at a 6° incline from the horizontal when in the normal upright position. The inner seat, including both seat pan and back, can be placed in a comfortable reclining position up to 12° further by depressing a seat positioning switch and leaning back. The entire inner seat reclines from a single pivot point, while in present air carriers only the back of the seat reclines. The outer shell, which fastens to the floor, is the primary structure to which the impact attenuating devices and the inner seat are attached. The outer shell is an aluminum structure formed over with fiberglass, and bolted to the aircraft floor. The shell is padded on either side and provides passenger protection from lateral jostle and free-flying objects during impact. As shown in Fig. 46, various locations of the outer shell house the lights, attache case compartment, stereo speakers, food tray, warning indicators, volume balance, sound control, stewardess call, light control, seat control switches, and ash tray. The padded inside top area of both sides of the outer shell house the stereo speakers and lights. The armrests are constructed as part of the outer shell and the food tray is built into the left armrest, eliminating many hazards.

The double torso belt with inertia reel seat belt restraint (Figs. 48 and 49) has been demonstrated to restrain a passenger safely at 22 G in the horizontal direction without submarining or ejection. In the NASA seat design, the peak load energy is absorbed by the stretching of energy absorbing cables and the activation of other energy absorbing mechanisms located between the inner and outer seat structures. The four portions of this structure include upper vertical and lower horizontal assemblies of Type 304 stainless steel wire, a pivoting hydraulic cylinder used to allow the fixed length cable to move with the inner seat, a nylon restraint webbing with specially stretched patterns, an outer shell structure, and inner energy absorbing seat cushions. The cushions (Temper Foam) were specially produced by Dynamic Systems, Inc. of Lercester, North Carolina.

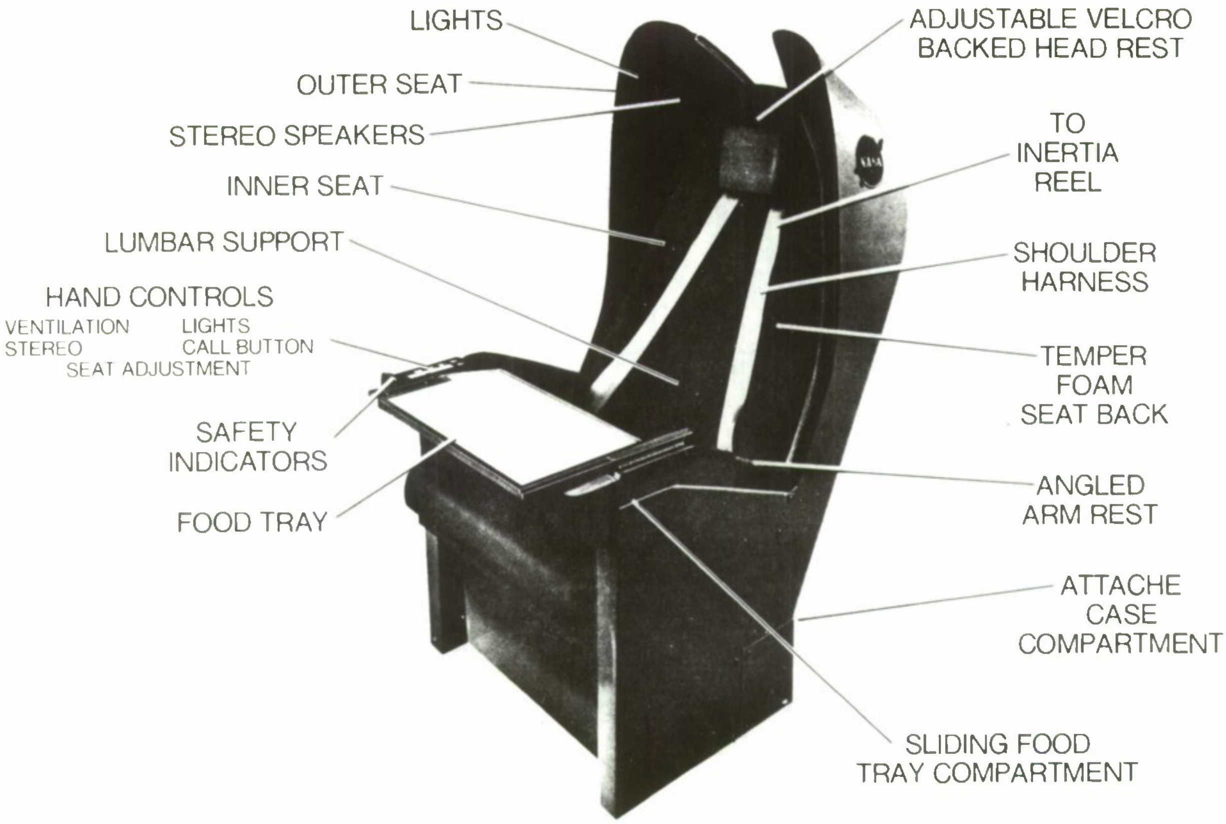


Fig. 46. NASA Ames integral aircraft passenger seat [After Kubokawa, 1974 (8)].

Fig. 47. Unrestrained passenger seated with food tray in place (folds back into side) in final configuration of NASA seat (Photo courtesy C. Kubokawa, NASA Ames).

Fig. 48. The restraint system shown in this mock-up seat features upper torso protection. Freedom of movement is allowed by inertia reels in the integrated seat (Photo courtesy C. Kubokawa, NASA Ames).

Fig. 49. Details of NASA Ames integrated restraint system in mock-up seat (Photo courtesy C. Kubokawa, NASA Ames).

Three series of impact tests were conducted on four prototype seats (8; 787; 788; 789). The first series was conducted in June, 1970 at the AVSER dynamic crash facilities of Dynamic Science, a division of Marshall Industries, in Phoenix, Arizona, utilizing test equipment made available by the U.S. Army Air Mobility Research and Development Laboratory at Ft. Eustis, Virginia (787). A second series of tests were conducted on two new seats in October, 1971 at the FAA's Civil Aeromedical Research Institute (CAMI) at Oklahoma City, and a third series of vertical tests were conducted at CAMI in March, 1972 to 45 $+G_z$ levels, exceeding the design objectives.

While this seat/restraint system has been designed specifically for airline passenger use, and it appears to have been the first to have such an extensive research effort in development, several questions, as posed by Kubokawa, remain unanswered. What use will the 20 G seat be when the aircraft starts to fall apart around 14-17 G? (Present floor anchorages are only designed for 9 G stress.) Is it economically feasible for airline use? (There is no weight penalty over current first class seats.) Will the air carriers or airframe manufacturers be willing to spend the funds necessary to restress the floor attachment points for new aircraft seats? What about passenger acceptance? It was also noted that the prototype seat reclining mechanism was electromechanical and the second was mechanical-hydraulic, while a simple nonspring loaded mechanical system would be even more desirable. Nevertheless, the NASA Ames airline passenger seat has been found to attenuate G loads of 21 $-G_x$ and 45 $+G_z$, or over twice the horizontal capability and 10 times the vertical capability of present seats. The capability of this seat has been well documented and it would appear that field testing in selected air carrier operations would be the logical next step.

4.5.1.2 Chrysler Corporate System. The Grumman Gulfstream G-2 corporate jet operated by the Air Transportation Division, Chrysler Corporation, Willow Run Airport, Ypsilanti, Michigan, contains a number of advanced safety devices, including passenger seats containing an upper torso integrated restraint system. As shown in Fig. 50, upper torso restraint is provided by a single diagonal belt (3-point system) attached to an inertia reel contained within the seat back. When the seat is not occupied, the belt retracts out of the way. The inertia reel allows comfortable normal forward movements of the head and shoulders, locking up and restraining the upper torso only in a deceleration exceeding approximately 2-3 G. When seated the belt is donned by buckling the lap belt and then bringing the upper torso belt down to attach (Fig. 51) at the center. In this respect it differs from the automotive 3-point belt, which generally attaches to the side. Additional protection from side (and head) impact is provided by deep side contours. This system (Fig. 52) is very similar to the integrated restraint system developed by Robbins et al. [1971 (784)] for NHTSA, at the University of Michigan (Fig. 53), except that in the latter system the upper torso connects to the lap belt at the side.

Fig. 50. Integrated seat utilized operationally in Chrysler Corporation's Grumman Gulfstream G-2 jet corporate aircraft.

Fig. 51. The upper torso belt is attached to an inertial reel, allowing freedom of motion, but restraint in +2G deceleration.

Fig. 52. In this configuration the belt buckles at the center. This seat is also capable of rotating 180° and can be used in a rearward-facing orientation.

Fig. 53. Integrated restraint system designed and developed by HSRI, The University of Michigan on NHTSA advanced concepts contract (Robbins et al., 1971).

4.5.2 Y-Yoke Inertia Reel System. The Y-yoke harness with inertia reel is not a new system, but represents a distinct variation of an aircraft torso harness and inertia reel system in that the torso harness is independent of the seat back. As shown in Fig. 54, the reel is attached overhead, rather than to the seat, thereby avoiding any downward force on the shoulders (which may contribute to the submarining action), and direct loading to the top of the seat back (high C.G.). This system also differs in that the left and right shoulder belts come together as a yoke ("inverted-Y") behind the head, continuing upward to the reel as a single belt. The 1957 work by Barecki of the American Seating Company was probably the first design of this type of system (790). In 1958, several tests of this device were conducted by Col. Stapp at Holloman AFB, using cars which were towed and snubbed to a stop (790). In three tests, human volunteers with head positioned forward (pre-flexion) were exposed to 18 (average) G on the chest (26 peak G). In more recent tests Snyder et al. (791) exposed baboon subjects on the Daisy track at Holloman AFB, New

Mexico to three tests in the forward-facing ($-G_x$) 0-0-0 body orientation at 30, 43, and 49 G peaks, and one lateral 90° test ($-G_y$) 0-90-0 at 32 peak G. Entrance velocities ranged from 22.4 to 28.8 m/sec (73.6 to 94.4 ft/sec), onset rates from 2,700 to 6,100 G/sec, and time plateaus from 0.045 to 0.060 second. Based upon relative comparisons with over 60 tests in identical deceleration patterns with similar subjects, it was concluded that this system offered better restraint than the lap belt alone, or the single upper torso restraint (3-point) system.

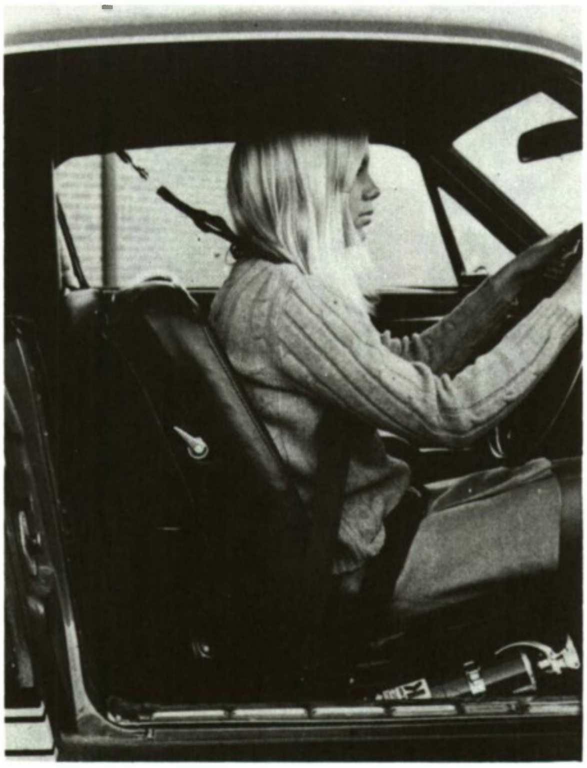


Fig. 54. Inverted Y-yoke harness system with inertia reel mounted in roll-bar, as used in specially modified Shelby American Ford G7-350 and GT-500 vehicles.

The inverted Y-yoke harness with inertia reel was tested in an integrated bucket seat concept, developed and impact tested for the National Highway Traffic Safety Administration by Robbins et al. [1971 (784)] at Highway Safety Research Institute, the University of Michigan. Fig. 55 illustrates the framework design of the prototype seat. This concept featured a bucket seat with side protection and was considered the most promising active system of those concepts considered, which included an airbag system.

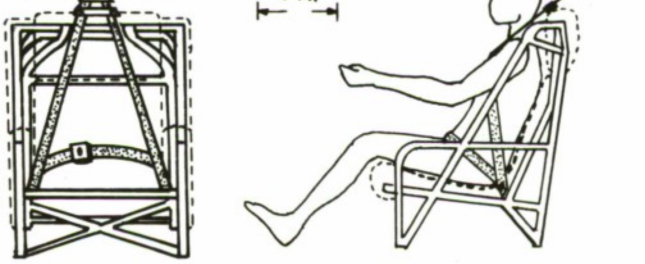


Fig. 55. Prototype inverted-Y integrated 40 G seat designed and impact tested for NHTSA by HSRI, The University of Michigan [Robbins et al., 1971 (784)].

The A-frame side structures are designed to withstand 40 G crash impacts from any direction with the added loading of a 95th percentile male occupant (97.5 kg [215 lb]). (Present FAR requirements for static tests are 77.1 kg [170 lb] dummies, with no requirement for dynamic testing.) Attached to the framework is 22-gauge sheet steel, designed to deform and absorb energy during impact. A 5.1 cm (2 in) layer of HD300 styrofoam covers the seat back, headrest, seat cushion, and inside of the side structures. This material is crushable under a load of about 10.5 kg/sq cm (150 psi). The prototype seat weighs 31.8 kg (70 lb), 10.4 kg (23 lb) heavier than current automotive production bucket seats, but this could be reduced. A series of fifteen impact sled tests were conducted at HSRI, the University of Michigan.

The inverted Y-yoke double torso restraint with inertia reel was installed in (1966-1969) specially modified Shelby Mustang GT 350 and GT 500 cars, after development and tests by Ford Motor Company. Modifications have also been used in racing cars and by Ohio State University in their fleet of Piper Cherokee 140 training aircraft. Performance in known crashes has been found to be unusually effective, with no injuries yet known to anyone wearing this system. Crashes included 3 automotive collisions exceeding 112.7 km/h (70 mph), and 2 aircraft, one which impacted at 144.8 km/h (90 mph), and subsequently impacted in an inverted orientation. This system could be used in an integrated seat such as the NASA Ames system, but since it is most effective with a higher roll-bar or ceiling mounting, probably would not be the best system for airline seats. One advantage is that it is easy to don; it slips over the shoulders and the two torso straps extend to the side rather than under the arms as in other double belt systems. This is more comfortable for females and more acceptable for dressy clothes as it does not wrinkle clothing as other belt systems may. In addition, the Y-yoke has acted as a head restraint in several accidents, although it has not been tested for that aspect.

4.5.3 Seating Energy Absorbing Devices. About 90 percent of all airline passenger seats are currently manufactured by four major manufacturers: Aerotherm Transportation Equipment Division of the Universal Oil Products Co., Bantam, Conn.; Fairchild-Hiller's Burns Aero Seat Co., Burbank, California; Dayco Corporation's Hardman Tool and Engineering Co., Los Angeles; and Weber Aircraft Division of Walter Kidde and Co., Inc., Burbank. The trend is toward lighter models of seats, which presently range from about 19.5 kg (43 lb) to 35.4 kg (78 lb) each. For future aircraft lighter seats could increase range or payload by several tons per airplane. Many of these seats are now designed to some extent for controlled structural deformation as a means of energy absorption which helps protect the occupant during an impact. In these, the front legs collapse as load is applied. Energy could be absorbed in various deceleration devices built into the seat system. While seats, energy absorbers, and hardware may seem peripheral to the scope of this paper, the seat is often an integral part of the restraint and several components will be briefly noted. Such devices absorb part of the energy of impact by allowing controlled forward displacement of the seat when subjected to load.

Early work was done by Pinkel and Rosenberg (759), and Hart (797) which showed the potential effectiveness of these devices. The "piccolo tube" decelerator is a linear hydraulic energy absorber which dissipates energy by the displacement of water through multiple, sharp-edged orifices in the tube wall. By varying the orifice hole sizes along the length of the tube, a constant pressure, and thus a constant retarding force, can be achieved throughout the arresting stroke. Another energy absorber is the stainless steel strap decelerator which absorbs energy in straining the material. The lengths depend upon the magnitude of deceleration and pulse time duration desired. The Kroell or invert tube (799) absorbs energy simply by turning a thin-walled ductile metal tube inside out. Another system, the load-limiting (allover) type of energy absorber, is based upon extrusions of wire-bending devices. These are recommended for cargo restraints [Russo, 1966 (802)] and take three major configurations. The two-spool, single-platen unit has two spools attached to one end of the platen, one of which stores all wires woven through the top side of the end hole in the platen, while the bottom spool stores wires woven out of the bottom side of the same hole. A variation of this is the two-spool, double-platen unit, utilizing two platens functioning as a single unit. A third type involves wires stored like a ball of twine in a canister. Another form of load limiter uses the shock-tube controlled collapse principle of some airline seats. Because of dissatisfaction with the performance of stainless steel straps, mechanical springs, and hydraulic energy absorber units, a unique energy absorption system was devised for the rear supporting legs of the Aerotherm passenger seats for air transport aircraft (20.4 kg [45 lb] double, 26.8 kg [59 lb] triple). The sheet metal seats deform, instead of fracturing as an extrusion or tube might, and the rear legs extend when a 9 G load is exceeded. This extension is produced by metal deformation functioning as the energy absorber, allowing the seat to pivot forward. Such a design can take a load of 30 G for 0.04 sec, or 20 G for 0.065 sec., allowing the seat and tie-downs to remain more intact in an impact.

An earlier Aerotherm concept called the Bennett Hammock-Type Aircraft Seat consisted of two large springs, between which the seat was suspended freely, designed to absorb the shock of turbulence. The passenger's seat position is controlled by his shift of weight, since his C.G. would always be below the hammock's pivot point (794). Other types, designed for cargo, but possible for seat packaging as well, would utilize a net system--a net attached to load limiters (attenuators), or an inextensible net attached to load limiters (793). One problem with shock-absorbing or energy-absorbing devices is that they are usually one-shot devices. Thus in cases of multiple deceleration peaks, no protection may be offered in the second jolt and the occupant may also be in a disadvantageous forward tilt at second impact.

Several types of energy absorbers for restraint or seating systems, acting as mechanical load limiting devices which attenuate the impact by yielding or tearing of metal, have been tested recently on an impact sled simulating a crash deceleration using anthropomorphic dummies and cadaver subjects [Bergeman and King, 1975 (795)]. These devices included the frangible metal tube [McGhee, 1962 (801)], Kroell's inverting tube (799), NASA's curling or folding tube devices (803), and a tearing strip absorber designed by the University of Denver. These are constant load-deflection absorbers, or load-limiting devices which begin to collapse when the limit is reached. It was found by Bergeman and King in tests conducted at Wayne State University, that if the absorber collapses 25.4 cm (10 in) or more, a substantial reduction in belt loads and occupant head acceleration occurs. Since there was a hazard in the fixed load energy absorber bottoming out, a solution proposed was to use a variable load energy absorber, and the steel curling type absorber was found to perform most reliably.

One high energy absorption system called TOR-SHOKS has been developed for the crashworthy armored helicopter seat by Aerospace Research Associates, West Covina, California for the U.S. Army and Navy Aviation Research and Development Service (800). Each seat utilizes a system of six TOR-SHOK energy absorbers. Each consists of a single layer coil of wire captured in the annular space between two cylinders. The radial clearance between the concentric cylinders is diminished and toleranced so that the wire is squeezed to create the necessary friction force to roll when the two cylinders are loaded with opposing forces. This stroking of the seat bucket allows it to move on any of three axes. In a Bell Iroquois UH-1 crash test, a 48 G force vertical impact at a velocity of 15.2 m/sec (50 ft/sec) was reduced to 20 G on the test seat (800). A major study by Desjardins and Singley (796) reviewed the U.S. Army's crashworthy helicopter seat program, and outlined various alternative energy absorbing devices to attain a limit load factor of 14.5 $+G_z$. One conclusion was that cushions should be designed as shock attenuators using rate sensitive foams. While the seating needs of military helicopter crew are different in many respects from those of the air carrier passenger, much of the current state-of-the-art research in seating is being conducted in this area and should provide some transfer of technology.

4.6 Passive Restraint Systems

Passive restraint systems are defined as systems which require no action on the part of the occupant to activate. Passive systems thus are completely automatic, and while such systems are commonly identified with inflatable restraints (air bag or air cushion), net "blanket," or webbing systems may also be automatically activated during an impact sequence. There have been a number of studies of passive restraint systems. Phillips [1973 (804, 805)] conducted a patent and literature search covering the period 1967-1972, which resulted in identification of 35 applicable concepts, to which additional concepts have been added in Table XVIII. Some 65 versions of passive restraints, excluding air bag concepts, are tabulated as follows:

TABLE XVIII.

PASSIVE RESTRAINT SYSTEM CONCEPTS (EXCLUDING AIR BAGS)

Protective Devices with Subclass	Reference
I. Passive Belt Systems	
1. Rigid bar of Rothschild	Patent No. 3,637,259 28 Jan 72 (804)
2. British auto restraint	Docket 69-7 Data, 1971
3. Inertial switch system	A.M. Brown, 1972 (804)
4. Swinging door bar	Patent No. 3,583,726 8 Jan 71 (804)
5. Volvo systems	
6. Eight configurations	Pilhall & Bohlin, 1972 (811)
7. Small American compact	Johannessen & Yates, 1972 (810)
8. American safety - Gremlin	Bradford et al., 1972 (807)
9. American safety - belt puller attached overhead	Bradford et al., 1972 (807)
10. American safety - belt puller attached in seat	Bradford et al., 1972 (807)
11. American safety - door slide/roof slide	Bradford et al., 1972 (807)
12. Takata - Sliding arm	Docket 69-7 Data, 1971
13. Takata - Moving buckle	Docket 69-7 Data, 1971
14. Takata - Slide rail	Docket 69-7 Data, 1971
15. Takata - Flexible arm	Docket 69-7 Data, 1971
16. Vehicle safety belt rigging	Patent No. 3,506,083 14 Apr 70 (804)
17. Volkswagen ESV	Smith et al., 1972
18. Volkswagen automatic (VW-RA)	Seiffert et al., 1974 (814, 815)
19. Ford full passive belt	Hellriegel & Rauthman, 1974 (809)
20. 12 automatic belt systems/Post Office vehicles	Powell, 1968 (812); Snyder, 1969 (785)
II. Passive Net Restraint	
1. Nissan	Maki et al., 1970 (819)
2. Permanent installation	Patent No. 3,525,535 25 Aug 70 (804)
3. Hamill net restraint	
III. Inflatable Belt Systems	
1. Self-fastening inflatable	Patent No. 3,414,326 3 Dec 68 (804)
2. Allied Inflataband	Allied Data, 1972
3. Tendon supported inflatable	Docket 69-7 Data, 1972
4. Minicars airbelt	1975
IV. Transparent Shields	
1. "U" inverted over occupant	Patent No. 3,663,037 16 May 72 (804)
2. Permanently installed shield	Patent No. 3,643,972 22 Feb 72 (804)
3. Inertia switch shield	Docket 69-7 Data, 1972
4. Transparent static air bag shield	Sobkow & Grenier, 1968
V. Blankets	
1. Firestone "Security Blanket"	Johannessen & Yates, 1972 (810)
2. Flexible blanket	Patent No. 3,633,936 11 Jan 72 (804)
VI. Cushions	
1. Static airbag	Patent No. 3,614,128 19 Oct 71 (Sobkow)
2. Super-cushion	Chrysler Reports, 1971 (804)
3. Nucon Incorporated	Nucon Data-Patent Pending, 1971 (804)
4. Compartmentalized air bags	Patent No. 3,614,129 19 Oct 71 (Sobkow)

TABLE XVIII - Continued

Protective Devices with Subclass	Reference
VII. Arms and Barriers	
1. Floating arm	SAE Paper No. 720439 May 1972
2. Fixed arm-barrier cushion	Patent No. 3,524,678 18 Aug 70 (804)
3. Overhead arm	Patent No. 3,640,572 16 Dec 69 (804)
4. Complex barrier cushion	Patent No. 3,545,789 8 Dec 70 (804)
5. Automatic crash pad	Patent No. 3,630,542 28 Dec 71 (804)
6. Winged bar	Patent No. 3,441,103 17 Jul 67 (804)
7. Roller-tape arm	Friedman et al., 1972
8. Inflatable arms	Docket 69-7 Data, 1972
VIII. Static/Capsule Passive Restraint	
1. Seating capsule	Snyder, 1968 (1969) (836)
2. Ford capsule	Egglestone & Suthurst, 1974 (835)
IX. Deployable Head Restraints	
1. B.F. Goodrich prototype	Hilyard et al., 1973 (838)
2. Goodyear airmat prototype	Hilyard et al., 1973 (838)
3. HSRI/Uniroyal prototype	Hilyard et al., 1973 (838)
X. Integrated Seat Design	
1. Integral arms about torso	Patent No. 3,623,768 30 Nov 71 (804)
2. Protect-o-matic	Docket 69-7 Data, 1972
3. Life-net seat	Patent No. 3,591,232 6 Jul 71 (804)
4. Barrier seat	Patent No. 3,556,585 19 Jan 71 (804)
5. Safety seat	Patent No. 3,409,326 5 Nov 68 (804)
6. HSRI Bucket seat with airbag torso restraints	Robbins et al., 1971 (784)
7. HSRI Bucket seat with Y-yoke restraint	Robbins et al., 1971 (784)
8. HSRI Bucket seat with automatic 3-point	Robbins et al., 1971 (784)
9. HSRI Triple bucket/bench modules	Robbins et al., 1971 (784)
10. Ford Techna	Snyder, 1969 (836)
11. Pontiac cockpit	General Motors Corporation, 1969
12. Peugeot deployable wall (panel)	Tarriere et al., 1974 (921)
13. Peugeot deployable wall (seat)	Tarriere et al., 1974 (921)
14. Peugeot deployable wall (seat/cylinder)	Tarriere et al., 1974 (921)

Sources: Phillips, 1973 (804, 805) and Snyder, 1976

Undoubtedly there are many more variations or concepts which are proprietary or advanced design concepts and have not been published. The mass of literature relative to restraint systems is considerable, with the author estimating between 5,000 and 6,000 publications in his personal files alone. In this monograph no attempt will be made to describe each system in detail; rather, general categories as tabulated in Table XVIII and specific devices or concepts believed most relevant to aircraft application will be briefly considered.

4.6.1 Passive Belt Systems. Various automotive manufacturers and suppliers have developed and tested automatic belt restraint systems which would conform to the characteristics which would be required by proposed Federal Motor Vehicle Safety Standards (FMVSS) for passive restraints in automotive vehicles manufactured for sale in the U.S. in 1977 (782). Such systems have been proposed as an alternative to inflatable (air bag) systems, and, for automobiles at least, offer the advantage of proven occupant protection by means of a lap belt and upper torso belt, together with an "automatic" means of donning the system. Most of the systems developed to date have similarities. One significant difference is between geometries of a belt with two attachment points on the door side and one at the middle of the car (standard arrangement), and a belt configuration with one point on the door side and two at the middle of the car (reversed belt). Most manufacturers and many suppliers have conducted research on the passive belt system, with most recent publications including work by AB Volvo (811), Hamill Division of Firestone Tire and Rubber Company (810), American Safety Equipment Corporation (807), Ford-werke AG Cologne (809), and Takata Kojyo Co., Ltd. (817).

One of the most successful of these is the system developed by researchers at Volkswagen called the "VW Restraint Automatic (VW-RA)" (813-815). The major components of the Volkswagen system consist of a diagonal upper torso belt, belt retractor, an energy absorbing knee bolster, and an emergency release. This system developed from Volkswagen's Experimental Safety Vehicle (ESV) Program at Volkswagenwerk AG, Germany, and was reported in detail in 1974 by Seiffert et al. (815).

The components of this system are shown in Fig. 56. The upper torso belt is attached at one end to a release latch which is mounted on the door. The other end of the belt is wound around the retractor spool on the central tunnel (between the seats). The D-ring, which is mounted on the seat, guides the webbing from the retractor around the seat back, and assures that the lower anchor point does not change relative to the occupant. The retractor automatically takes up any slack webbing and maintains "gentle" tension on the belt. The retractor locks, for automotive application, at a vehicle acceleration of 0.45 G.

The upper end of the torso restraint is anchored by a tongue in the emergency release hatch. When the door is closed, the belt latch engages an anchor plate which is bolted to the normal torso belt anchor point of the B-pillar. This allows the belt forces during a crash to be transmitted to the anchor point rather than to the door itself. The knee restraint is a sheet metal frame covered with energy dissipating foam and is attached below the instrument panel. There is also an emergency release to allow separation of the belt from the door anchor in case the retractor remains locked after a crash. In this system the belt automatically is positioned on the occupant (right and left front seats) when he or she opens the door, seats himself, and closes the door. No lap belt is used with this system, only the single upper torso diagonal belt, and knee cushion. The elimination of the lap belt requirement was approved by the National Highway Traffic Safety Administration in Federal Register 39 (81) 14594, April 25, 1974 as a result of a letter by Volkswagen of 8 March, 1974 requesting clarification of 57.2(b) of FMVSS 208. This system is currently standard equipment on 1975 and 1976 Volkswagen automotive vehicles.

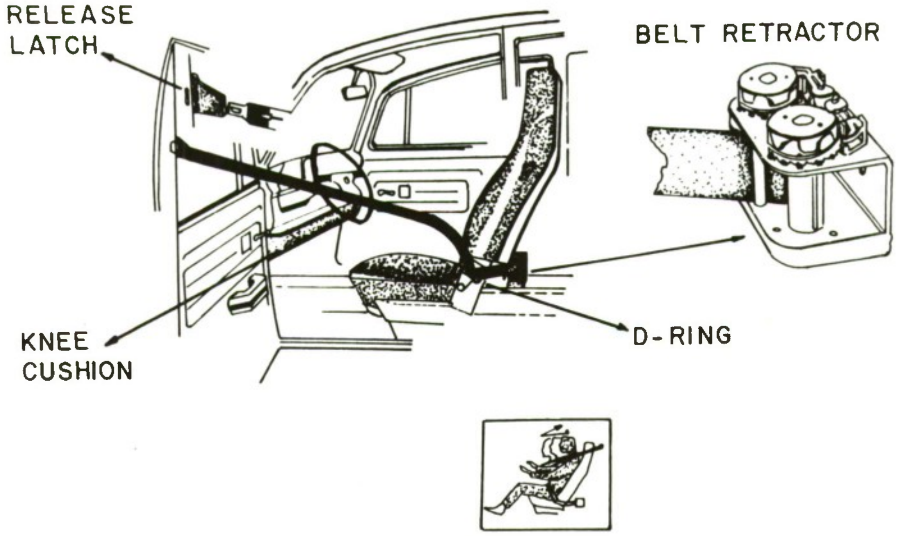


Fig. 56. VW Automatic Restraint (VW-RA) passive system as developed for automotive vehicles [Redrawn after Seiffert et al., 1974 (815)].

This system, as exemplified by the VW-RA, is one method of getting the occupant to wear a restraint without any action on his part. However, such a system would obviously present serious problems of donning for present airline passenger seat configurations. Further, previous tests of restraint system effectiveness conducted at Holloman Air Force Base [Snyder et al., 1967 (708)] have indicated that a single upper diagonal torso harness, without lap belt, allowed the subject to rotate out of the seat with fatal injuries in the tests conducted. In the confined space of the Volkswagen vehicle the upper diagonal belt may be sufficient, but in other environments, such as large American cars or aircraft, such a system could present hazardous restraint without the addition of lap belts.

Ford Motor Company of Germany (Ford-werke AG, Cologne) at the 1974 5th ESV Conference in London, proposed a "full passive safety belt system" using the same general principle as Volkswagen, but with some interesting refinements [Hellriegel and Rauthmann, 1974 (809)]. As shown in Fig. 57, this system features a "self-applying" three-point harness (lap belt plus single upper torso diagonal belt) with anchorage to the seat-frame structure and seat-back frame in the area of the headrest and door sill. An inertia reel (Ford Pyro-Reel), which combines functions as a webbing-retractor and load limiting inertia reel, is located on the outboard upper seat.

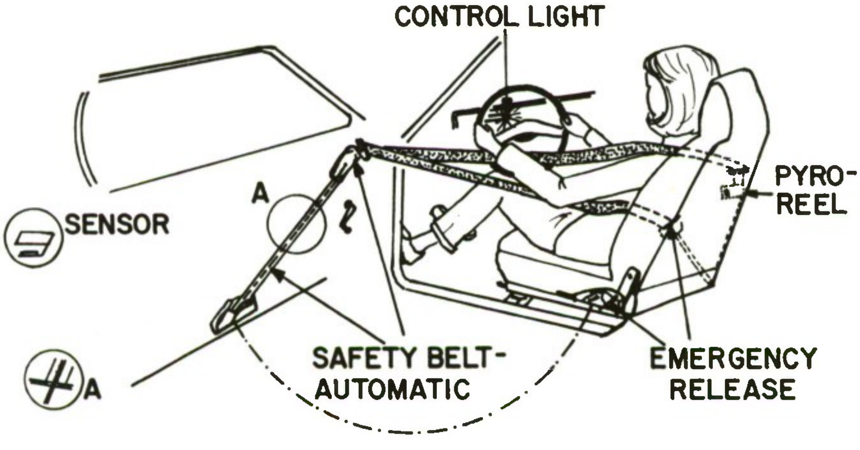


Fig. 57. Schematic of a "full passive safety belt system" designed by Ford-werke AG, Cologne, Germany [Redrawn after Hellriegel and Rauthmann, 1974 (809)].

The electronic system includes a sensor, seat-contact switch, ignition interlock (required under U.S. FMVSS at that time, but since rescinded by Congress), and non-function alert control. The belt transport system located in the door operates automatically, and the belt has an emergency release at the door sill and seat frame.

The electronic impact sensor identifies impact by G level and time duration and, by closing the electric circuit, activates a propellant charge within the Pyro-Reel. Expanding gas in the Pyro-Reel causes the belt webbing to wind up by about 150 mm (6 in), so that the seated occupant is fully tightened by his restraint at 18 ms after impact. This system has been tested in 48km/h (30mph) barrier impacts with a 1974 Capri, resulting in maximum dummy head acceleration of 31 G.

Earlier work had been directed at solving the unique restraint problems provided by U.S. Post Office Department postmen who may operate either a 1/2 ton right-hand drive vehicle, a one-ton parcel delivery vehicle, or a 1/4 ton three-wheel cycle vehicle, and in some combinations must be able to drive from either a standing or seated position. All-American Engineering Company of Wilmington, Delaware completed a study for the Post Office Department which included over a dozen unique designs for automatic restraint activation by post office drivers [Powell, 1968 (812); Snyder, 1969 (785)].

In the sit or stand hinged-arm restraint designed for a 1/2 ton right-hand drive vehicle, the system is activated when the driver gets into the seat, or stands in position and pulls the restraint bar down in a single action. This automatically positions a Y-belt joined at the mid-chest in a yoke, which is attached over the left seat back by an inertia-locking reel. In a second concept, a ring gate/shoulder harness device considered for one ton parcel delivery trucks, the one-handed operation positions both the circular lap restraint and a diagonal shoulder harness attached to an inertia reel. A third concept utilizes a swing arm/full harness type of restraint for use in a 1/4 ton three wheeler. The system can be positioned or removed easily and is stored by overhead bands, allowing it to swing easily into position. A fourth concept features a lap plus diagonal restraint which swings into position from a single point attachment to the steering column. Other advanced techniques investigated to solve these unique restraint problems included automatic magnetic restraint locks built into clothing.

None of these concepts or devices, however, would appear directly appropriate to requirements for air transport passenger application.

4.6.2 Passive Net Systems. Although the preponderance of research and development in passive or automatic restraint systems has been concerned with variations of its inflatable (air bag) system, several alternative passive systems have been designed and tested. Both Nissan Motor Company, Ltd. [Maki et al., 1970 (819)] and Hamill Manufacturing Company have proposed passive net restraint systems for automobile occupant protection. General Motors has also conducted work in this area but published data are not known to be available. Deployable nets have both advantages and disadvantages when compared with air bags. It should also be noted that both types of systems require the use of a crash sensor. The Nissan system is called "automatic falling occupant-protecting net." Operation is in the following sequence:

(1) A G-sensor is actuated by the shock of collision. In tests this setting was established as 8 G and in case the impact is a half sine pulse and the peak value is above 20 G, the time delay between the onset of the jolt and the initiation of the G sensor is 9-10 msec.
(2) An SCR (silicon controlled rectifier, 2SF124) control circuit is activated, supplying electric current to solenoids of triggers. The SCR is used to supply a current of approximately 150 amps to the solenoid of the trigger continuously.
(3) Plungers of solenoids act to release the spring lock. The triggering device consists of four triggers, two for the front net and two for the rear net in the automobile. An electric current of 30 to 40 amps sent to the solenoid releases the spring locks, the force of the spring pulls the rope, and the net is stretched.

A schematic of the Nissan system is shown in Fig. 58.

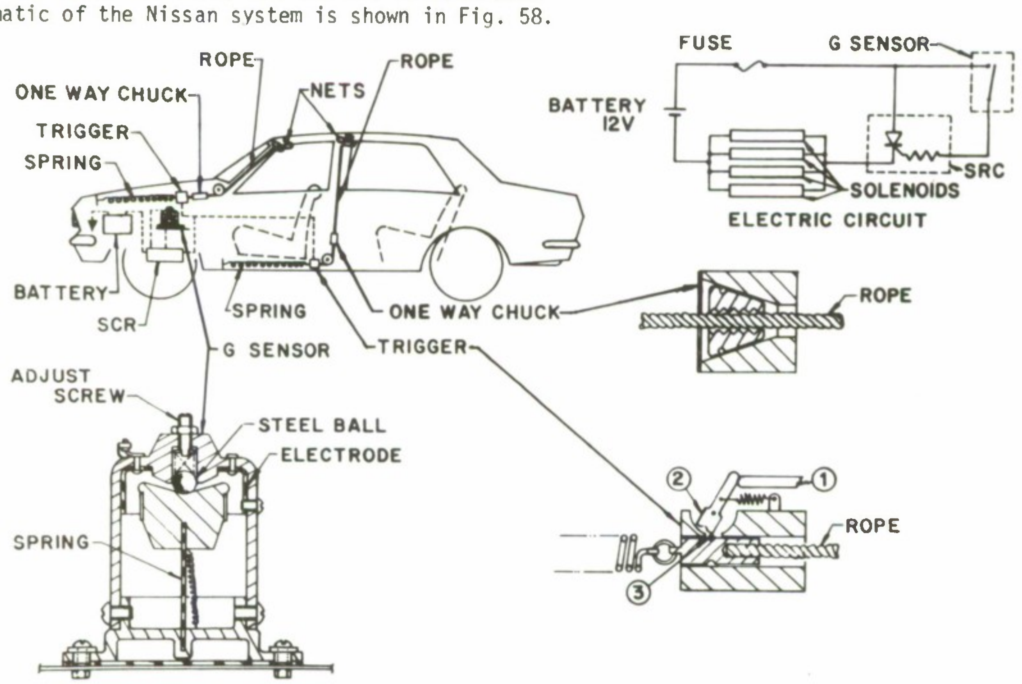


Fig. 58. Schematic composite diagram of Nissan automatic falling occupant-protecting net as developed for automotive use [Redrawn after Maki et al., 1970 (819)].

The nets tested were about 47 cm (18.5 in) wide and 105 cm (41 in) long (front seat), and 45 by 105 cm (17.5 by 41 in) for the rear seat of automobiles. Each upper end of the net is attached to the roof structure and the lower ends are tensioned by the nylon rope. The rope extends from the spring to the lower end of the net, has a breaking strength of 700 kg (1,543 lb), and is made of 3 nylon strands of .9 cm (.4 in) total diameter.

In tests the net was reported to have remained intact when subjected to a 2000 kg (4,410 lb) force from two dummies. The fall time of the net was 33-49 msec (which compares to approximately 40 msec for the air bag inflation time). Barrier crash tests have been conducted to 52 km/h (32 mph), with a maximum car acceleration of 84 G, with a net fall time of 37 msec. A number of different netting materials and configurations have been tested.

Net material is highly suitable as a restraint material. It is light in weight, can be fabricated with excellent shock energy absorption properties and is sufficiently strong. In the automotive application the net has been folded inside the header and in the center of the ceiling and covered with vinyl.

Configurations have been tested involving both front and rear seat automobile occupants as well as the driver. Gross body motions were observed to be arrested but certain biomechanical details will require further studies. One of these is the localized loading of the mesh on the skin of the occupant. Mesh size appears to be an important variable in system design. Another problem is the observation of whiplash as occupant motion is arrested. It appears that a net must be designed with mechanical properties which vary with the impinging occupant body segment. For instance, the head should be allowed to penetrate the net to a greater extent than the chest at a lower load.

The "automatic falling occupant-protecting net" restraint system does not have problems with noise or pressure, as in the air bag, and it is a simple mechanism. Following solution of the biomechanical problems, this system should be at least as competitive as air bags for application in jet transport aircraft. However, it has the same problem as air bags in initial sensor crash impact detection. Maki et al., 1970 (819) should be referred to for the most detailed test data published to date. As of March, 1976, no further advances of large-scale testing have been published.

4.6.3 Inflatable Belt Systems. Another alternative system to the "air bag" passive restraint system has been developed by Allied Chemical Co. (820). The Allied Chemical Inflataband™ consists of an inflatable three-point harness system with both lap belt and upper torso diagonal belt. The system is comprised of four major assemblies consisting of the inflator, the buckle, the tongue and manifold, and the band (including both lap and upper torso portions).

Inflation is provided by a pressurized gas cylinder housing two electroexplosive devices. When an impact condition is detected by the sensor, an electrical signal is generated which activates the squibs. The activation of the squibs creates sufficient overpressure of the stored argon gas in the inflator to rupture a disk, which permits gas to flow through the ports in the buckle assembly and into the lap and shoulder segments. At full inflation the shoulder and lap band segments are reported to be approximately 45.5 cm (18 in) in circumference. Fig. 59 shows the Inflataband components.

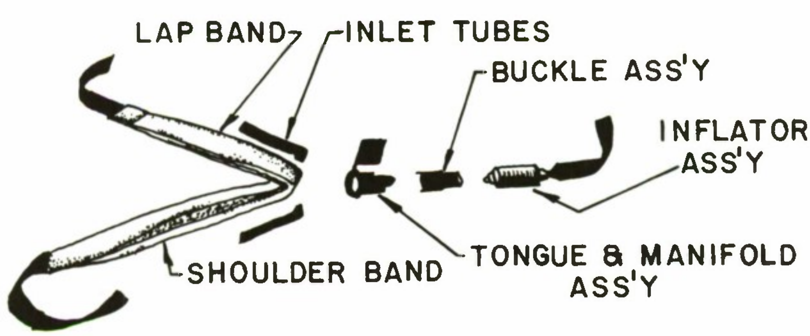


Fig. 59. Exploded view of Inflataband™ components [Redrawn after Burkes et al., 1975 (820)].

This system combines the best features of the standard belt restraint system with the additional protection of the inflatable system (Figs. 60 and 61), except that while the system is automatically activated, it is not a passive system from the viewpoint that the wearer has to take action to don it. Once donned it then functions as an automatic system. One advantage is that should the inflation system fail, protection is still afforded by the locking standard restraint function.

This system could be more easily adapted for aircraft use than other advanced systems presented. However, it still presents a question as to what impact levels should initiate the sensor, for both crash impact and inflight turbulence conditions. Other questions might relate to potential hazards from explosion of overpressure of the argon gas during post-crash fire, and potential toxic hazards. Nevertheless, 39 dynamic sled tests utilizing human volunteer subjects recently conducted by Burkes et al. [1975 (820)] at Southwest Research Institute with prototype Inflataband restraints demonstrated promising occupant protection. System activation occurred at 18 to 20 msec post-impact. Impact loads were effectively distributed over the chest and lower abdomen and severity indicators were below injury tolerances. In these tests three subjects reported stiff or sore necks, but these symptoms were transient.

Fig. 60. The inactive system is donned as a regular active restraint system (Photo courtesy Automotive News).

Fig. 61. Upon initiation, the Inflataband™ system inflates, providing additional passive protection to the occupant (Photo courtesy Automotive News).

Under contract to the Department of Transportation, National Highway Traffic Safety Administration, researchers at Minicars, Galeta, California, have designed and tested an airbelt restraint system for the subcompact automotive vehicle which reportedly is capable of protecting the restrained occupant in frontal and frontal oblique crashes up to 80.5 km/h (50 mph). This system was intended to "retain the positive features of a belt system, such as its rollover protection, lower cost (as compared to air bags), and mass production features..." [Fitzpatrick and Egbert, 1975 (821)].

The airbelt restraint system is primarily a two-point or three-point belt restraint modified to inflate upon impact, and anchor points modified to provide a controlled yielding in the system. Inflation of the belt is advantageous in substantially increasing the belt contact area thereby distributing the load over greater body surface area, preventing substantial forward head movement, and automatically taking all belt slack out of the system. A three-point belt system was found to be superior to the two-point diagonal torso belt as the latter allowed rotation "almost completely out of the restraint" (p.3-3). The energy-absorbing belt anchors (force limiters) are designed to attenuate the G levels transmitted to the passenger. This system is schematically illustrated in Fig. 62.

At this time additional testing is needed to verify performance of the inflator in a variety of environmental conditions, to assess the statistical probability of reproducible performance, to determine shelf life, and to design a new lightweight, less expensive, non-reloadable inflator case.

The "air bag" portion of the system is a section 76 cm (30 in) long by 20 cm (8 in) in diameter, constructed of two layers of nylon material, which inflates. Along two sides of the inflated cylinder are longitudinal strips of conventional seat belt webbing, which join together as a double layer to form the lap belt and connecting webbing to the upper force limiter and belt anchor.

A 1.6 cm (5/8 in) diameter vent, located in the air bag portion attenuates rebound by dissipating a portion of the stored compressive energy in the gas. A diffuser is attached to the inflator inside the bag, and is designed to distribute the gas to various areas of the bag in order to prevent a local hot gas jet from burning a hole in the bag. The diffuser is constructed of radiator hose, 4.4 cm (1-3/4 in) inside diameter and 42 cm (16-1/2 in) long with .9 cm (3/8 in) diameter holes punched on 5.1 cm (2 in) centers. One end of the hose fits over the inflator nozzles, while the other end is pinched with a rivet, forming two holes in the end of the tube.

A pyrotechnic, rather than a stored gas, inflator was selected. Minicars reasoned that a stored gas system is prone to gas leakage (especially at 316.6 kg/sq cm [4,500 psi]), and secondly that the combined effect of the inflator's high pressure and low volume make the flow duration of a stored gas system very short (approximately 10 msec). One result is that there is insufficient gas available to support the head

50-60 msec post-crash. On the other hand, the pyrotechnic system reaches its maximum rate of gas flow later in the event when the gas pressure in the inflator case reaches its maximum value (approximately 40 msec after squib initiation). The inflator is 10.2 cm (4 in) long and 4.4 cm (1-3/4 in) in diameter, and contains 60 grams (2 oz) of propellant.

The primary energy absorbers in the restraint system are the force limiters located at each of the three belt anchor positions. The roller diameters for the lap belt force limiters are 1.6 cm (5/8 in), while the roller diameters for the upper anchor is 1.9 cm (3/4 in). The lower outboard force limiter must react to both the force transmitted through the lower part of the torso belt as well as a portion of the lap belt load.

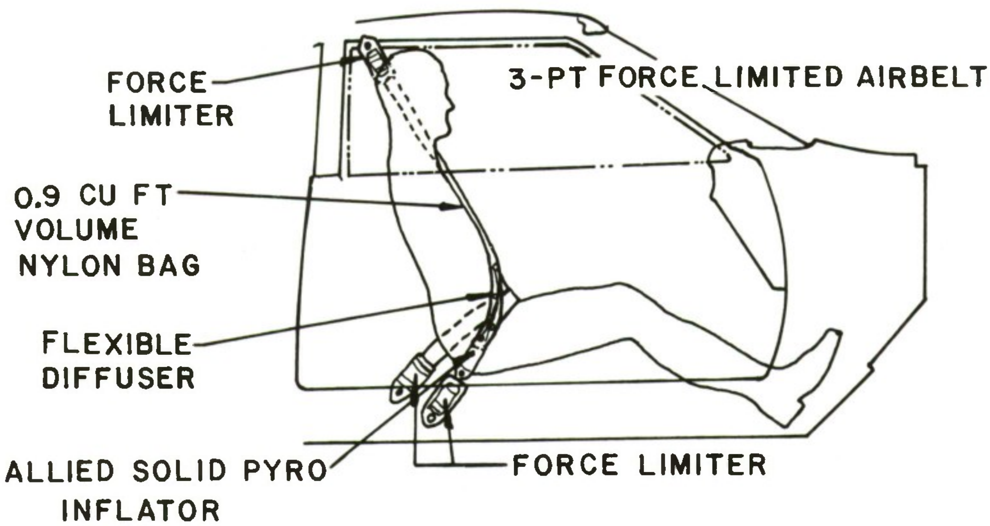


Fig. 62. Minicars Airbelt Restraint System developed under NHTSA contract [Redrawn after Fitzpatrick and Egbert, 1975 (821)].

The airbelt restraint system of Minicars as well as the Allied Chemical Inflataband offer some important advantages over conventional belt systems. But in aircraft use the total seat/restraint system must be considered, and to be of benefit, the passenger seat would have to be modified to employ upper torso anchorage. The use of upper torso restraints for air carrier passengers in forward-facing seats would increase impact protection (assuming the seat was redesigned and strengthened, as well as the anchorage strengthened). However, serious questions of passenger usage and acceptance of an upper torso harness which is not automatically donned must be considered, especially in wide body airbus configurations.

4.6.4 Transparent Shields. At least three concepts have been patented related to the idea of protecting automotive vehicle occupants through a device which surrounds the occupant or occupant compartment. A 1972 patent [Wohn-Machowski (824)] envisions an individual being protected by an inverted U-shaped flexible transparent shield, anchored to the ceiling and to the floor attachment points of the seat belt. Another concept [Calati and Lehle, 1972 (823)] consists of a permanently installed flexible transparent shield between the roof and top of the seat or instrument panel. In contrast to the first concept, this system is fully passive and does not interfere with occupant egress. A third fully passive system consists of an inertial switch flexible shield stored overhead, but pulled into position by pendulum weights by the inertial forces generated at frontal impact. This system requires no power sources for activation [Brown, 1972 (822)] and is illustrated in Fig. 63. However, none of these concepts appear too practical when considered in relation to other advanced systems and when one considers that they have not been developed or tested. The flexible shield of Wohn-Machowski, for example, could present problems in post-crash emergency escape, would be difficult to make comfortable for the wearer in hot environments due to little air circulation area, and would meet with certain occupant reluctance to be so enclosed, whether it be in an automotive vehicle or an air transport. The inertial switch concept does not take into consideration protection for any mode but frontal collision.

An interesting transparent shield restraint was conceived and developed (and a subsequent device tested) by Sobkow and Grenier in early Ford Motor Company safety concept programs. Designed for the front seat passengers in motor vehicles, this restraint device consisted of an outer skin of transparent plastic sheeting, formed by four ribs with two end pieces to maintain shape and support. It was contoured to extend down vertically from the ceiling to the passenger's lap, then forward horizontally to the glove box and was hinged at the lower part of the instrument panel. The forward sheeting extended from roof contour down the line of the windshield. The device could be deflated when not in use. It reportedly could be inflated in 20-40 seconds when the passenger initially sat in the vehicle by pressing a button which activated a small air motor which blew up the transparent bag with air. At the end of a trip it could be deflated by the same motor, through a reverse (vacuum) pump sucking the air out again. This transparent static air bag shield was designed to be forward of the passenger with only a few inches of space between the body and the rear portion of the bag. A later (non-transparent) version of this concept utilized solid foam with encapsulated air bubbles (U.S. Rubber) to replace the air, and this reportedly performed very well in dynamic tests. This later non-transparent version, when inflated, extended vertically to approximately eye level in front of the occupant, so that there was forward visibility over the top of the bag.

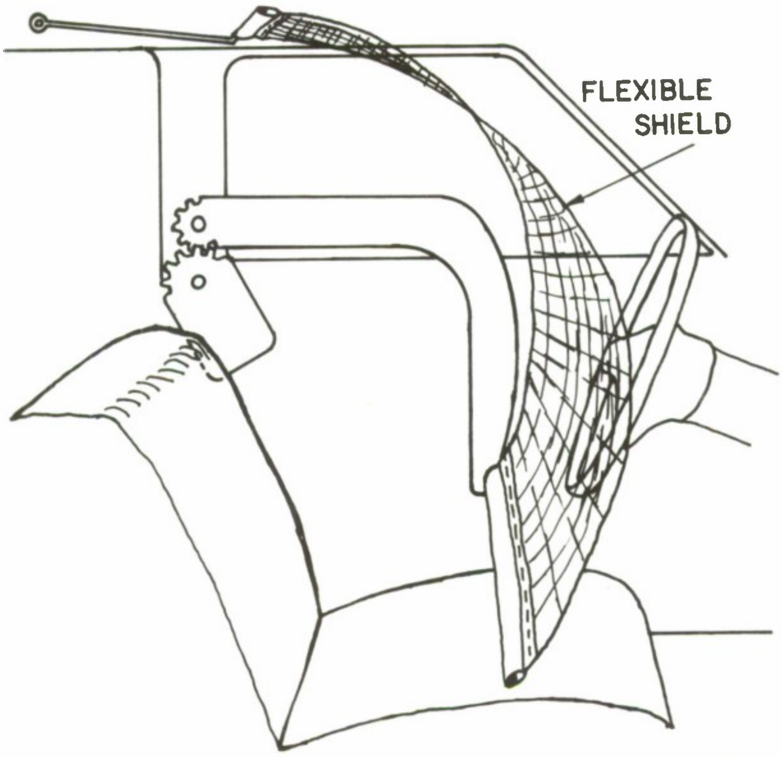


Fig. 63. Inertia switch flexible shield, stored overhead but swings into place during impact [Brown, 1972 (822)].

4.6.5 Blankets. One means of providing restraint, similar to nets or shields, is by use of an automatically activated blanket. The Firestone "Security Blanket," proposed principally as protection for motor vehicle rear seat occupants, consists of a blanket secured to a belt at the upper portion. This is automatically pulled up across the chest during an impact, keeping the occupant from being thrown forward (804, 810). In 1972 Huber was granted a patent on an automatic flexible blanket designed for the front seat vehicle occupant as well as the rear occupant (825). This device contains a support beam with the blanket to restrain the torso like a lap belt. One good feature about this category of restraint concept is that it acts to distribute the loading over a large area of the body. It has not been seriously pursued in recent years.

4.6.6 Cushions. In 1971 Sobkow at Ford Motor Company designed a static foam-filled air bag which would cushion the body in impact (826). This restraint device consists of an open-celled, resiliently deformable foam which is enclosed in an air bag at atmospheric pressure. At impact the bag is pressurized in proportion to occupant displacement, and the flow out of the bag is restricted by a valve. A variation, involving a super cushioning of the instrument panel, has been explored by Chrysler Corporation (804).

4.6.7 Arms and Barriers. Concepts using arms or barriers for occupant protection include many variations. Minicars, Inc. of Galeta, California has developed a torso restraint roller-tape mechanism that is designed to swing into place as the door is closed [Friedman, 1972 (829)]. This work was done under contract to the National Highway Traffic Safety Administration. The bar consists of a roller-tape device that is designed to provide a constant force loading on the occupant's chest during impact. Five different concepts had been explored, and one operational device constructed and subjected to 14 impact tests using a Chevrolet Nova back. Among conclusions from these tests was that stroke and rebound must be handled by substantially reducing the exit velocity from the restraint. It was believed that the occupant could be returned to his or her original seated position after impact by providing more rebound velocity in the knee restraint than in the chest restraint. Fig. 64 shows one of two energy absorbing pylon configurations listed.

Another approach, taken by Britax, Ltd., U.K., consists of a cushioned pad resting in the area of the upper torso that produces a constant force of 680 kg (1,500 lb) at the chest pad, and a knee restraint energy absorber which exerts a force of 907 kg (2,000 lb) [Grime, 1972 (831)]. As diagrammed in Fig. 65, this system is claimed to be effective in motor vehicle impacts for rollover, frontal, and side modes. A prototype has been used in a motor vehicle, and occupant response indicates there is ample freedom of shoulder and upper body movement. The major feature of the Britax automatic cushion restraint is that a pad or cushion is held in contact with, or close to, the chest of the vehicle occupant at all times. The pad can be pushed forward against light spring pressure so that the occupant is free to lean forward. At impact the arm is locked by a mechanism sensitive to vehicle deceleration. The lower part of the body is decelerated and prevented from submarining by a knee pad placed a short distance in front of the knees.

Peugeot of Paris has also developed a fixed arm barrier cushion [DeLavenne, 1970 (827)]. An overhead "vehicle safety guard" concept of Doehler [1969 (828)] was originally conceived as an active restraint, requiring the occupant to swing an arm pivoted at the top of the seat into place in front of the chest. A more complex technique was devised by Graham [1970 (830)], whose concept would utilize a number of protective shields that are stored during normal use of the vehicle and move into position when triggered by an impact. Another arm concept is the automatic crash pad of Wycech [1971 (834)], which incorporates a shock absorber pad which, when triggered by an impact, is lowered into place to protect the upper torso. The Lymar winged bar concept consists of a bar that moves from the vehicle instrument panel to restrain the lower torso [1967 (833)]. An inflatable system with flexible configuration restrains the shoulders and lower torso, as conceived by Kilronski of the Naval Underwater Systems Center [1972 (832)]. These systems, and other similar concepts, range from simply ideas to those, like the Britax automatic cushion restraint, which have been designed, developed, crash tested, and tested in operational use.

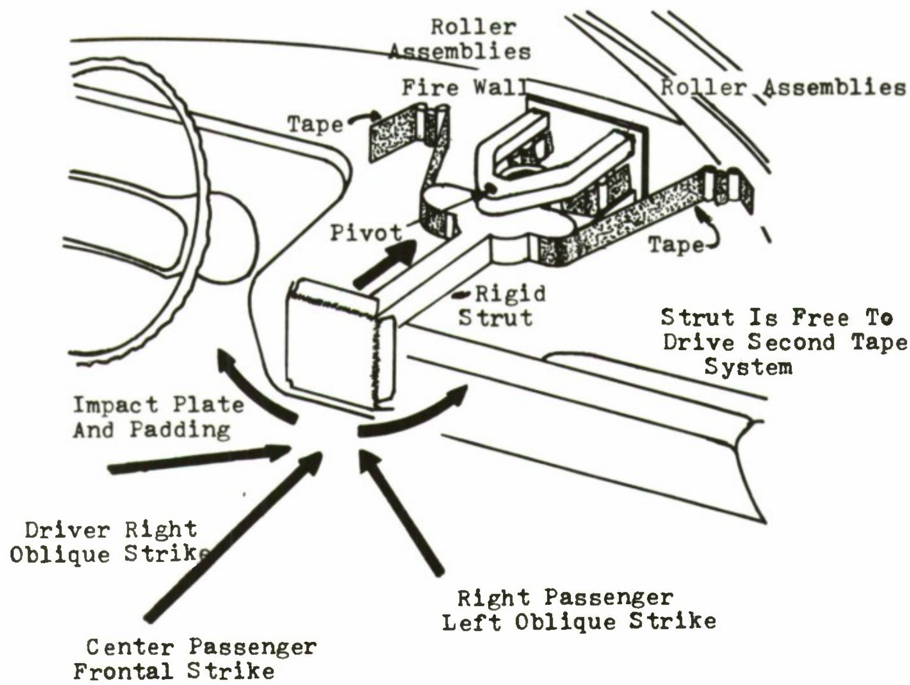


Fig. 64. Minicars Energy Absorbing Pylon Restraint configuration [Friedman et al., 1972 (829)].

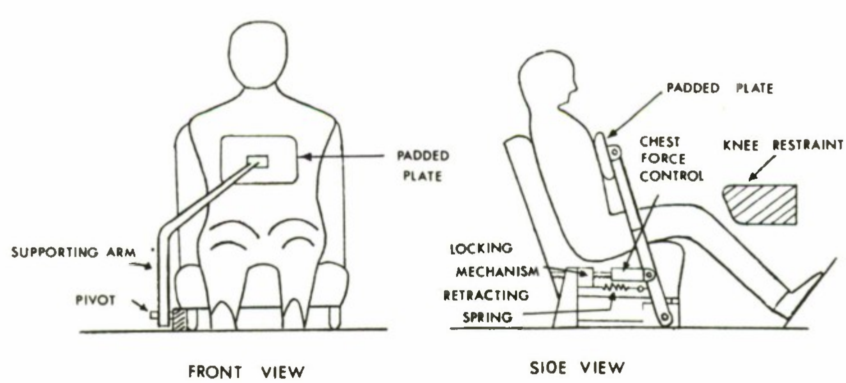


Fig. 65. Britax, Ltd. automatic cushion restraint [Grime, 1972 (831)].

4.6.8 Static/Capsule Passive Restraint. Occupant protection can also be achieved by encapsulating the environment about the seat area to provide energy absorbing contact surfaces. In a concept designed for advanced automotive vehicles, Snyder suggested a capsule system using wrist-twist steering controls, which had been extensively developed and tested by both General Motors Corporation and Ford Motor Company by 1968 [Snyder, 1969 (836)], combined with a foam energy-absorbing forward panel and deep bucket side and head protection (Fig. 66). Advanced variations of this "static passive restraint" concept have been further explored by Ford of England [Egglestone and Suthurst, 1974 (835)], as reported at the Fifth International Conference on Experimental Safety Vehicles. No belts or other body contact restraints are envisioned with such a passive capsule environment.

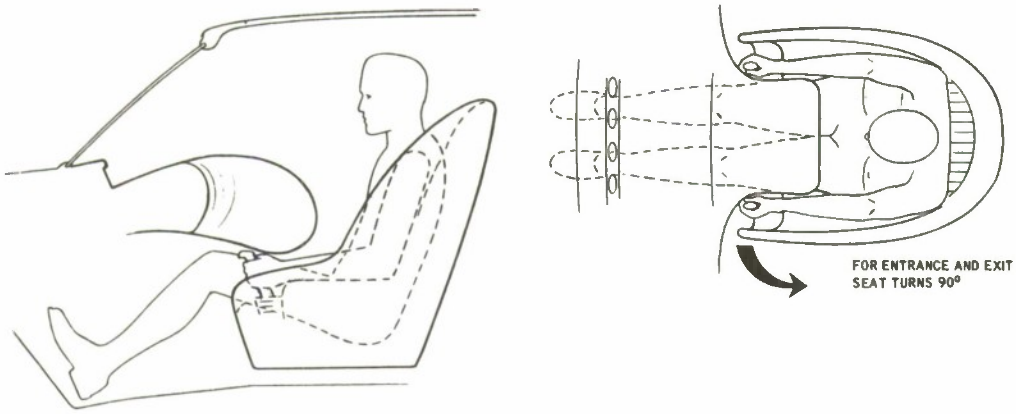


Fig. 66. Concept of seating capsule with protective energy-absorbing forward panel. Removal of steering assembly would allow use of passive restraint concept with no occupant belt system necessary. High sides of capsule offer side impact protection and head protection. Capsule could swivel to enter, or outboard section could be integrated with door [Snyder, 1969 (836)].

4.6.9 Deployable Head Restraints. Seating head restraint protection has been required in all new automotive vehicles manufactured for sale in the U.S. since 1 January, 1969. FMVSS Standard 202 relative to head restraints requires that during a half-sine acceleration pulse of 8-9.6 G amplitude and 80-96 msec duration the rearward rotation of the head relative to the torso should be limited to 45 degrees by the action of the head restraint (841). The two most common forms of head restraint presently in use in motor vehicles are: (1) a fixed extension of the seat back, providing 71 cm (28 in) height, or (2) a separate head cushion, adjustable for height, attached to the seat back. However, a number of other variations have been developed or conceived, including net, webbing, and harness restraints [Snyder, 1970 (792)]. Such systems may adversely restrict rearward visibility for some drivers and, if not properly adjusted, may not provide effective protection.

Under NHTSA Contract FH-11-7612 (1 July, 1970 - 30 June, 1971), Melvin and McElhaney at the Highway Safety Research Institute, the University of Michigan, developed and tested two automatically deploying head restraint systems. One of these was an inflating-bag system and the other a rigid sliding panel system. Advantages which they reported of the inflating-bag over the rigid system included: (1) more compact packaging, (2) lower inertia during deployment, (3) greater potential for contact-surface shaping, and (4) ability to expand fore and aft while deploying vertically. Problems found were related to provision for adequate fore and aft stiffness, and need for oblique impact protection [Melvin and McElhaney, 1971 (839); Melvin et al., 1971 (840)]. In a follow-on program, also contracted by NHTSA (HS-031-2-281), further development proceeded [Hilyard et al., 1973 (838)].

In the HSRI studies, three prototype systems were tested: the B.F. Goodrich, Goodyear Airmat, and HSRI/UniRoyal deployable head restraints. The B.F. Goodrich prototype system consisted of a "curved tube" structure similar in construction to a segment of a fire hose--a tube of rubber bladder material enclosed within a tubular sheath of coarse-woven abrasion-resistant fabric. Adjustable cables were incorporated to control the shape and curve of the sheath as the rubber bladder within expanded upon inflation to .7 to 1.1 kg/sq cm (10 to 15 psi). Goodyear Aerospace "Airmat," a drop-weave material with unusual mechanical properties, was also considered. This fabric is woven in a three-dimensional manner, which, when sealed or coated to provide an air-tight system, results in a stiff structure which would not require external mechanical support in a head restraint. The third system tested, and that found most promising, was a neoprene-coated nylon bag supplied by UniRoyal, Inc., and inflated by an Olin "Safe-T-Flate" inflator (838).

The HSRI/UniRoyal deployable head restraint, shown in Fig. 67 consisted of a coated fabric bag of elliptical cross-section, 25.4 cm (10 in) high, 20 cm (8 in) deep, and 45.7 cm (18 in) high. An inlet port for the Olin inflator (below the baseplate) was located in the bottom of the baseplate and bag. A gas generator system developed by Rocket Research Corporation (Redmond, Washington) was also considered but the Olin system tested was selected. To provide resistance to rearward loading, a fiberglass-reinforced vinyl hood 45.7 cm (18 in) wide was fastened to the front and rear of the baseplate. This allowed rearward loads applied to the hood/bag to be transmitted to the baseplate and seat structure. An additional load-strap was sewn across the top rear of the hood, then attached at its ends to the edges of the seat pan.

The HSRI/UniRoyal deployable head restraint system was subjected to 16 impact-sled tests simulating rear-end collisions of 32 km/h (20 mph), 96.5 km/h (60 mph), and 129 km/h (80 mph) car to car closing velocities, or velocity changes for the struck vehicle of 16, 48.3, and 64.4 km/h (10, 30, and 40 mph), equivalent to 10, 18, and 40 G peak sled pulses. Tests were conducted on the HSRI impact sled utilizing both 95th percentile male (98.4 kg [217 lb]) and 5th percentile female (48.1 kg [106 lb]) dummies. Fig. 68 illustrates an instrumented test dummy and prototype HSRI/UniRoyal deployable head restraint. In addition, 4 vehicle crash tests were conducted at Dynamic Science in Deer Valley, Arizona.

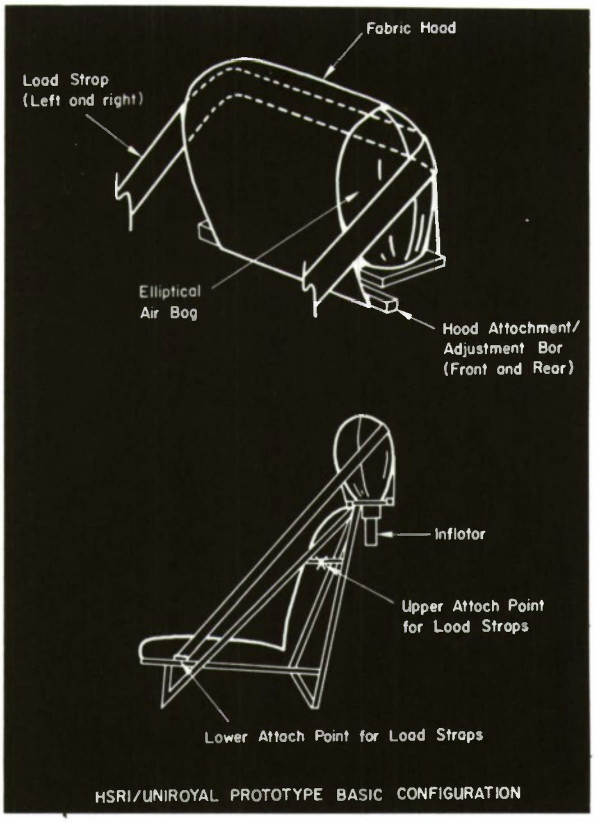


Fig. 67. HSRI/UniRoyal prototype deployable head restraint basic configuration (Photo courtesy J. Melvin, HSRI).

Fig. 68. Instrumented dummy and prototype deployable head restraint (Photo courtesy J. Melvin, HSRI).

It was found that the deployable head restraint effectively reduces head/neck hyperextension ("whiplash") that characterizes rear-impact kinematics. Typical performance for a 95th percentile male dummy, lap belted, in a 64 km/h (40 mph)/32 G direct rear impact was 32 msec deployment time, maximum head/neck extension 10-1/4°, peak head A-P acceleration 71 G, with moderate ramping and rebound. Storage volume was 51 x 10 x 2.5 cm (20 x 4 x 1 in). Since these tests of deployable head restraints were primarily a feasibility study, product development problems of packaging, protection from the elements, crash sensor integration, etc., were recognized but not explored. Tests of the oblique impact and out-of-position occupant were inconclusive. Although rear-end collisions in aircraft are rare, the aircraft passenger may be subjected to crashes in which head protection is needed. Headrests are required to provide adequate crew protection for the crash environments currently specified in both Army and Air Force crew seat design criteria. Currently proposed Army and Air Force design criteria call for crashworthiness at impact levels up to 18 G in the lateral direction and 30 G in the longitudinal direction (MIL-S-58095). The velocities associated with these G levels are 9.1 m/sec (30 ft/sec) and 15.2 m/sec (50 ft/sec) respectively, and significantly exceed the conditions known to be tolerable without a headrest. Injuries in USAF helicopter accidents to both crew and passengers have been attributed to lack of head restraint protection [Brinkley, 1973 (837)]. The deployable head restraint concept remains a promising solution.

4.6.10 Integrated Passive Restraints. In Section 4.5.1 integrated active harness restraint systems were discussed. Many of those systems could be modified to become passive; however, at least five additional concepts and devices (using mechanisms other than belts) may be classed as fully passive systems under the definition of requiring no occupant action to don or activate in a crash. These include the Protect-o-Matic system (or Kinematic Safety Seat system), the Life-net Seat, the Integral Arms about Torso concept, the Barrier Seat, and the Vehicular Safety Seat.

The Protect-o-Matic system is a device which has a tilting seat pan and back that pivot to cradle the occupant under impact conditions. The seat rotates to orient the body in a more inclined position, with the buttocks toward the front of the vehicle. A number of crash tests have been conducted with this automotive system, but it was not considered by the major manufacturers to be as reliable as seat belts, especially since this system offered virtually no protection in side impact, rear impact, or roll-over. The Vehicular Safety Seat consists of functional armrests which contain inflatable devices that were designed to cushion the upper torso while the structural arms enclose the lower torso about the waist. This was developed at and patent assigned to Stanford Research Institute (No. 3,623,768) by E.L. Capener in 1971 (843). Two devices patented by L.B. Simon, a Life-net Seat and a Barrier Seat are not known to have yet been developed or tested. One contains a member along the front edge of the seat that raises the leg and places the body in a fetal position in an impact, and the other rotates the entire seat pan forward and upward to place the knees against the chest at impact (845,846). A fifth concept for an integrated seat design features integral arms that are placed in front of the occupant and has openings in the seat back and pan to provide suction on the body (844).

Fig. 69 illustrates yet another integrated seat-restraint concept which was proposed by Robbins et al. [1971 (784)] in a research study of advanced passive restraint systems undertaken for the National Highway Traffic Safety Administration. In this system the occupants are seated in specially designed seats providing head restraint and some side restraint integral to the structure itself. Upon impact an air bag is deployed in front of the occupant to provide forward restraint. For airline use such a system would most effectively utilize a lap belt in addition which would retain an occupant in situations where turbulence was encountered below air bag deployable impact loads.

A number of additional devices not described here have been considered.

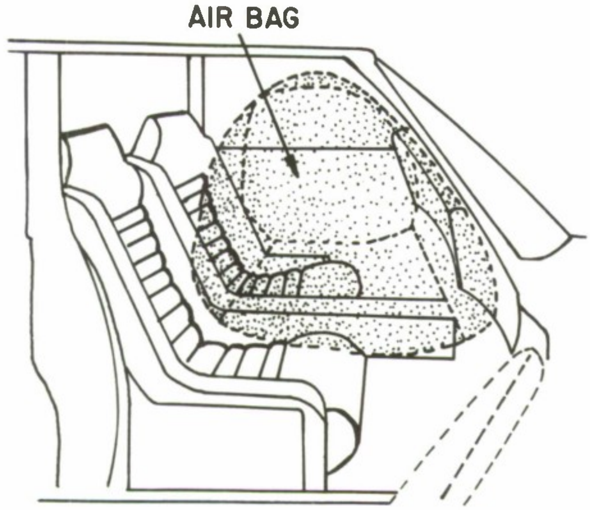


Fig. 69. Integrated seat-restraint system with air bag designed in University of Michigan HSRI concepts study for NHTSA [Robbins et al., 1971 (784)].

None of these concepts or devices yet appear feasible for use in aircraft when compared to existing techniques, and when other factors such as cost, reliability, maintainability, human factors, and protective capability are considered.

4.6.11 Inflatable (Air Bag) Passive Restraint System. A considerable amount of research effort in recent years has gone into development of inflatable occupant restraint systems, commonly (but technically erroneously), called "air bags." (Compressed air was used in some initial tests, hence the name "air bag," but later developments have used other gases.) However, while most people consider this to be a new development, its roots go back many years. Studies of occupant protection carried out before the early 1960's were primarily concerned with various types of belt systems. In the majority of cases, these systems were intended for use by aircraft occupants. Inflatable restraint systems were also closely associated with aircraft in conceptual development; however, almost all subsequent development has been for proposed automotive requirements.

4.6.11.1 History and Background of Development. Although the "air cushion" was evolved at least by 1918 as a seat [Mosely, 1918 (897)] and used in Webster's Schneider Cup winner and other aircraft such as the de Havilland Moth, its use as an abdominal support was suggested in 1933 by Wing Commander Marshall of the Royal Air Force, who devised an air cushion belt for acceleration protection. During the 1930's the U.S. Naval Air Corps experimented extensively with self-inflating air bags on aircraft wings for the purpose of providing flotation after crash landings at sea. The concept was dropped before World War II, but continued interest in this technology produced rapidly inflating life rafts and paragliders [Frey, 1970 (872)].

During World War II there were reports of use of premature inflating of the Mae West on life rafts prior to crash landings (888) as impact protection (one of the author's 8-man crew did this during a North American [Mitchell] B-25 crash landing). However, use of a gaseous inflatable restraint system for crash protection may date from the work of Pekarek, a Czechoslovakian engineer with the RAF, who devised the "Pekarek Safety Cell" in 1943-1944 (903-907; 872). In 1952 Jordanoff (880) reported a manually triggered air bag restraint system. Hetrick [1952 (876)] and later Bertrand (849) in 1955 filed for a patent on an air bag filled on manual switch application with automatic deflation after a time delay. In 1959 several restraint systems utilizing air inflation were proposed to the Air Force by Snyder at the University of Arizona (916) for astronaut protection, but a Chance-Vought system was selected for development [Snyder (792)]. An air bag passenger seat was proposed by Lamm in 1961 (889). During the past 25 years there have been literally hundreds of ideas and proposals for inflatable restraint systems.

A proposal for a formal air bag study at Ford Motor Company was dated January, 1957, following preliminary studies in 1956 [Kohn, 1957 (887)], and described an air cushion to protect the front seat passengers from windshield impact, a steering wheel mounted air cushion, and a combination inflatable front seat head restraint and rear seat passenger cushion [Frey, 1970 (872); Kemmerer, 1967 (882)].

A pneumatic life raft was purchased in 1957 and evaluated. It was found that the package was too bulky and that the time required to fill the bag from high-pressure cylinders was too great to protect vehicle occupants during a crash [Kemmerer, 1967 (882)]. In 1960 the Vehicle Safety Section at Ford proposed to use the gas from a propellant charge to inflate a bag [Daniel, 1960 (868)]. The concept of an air bag restraint for automotive occupant crash protection was probably first initiated at General Motors about 1958.

During the early 1960's the concept of an air bag ("airstop") restraint system was extensively explored by Clark and Blechschmidt at the Martin Company in Baltimore (850, 853-863; Cooper et al., 1963 (864)]. Their reports should be referred to for further historical background; however, in contrast to current air bag technology, these early tests involved pre-inflated bags. The pre-inflated Martin Airstop system, developed by Clark and Blechschmidt, has been crash tested in several aircraft crash tests, including the FAA crash test of a Douglas DC-7 transport at Av-Ser Division, Flight Safety Foundation, Deer Valley, Arizona in April, 1964 [Clark and Blechschmidt, 1966 (863)]. This was followed by a NASA rear-facing seat crash test of a Beechcraft C-45 into a hill at 129 km/h (80 mph) in April, 1965, and a series of 10 forward-facing crashes carried out at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, in November, 1965, at impact speeds up to 140 km/h (87 mph) into snatch wire arresting gear. Although demonstrating the feasibility of the system, rebound was excessive, and in air transport use these prototype bags would have hindered emergency evacuation. Clark and Blechschmidt subsequently sought means to remove the bag once it was deployed, and experimented with several techniques (coil springs, elastic bands, vacuum system) to automatically roll up the bags into the seat storage compartments (863). They envisioned transparent bags in the backs of airline seats, possibly inflated by the stewardess activating a switch prior to every takeoff or landing as part of the normal procedure, rather than attempting to inflate them just prior to an emergency. These early aircraft tests have been more recently followed up by additional FAA tests, and a considerable number of proprietary studies within the automotive industry, with impetus from the National Highway Traffic Safety Administration's proposed FMVSS requirements (782).

The first full-scale testing program involving living test subjects (baboons) restrained by air bag systems was reported by Snyder et al. in 1967 (791) in FAA studies conducted at Holloman AFB, New Mexico, in cooperation with the USAF. The level of protection offered by the air bag system appeared to be higher than for other systems evaluated in that program. Shortly after this series of tests was reported, Ford Motor Company and Eaton, Yale and Towne, Inc. collaborated in a report presented at the January, 1968 SAE Automotive Engineering Congress held in Detroit [Kemmerer et al., 1968 (883, 884)]. The feasibility of concept, systems development, performance requirements and the implication of producing inflating restraint systems on a large-scale production basis were discussed, and conclusions were drawn such as: (1) inflating restraint systems can reduce occupant loadings; (2) energy absorption must be provided to prevent excessive occupant rebound by means of a bag pressure relief system; (3) an inflating restraint system can be automatically activated by a crash sensor and deployed in the short time between crash initiation and the second collision of the occupant with the vehicle interior; (4) a parameter study is needed to determine system performance as occupant size is varied; (5) an operational criterion for sensors is needed; (6) reliability must be demonstrated; and, (7) the effects of noise should be investigated.

In 1968, a project (Contract No. FH-11-6962) was initiated at the Highway Safety Research Institute under contract to the National Highway Traffic Safety Administration of the U.S. Department of Transportation [Robbins et al., 1971 (909)]. Part of this project was to conduct a detailed analysis of work carried out on air bag restraint systems to determine their feasibility, and the remainder was to conduct an experimental impact sled test program involving dummies restrained by air bags.

In the spring of 1969, initial impact sled tests involving pre-inflated air bags restraining 50th percentile male dummies were carried out at HSRI. Rapidly inflating air bags were in use for all sled tests conducted after June, 1969. By the end of that month the system had been tested up to 48 km/h (30 mph) in frontal collisions involving dummies both restrained and unrestrained by supplemental lap belts (909). Further air bag development research, including vehicle crash tests, was carried out by Cornell Aeronautical Laboratory, under NHTSA contract [1971 (866, 867)].

Extensive activity was begun in government, industry and independent research organizations on July 1, 1969, as the Secretary of Transportation issued an Advance Notice of Proposed Rule Making on inflatable occupant restraint systems. At an open meeting sponsored by the Department of Transportation, the great potential for these systems was demonstrated, as well as potential problems such as danger to the out-of-position occupant and the danger of inadvertent actuation to a child passenger.

During the winter of 1969-70 the importance of supplemental knee support was demonstrated and implemented in hardware both by a low-deploying, knee-catching air bag produced by General Motors Corporation (851), and by an energy-absorbing lower instrument panel developed at the Highway Safety Research Institute for use with an air bag deployed from an automobile upper instrument panel. By spring, 1970 successful tests were carried out at HSRI at 64 km/h (40 mph) impact velocity and in right front oblique impact (909).

An International Automotive Passive Restraints Conference was held at the General Motors Proving Grounds in May, 1970 (899), sponsored by the North Atlantic Treaty Organization, and hosted jointly by the U.S. Department of Transportation and the U.S. automobile industry. This yielded information on the state-of-the-art of passive restraints up to that date. A wide range of views and technical data were presented by representatives from government and industry. This document and National Highway Traffic Safety Administration Docket No. 69-7 of the Department of Transportation provided the most comprehensive published data through 1970 (898).

Since the 1970 NATO Conference, technical data on air bag restraints have been featured at numerous meetings and conferences, including the Stapp Car Conferences held at San Diego in 1971 [Melvin et al. (840), Martin and Romeo (892)], Detroit in 1972 [Romeo and Rose (910), Patrick et al. (902)], and in San Diego in 1975 [Dejeammes and Quincy (869)], and at the annual SAE Automotive Conferences in Detroit (873, 875, 878, 883, 885, 914, and others). The American Association for Automotive Medicine has also published air bag research annually [Yost, 1972 (1002), 1973 (1003); Schmidt, 1972 (998), Greer, 1973 (965); Aldman et al., 1974 (847); Smith and Moffatt, 1975 (915)].

In 1971 NAFEC, Federal Aviation Administration, Atlantic City, New Jersey put out a request for proposals (RFP-1-27) for an engineering research study to develop a concept of an inflatable restraint system for use in general aviation aircraft. This study was conducted by Beta Industries, Dayton, Ohio by Carr and Phillips who investigated inflatable restraint design criteria and developed an air bag restraint system for use in a general aviation aircraft. Although they concluded that significant modifications would be necessary to the seat support structure and seat pan to provide necessary energy absorption characteristics for attenuation of the vertical crash load, their study indicated that an air bag system could fully protect the occupant of a general aviation aircraft in a crash impact [Carr and Phillips, 1973 (852)].

The FAA conducted a test of a prototype air bag system at the NAFEC facilities, mounted in an aircraft cabin arrested at 130 km/h (81 mph). In comparison with a lap belt-shoulder harness restraint the air bag lessened peak loads on the torso but resulted in an initial "violent" rearward head acceleration as the bag inflated. Apparently only the single dynamic test was conducted, although other static tests were done. This work was reported in May, 1972 [Sommers (919)].

On February 28, 1972, the final report was published which had been prepared for the Office of Science and Technology, Office of the President, entitled Cumulative Regulatory Effects on the Cost of Automotive Transportation, or the "RECAT" study. This study presented an overview relative to cost-effectiveness and pointed out a number of concerns, unsolved as of that date (900, 1004).

In August, 1973 the U.S. Senate Committee on Commerce held hearings on air bag development and technology, the Honorable Vance Hartke, presiding, which again brought together both a large amount of data and conflicting viewpoints (865).

On May 22-25, 1972, a 2nd International Conference on Passive Restraints, co-sponsored by the Society of Automotive Engineers, the National Highway Traffic Safety Administration, and NATO, was held in Detroit, Michigan. General topics covered included "Air Cushion" systems development, energy sources, crash sensors, and consumer considerations, as well as discussions of system effectiveness and passive belt systems. This conference represented the state-of-the-art as of May, 1972 (917).

A 3rd International Conference on Occupant Protection was held July 10-12, 1974 in Troy, Michigan, sponsored by the Passenger Protection Committee of the Society of Automotive Engineers (918). However, in contrast to the 29 papers on the air bag given at the 1972 conference, only 5 papers concerned with air bag studies were given [Ross, 1974 (938); Ikeda et al., 1974 (933); Shoemaker and Biss, 1974 (913); Abe and Satoh, 1974 (941); Smith et al., 1974 (972)].

On May 19-23, 1975, a five-day public meeting was held in Washington on the subject of requirements for occupant crash protection under FMVSS 208 [Occupant Crash Protection - 49 CFR 571.208 (782)]. More than 40 representatives of suppliers, the auto industry, and various organizations presented data relative to passive restraints. Issues were emphasized related to lead time, cost, weight, field testing, reliability, out-of-position occupants, public acceptance, retrofit, test dummy reproducibility, and relative effectiveness of air bags and belt systems. National Highway Traffic Safety Administration Motor Vehicle Safety Standard No. 208 has required passenger cars manufactured from January 1, 1972 to present to meet three options of occupant restraint, the first of which involves completely passive protection. As of 15 August, 1977 it has been proposed that such passive protection be made mandatory, although now such a regulatory action seems to be in doubt. Active investigation of air bag-equipped motor vehicles has been underway for several years, with some air bag-equipped vehicles reported in accidents to date. As of 10 March, 1976, there has been no decision as to mandatory imposition by the National Highway Traffic Safety Administration of requirements for passive restraints in automobiles manufactured for sale in the United States.

Besides the active developmental work being conducted in the automotive industry and by its suppliers, several organizations have been funded for various studies by NHTSA, Department of Transportation. Among these are the Cornell Aeronautical Laboratories (CALSPAN), Wayne State University, the Daisy Track at Holloman AFB, Mini-Car, Inc., Dynamic Science, Inc., Southwest Research Institute, Beta Industries, Inc., and Dynamic Science Division of Marshall Industries.

Inflatable restraint systems have been applied to attenuate lateral ($-G_y$) impact for Air Force crew escape modules such as the General Dynamics F-111 [Shaffer and Brinkley, 1974 (17)], and to the impact attenuator bladders of the USAF B-1 bomber, although crew restraint in each is a belt system utilizing inertia reels [Beers et al., 1975 (848)]. To date no studies are known to have been conducted or reported relative to the air bag restraint application to air transport passengers since the early 1960's work of Clark and Blechschmidt (850, 853-862), except for consideration by McDonnell Douglas of an inflatable application on the back seat cushion of DC-10 seats [Hawkins, 1974 (671)], and a prototype DC-10 seat back application by F.L. Diamond Co. [1976 (1005)].

4.6.11.2 Inflating Occupant Restraint System Components. There are six basic components in an air bag type of passive restraint system. These consist of: (1) crash sensor-initiator, (2) energy (gas) source (stored gas and/or solid gas generator),(3) valve to release gas, (4) manifold (to distribute gas), (5) inflatable bag, and (6) malfunction detector and system readiness monitor. Each of these subsystems has its own set of environmental problems and components. Although the vehicle manufacturer, as well as NHTSA, is concerned with the total system, many of the suppliers concentrate their development efforts on one or more components. Fig. 70 illustrates these major subsystems.

The subsystems have been developed for automotive use, and the few aircraft tests conducted have utilized or adapted from these components. The sensor-initiator consists of an inertial switch or other device capable of sensing that a crash is about to or has begun to occur. The signal from the sensor is then fed to an initiator which triggers a supply of gas to the deployable bag. In the case of pyrotechnic gas sources, the initiator is an igniter whereas for the stored gas systems, the initiator is an explosive squib which fractures a diaphragm sealing the stored gas bottle. In all cases the necessary electrical signal is provided by a power source such as a battery, although a detonating cord has been proposed by one supplier.

As reviewed in Section 4.6.11.5, several types of energy (gas) sources have been utilized so far, including stored gas, chemical, and hybrid types. The chemical type generates the inflation gas after actuation and the hybrid combines the stored gas and chemical types. The most commonly used is a bottle of stored air or nitrogen. The bottles are, of course, bulky and heavy, weighing up to 9 kg (20 lb) in the case of a single right front automobile occupant restraint system. A second gas source system is pyrotechnic and, because of the solid fuel use, is much lighter and compact. However, in some cases the gases may present toxic problems. A third system is a hybrid form combining the two. Most often this consists of a pyrotechnic device providing rapid inflation supplemented by stored gas delivered over a specified period to provide some potential for protection in multiple impacts. Aspirator systems, representing an extension of the techniques used to inflate escape slides, have also been developed.

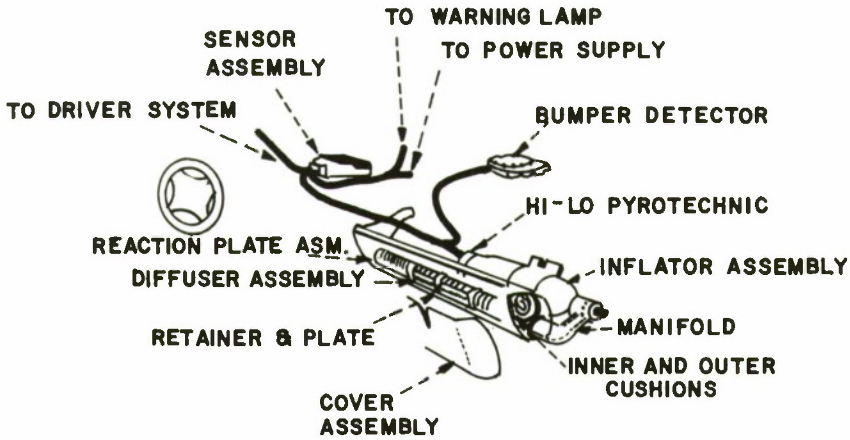


Fig. 70. Schematic of the basic driver and passenger air bag restraint system.

A variety of materials have been proposed for the inflating cushion itself. Among these are coated fabric and films. Coated fabrics have been generally selected because of high strength and favorable weight. Fabrics such as nylon, dacron, rayon, glass and cotton have been studied with nylon most commonly used.

Release mechanisms are normally electro-explosive devices (EED), or pyrotechnic chains. Mechanical devices investigated to date are too slow for this purpose. EED considerations reported by Jones and McCarter, 1972 (935) are reliability, fire/no-fire energy, and Electro-Magnetic Interference (EMI) immunity.

4.6.11.3 Air Bag Design. Air bag design has undergone a number of changes from the pre-inflated bag systems of Clark and Blechschmidt to the current more sophisticated systems. Factors which must be considered in the design include bag size, bag shape, material, use of vents, and other special requirements, such as bags with high and low deployment capabilities. The size or volume of the bags which have been designed for automotive use depends upon the occupant position in the vehicle. A right front passenger air bag system may have a volume of 283 liters to 410 liters (10 to 14.5 cu ft), extending laterally from the steering wheel to the door, while an air bag designed for the driver's steering wheel may have a volume of about 28 liters (1 cu ft) in a standard size vehicle. In a smaller vehicle, such as a Volkswagen, the right front passenger air bag volume is 150 liters (5.3 cu ft), while the driver's air bag ranges about 55 to 68.5 liters (2 to 2.5 cu ft) [Seiffert and Borenius, 1972 (912)].

Calspan has developed an air bag on collapsible dashpanel (ABCD) passive restraint system having a total bag volume (76 liters [2.7 cu ft]) approximately one-half that of the conventional standard-size right front passenger system [Shoemaker and Biss, 1974 (913)]. This system includes a collapsible dashpanel, two small air bags which deploy at speeds above 32 km/h (20 mph) and a crushable kneebar for lower body restraint. Fig. 71 shows general types of air bags developed for automotive use.

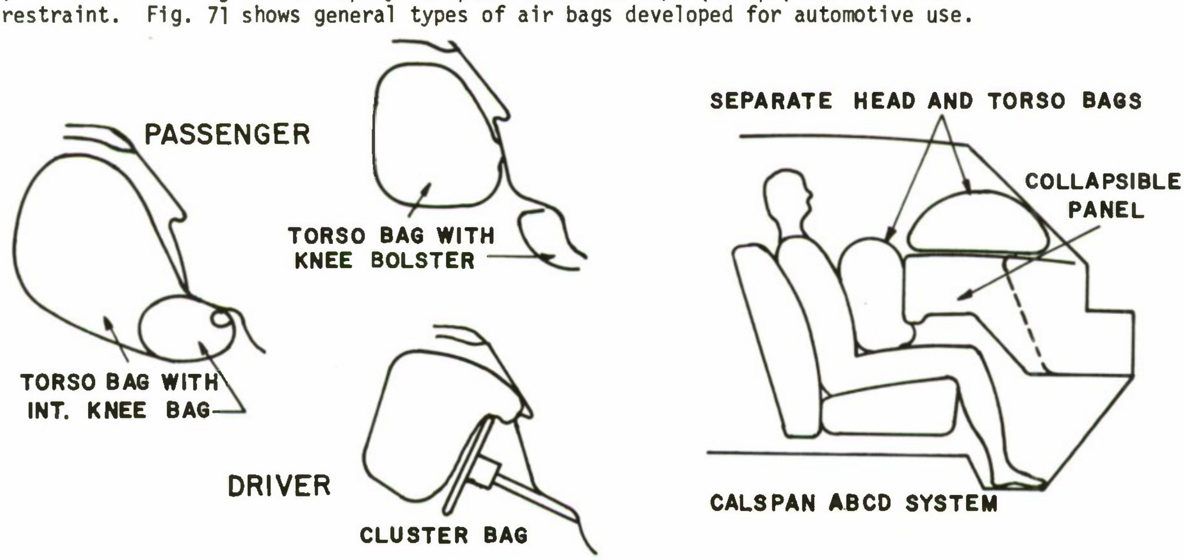


Fig. 71. General types of air bag configurations developed for automotive use [Seiffert and Borenius, 1972 (912); Shoemaker and Biss, 1974 (913)].

In a transport aircraft application, the back of the seat in front of an occupant is much closer than the instrument panel and windshield would be in front of a right front auto occupant. Because of this, it is likely that a bag used in a jet transport could be smaller, and possibly only half the size of its automotive counterpart.

The shape and deployment of the bag for aircraft use would be governed by approximately the same principles which apply to automotive use. A bag deploying from a position in front of the occupant's knees would provide a cushion for the knees and torso of the occupant. A bag deploying at chest level from a position in the seat back in front of the occupant would have to be supplemented by an energy-absorbing structure designed to minimize motion of the legs. Both of these designs have been tested widely and can provide equally high levels of protection. The high deploying bag concept has slight advantages in that the bag can be deployed more rapidly. An air bag system mocked up for general aviation aircraft use at HSRI, the University of Michigan in 1970, is illustrated in Fig. 72.

Fig. 72. Mock-up of air bag system for light aircraft use [HSRI, The University of Michigan, 1970].

Several factors have governed the selection of fabric bag materials as a base for an air bag rather than film material [Streed et al., 1971 (926)]. Among these are: (1) the need for a high strength-to-weight ratio for the material due to the necessity for the use of as thin and flexible construction of material as possible, in order to meet compact packaging requirements, (2) the necessity for this construction to be almost insensitive to temperature of storage and deployment, and (3) the need for ultimate reliability as to resistance to snag or tear, coupled with minimal thickness and tear resistance, since tear resistance is the most outstanding property of a woven fabric.

Three factors govern the use of coatings on most fabrics which have been chosen for application in air bags. The first of these is the ability to control the gas permeability of the fabric. Second, a coating serves to protect the fabric and occupant from heat if a pyrotechnic inflation device is used. Third, a coating on the fabric permits the designer more flexibility in the design of the air bag since it permits him to obtain seams that are as strong as the fabric itself with any contour, as compared to the limitations imposed by the use of an uncoated fabric with its need for sewn or adhesive bonded seams.

Fabric requirements are based on high strength-to-weight ratio, maximum elongation, minimal weight, temperature insensitivity, high cover factor, and capability of coating by commercial process. Candidate materials are nylon, dacron, rayon, glass and cotton. Favorable properties seem to be embodied in a 171 gram (5.5 oz) ripstop nylon.

Human volunteer tests conducted by the USAF at Holloman AFB in 1971 for the NHTSA, utilizing early General Motors state-of-the-art bags, indicated unacceptable rebound characteristics. As a result, the air cushion fabric was modified in construction and shape to reduce this action. It was also found that the material porosity greatly reduced the rebound action, and eliminated the need for fabric coatings. [Klove and Oglesby, 1972 (886)]. Controlled porosity was accomplished by specifying a tighter weave construction.

Air bag systems may be either vented or unvented. Generally driver bags installed in the steering column are unvented whereas the right front passenger systems employ venting techniques. One of the main functions of a driver bag is to distribute the load uniformly over the chest. Energy can be absorbed during collapse of the energy-absorbing column. Passenger bags of current design require some type of venting primarily to allow energy absorption and to prevent potentially dangerous rebound of the occupant into the seat back. Present venting systems consist of either plastic patches which blow out, allowing gas to escape from the bag, or porous panels which allow the gas to escape through the bag material itself. Both of these techniques have been employed in passenger bags. No large differences in performance have been noted when a 50th percentile male dummy is used [Robbins et al., 1971 (909)]. More recent woven, uncoated fabrics specified utilize a rip or tear stop construction. This inhibits small tears from developing into large openings.

4.6.11.4 Crash Sensors. The purpose of a crash sensor is to predict an impending impact or to determine the occurrence of a collision. Crash sensors may be divided into three general categories: (1) predictive sensors, which activate when a crash is imminent, (2) impact sensors, which activate after the crash event has started, and (3) combination sensors, of which a variety of types have been developed and tested. Predictive sensors include systems employing radar, sonar, laser, or infrared techniques, while predictive mechanized sensors may be classed as passive, active, cooperative, or combinations. Crash sensors depend upon the measurement of parameters such as crush, acceleration, or velocity change.

Several locations for crash sensors in automobiles have been evaluated. In principle, rapid crash detection can be achieved by placing the crash detectors at the vehicle location experiencing earliest deceleration in a crash, or the point of initial contact. The bumper is the primary vehicle location for a frontal crash. Bumper sensors have been found to complete crash detection in 6 msec, but this time can be reduced to 1 msec or 2 msec by utilizing a pressure switch monitoring the pressure in a hydraulic shock absorber [Pujdowski, 1972 (937)]. Due to bumper height mismatch in collisions, additional sensors may be mounted in parallel on the firewall. An alternative location is on both sides of the radiator, 15.2 to 25.4 cm (6 to 10 in) above the bumper. At present, sensors are required to function at vehicle impact of 48 km/h (30 mph) into a barrier at angles up to ±30° from frontal, although the lower speed at which the sensor must deploy restraint is left to the manufacturer.

Depending upon the particular crash sensor scheme, post-impact sensors utilize from 5 msec to about 2 msec of critical post-impact time to receive, process, and transmit crash data for a 48 km/h (30 mph) equivalent fixed barrier impact. However, for non-barrier crashes of equivalent severity, longer times may be required. A crash sensor must make a crash/non-crash determination with an extremely high degree of certainty. Failure, or "inadvertence," has been determined to result from two principal causes. The first is the mobility of a sensor to "operate precisely at the minimum threshold and not to operate below that minimum threshold during frontal impacts that occur within the angular zone of protection" [Jones et al., 1972 (934)]. The second cause of inadvertence relates to the translation of large rough-road vertical accelerations into horizontal accelerations which exceed the minimum threshold of the sensor. As a result of these problems, the anticipatory systems, such as radar, have evolved. However, the predictive sensor system can also mistakenly identify safe objects as being dangerous and result in an inadvertent triggering of the system.

In current systems of crash sensing two separate devices may be utilized to signal the energy source of collision conditions. A bumper-mounted switch will operate early in the collision sequence. If the collision is of sufficient level, a portion of the deployment-restraint energy for the passenger's system is released. At low levels of impact no deployment of the driver's air bag (steering wheel, knee bags) is planned, to allow maximum control in low speed collisions. A sensor mounted in the passenger's compartment will also provide a signal to the passenger's system, deploying the right front passenger air bag. This latter system also is intended to operate for accident cases not involving the bumper, such as angular collisions. If a collision is of sufficient magnitude above the bumper-mounted and low level deceleration detector thresholds, another deceleration detector, such as the radiator-or firewall-mounted device will be most effective.

Air bag requirements for motor vehicles vary both with the occupant's position and vehicle deceleration. In a low speed impact the right front seated passenger requires a relatively slow cushion deployment, reducing noise level and hazard due to air bag deployment velocity contacting him. Low speed inflation is also desirable for the standing child or out-of-position occupant. In a high speed impact, rapid inflation is required to provide optimal protection. On the other hand, the driver absorbs energy in impacting the energy absorbing column, and may not require inflation at low speeds. In a typical automotive barrier crash at 48 km/h (30 mph) where bumper contact occurs at 0 msec, the sensor would trigger the system at 30 msec, the air bag would deploy at 57 msec, the forward motion of the occupant would be arrested at 95 msec, and the forward motion of the vehicle stopped at 115 msec. This sequence is shown in Fig. 73 which shows an anthropomorphic dummy simulating deceleration and kinematics of an unbelted 50th percentile adult male in an HSRI sled test at 32 km/h (20 mph) velocity. The first frame shows initial bag deployment, and subsequent sequences show the forward motion of the dummy into the deploying bag (with concurrent venting of the gas), and finally rebound back into the seat. In standard size vehicles some 50 to 60 msec elapses from contact to full air bag inflation at 48 km/h (30 mph). Sensor activation varies somewhat between manufacturers, the Volkswagen Type I Beetle for example, having a crash threshold for sensor activation of 25 km/h (16 mph) for the "must-fire" condition, and 20 km/h (12 mph) for the "no-fire" condition [Seiffert and Borenius, 1972 (912)].

Two types of systems are used, a single level system which activates at a low level 19-29 km/h (12-18 mph), and a two level system utilizing 2 gas generators at higher impact velocities. A typical time sequence for a single level system (at 48 km/h) is 20 msec to sense, 2 msec to activate, 3 msec for distribution, and 30 msec for bag inflation, for a total of 55 msec. For a bumper activated system 5 msec are required to sense, 2 msec to activate, 3 msec to distribute, and 45 msec to inflate the bag. In comparison, a typical time budget for a 20 km/h (12 mph) low level impact system is 30 msec to sense, 2 msec to activate, 3 msec to distribute, and 60 msec to inflate the bag, requiring a total of 95 msec [Jones and McCarter, 1972 (936)].

Requirements of a crash sensor can be related to performance, reliability, and economic factors. Performance requirements include factors of operating time, threshold capability, and directional capability. In considering reliability, the most important factors (for automotive use) are inadvertent activation, failure to operate, and crash/non-crash discrimination. Economic factors include maintenance frequency, malfunction indication, and cost. Table XIX summarizes crash sensor requirements for automotive vehicles according to relative importance by parameters of performance, reliability, and economic factors, with values assigned by Jones and McCarter in General Motors studies (934-936).

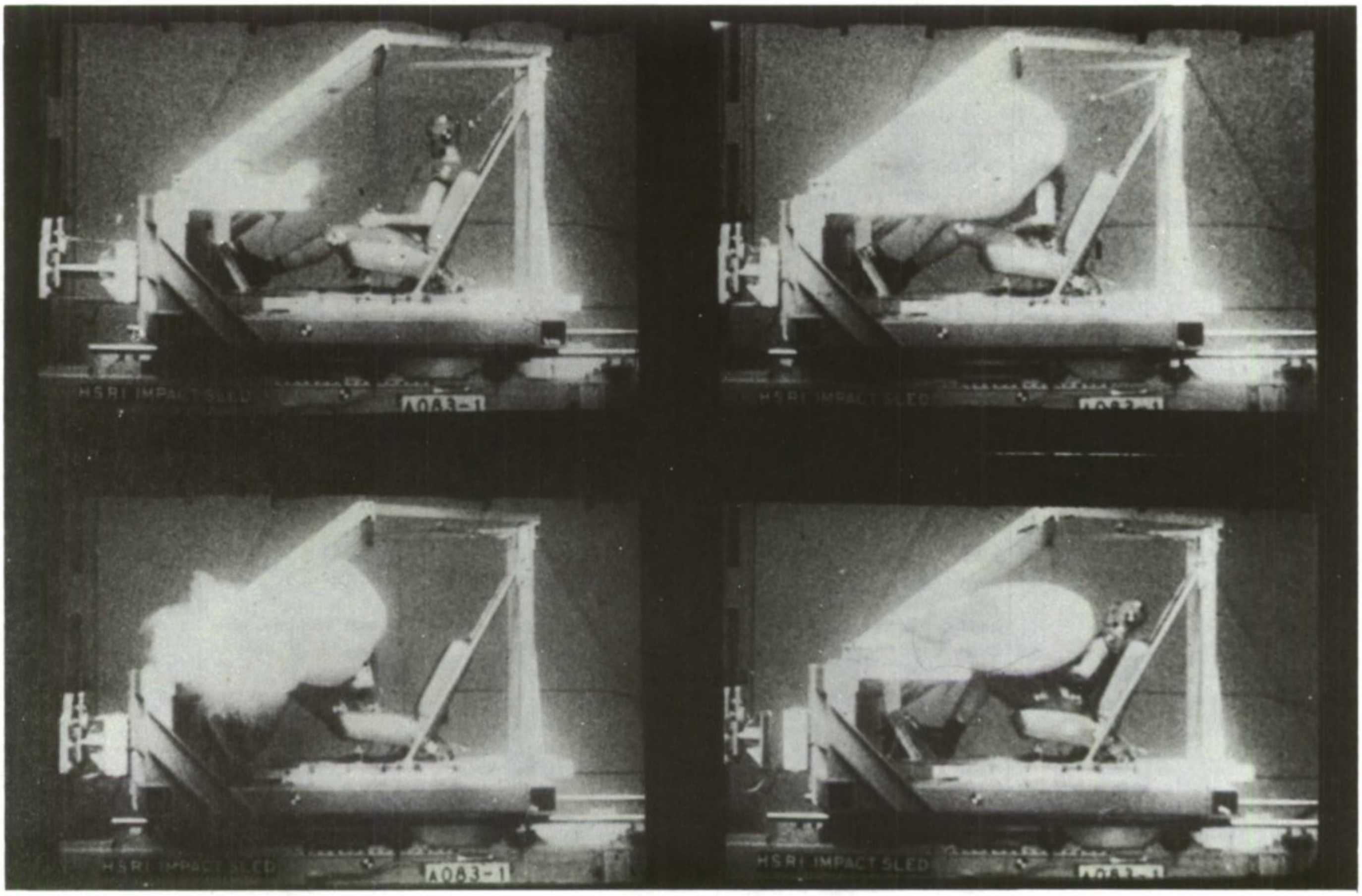


Fig. 73. Unbelted 50th percentile adult male dummy in HSRI sled deceleration at 32 km/h (20 mph) impact velocity, showing initial bag deployment, forward motion of the dummy into the deploying bag, and finally rebound back into the seat.

TABLE XIX.

CRASH SENSOR PERFORMANCE FACTORS

Category Level of Importance	PERFORMANCE (31%)	RELIABILITY (41%)	ECONOMIC (28%)
A: Each Characteristic Rated at 6%	Threshold Tolerance Directional Capability Operating Time	Inadvertence Operation in Crash Non-Crash Discrimination Positive Fire Mechanism Withstand Car Environment	Development Status Cost Maintenance Frequency
(66%)	(18%)	(30%)	(18%)
B: Each Characteristic Rated at 3%	Dynamic Range Deactivatable Selectable Location	Life Movement Below Threshold Malfunction Detection	Producibility Interchangeability
(24%)	(9%)	(9%)	(6%)
C: Each Characteristic Rated at 2%	Status Indication Compatible with Initiator	Ability to Test-fire and Rearm	Size Power
(10%)	(4%)	(2%)	(4%)

Source: Jones and McCarter, 1972 (935)

These criteria of performance, reliability, and economic factors have also been evaluated in terms of various characteristics required. As related to performance, operating time must be short enough to allow air bag inflation for occupant protection, threshold tolerance includes measurement of closing velocity and of target density to indicate significant impact, target density determination, and directional capability. Reliability relates primarily to inadvertence and operation in a crash, and non-crash discrimination. Finally, maintenance frequency and malfunction detection system as related to economic factors must be considered. Table XX presents crash sensor characteristics as evaluated by Jones & McCarter.

TABLE XX.

CRASH SENSOR CHARACTERISTIC PROFICIENCY EVALUATION

Category	Characteristic	Proficiency		
		Excellent	Good	Acceptable
Performance	30 mph Barrier Operating Time	≤ 5 MS	5 to 15 MS	15 to 25 MS
	Closing Velocity Measurement	± 1 mph (1.6 Kmph)	± 2mph (3.2 Kmph)	± 2.5 mph (4.0 Kmph)
	Target Density	Detect several critical levels	Distinguish critical from non-critical	Auxilary detector required
	Directional Capability	Frontal 30°, lateral, rollover & rear	Frontal 30°, lateral & rollover	Frontal 30°
Reliability	Crash non operating per 10,000 accidents/year	<< 1.0	< 1.0	1.0
	The advertent Operation per 10^6 vehicles/year	<< 1.0	< 1.0	1.0
	Non Crash Discrimination Barrier Speed	1 mph (1.6 Kmph) lower threshold definition	2mph (3.2 Kmph) lower threshold definition	2.5 mph (4.0 Kmph) lower threshold definition
	Restoration time	zero	10 MS	20MS
Economic	Maintenance	none required	3 year inspection	Same as other elements
	Malfunction Detection	Fail Safe, monitor critical elements, alarm & self test	Fail Safe, monitor critical elements & alarm	Meet current MVSS 208 requirements

Three commercially available crash sensors were evaluated in 1971 by Robbins et al. (909) at HSRI, the University of Michigan. These included the early Eaton Autoceptor, the General Motors Delco Electronics Mechanical crash sensor, and the Delco Electronics Safety Sentinel.

The Eaton Autoceptor crash sensor is a uniaxial mechanical spring-mass system which fires when the mass is displaced in a predetermined distance. The spring holds the mass against an end of the sensor in order to produce a bias force against the mass. This first-generation Eaton spring mass sensor (Fig. 74 was designed for the following characteristics: 1.3 cm (0.5 in) travel, 5 G preload, and 2 G/in spring rate. To 1972 some 3 million miles of road tests without inadvertent activation were reported by Eaton [Pujdowski, 1972 (937)].

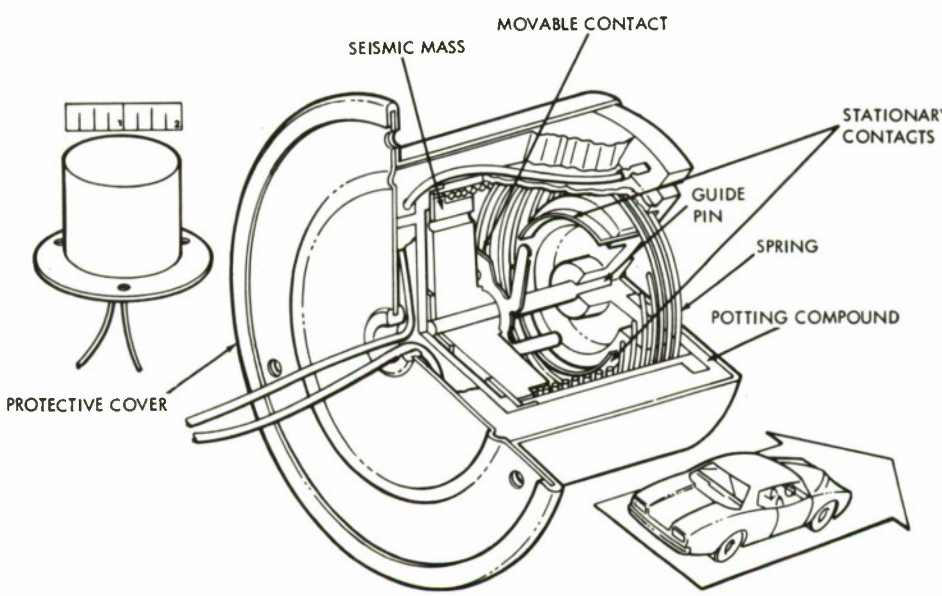


Fig. 74. Eaton Autoceptor first-generation crash sensor [Pujdowski, 1972 (937)].

The Delco Electronics Mechanical Crash Sensor Model 8-1000 is a ball sear type mechanism fired by displacement of a mass which is restrained by magnetic force. The sensor is essentially omni-directional in a plane and nominally set to trigger on an 11 G, 80 msec haversine shock wave which is a rough representation of an average rear end automobile collision.

The Delco Electronics Safety Sentinel 4 Electronic Crash Sensor is omni-directional in a plane. It consists of a ball restrained by magnetic force. A ring surrounds the ball which can be displaced by deceleration until it contacts the ring, thereby energizing the firing switch. The system is double redundant, self-diagnostic and is set (at delivery) to trigger on a 16 G, 60 msec haversine shock wave.

In the Eaton and GM sensors tested at HSRI, each of the sensors was mounted on the ram of a Plastechon high speed universal testing machine. This hydraulically actuated, electronically servo-controlled machine was programmed to subject the sensors to a variety of acceleration-time profiles. A Setra Model 110 accelerometer was mounted on the ram to measure the acceleration input to the sensor. The accelerometer output was filtered through a Burr-Brown filter meeting SAE J211 channel class 180 specifications. An automobile 12-volt battery was the power source for the sensors. Typical results are shown in Fig.75. It should be noted that for these 30 G pulses typical of the initial sheet metal crush in a motor vehicle barrier crash, the air bag would have been triggered in from 10 to 14 msec.

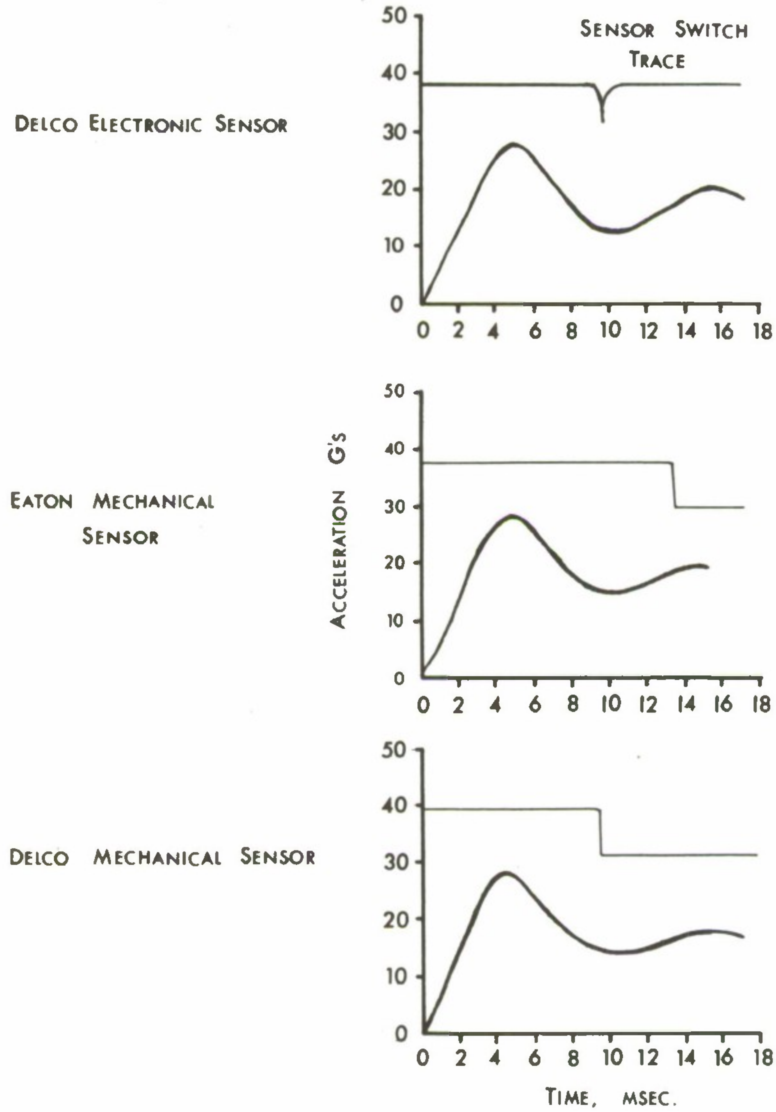


Fig. 75. Crash sensor response tests [Robbins et al., 1971 (909)].

Tests were performed on the Eaton sensor to establish the effect of off-axis acceleration on trigger time. Two different amplitude (11 G peak and 24 G peak) acceleration-time profiles were used. The sensor was subjected to the same pulse each time at angular increments of 10 off-axis starting at 0 and increasing until the sensor would not trigger. For the 11 G pulse, the G-switch triggered at 24 msec. At 20° off center, the triggering was delayed at 33 msec and the sensor would not trigger for larger off-axis angles. In the case of the 24 G pulses, the sensor triggered at 15 msec for a direct frontal pulse. This was delayed to 20 msec for a 30° oblique pulse. The system did not fire for larger angles (See Fig. 76).

These results lead to two observations which may be made concerning sensing an aircraft transport G-pulse. First, the pulse is not estimated to be unidirectional along the longitudinal axis of the aircraft. Rather, both horizontal and vertical components of the impact will be present. The vertical component may be as great or even greater than the horizontal component in some cases. Second, a unidirectional sensor which is used for sensing one component of an aircraft impact must not be sensitive in its operations to accelerations in directions other than the direction of its axis. The Eaton sensor, for example, could possibly "stick" due to friction when impacted from the side. Omnidirectional sensors would be necessary for use in an aircraft crash incident.

The sensors tested at HSRI can be modified to fit a range of different crash pulses. Thus, it is possible that current designs could be modified for Air Force application. This could be done by modifying the G bias. In the Eaton system, this would require stiffening or softening the spring element to either increase or decrease the bias. It would be necessary to modify the magnetic characteristics in the GM systems. The mass displacement limit is also variable in the various cases. This would affect the time duration of the G-pulse required to trigger the bag inflation.

All of the commercial sensors evaluated were of basically simple design although the Delco sensors had sophisticated electronic components associated with them. The sensors were potted in tough plastic and hermetically sealed to such an extent that the effects of environment and tampering on the basic sensor components are minimal.

A more recent crash-active type of sensor is the wide angle crash sensor developed by Eaton as shown in Fig. 76.

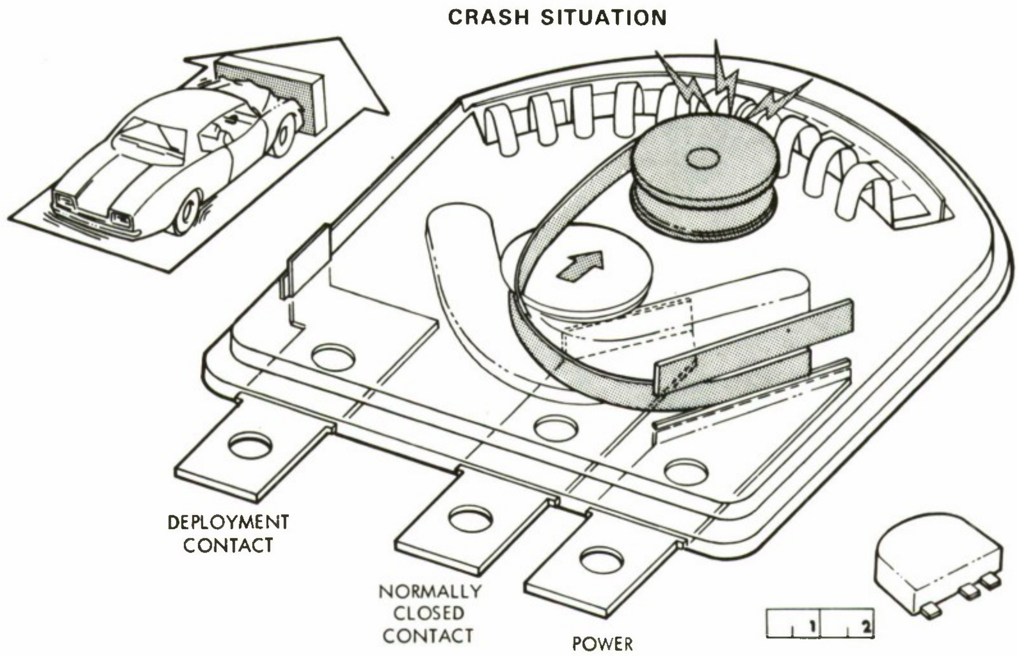


Fig. 76. Eaton wide angle crash active sensor [Pujdowski, 1972 (937)].

While inertial sensors, typified by the spring mass and the magnet types, are relatively simple, inexpensive, may have a wide angle sensing capability, and are easily mounted in a number of locations, predictive sensors have many advantages. Table XXI provides a summary of acoustic (ultrasonic, sonic), optical (laser, infrared), radar (microwave), radar-impact switch combination, proximity (capacitive, inductive), mechanically-extended probes, and electro-mechanical (inertial) comparisons.

A sophisticated sensor has been developed by Toyota which calculates and predicts the collision before it occurs by sensing relative speed and distance between the car and the object of the collision. The sensor includes an oscillator, circulator, detector, amplifier, and computer. A microwave is continually emitted which can sense an object. The Doppler effect by reflection of the wave triggers the IORS. This system is not G-dependent and requires only that an object be within a collision envelope around the vehicle. It is commonly known in the auto industry as the "radar sensor."

An additional system which is being investigated for its feasibility is the inertial navigation system (INS). In this case onboard gyroscopes and accelerometers which are already part of this system could be monitored by a special hazard predictor logic circuit to sense emergency situations. This could be coupled with onboard radar equipment to give a rather complete picture of the aircraft's safety status relative to impact. Data on INS has been obtained from the AC Electronics Division of General Motors. INS systems are currently used on commercial jet transports such as the Boeing 727 and 747 and are retrofitted on some Boeing 707's. This system has also been installed in one operational EC-135 according to AC Electronics.

A comprehensive examination of anticipatory sensing devices has been carried out by the Transportation Systems Center for the National Highway Traffic Safety Administration in order to determine basic system constraints and required operational characteristics [Hopkins, 1971 (929)]. Two promising methods were selected as deserving further study, including microwave radar and ultrasonic sonar.

TABLE I
COMPARISON OF CRASH SENSOR APPROACHES

	Acoustic (Ultrasonic; Sonic)	Optical (Laser, Infra-Red)	Radar (Microwave)	Radar-Impact Switch Combination	Proximity (Capacitive, Inductive)	Mechanically-Extended Probes	Electro-Mechanical (Inertial)
Advantages	Relatively easy signal processing due to lower frequencies (probably between 20 and 100 KHz); reflection coefficient depends on bulk modulus and density of obstacle, perhaps better correlation with mass can be expected when compared to microwaves; reduced vehicle-to-vehicle interference due to attenuation.	Allows accurate determination of target position; and size relative velocity measurement possible; solid state sources available; potentially low cost in 5 years in large quantities.	Allows position and velocity measurement of obstacle relative to protected vehicle; solid state sources available; potentially low cost in 5 years in large quantities; negligible attenuation for distances involved; essentially unaffected by temperatures, humidity, and precipitation; desired area of protection possible with some compromise.	Improved crash discrimination; other advantages same as in previous column.	Used in industrial controls applications; determination of relative vehicle speed possible with some compromise.	No significant advantages are apparent.	Good crash discrimination; inadvertent actuation can be eliminated; performance has been demonstrated in numerous tests; insensitive to environment; can be protected easily against vandalism; simplicity, small size, low cost; sensor response time improves as vehicle crashworthiness improves; analog relationship between sensing element and occupant.
Disadvantages	Performance degraded by by environment (ice, snow, mud, noise, debris); desired area of protection difficult to achieve; relatively high cost; much transducer development needed.	Performance degraded by foreign material in aperture — dust, fog, water, spray, snow, relatively high cost; desired area of protection difficult to achieve; inability to perform mass discrimination.	Radar echo may not be true indication of hazard posed by obstacle, i.e., poor crash discrimination; false alarm possibility due to inter-vehicle interference; no system actuation for certain impact configurations; relatively high cost; protection against vandalism may be difficult to achieve; inability to perform mass discrimination.	Inadvertent actuation still possible; limited reduction in crash sensor response time feasible which may not warrant associated cost increase.	Inherent problems in determining hazardous targets other than vehicles (especially inductive types); requires large sensing structure; sensitive to environmental conditions (especially capacitive types); inability to perform mass discrimination.	Probe must be struck; difficult to reduce to practice; only limited improvement in sensor response time can be expected.	Sensing and restraint actuation accomplished after contact between vehicle and obstacle; response depends on vehicle construction, impact speed, sensor parameters and location, and nature of struck obstacle.
Remarks	Ultrasonic system proposed by Sylvania. Automatically flashes warning light when vehicle travels at least 35 mph and comes within 25 feet of protected car, operates at 100 mw power.	Robert Bosch Co. found laser impractical for collision avoidance system.	X-Band, CW, Bistatic proposed by TSC* to DOT**; X-Band, CW proposed by Toyota; X-Band proposed by Bendix for braking; X-Band (10.5 GHz) proposed by Bentley Associates; radar found as impractical for collision avoidances system by Robert Bosch Co.	Proposed by TSC to DOT to overcome shortcomings of radar.	Collision avoidance system using inductive loop proposed by Robert Bosch Co., but termed "too expensive."	No concept proposed so far; probe can also be embedded in bumper bar.	Crash sensors of this type have been developed and used by Eaton, General Motors, Allied Chemical, and Hamilton Watch.

* Transportation Systems Center (TSC)

** Department of Transportation (DOT)

The radar sensor, comprising standard microwave components and solid state circuitry, was installed on a test vehicle for study. Results were reported to be promising but preliminary. It was stated that the complexity of the sensing task and the reliability demands on the system require extensive analysis and testing before a conclusion can be drawn as to overall viability. Table XXII outlines the applicability of various types of radar to automotive crash sensing [Jones et al., 1972 (936)]. The sonar approach is a translation of the radar sensor into acoustic form. Preliminary results suggested that environmental considerations and adequate target discrimination will be the major problem areas.

TABLE XXII.

APPLICABILITY OF BASIC TYPES OF RADAR TO AUTOMOTIVE RADAR

Radar Property type	Pulse Radar	CW Bistatic Radar	Noise Radar	FM Radar	Double-Doppler Radar(Pulse or FM)
Implementation	State-of-the-art (moderately complex)	State-of-the-art (simple)	Development needed	Development needed	Extensive development needed
Range .resolution .absolute value	 .variable .variable	 .one fixed range gate fixed by beam shaping	 .variable .variable	 .variable .variable	 .variable .variable
Doppler velocity	.available	.available	.not available .can measure velocity from multiple range gates	.available	.available
Threat .number (single or multiple) .direction	 .mult.,with beam scan and logic .with mult. range gates,beam-scan and logic	 .single .no	 .mult.,with beam scan and logic .with mult. range gates,beam-scan	 .mult.,with beam scan and logic .with mult. range gates,beam-scan	 .mult.,with beam-scan and logic .available on each resolved target
Jamming susceptibility	.low(with pulse coding)except for receiver blocking	.very high,unless some form of coding used	.very low	.low with waveform coding	.low with waveform coding
Health hazard	.high(peak power)	.low	.low	.low	.low
Complexity	.great	.simple	.great	.great	.great
Comparative cost	.high to very high	.low	.high to very high	.high to very high	.high to very high
Threat evaluation	.poor	.poor	.poor	.poor	.poor

Source: Jones et al., 1972 (936)

In addition to the types in Table XXII, new concepts are under research and development. A fluid crash sensor has been developed by Asahi Chemical Industry Co., Ltd., Japan, using the electro-magnetic effect of electric-conductive fluid (mercury) [Ikeda et al., 1974 (933)]. The electric conductive fluid flows in response to the acceleration force externally applied. The fluid velocity is proportioned to car velocity changes and can be detected by the electro-magnetic effect. The fluid movement can be restricted by the threshold-G level setting which utilizes the surface tension of mercury. The sensor consists of mercury as electric-conductive liquid, a permanent magnet, Y-shaped liquid passage, electrodes to detect liquid velocity, multi-hollow fibers as a G-level setting method, non-return ball valve, electronic voltage amplifier, comparator, and thyristor switches. This crash sensor has been found usable for a wide range from 10 to over 300 G's. Problems include the quality degradation and leakage of mercury likely to occur when used for a long period. Work is continuing on modification to a multi-directional type of crash sensor. Sperry Rand Corporation has recently proposed an electromagnetic detection scheme which may obviate many of the deficiencies of conventional radar techniques. The system is called BARBI, an acronym for BAsebond Radar Bog Initiator [Ross, 1974 (938)]. The proposed technique involves the transmission and reception of a sub-nanosecond basebond or video impulse-like signal (i.e., no RF carrier) and requires virtually no microwave components.

As of this date little objective data on crash deceleration profiles are available for transport aircraft. Previously reported tests have utilized Beechcraft C-45, Fairchild C-82, Piper J-3, Cessna 150, Douglas DC-7, Lockheed L-1049, helicopters, and other aircraft, but no experimental data relative to current jet transports are known, although extrapolations and calculations are found in various crashworthiness design manuals, and crash acceleration profiles have been assumed as a base in several studies (e.g., Yost and Oates, 1969 [682] for air transports, Carr and Phillips, 1973 [852] for light aircraft). Although the anticipatory sensors such as radar, acoustic, or optical systems, would appear to be promising as aircraft sensors, development and research have not yet progressed to the point where a particular system appears to be completely adaptable. In considering the best crash sensor for use with an inflatable restraint system concept for light aircraft, Carr and Phillips [1973 (852)] concluded that an inertia sensor was more appropriate than a radar or anticipatory sensor within the state-of-the-art at that time. Still a third alternative [Snyder and Robbins, 1971 (22); Diamond, 1973 (1005)] is active deployment of the inflatable restraint systems by a crew member when a crash situation appears imminent. This degrades the passive aspects of the system and also would not provide protection in the case of accidents where the impact occurs without adequate warning for the crew member to deploy the air bags.

At this time the data gathered in automotive crash testing are not directly applicable to aircraft crash sensors because of differences in crash pulse. Automotive crash pulses are of shorter duration, usually of greater magnitude, and primarily have a horizontal acceleration vector. It is concluded that information is still too incomplete for the selection of a reliable sensor system for the deployment of inflatable restraint systems in jet transport aircraft.

4.6.11.5 Inflation Energy (Gas) Sources. The function of the energy source is to provide, release, and control a volume of gas at a rapid rate to inflate the air bag. Basic energy sources include stored gas, generated gas, and hybrid sources, or looked at another way, stored gas, augmented air, pyrotechnic, and aspirator systems. Companies active in research and development of energy sources include Olin Corporation, Allied Chemical Company, Thiokol Corporation, Eaton Corporation, Rocket Research Corporation, Ensign-Bickford Company, Dow Chemical Company, and other domestic as well as foreign manufacturers.

At present there are seven generations of inflation systems which have been developed or are under development.

4.6.11.5.1 Stored gas system. This system provides a rapid supply of non-toxic gas for any size bag system. The stored gas system is by far the heaviest and most bulky of the systems being considered for introduction into motor vehicles. The air bottle, a thick-walled cylindrical pressure vessel with spherical caps at the ends, has a volume of 2.6 liters (160 cu in) and a filled pressure of 246 kg/sq cm (3,500 psi) for a right front passenger installation with a volume of 283 liters (10 cu ft). Representative systems have a weight of approximately 9 kg (20 lb). Because of the propellant properties of the bottle, a substantial structure is required to support it during bag inflation. The system has the advantage of a cool operating temperature and nontoxic gases.

4.6.11.5.2 Stored gas system with modulated flow. This is the same as the stored gas system with the exception that the gas delivery valve regulates flow to provide a gentler stage of initial inflation. This reduces the inflation sound level and the impact of the bag on an out-of-position occupant.

4.6.11.5.3 Augmented air system. This consists of a solid propellant which, when ignited, heats a small volume of stored air and then inflates the bag. The size of the package is much smaller than a stored gas system but there is some danger of toxic fumes. The system proposed by Olin Corporation supplements propellant energy with stored air. A prime advantage of this system is smaller storage volume. Specifically, a 283 liter (10 cu ft) bag requires only 983 cu cm (60 cu in) of storage compared with 2,622 cu cm (160 cu in) for a pure stored gas system. Olin has chosen aluminum alloy for system fabrication. As a result the Olin system compares favorably from the viewpoint of weight with the pure pyrotechnic device. An additional advantage is that the gases generated by the augmented air concept do not present a toxicity problem. However, when combined with the smoke which could be present in an aircraft crash, toxic levels would develop more quickly than would be the case when a pure air system is used. An additional advantage over a pure pyrotechnic system concerns bag surface temperatures which have been measured to not increase more than 21°C (70°F) above the test ambient air temperature. An augmented air system of this type appears to have some advantages over either a pure stored air or a pyrotechnic inflation device.

4.6.11.5.4 Augmented air system with staging. This is the same as the augmented air system with the exception that not all the propellant is ignited in low level impacts, thus leading to a soft bag for low level impacts and a hard bag for high level impacts. Staging has also been proposed as a concept to deal with the problem of multiple impacts. Stages of inflation could be added for each impact. This concept has been proposed informally by Eaton Corporation in their activities with Rocket Research Corporation.

4.6.11.5.5 Liquid-cooled solid propellant gas generator system. A solid propellant provides the gas source which is then liquid cooled, usually by freon. The major difficulties in adapting conventional gas generator technology to the inflation of air bag restraints relate to time, temperature, and toxicity problems. The air bag must be inflated in hundredths of a second, and the propellant combustion must be accordingly rapid. Cool-burning propellants must be used, or hot product gases must be cooled in the generator. Gases and smoke vented from the generator and cushion must be sufficiently safe that occupants are not injured.

In Sweden a study of the solid fuel gas generator has been reported [Jacobsson and Thoren, 1972 (943)]. A bag of 60 liter (2 cu ft) capacity was filled in 75 msec. Bag failure occurred in several cases, and was assumed to be due to the temperature of the solid fuel gas and its composition. A review of compact, all-solid gas generators is provided by Lane et al. [1972 (947)].

The use of a pure gas generation inflation system has several advantages as well as disadvantages when compred to a stored gas system. A typical system is approximately 30.5 cm (12 in) long and has a diameter of 8.3 cm (3.25 in). The shape is roughly cylindrical. The weight of prototypes is approximately 3.2 kg (7 lb), offering a considerable advantage over the stored gas systems. During inflation, the gas generator operating pressure is 211 kg/sq cm (3,000 psi) which is comparable with the stored gas system. A possible disadvantage is the bag surface temperature which can easily exceed 93° C (200° F). Because of the fact that a propellant is required for actuation of the system, certain federal regulations must be met in the transport of systems, either in bulk prior to assembly in a vehicle or by the vehicle owner himself. The legal problems of installing gas generation systems in motor vehicles have not yet been completely solved. Additional controversy arises over the presence of toxic gases resulting during inflation. The major problem appears to be carbon monoxide. Most of the gas generation systems appear to be minimally acceptable relative to carbon monoxide. Serious consideration must be given to the toxicity problem because of the fact that the aircraft could possibly be full of smoke due to the crash. Any additional toxic fumes in a marginal environment could present a serious problem. The major advantages of the system appear to be smaller size and lighter weight, fewer leakage problems, and greater design versatility.

4.6.11.5.6 Solid-cooled solid propellant gas generator system. This light system which is in the early stages of development appears to avoid toxicity problems by the addition of a mechanical filter for solid particulate matter and a chemical filter for toxic fumes, as shown in Fig. 77.

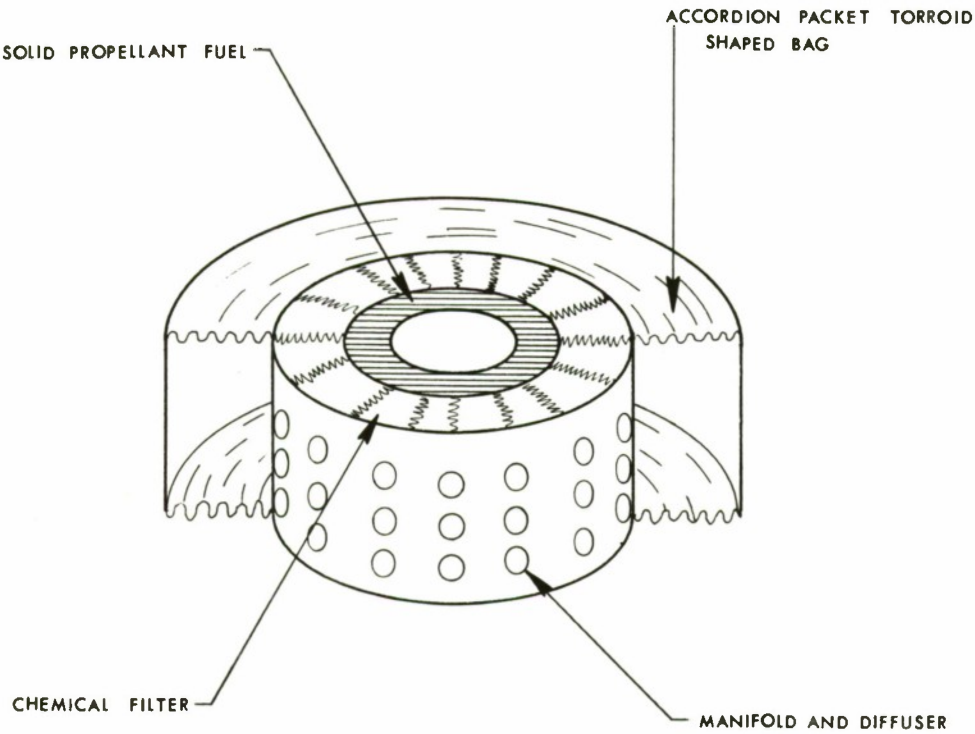


Fig. 77. Solid-cooled solid propellant gas generator system.

In January, 1976, the National Highway Traffic Safety Administration issued a request for proposals for development of a solid propellant inflation technique for the subcompact car passenger restraint systems. This study will also require review of the test evaluation of Thiokol inflators (Contract DOT-HS-801-748).

4.6.11.5.7 Aspirator systems. An aspirator is essentially a pump that utilizes the kinetic energy of one fluid to cause motion of another fluid. A primary high velocity fluid is supplied to the aspirator and its kinetic energy includes motion of the ambient fluid near the inlet. These two fluids pass through a mixing section where a portion of the fluids' kinetic energy is converted into an increase in static pressure. A generalized aspirator consists of a primary flow tube, an inlet area and a diffuser or flow channel.

Three types of systems are under early development. In the first of these air is mixed with the propellant gas to fill the bag with cool gas. In the second, support structure for the bag is inflated with a gas generation system and the remainder of the bag by aspiration of cabin air. The major concern is that the amount of ambient air used decreases as inflation time decreases. For a jet transport the available inflation time is probably sufficient to make this system particularly attractive. (See Fig. 78.)

A third aspirator system is the self-deployed air induction inflation system which has been proposed by Rocket Research Corporation. In this system a series of about 20 small thrusters is attached to the bag material. The thrusters are ignited by the sensor and actually push the bag out while drawing air into the bag. The mass of the individual thrusters is very low and the thrust forces are distributed over the air bag material. Therefore, if an occupant would contact the system during deployment, the local mass concentrations should not be large enough to cause injury. A considerable weight saving is inherent in this system because there is no need for stored gas or for a diffuser. A rough estimate of the weight of inflation hardware is .9 kg (2 lb). The weight of the gas source alone in the other augmented air systems and in the pure pyrotechnic system is 3.2 kg (7 lb), while the weight of the air bottle in the pure air system is about 9 kg (20 lb). Rocket Research Corporation is aiming to draw 80 to 90% of the inflation gas required to fill the bag from the vehicle interior. This obviously will result in a lower over-pressure in the vehicle which would be a great advantage when many systems are deployed. No data have yet been obtained concerning deployment accuracy of this system. If protective performance equal to the other systems is available and the low percentage of gases are found to be non-toxic, it would be a likely candidate for use in USAF transports, provided problems of heat where the thrusters contact the occupant's body are solved.

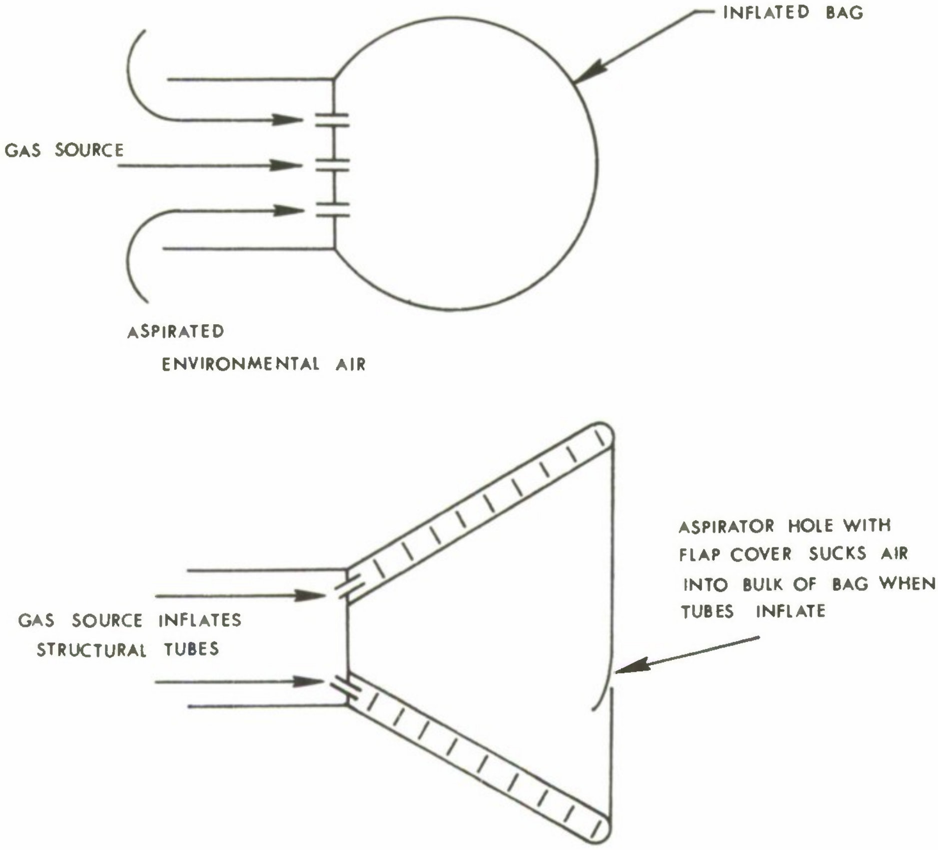


Fig. 78. Two types of aspirator systems.

4.6.11.6 Diffuser Design. The diffuser is that component of the system which delivers the gas supply to the deploying bag. As such it controls the rate and direction of flow into the bag. Therefore, the design of the diffuser is critical in providing a successful deployment.

Most diffuser designs which are used in right front inflating restraint systems consist of a cylindrical steel tube with a series of vertical slots through which the gas supply can flow. One important variable is diffuser diameter (as diameter is increased, slot area is also increased). Initial air bag tests at HSRI [Robbins et al., 1971 (909)] were conducted using a diffuser with a diameter of 5 cm (2 in). It was found that a small out-of-position dummy occupant placed close to the bag experienced potentially dangerous G-loadings on the head and torso due to bag inflation alone. When the diameter of the diffuser was increased to 7.6 cm (3 in), thus reducing the initial velocity of the deploying bag, the G-loadings were reduced to acceptable levels based on current human tolerance data.

Another aspect of diffuser design which was studied at HSRI is the effect of the slots on sound pressure levels [Nicholls, 1970 (988)]. The gas dynamics of the reservoir blowdown-bag inflation process have been considered and characteristic values of the more important parameters have been computed by the use of a somewhat simplified mathematical model of the system. A series of tests has been made to determine the noise level produced by various types of slots on a steady flow over a range of pressures. Schlieren photographs (still and high speed movies) have been taken of the flow from the slots. The preliminary data indicate that interference effects between the individual jets lead to higher noise levels than would be expected from increase of mass flow rates alone. Further steady flow tests of various slot configurations have been planned. It is anticipated that these steady flow tests will be compared with projected blowdown tests of a typical air bag system in order to define the characteristics of the major noise generating mechanisms and thereby indicate the techniques most likely to result in reduction of peak noise levels.

4.6.11.7 Human Volunteer Tests. Preceded by, and concurrent with, studies utilizing baboon subjects [Snyder et al., 1967 (791); Clarke et al., 1970 (7, 959)] and anthropomorphic dummies, several programs related to human subject tests and evaluation of air bag restraint systems have been conducted.

A program to compare man's subjective tolerance levels during impact using (1) a lap belt only and (2) a lap belt plus air bag was conducted at Holloman AFB, New Mexico from August, 1969 through March, 1970. This program was directed by the Aerospace Medical Research Laboratory, Wright-Patterson AFB under interagency agreement with the Department of Transportation. The experimental approach was to expose five male subjects to increasingly severe impacts until in the medical monitor's judgement testing should be terminated. The lap belt tests were conducted using a 4.4 cm (1-3/4 in) wide webbed dacron belt rated at 2,721 kg (6,000 lb) strength. Lap belt tests were terminated at 15 G since "there was a marked increase in severity of post-run neck and hip pain complaints and secondly, the mean lap belt load peak had risen from 760 lb at 12 G's to 975 at 15 G's with one subject's belt loading as high as 1,163 lb. Assuming a linear extrapolation to an 18 G level it was felt that a proper safety factor of belt strength to belt load could not be maintained"

[Bendixen, 1970 (955)]. Initial dummy tests with a pre-inflated air bag (plus lap belt restraint) were unsuccessful as it was too soft for subject support, although 3 human tests were conducted at 9 G. A hybrid air bag (plus lap belt restraint) was then developed, consisting of a pre-inflated bag into which additional gas was discharged during impact; however, films of six subjects being impacted at 12 G revealed an excessive amount of rebound accompanied by hyperextension of the neck. In a third series of tests, an Eaton, Yale and Towne rapidly-inflating air bag system (plus lap belt restraint) was used, with 5 volunteer test subjects impacted at 12 G.

The pre-inflated bag tests reported by Gragg [1970 (963, 964)] may have application to the current discussion in that there may be a short time before a crash occurs for the occupant to position himself in the restraint system. The conclusions of these tests were as follows: (1) The legs are able to transmit considerable force during an impact, which verifies the work of other investigators; (2) The bag is most effective when the occupant is in contact with it prior to impact so that he loads the bag before the belt, thereby eliminating the phase lag which can occur between belt and bag loading; (3) A version of this type air bag would reduce the incidence of head and thorax contact with hazardous interior surfaces during crash landings, materially reducing the fatalities and trauma resulting from such impacts; (4) The air bag gave the sled subjects a relaxed, confident feeling prior to impact and they were enthusiastic in their acceptance of the device; and (5) It was difficult to control the amount of bracing of the subjects' legs. This factor appeared to be related to the subjects' emotions.

A comparison between lap belt, Air Force harness, and air bag restraint systems was also reported by Gragg [1970 (963, 964)]. The air bags were deployed upon impact for this test series. In addition to similar results related to subject bracing, the following conclusions were reached: (1) The lap belt plus air bag lowered both impulse and peak force loadings to the pelvis when compared to the lap belt only (obviously because the loading is distributed between two devices during the air bag tests); (2) The Air Force harness produced slightly less reduction of the pelvic loading when compared to the lap belt only. In cases where the stiff belt system is snug, as was the case in these tests, the occupant tends to interact with the lap belt before reaching peak interaction with the softer bag. Thus the bag, as currently used, can do little to reduce pelvic or knee loads. The combination of an energy-absorbing lap belt in combination with the air bag can be shown to aid in overcoming this problem in phasing the forces applied to the occupant; and, (3) The lap belt plus air bag increased the foot loading significantly when compared to the lap belt only and the Air Force harness. Because of the potential of the legs for carrying impact loads this redistribution of loading is desirable.

A second test program involving air bags was conducted at Holloman AFB under inter-agency agreement for the National Highway Traffic Safety Administration of the Department of Transportation, utilizing General Motors Corporation "air cushion" developments. Extending from November, 1970 through August, 1971, tests included both static and dynamic deployments. Although these 1970 tests do not go further, and failed in their objective to reach subjective tolerance levels, much useful data were obtained. Important because they represented the first dynamic tests of human volunteer subjects exposed to rapidly-inflating air bag restraints, these tests showed that the lap belt plus air bag was capable of significantly reducing the impulses and peak forces transmitted to the pelvis when compared to the lap belt alone [Gragg et al., 1970 (963)]. The failure of these tests was subsequently analyzed by HSRI, the University of Michigan [McElhaney et al., 1971 (969)], and McElhaney also analyzed data gathered in a test program conducted by Bendixen [1970 (955)] at the Daisy Track, Holloman AFB. Analysis of the Bendixen study indicated that a lap belt plus a rapidly-inflating bag performs significantly better than the lap belt alone by reducing: (1) linear and angular head motion, (2) linear head acceleration, (3) shoulder motion, (4) pelvic pain, (5) foot pan load, and (6) seat back rebound load. Most of these observations agree with the results of Gragg. (See Table XXIII.)

Static tests were conducted in January, 1971, consisting of 41 human exposures to full air cushion deployment by 16 male volunteer subjects. These involved a production bench seat mounted in a 1971 GMC Chevrolet Impala, and seven different body positions were studied: right front passenger, center front passenger, right and center front passengers, and right front passenger with legs crossed, seated sideways, arms forward, and leaning forward. For this program the reliability of the air bag operation was 0.969, two failures occurring out of the 65 tests [Greer and Gragg, 1971 (966)]. The results of the Temporal Estimation Test indicated that the explosive inflation of the air bag disturbed the subjects' ability to perform a simple behavioral task for a duration of up to four seconds. During bag blossoming, the bag displaced the legs of subjects 3 to 11.2 cm (1.2 to 4.4 in) at velocities ranging from .5 to 7.9 m/sec (1.7 to 26 ft/sec). The arms were similarly displaced 4 to 43 degrees at an angular velocity of 112 to 517 degrees a second. Head velocities reached 7.2 m/sec (23.5 ft/sec).

Dynamic tests of 13 male volunteer subjects were conducted during the summer of 1971 at Holloman AFB, using the General Motors "production" air cushion ("soft bag"). An overall view of this series has been reported by Smith et al. [1972 (971)]. Problems found during the 1971 tests included: (1) rebound, (2) high head acceleration, (3) "bottoming" of the knees against the diffuser (subjects wore shin guard protection), (4) hyperextension of the knees, and (5) induced lateral head rotation.

A 1972 experimental design was intended to include 35 human runs, preceded by 12 to 20 dummy tests, at velocities up to 48 km/h (30 mph) in Phase I, and 35 runs with a different head rest design in Phase II. These were designed to duplicate some 80 dummy simulator tests conducted by General Motors [Buschman and Russell, 1972 (957); Smith et al., 1975 (973)]. Major differences between the 1972 production system to be tested in these tests and the preceding 1971 tests were in use of a larger bag (410 liters vs. 283 liters [14.5 cu ft vs. 10 cu ft]), higher pressure in the knee bag (.5 vs. .28 kg/sq cm [7 vs. 4 psi]), outer bag lower pressure (.14 vs. .5 kg/sq cm [2 vs. 7 psi]), entire bag porous (1971 bag only side panels porous), and inflator orifice size reduced from 2.5 to 1.5 cm (1 to .6 in). Although this results in a softer, more slowly deploying bag with better energy dissipation, it may increase the risk of bottoming out for larger individuals at high speeds. The 1972 tests using human volunteers were delayed from late spring until August due to deficiencies in the air bag protection found in the preliminary tests. A total of 33 impact tests were conducted with 13 subjects. Observed trauma was "mild" for all test subjects, and, as compared to the earlier program, Head Severity Indices (HSI) averaged 851 in the 1971 tests and 258 in the 1972 tests at 48 km/h (30 mph) [Brinkley et al., 1974 (956)]. The most adverse finding reported was a

TABLE XXIII.

SUMMARY DATA PEAK VALUES

Restraint System	Run No.	Subject No.	Weight #	Height cm.	Pulse g's	Lap Belt #	Foot Pan #	Seat Back Rebound #	Neck Pain	Pelvis Pain	Chest g's	Head* Δx in	Head* Δy in	Head* $\Delta\theta$ degrees	Head* $\Delta\dot{x}$ ft/sec	Head* $\Delta\dot{y}$ ft/sec	Head* $\Delta\dot{\theta}$ rad/sec	Head* $\Delta\ddot{x}$ g's	Head* $\Delta\ddot{y}$ g's	Head* $\ddot{\theta}$ rad/sec²	Shoulder* Δx in	Shoulder* Δy in	Knee* Δx in	Knee* Δy in	Thigh* Δx in	Thigh* Δy in	Thigh* $\Delta\theta$ degrees
Lap Belt Only	4795	144	158	169	8.3	240	717	594	-	-	7.0	13	9	47	29	10	8	11	5	200	7	2	1	1	1	1	5
	4796	146	199	176	9.8	563	384	975	+++	-	8.8	18	18	75	34	31	29	13	14	800	15	6	3	3	3	1	12
Pre-Inflated Bag	4800	151	178	177	9.4	683	131	140	-	-	9.6	18	5	65	29	6	22	10	4	1100	11	2	0	1	2	1	21
Lap Belt Only	5082	118	136	180	11.6	666	150	410	-	-	10.5	25	27	108	37	41	33	18	16	400	21	13	4	4	4	3	11
	5081	128	155	171	12.4	949	245	163	++	-	18.3	28	27	127	39	46	45	24	18	1600	19	8	5	5	4	2	20
	5077	144	158	169	12.6	687	445	673	+++	-	12.6	21	16	110	32	16	16	11	8	500	14	3	1	2	1	1	6
	5078	127	177	185	11.5	703	340	551	++	-	8.5	17	12	85	32	20	24	11	8	500	14	5	1	2	1	1	10
	5079	151	178	177	11.4	1030	282	760	++	+	22.1	19	16	100	37	28	45	17	18	1700	16	6	1	3	1	1	16
	5080	146	199	176	10.1	530	605	949	+++	-	17.3	15	14	72	31	23	24	11	10	400	11	6	1	2	1	1	9
Lap Belt Plus Hybrid Airbag	5095	118	136	180	11.0	603	101	240	+	-	15.2	13	1	20	36	3	14	25	3	550	1	1	1	1	1	1	8
	5094	128	155	171	11.9	147	283	880	-	-	15.0	11	2	62	36	5	31	19	5	1000	4	1	1	2	1	1	14
	5097	144	158	169	12.4	500	920	808	++	+	16.2	17	6	100	44	16	43	22	14	1200	1	1	1	1	1	1	7
	5096	127	177	185	13.0	990	262	980	++	-	17.2	15	6	70	41	13	30	20	14	700	3	1	1	1	1	1	6
	5099	151	178	177	12.1	1126	122	430	-	+	14.8	9	2	27	9	34	17	18	8	250	4	2	1	1	1	1	29
	5100	146	199	176	10.0	500	590	1348	-	+	17.2	8	3	19	33	8	26	32	10	1000	0	0	3	3	3	1	14
Lap Belt Only	5179	118	136	180	14.6	800	540	360	++	-	11.4	18	20	13	33	29	36	13	10	550	15	13	0	4	1	2	12
	5175	128	155	171	15.3	903	404	500	++	-	16.4	25	27	138	38	41	36	19	11	700	15	11	1	3	0	1	13
	5177	144	158	169	15.4	808	755	440	-	+	14.6	22	18	122	36	24	25	13	12	1050	16	7	0	3	0	2	9
	5174	127	177	185	16.8	1050	474	640	++	++	15.9	25	25	128	36	36	35	17	13	900	16	10	1	3	0	2	12
	5178	151	178	177	15.0	1163	370	860	++	-	18.3	18	18	23	33	29	41	14	11	650	18	9	0	3	1	2	16
	5176	146	199	176	15.4	1120	714	760	-	+++	23.4	23	22	102	31	29	39	13	10	1500	19	11	1	4	1	2	13
Lap Belt Plus Rapidly Inflating Airbag	5225	118	136	180	11.6	600	301	N/A	-	-	12.1	7	3	40	30	5	26	12	10	1100	3	1	1	5	2	1	15
	5224	128	155	171	11.3	780	560	N/A	+	-	12.1	7	4	38	19	8	27	8	4	480	8	2	0	2	0	1	12
	5226	144	158	169	11.8	510	686	N/A	-	-	11.6	10	3	76	34	6	22	8	5	600	6	1	1	2	0	1	3
	5227	127	177	185	11.8	600	368	N/A	+	-	11.6	7	1	43	3[illegible]	3	14	10	4	600	4	2	2	1	2	1	6*
	5228	151	178	177	11.8	890	144	N/A	+	-	16.2	7	3	61	27	10	20	9	14	600	3	2	0	3	1	1	10

- = No reported symptoms
+ = Immediate Symptoms Only
++ = Persisting symptoms 24 hours
+++ = Persisting symptoms 48 hours

*From photometric analysis

muscle spasm in one subject which continued for about a week after the test, and was explained as poor pre-impact body and head position by the investigators. Table XXIV presents a summary of the data from these most recent tests.

In the fall of 1973 the Southwest Research Institute in San Antonio, Texas initiated additional human volunteer studies under contract to General Motors to evaluate further aspects of air cushion protective performance. One series of tests involved "startle" experiments in which deployment (without vehicle impact) occurred in vehicles, with subjects from 17 to 72 years of age closely monitored for medical and physiological reactions. Other tests involved human volunteers exposed to air cushion deployments on a test deceleration to 48 km/h (30 mph) velocity. These data have not been published.

Although there appears to be some discrepancy between the same test data reported by different individuals and a tendency for some reports to favor the successes and minimize the problems, the fact remains that the air bag as reported tested to a maximum of 48.4 km/h (30.1 mph) (sled velocity) offers excellent potential as an occupant restraint system. (This same capability has also been shown by an advanced passive 3-point belt, with volunteer male subjects who were exposed to crash velocities of 48 km/h [30 mph]. These subjects tensed muscles, braced, and flexed the head prior to impact, and suffered no reported significant pain or injury [Hendler et al., 1974 (968)].) However, the human voluntary tests conducted to date using healthy young male subjects under optimum conditions, require continued research to explore potential effects of restraint systems upon other segments of the population. It is often overlooked that these tests were conducted with lap belts as well as air bag systems. Until tests of the air bag alone are conducted with human volunteers, its value as a purely passive system remains incompletely documented.

TABLE XXIV.

SUMMARY OF DATA FROM TESTS WITH HUMAN SUBJECTS

Test No	Subj No	Sled Accel (g_x)	Sled Vel (mph)	Head Accel Impact (g_x)	Head Accel Rebound (g_x)	Sever Index	Chest Accel Impact (lbs)	Chest Accel Rebound (lbs)
6507	A	9.3	16.0	15.0	4	31	12.5	5
6508	B	9.1	15.6	11.5	4	19	11.0	6
6510	C	8.3	14.9	13.5	3	18	14.0	3
6511	D	8.9	15.5	14.0	3	35	28.1	0
6514	E	13.0	20.5	22.3	9	89	14.0	5
6515	F	13.4	20.9	15.1	4	158	28.4	0
6524	C	13.4	20.9	15.2	6	97	15.0	3
6525	G	12.9	20.5	18.3	5	135	29.1	3
6528	H	15.4	22.0	22.0	3	298	30.0	3
6529	I	16.3	22.3	22.4	4	155	26.1	3
6531	K	15.2	21.5	20.7	3	216	15.1	X
6532	J	15.0	21.5	21.2	6	133	33.8	2
6534	M	20.0	24.0	19.1	11	359	24.9	5
6535	B	19.4	23.7	23.4	4	521	20.3	4
6537	E	19.2	24.1	19.2	3	160	29.6	3
6538	J	19.9	24.3	19.9	3	183	44.2	2
6556	B	19.0	24.2	19.0	9	94	24.5	3
6557	C	19.4	24.3	19.4	7	108	20.0	3
6540	G	18.1	25.9	32.7	3	297	38.0	2
6541	H	18.2	26.0	30.1	8	240	29.4	3
6543	I	18.7	26.5	26.9	10	216	27.4	6
6544	K	18.5	26.2	37.7	4	339	45.4	3
6559	E	17.6	25.5	24.4	1	200	31.9	3
6563	D	18.3	26.2	34.4	2	166	46.2	2
6564	F	18.2	26.2	37.1	3	168	22.5	2
6561	G	18.8	28.1	35.1	3	373	47.2	2
6566	I	19.2	28.2	34.3	12	420	26.0	9
6567	M	18.6	27.7	32.8	4	229	34.7	3
6569	B	19.5	28.0	26.6	1	127	31.7	1
6571	G	19.4	29.7	38.6	4	282	50.5	2
6572	C	18.7	29.8	28.6	X	150	35.0	3
6574	H	21.1	30.8	33.9	4	256	29.7	3
6575	M	20.3	30.1	34.1	4	297	32.6	3

4.6.11.8 Noise. Potential noise hazard from air bag inflation has been reviewed in a comprehensive study by Bolt, Beranek and Newman, Inc. [Allen et al., 1970 (975)] under contract with the NHTSA (Contract No. DOT-HS-006-1-006). The three objectives of their study were to: (1) establish tentative criteria for exposure to air bag noise, (2) find the noise levels expected in motor vehicles, and (3) estimate the percentage of the population, if any, where hearing might be permanently affected by widespread exposure to the noise of inflatable restraint systems.

This study concluded that, based on tolerance data developed during the project, exposure to a full complement of motor vehicle air bags inflated simultaneously could lead to hearing damage in 15% to 30% of the exposed persons. This indicates a considerable problem with air bags of 1970 vintage. They have also interpreted limited available information to conclude that various special groups (young, aged, infirm, or those with hearing related problems) are not substantially different from the normal population and therefore could be considered by their general tentative criteria.

The possibility of reducing the sound levels to more acceptable levels using available acoustical engineering techniques has been pointed out and recommended. For example, they estimate that a reduction of 15 db in air bag noise would ensure that essentially the entire exposed population would be protected from hearing damage.

Because of the tentative nature of their noise criteria the following research studies should be conducted: (1) psycho-acoustic studies of temporary threshold shift produced by pulses of noise and/or pure tones at the frequencies, levels, and durations anticipated for air bag deployment; (2) analyses of the noise signal as a function of frequency, duration, and occupant position for each of the several sources of noise in a deployment of a realistic air bag; and, (3) complete literature survey covering all types of impact noise exposure along with the physical and clinical aspects.

The diffuser system most prominently employed in delivering gas to an air bag system (a manifold with slots) has been subjected to a limited set of tests at the University of Michigan by Nicholls [1970 (988)]. The noise levels were determined for one, two, and three manifold type slots on a steady flow basis over a range of pressures. Still and high speed Schlieren photographs were taken of the flow from the slots.

The preliminary data has indicated that interference effects between individual jets lead to higher noise levels than would be expected from increase of mass flow rates alone. The conclusion reached is that the manifold slot configuration is capable of producing very high noise levels, when a large number of slots are supplied with expected operating manifold pressures. Although the configuration of the reservoirs, throat, and the manifold entrance section may, directly or indirectly, contribute to the overall sound level, the potential for noise reduction appears to be greatest in the area of manifold "slot" design. Both automobile manufacturers and suppliers are working on this problem with some apparent progress.

The question of human auditory response to an air bag inflation noise was also considered in an often-cited report by Nixon [1969 (989)] and in a subsequent report presented at the annual conference of the American Association of Automotive Medicine in 1970. However, this work failed to answer several key questions, such as would the direct slap of an air bag acceleration against the ear cause serious structural damage and hearing loss? And would the infant ear be more susceptible to noise trauma? Since the surface of the inflating air bag is traveling at a velocity in excess of 160 km/h (100 mph), and Nixon's subjects were never in direct contact with the bag, Richter et al. [1974 (990)] undertook further tests. Using infant squirrel monkeys in tests at the University of Michigan, no permanent hearing damage, eardrum perforation, or disruption of ossicles occurred at air bag velocities up to 160 km/h (100 mph) and a sound intensity of 150 db. Other studies have been conducted by General Motors Corporation [Hickling, 1974 (987)]. These reports generally minimized the noise problem for the general population based upon right front passenger air bag inflations in the presence of human volunteers. Although early industry work had indicated pressures of .35 kg/sq cm (5 psi) might be expected [Van Wagoner, 1967 (992)], subsequent developments have not validated such high pressures, and noise is not generally considered to be a problem. However, it is obvious that this area requires further research, particularly in regard to physiological effects on the occupant.

4.6.11.9 Toxicity. Since the air bag system utilizes a highly compressed gas or pyrotechnic gas source for inflation there is a possibility that if occupants of a vehicle are unable to egress immediately post-crash, they may be exposed to emissions which are toxic or which deprive them of critical oxygen. Due to the potential legal questions this is of concern to the suppliers and manufacturers, and attempts to reduce or eliminate this hazard have been studied. One of the most comprehensive reports in the literature is by Rocket Research Corporation [Schmidt, 1972 (997)], and another is by Olin Corporation [McDonnell, 1971 (996)]. Early air bags used compressed air (hence the name "air bag"). However, compressed air, particularly in augmented systems, was abandoned after finding a potential for reaction of oxygen with structural materials in the highly compressed air. Nitrogen or argon was subsequently used in compressed or augmented systems.

Hypoxia and suffocation may occur if the oxygen concentration in the car falls below its normal level through dilution with an inert gas such as nitrogen. The rate of breathing is increased 1.5 times at 10% O_2, doubled at 9% O_2, and tripled at 5% O_2. Stress on the cardiovascular system may also occur in an O_2 deficient environment, and prolonged exposure to less than 10% O_2 may not be survivable for some individuals. Cardiac arrest may occur within a minute when the oxygen content drops below 5% [Schmidt, 1972 (997)].

Early tests at General Motors indicated that inflation of a right front seat air bag only from a compressed nitrogen source resulted in the local O_2 content dropping below 13.5% and remaining there for several minutes. One of the trade-offs is that the cleanest gas generators and aspirators require more space and weight.

At the time of the 3rd International Conference on Occupant Protection (Troy, Michigan, July, 1974), the Society of Automotive Engineers Inflatable Occupant Restraint System Task Force met to consider the feasibility or desirability of preparing an information report containing guidelines for the use of chemically generated gas in air bag systems. Although it was obvious that there were a multitude of unknown factors requiring further study, this committee was disbanded. Tarriere [1972 (921)], in reviewing French tests with air bag systems, emphasized that generators using the pyrotechnic principle "still present an unsolved toxicity problem" and went on to conclude: "It is not even certain that the doctors in charge of determining the thresholds of tolerance possess all the elements necessary to make a judgement" (p. 6).

Lawwill [1972 (948)], in reviewing the potential reaction products of augmented inflators, found only three in sufficient quantity to be significant: carbon monoxide (CO), nitrogen dioxide (NO_2), and nitric oxide (NO). However, other gases produced include carbon dioxide (CO_2), chlorine (Cl_2), nitrous oxide (N_2O), sulphur oxide (SO), sulphur dioxide (SO_2), sodium chloride (NaCl), hydrogen (H_2), hydrogen chloride (HCl), hydrocarbons, ammonia (NH_3), water (H_2O), oxygen (O_2), potassium chloride (KCl), phosgene ($CoCl_2$), hydrogen sulfide (H_2S), and nitrogen (N_2). Dow Chemical Company [Lane et al., 1972 (947)] has conducted experiments with gas-generating propellants which yield only nitrogen gas or carbon dioxide, and report only minor effects on animals tested. Johnson et al. [1971 (944)] provides tables of gas analysis in the Olin Safe-T-Flate, and useful toxicity tables.

It is clear that at the present time there are no toxicological test procedures or guidelines available to engineers in selecting the propellants for the air bag restraint systems. Published toxicological data generally do not apply to exposures as brief as those anticipated in automotive collisions. A major problem is that data are not available concerning the toxicity of mixtures of gases, vapors, and particles likely to be encountered in such exposures. The question of toxicity effects has not received the research required to determine if potential hazards may be significant.

4.6.11.10 Accident Experience. A large number of air bag restraint systems have been placed in vehicles to date and approximately 75 accidents severe enough to result in bag deployment have occurred to date.

Ford Motor Company equipped 831 Mercurys with air bags for field testing in March, 1972. Of these, 203 went to Allstate Insurance Company, 101 to Allied Chemical Company, 323 to Eaton Corporation, 125 to General Services Administration, and 79 were retained by Ford Motor Company employees. In the third crash which occurred, an air bag-equipped Mercury struck the rear of a police car at 109 km/h (68 mph), according to the police radar tape, crushing the rear of it in 1.7 m (5.5 ft) [Yost, 1973 (1003)]. The driver escaped with a fractured wrist and leg cuts and bruises, and this is of particular interest in that the driver was not wearing a seat belt.

The "first" air bag accident (another Ford "first") occurred 9 October, 1972 in Santa Barbara, California and involved an air bag-equipped 1972 Mercury Monterey two-door hardtop that was struck at the right front corner by a 1966 Reo garbage truck. But since there was only a driver and no right front seat occupant, and the sole air bag was on the passenger side, little information was obtained concerning occupant protection. It is interesting to note that the driver, a claims adjuster for Allstate Insurance Company, indicated "that he experienced a pronounced ringing sensation in his ears immediately after the accident but that it had disappeared within a few hours" [Yost, 1972 (1002)].

The first General Motors air cushion deployment occurred 21 April, 1973, when a U.S. Park Police 1973 Chevrolet was hit at a curve by a skidding vehicle at 80.5 km/h (50 mph). The air bag deployed properly but it was not possible to determine the effectiveness of the system due to the nature of the impact. However, the driver's eye glasses stayed on, and he did not notice the noise of the deployment.

The General Motors Air Cushion Restraint System Field Trial Program was initiated in November, 1972 (subsequent to the successful human volunteer tests reported during August, 1972 at Holloman AFB), with an intent to place 1,000 1973 Chevrolet Impala 4-door sedans in high mileage fleets. Approximately 850 air cushion-equipped vehicles were actually placed in service. In the first year of operation, with over 19 million miles of fleet experience, there were 9 impacts of sufficient severity to cause deployment, and over 230 non-deployment accidents. There was also one inadvertent activation. These accidents have been detailed by Smith [1973 (1001)]. As of March, 1976, it is estimated that some 10,000 GM "air cushion" equipped vehicles are in service, having been offered to customers as an option.

O'Day and Morgan [1972 (1000)] calculated that if the first 1,000 air bags were put into operation in Denver, Colorado, 15 deployments might occur over a year's period, based upon current accident statistics. Using accident data from Denver in 1969, they theorized that of 40,140 accidents involving cars, only 6,923 (17.23%) were severe enough to have deployed an air bag. Only 30.7% of these cases (2,126 vehicles) reported any injuries. In comparison, using accident data from the Ohio turnpike over a 4-year period, they predicted that in air bag-equipped cars, deployment would have resulted in 4,046 out of 6,437 (63%), substantially higher than in the urban Denver environment. Based upon accidents studied in England, Mackay projected that to obtain benefits equal to those of passive air bag systems, seat belt usage would have to be 78%, considerably higher than present experience in most countries. However, he concluded that "because of the incidence of ejection, multiple impacts, side, rear and rollover accidents, seat belts have greater benefits in the real world of accidents than airbags as currently envisaged" [1972 (999)].

Air bag deployments in actual collisions to date have provided some useful data, although inconclusive to date. Frontal impacts up to 16 km/h (10 mph), and side and rear impacts at 40 km/h (25 mph) did not deploy the bags. There have been no adverse effects from noise, nor reported toxicity effects (although no occupants were trapped in the environment for an extended time). There have been three fatalities in air bag vehicles to date, although one case would not have been survivable with any protective system. Two individuals were smoking pipes, and received insignificant injury from the deployment. It may be significant to note that of a large number of legal actions resulting from air bag-equipped vehicle accidents, one lawsuit against General Motors alone is for 8 million dollars. More field experience will be necessary before further conclusions can be drawn, as the data to date are insufficient.

4.6.11.11 Air Transport Application. The foregoing has provided a brief summary of current data relative to many aspects of the air bag inflatable restraint system which may be considered important to aircraft application. Reviewing each of these suggests that while major advances have been made in some technological aspects, almost all areas present problems which have not yet been resolved for the automotive vehicle after a decade of effort and at considerable cost.

To date, other than the pioneering work of Clark and Blechschmidt at the Martin Company [1966 (863); also (850, 854-862)], the only published study relative to assessing air bag feasibility based upon recent (but not present) technology in aircraft consists of a preliminary conceptual study for light aircraft only [Carr and Phillips, 1973 (852)]. One dynamic test and several static tests of a prototype system for light aircraft have also been conducted by the FAA [Sommers, 1972 (919)]. McDonnell Douglas has developed a foam-filled air cushion, integral with the seat back cushion, which can be inflated and deflated at will and which conforms to the individual body contours [Hawkins, 1974 (671)]; however, this is a comfort item rather than one which provides occupant protection.

The most direct recent application to air transport occupant protection has probably been made by the F.L. Diamond Corporation of Granada Hills, California. In 1973 they initiated development of an inflatable air bag which was designed to mount in the back of an airline seat. The initial prototype was designed for a McDonnell Douglas DC-10 passenger seat, and the seat back was protected by an asbestos shield. Initial activation was intended to be by means of either manual operation or operation from the flight deck, although the manufacturer felt that it could be electronically activated by means of a variety of sensors [Diamond, 1976 (1005)]. As shown in Figs. 79-82, this restraint system stows compactly in the seat back along with the passenger's emergency oxygen system. Activation of the prototype shown is by means of the same size carbon dioxide cylinder used for inflation of pneumatic life preservers (MIL-C-25369A Type# 137.5 gr). The prototype bag holds approximately 13 liters (793 cu in) of gas and has dimensions of 30.5 cm (12 in) wide, 28 cm (11 in) high, and 7.6 cm (3 in) deep. Weight of the prototype system, including the container structure, is approximately 2.9 kg (6.5 lb), less than previous estimates of Clark (863) and Carr and Phillips (852), but does not include any electronic initiator device. The air bag and CO_2 inflation system itself weighs only 435 grams (14 oz). (It should be noted that these data have been obtained from inspection of the prototype device and are not manufacturer's specifications.) In contrast to current automotive inflatable restraints, which would cost from $75 to $300 each to replace each time used, the Diamond system is equipped with a simple exhaust gas release, and once the bag has been deployed, it can be packed up again and reused immediately at no cost except for a new CO_2 cylinder. At present this device is only in a prototype stage and would require further development and dynamic testing; however, the concept and application to air transports merit further consideration.

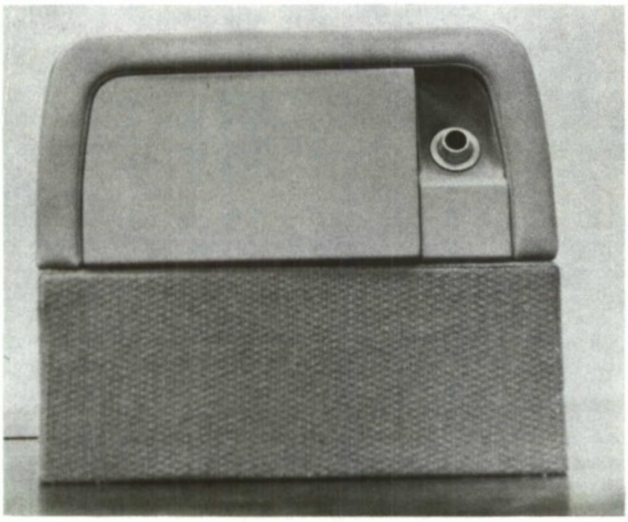


Fig. 79. Prototype inflatable air bag restraint system stowed in passenger seat back, under development by F.L. Diamond Corporation, Granada Hills, California.

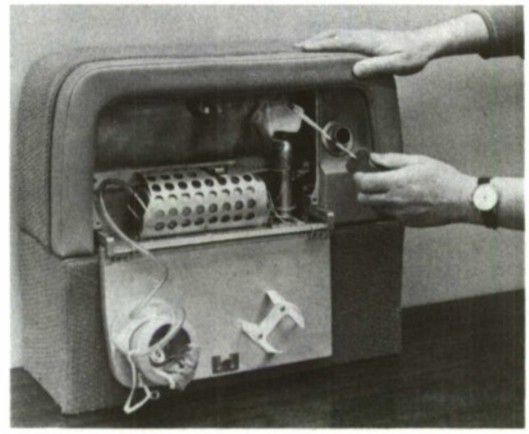


Fig. 80. Cover removed, showing stowage of bag at top, CO_2 cylinder at right. Activation is manual in this prototype.

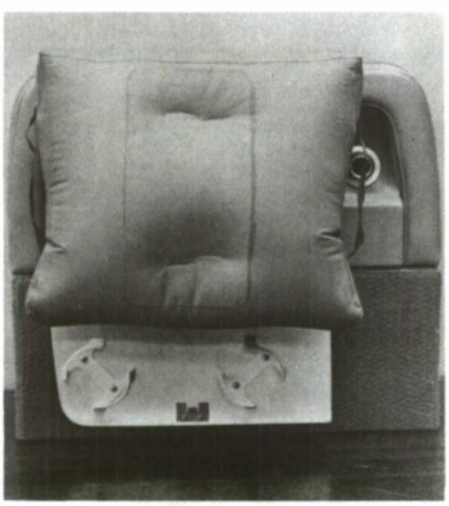


Fig. 81. Once the bag is inflated, it forms a protective cushion for head impact.

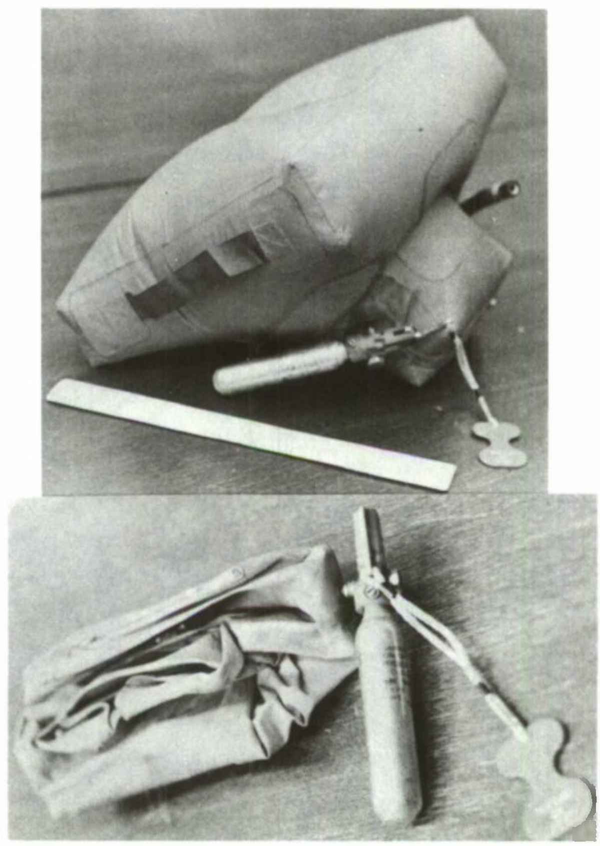


Fig. 82. The inflatable bag, shown in deflated and inflated configurations.

One important consideration for civil air transport use of passive restraint systems, besides economic, maintenance, and reliability concerns, is whether additional weight penalty may be involved. Carr and Phillips [1973 (852)] have estimated additional weight requirements for general aviation air bag restraints as 3.63 kg (8 lb) per occupant. Assuming similar bag specifications and requirements for air transport aircraft, this would add over a ton weight penalty to a wide body transport. Earlier Clark et al. [1966 (863)] had estimated their four chest and foot bags and inflating system would weigh 7.26 kg (15 lb) at each double seat; however, the prototype double airline passenger seat designed at the Martin Company, Baltimore, for testing weighed only 15.87 kg (35 lb), compared to the standard 26.76 kg (59 lb) airline seat being used at that time by air carriers. Thus use of a lighter seat could nullify the weight penalty of air bag systems, provided the seat met other operational requirements including strength and comfort factors.

At present the air bag remains extremely controversial, with proposed federal mandatory requirements for passive restraint (air bags) for automotive use continuing to be postponed by NHTSA. Since it is not within the scope of this study to discuss this in greater detail, primary references which should be examined for in-depth information would include data in the FMVSS 208 docket (898), the 1973 Congressional Hearings (865), the Office of Science and Technology RECAT report (900), especially the evolution of the state-of-the-art on restraint systems to 1972 by Brown (1004), and papers previously cited in the 1st, 2nd, and 3rd International Conferences on Occupant Protection/Passive Restraints [1970 (899); 1972 (917); 1974 (918)]. In addition to the Brown overview and assessment of passive restraint systems in the RECAT report (900, 1004), NHTSA research efforts and conclusions have been reported by Carter [1972 (853)] who predicted an automotive 80.5 km/h (50 mph) capability for the air bag system, in a report by Strother and Morgan [1974 (920)], in discussion of societal priorities [Warner et al., 1975 (925)], in a number of mathematical modeling reports [King et al., 1972 (885); Robbins et al., 1971 (909); Hammond, 1971 (875)], and in numerous other reports and studies related to economic, technical, and protective aspects of the air bag. A favorable report has also been issued by DeLorean [1975 (879)]. While a cost/benefit critique is found in Gates [1975 (874)] and in RECAT (900), NHTSA has also published an extensive bibliography [1973 (1006)] and "Vital Facts" (924). The Insurance Institute for Highway Safety has published a chronological review (Status Report, 21 February, 1974, vol. 9, no. 4). Unfortunately, like the Concorde, the air bag has become entwined in political aspects rather than strictly technical issues.

Results of extensive tests, accident data, and human volunteer testing clearly indicate that the air bag restraint system, as developed for automotive vehicles, is capable of offering excellent occupant protection in frontal collisions of a severe nature. However, often such data have been obtained in conjunction with a lap belt restraint, which means that the air bag system is not entirely a passive restraint under such conditions. Further, questions of occupant protection in side impact, rollovers, multiple impacts, and in a number of other modes have not yet been adequately answered by the current air bag systems. Since the automotive crash conditions differ significantly from those encountered in air transport crashes, it is uncertain how this system will work in aircraft until further testing is conducted. No system of crash sensor, for example, is yet known to be capable of reliably sensing an impending aircraft crash (the FAA Carr and Phillips light aircraft conceptual study recommended active mechanical sensors, and the Diamond prototype air bag is at present manually operated). It is concluded that, while the air bag system is promising, at this point in the state-of-the-art, the NASA Ames air transport seat, the rearward-facing seat, or one of several integral restraints would offer better all-around crash protection for the air transport passenger.

5. AISLE AND EVACUATION MARKERS

Accident data from a number of studies indicate that in most "survivable" jet transport crashes to date occupant survival has been largely determined by the ability of uninjured passengers to leave their seats and find an exit before succumbing to fire or smoke. The aisle and evacuation path markers, placards, lights, and other devices which assist in efficient and orderly evacuation in case of a crash emergency must be considered with respect to known human factors considerations such as size, illumination, color, background, form, location, and ease in understanding, as well as reliability, maintainability, and system safety aspects.

Aisle markers and emergency evacuation path markers include reflective tapes, signs, arrows, and non-radioactive luminous strips for use in marking evacuation routes. In addition, other products can be applied to floors, wainscotings, and other interior surfaces. While some require a self-contained power supply, other systems require no power supply at all. Aisle width requirements are also briefly examined in this section.

5.1 Aisle Width

Due to the variable cargo/passenger configurations of military air transport aircraft there is no standard aisle width. For civil jet transports minimum aisle width is specified by Federal Air Regulation 25.815 (1010) as not less than 38 cm (15 in) measured less than 63.5 cm (25 in) from the floor, and 50.8 cm (20 in) measured 63.5 cm (25 in) or more from the floor, for air transport aircraft having a seating capacity of 20 or more passengers (Table XXV). Part 25.817 of the FAR's also specifies that on airplanes having only one passenger aisle, no more than 3 seats abreast may be placed on each side of the aisle (1011).

TABLE XXV.

CIVIL AIR CARRIER PASSENGER AISLE WIDTH REQUIREMENTS
SPECIFIED IN F.A.R. PART 25.815

Passenger Seating Capacity	Minimum passenger aisle width (inches)	
	Less than 25 inches from floor	25 inches or more from floor
10 or less	12	15
11 through 19	12	20
20 or more	15	20

A typical incident points out an unanticipated problem with current (FAR) civil air carrier aisle widths. As a result of inflight turbulence encountered by a Boeing 747, 6 passengers and one stewardess were hospitalized and 15 passengers and one stewardess received minor injuries [Flight Safety Focus, 1971 (1012)]. Injuries were caused by failure to wear seat belts during the turbulence, failure of overhead storage bins, and failure of economy seat headrests; however, following landing, great difficulty was encountered in removing injured passengers because the aisles were too narrow for standard stretchers. Fig. 16 (Section 2.2.1.6) shows the litter in the aisle and in the passenger cabin as a result of an Icelandic McDonnell Douglas DC-8 crash.

On military aircraft minimum aisle width conditions occur when maximum capacity seating accommodations are required for troop movement. Examples are 154 troops being carried in the maximum density seating configuration of the Lockheed C-141A in which four rows of side-facing nylon collapsible seats extend the length of the cabin area. In instances where troops are being airlifted for long distances and must remain in these cramped quarters for long periods of time, significant decrement in their task performance has been reported [Knapp, 1971 (1014)]. For example, the aisle spacing between the inner- and outer-facing rows on each side of the cabin is so small that it has been found that at night a passenger cannot proceed up the aisle to a comfort station without climbing over (and waking up) many others. In practice, therefore, Knapp reported that passengers climbed along the center netting rather than use the crowded aisles. When two rows abreast of triple aft-facing seats are used in the Boeing C-135, the aisle width is also minimal (1016). However, even when cargo is carried, the spacing left along the sides for passengers to reach an exit may also be marginal. In the case of one Boeing C-135 crash illustrated in Fig. 19, note that the spillage of small cargo into the left-hand aisle effectively blocked that aisle completely, contributing to the fatalities of four individuals. It is not uncommon for already narrow aisles to be further littered with debris and baggage after a crash, as many of the civil air carrier accident reports have indicated.

Since the aisle width specifications of the FAR were established 25 years ago in a 1951 study by King (1013), and there is known to be a significant generational body size increase, current anthropometric data were examined to provide a means of comparing a 38 cm (15 in) minimum aisle width (at 63.5 cm [25 in] floor height) with the potential aisle user. In this regard the 1967 anthropometric survey of USAF flying personnel [Clauser, unpublished data, 1971 (1008)] shows that the mean airman hip breadth is 35.25 cm (13.88 in), the 95th percentile is 38.48 cm (15.15 in), and the 99th percentile is 40.23 cm (15.84 in). If an allowance for clothing is made, it appears that a 38 cm (15 in) aisle width at hip height will be a tight fit for much of the potential military male user population, and many would be forced to go through this narrow space sideways, which would also slow down evacuation time. Females would probably exceed these male values by an estimated 2.5 to 5.1 cm (1 to 2 in). However, the most recent public health survey has not yet been published for the statistic of hip breadth in the general U.S. population. Further human factors or anthropometric data can be found in Damon et al. [1971 (1009)], Mohler et al. [1964 (1015)], and Alexander et al. [1971 (1007)].

In the BAC/Aerospatiale Concorde the first and last seat in each cabin has been modified to provide the minimum aisle width as specified in TSS Standard 5-2 and FAR Part 25.815.

To assist the passenger in emergency egress, several aisle and evacuation path marker concepts have been proposed. These include the application of chemical luminescence for emergency signs, direction indicators, egress areas, and for marking and identifying emergency equipment; ultraviolet light activation of egress signs; use of fluorescent spray; tactile aids; floor level marker illumination; and pulsating indicators.

5.2 Chemo-Illuminescence

Two principal systems which employ chemical reactions for the production of visible light ("chemical light") have been developed. One system developed by E.I. duPont de Nemours and Co. and marketed by Remington Arms Company employs a chemo-illuminescent material which, upon exposure to oxygen in the air, produces visible light. This material is utilized inside long, sealed transparent plastic tubes for illumination of the side tubes of the escape slides carried aboard some civil air carrier transports. Activation of the inflation system injects air into the sealed tubes and therefore activates the material, producing visible light. It can be provided in any width or length. Since only air is required to produce light from this chemical, advantages appear to be that it can be isolated from other lighting systems independently and presents no fire or explosion hazard. It is also reported to be fail-safe, lightweight, submersible, and to have long maintenance-free standby life. This system can be applied to emergency signs, direction indicators, emergency equipment, life rafts, emergency exit doorways, life jacket devices, and for illuminating controls and egress areas, as well as escape slides or other devices. United Airlines has used chemical luminescence for a number of years to outline escape slides and to provide some exterior illumination.

Another system developed by the American Cyanamid Company employs two liquids which, when brought together, produce visible light which may be piped to various points in order to illuminate specific areas. Similarly, a two-compartment container has been produced which, when squeezed, fractures a barrier or ampoule of one liquid so that when they come in contact a visible light is produced. A variety of concepts utilizing these materials have been pursued. These include a Remington Chemical System suspended in a gel base which will float on water producing light all around a life raft or downed aircraft. A potential exists for development of a pencil in a wax base or a marker which may be used to write on surfaces in light. It is possible that the American Cyanamid 2-liquid system can be packaged in a two-compartment aerosol container, activation of which could produce a cloud of light in the air. Many of these potential uses are under current investigation and development. "Liqui-Light" is presently being manufactured and sold, for example, for a wide variety of uses. Lasting a minimum of 3 hours, it is advertised as being "more safe than candles or flares and more sure than flashlights, Liqui-Light won't blow out, needs no batteries or outside energy source of any kind that could fail, does not spark or ignite--eliminating possible explosions--and works in rain and even under water. Small and lightweight (only 6 inches [15 cm] in length, weighing less than 1 ounce [28 grams])...Liqui-Light can be stored for two years without losing its effectiveness" [General Aviation News, 1974 (1018)]. In general, chemo-illuminescence formulations producing the highest brightness also exhibit the shortest duration. And the longer the duration, the lower the initial brightness.

Chemo-illuminescence was evaluated for the FAA in 1968 [Roebuck (15)] and it was concluded that "reliability would be improved 100 percent" through use of this concept in egress path marking applications. Test data, properties, and characteristics are as follows:

The light output is a function of ambient temperature, the humidity of the activating air, and the form in which the product is prepared. Brightness varies from 65 foot-lamberts downward; for comparison, a 600-volt electro-illuminescent light has a brightness of about 20 foot-lamberts. Duration of useful light output ranges from 5 minutes to 4 hours.

However, Strongin [1969 (1017)] reported emission life as between a few minutes and 2-3 hours, with light outputs up to 35 microlamberts. The light spectrum covers the entire visible range, with a peak in the vicinity of 500 nanometers wavelength (blue-green). It requires approximately 35 cc (2.1 cu in) of air at atmospheric pressure to completely oxidize the active chemical in 6.5 sq cm (1 sq in) of a "chemical light" panel. Light output ceases after complete oxidation.

(1) Weight of "chemical light" devices: 6.5 sq cm (1 sq in) of light area of a panel weighs approximately 1/2 gram (.016 oz).

(2) Heat generation: It is cold light, and is not subject to spontaneous combustion.

(3) Light stability: Not affected by exposure to visible light.

(4) Storage life: In its sealed container, and with storage temperature below 48.8° C (120° F), "chemical light" can be stored for about 2 years.

(5) Chemical compatibility: It is compatible with inert materials such as saturated hydrocarbons, nylon, teflon, mylar.

(6) Toxicity of active ingredient: The amount of exposure to the active chemical which will occur with normal use of a "chemical light" device will have no harmful effect. However, if a large quantity of the active chemical contained in such a device is ingested, or placed on the skin or in the eyes, and allowed to remain for a long period of time, or if a concentration of its vapors is inhaled for a long period of time, mild temporary irritation may occur. Irritation can be avoided by washing out the chemical (or inhaling fresh air) immediately after such overexposure.

(7) Testing of chemical light devices: It is not necessary to turn on a "chemical light" device to determine whether it is in operating condition. A "passive" check can be made with ultraviolet light.

(8) The characteristics which make "chemical light" useful in solving unusual lighting problems are the following:

- (a) Unlimited variety of shapes and sizes in flexible or rigid form.
- (b) Requires no power supply.
- (c) Isolated system; submersible.
- (d) Long standby life.
- (e) Lightweight and unbreakable.
- (f) Reuse: requires replacement of sealed bags. The check for capability to light is inexpensive--it is performed by exposing to ultraviolet lamp.
- (g) Duration: can be produced for variable times, sufficient for most crash egress requirements.
- (h) Crashworthiness: excellent.
- (i) Toxicity: No toxic effect reported.
- (j) Vision: Greatly improved.

Chemical light could also be useful in marking emergency evacuation routes. While it has been reported to be very effective in increasing visibility under conditions of darkness, no information on visibility under smoke conditions has been noted.

Reflective arrows which indicate passenger direction to the nearest exit have been suggested as an aid to emergency egress [Brown, 1969 (3)]. These could be placed on the cabin walls or along the aisles on the floor. However, retroreflective materials which reflect light (they do not glow or emit light) are only useful as long as a light source is available. Such arrow markers could be painted with a fluorescent paint or could use chemical light for illumination in conditions of low visibility. Some air carriers, such as American Airlines, presently use arrows and/or rough surfacing on the top of the wings adjacent to the fuselage for emergency egress.

5.3 Electro-Illuminescence

Electro-illuminescent tapes have been developed which may be applied to the upper surface of the escape slides or used to outline the configuration of emergency exits, pathways, etc. In electroluminescence, an insulated, phosphor-coated panel is activated by an electric current in the ranges of 125 to 600 volts, although 400 volts is most commonly used. It has been used for dials and panels but not extensively. Disadvantages of the electroluminescent system include requirements for a relatively high-voltage energy source and problems associated with failure due to bending the tape at sharp angles when slide rafts or escape slides are packaged.

5.4 Ultraviolet-Activated Pathway Systems

These systems employ a floor covering treated with an ultraviolet-sensitive material which is activated by ultraviolet radiation sources, or utilize an ultraviolet light source and special fluorescent spray lacquer, or other material normally not visible in incandescent light. Evacuation markings could thereby be placed on floors, walls, seats, or emergency egress exits. A patent application was made by Luminex, Inc., Santa Barbara, California; however, there is insufficient data available to evaluate this as a potential aisle marker system. Evidently this concept would utilize an ultraviolet collimated (indirect) light source with battery power. Aspects of toxicity, wear resistance, smoke scattering of light, and compatibility with other strong white lights are unknown. The principal disadvantages are the relative high electrical power requirements for the ultraviolet sources and the relatively low level of visible light which results. This level of light may be rapidly obscured by low concentrations of smoke in the cabin. Alternative techniques appear to offer greater improvements at this time.

5.5 Self-Luminous Sources (Tritium)

Current air carrier aircraft utilize self-luminous exit markers which employ gaseous radioactive H_3 (tritium). The tritium gas is sealed in a cerium glass envelope, the air surface of which is coated with a zinc sulfide phosphor [McFadden et al., 1965 (1020)]. Radioactive bombardment of the phosphor produces visible light. This assembly is embedded in a lucite envelope, and since tritium is primarily a beta-radioactive emitter, there is no detectable radiation at the surface of the unit. If broken, the light tritium gas dissipates into the atmosphere very rapidly. It is postulated that for an individual to absorb significant quantities of radiation from such a source, the individual concerned would have to breathe the gas for a number of hours in a very confined area.

Self-luminous sources have been developed for life rafts to aid in boarding and detection. The principal disadvantage of self-luminous sources is the relatively low level of illumination provided by the system, since care must be taken not to exceed the allowable quantity of tritium as permitted by the U.S. Atomic Energy Commission. A detailed radiation safety analysis has been made and published in the Federal Register (12 September, 1961) prior to granting of a general license for use of tritium self-luminous devices in aircraft [AEC, 1962 (1019)]. Recent developments have produced units with double the brightness of former units. Duration of luminescence is primarily a function of the half-life of tritium (12.6 years). The tritium self-luminous light source has several advantages. It is very reliable and operates continuously since no external mechanical or electrical devices are required for its activation, and it is also insensitive to environmental extremes.

5.6 Phosphorescent Markers

Phosphorescence is the property of a material to emit light in the visible spectral range after all outside excitation of the material has ceased. Phosphorescent materials which are exposed to a light source (incandescent, fluorescent, sunlight, etc.) will continue to glow in the dark for extended periods of time after the removal of the light source. Such materials are available in the form of paint or plastic film with pressure-sensitive adhesive. There are two basic types of phosphorescent materials: those with a blue color, which contain CaSnS pigment providing a low initial glow and low long afterglow, and those with a green color which contain ZnS pigment and characteristically provide a high initial glow and, in some types, a long low afterglow. The paints have been used in some aircraft dials and vinyl pressure-sensitive signs have been used in some air carriers [Strongin, 1969 (1017)]. They can be used on exit signs in case of a power failure, but are dependent upon prior excitation by an independent light source.

5.7 Incandescent Sources

Incandescent sources are used extensively for general cabin illumination, specific illumination level requirements for aisles, as well as over emergency exit signs and for spot illumination near exits. Most of these systems utilize rechargeable batteries at each source. These batteries are triple-charged by the aircraft electrical system and are activated by the drop-out switch upon failure of the main aircraft system. The inertial switching system is no longer utilized extensively in air carrier aircraft. Incandescent sources are also utilized to illuminate escape pathways on the wing by installation of light fixtures in the rear junction with the wing. Incandescent fuselage-installed light sources are used to meet requirements for illumination of the escape slide and the ground at the end of the slide. Small wiring harnesses utilizing miniature "wheat bulbs" were developed which may be affixed to the upper surfaces of the escape slide in order to illuminate them and to define the geometry limits and attitude of the slide.

To penetrate a concentrated smoke environment a higher initial brilliance, with less duration (10 minutes), would seem an improved tradeoff for current lower brilliance with 30 minutes duration. There has been disagreement among experts in this area.

5.8 Gaseous Discharge Systems

Xenon strobe lights powered by small batteries have been developed and extensively utilized as survivor locator lights. In general these lights emit approximately 100,000 illumins per flash at a rate of 50 to 60 flashes per minute. Small units emitting approximately 1 million illumins per flash have been developed for use on life rafts. This type of unit was evaluated in the FAA crash tests of transport aircraft units carried out in Phoenix, Arizona in 1965 (1021, 1022). The unit was installed at the emergency exits as an aid to locating the exits from the outside of the aircraft during a rescue operation. It was noted that even after the exits had been covered with about 5 cm (2 in) of water foam, the flash of the strobe light was clearly visible through this material even under bright desert sunlight conditions.

5.9 Floor-Level Lighting

Emergency evacuation environments involving degraded visibility due to smoke or darkness suggest that floor-level lighting could decrease egress time, since smoke least obscures the area of the floor. This type of lighting could be battery powered and automatically energized in case of loss of the main power supply, or could be activated manually by the crew. If lighting consisted of floor-level flood lighting, fluorescent or incandescent lamps could be mounted on walls or seats to illuminate aisles or exits, or electroluminescent lamps could provide illumination for pathway markings. Due to the variable cargo/passenger configurations in military type aircraft, such a system might not be as practical for military as for standard civil air carrier aircraft.

5.10 Directional Aisle and Evacuation On-Off Lights

In this system progressive on-off timed lamps give an impression of movement (similar to segmented automobile turn signals, neon outdoor advertising signs, or runway landing light systems) which are intended to catch the passengers' attention and direct them toward emergency exits. The lamps could be located on the ceiling, the side of the fuselage, the sides of aisle seats, or in other locations where they would be most visible during emergency evacuation conditions. This system reportedly has the capability to increase exit and egress route visibility, distribute passengers to various exits, and to thereby provide for optimum evacuation flow.

This concept could be manually operated by the crew or used in automatic mode. Crew control panels would consist of on/off (each unit), directional control (each unit), test control, and manual override. This permits the crew to manually control the initiation of the system and to control the direction of the signal for control of passenger flow. This also allows the crew to test the system or use it as part of the preflight briefing.

For automatic operation, the system could be equipped with sensors which detect conditions requiring evacuation (g-load or heat) and unusable exit conditions (heat, structural deformation). Thus, the system would activate upon detection of excessive impact or fire and then select proper directions to primary exits. For example, by using heat sensitive sensors, lights near a burning area would not activate, leaving only pulsating lights in a non-fire area.

The directional signals could be located on the walls, possibly along the molding or luggage racks, as well as on the ceiling and floor, which would make them conspicuous even during conditions of poor visibility or abnormal aircraft attitude. Another possible use of directional signals would be in airport terminals where the signals could function both to orient and direct boarding passengers. The directional signals can be composed of standard lamps or electroluminescent material. The latter would permit installation in a more inconspicuous manner until actuated. The lamps would momentarily illuminate progressively toward the preferred exit, thereby serving both as directional indicators and exit locator aids. The intensity and flash rate of the lamps could be such as to permit the perception of movement and to ensure visibility in expected degraded visibility conditions. These magnitudes would have to be selected by laboratory tests. It has been proposed that a slower flash rate could be used for boarding and deplaning under normal conditions than would be used for the emergency conditions.

All of the components of this concept are within the current state-of-the-art. Although no readily adaptable units have been identified as available, no development difficulties are evident. Maintenance and repair costs could be relatively low if high-reliability solid-state timing and control devices are used. Fail-safe logic for circuitry could be the greatest problem, and sensor reliability is also critical. A small effect on aircraft structure and interior decor is foreseen, but space requirements are negligible.

This pulsating light system offers a significant increase over current techniques in informational content, both as to exit location and recommended direction for egress. The selection of flash rate and intensity is important for effectiveness in evacuation conditions of reduced visibility caused by darkness, smoke, or flame. Electroluminescent displays would require careful evaluation in this regard. The capability for manual operation by the crew must be carefully considered to ensure operability and ability to correctly select displays and directions. Factors to be considered must include determination of control location, visibility of crew, and awareness of conditions (external fire or hidden structural damage) which can influence the capability to operate the system. For these reasons, the proposed system should be primarily designed for automatic operation.

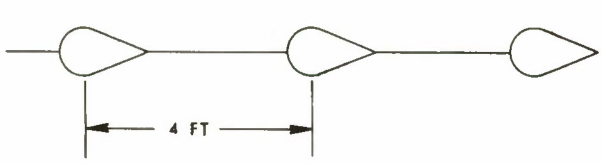
An evaluation of this system for the FAA was conducted by North American Rockwell [Roebuck, 1968 (15)] and at that time it was concluded that such a system would provide a significant improvement in passenger emergency evacuation flow under a variety of egress conditions. It was considered to be compatible with existing systems, and estimated that in cases of exit blockage or crowding this concept could improve flow by 10% or 30% "in situations requiring redirected flow."

5.11 Tactile Aisle Markers

The purpose of tactual indicators is to provide a means of directional identification of emergency exit locations and/or equipment under conditions in which visual cues are not available. Such markers need rely on only the sense of touch. Other advantages over other path marker concepts are that tactile indicators would be available no matter what the aircraft attitude, and are independent of any power requirements or environmental conditions. Markers could be placed on the floor (to provide directional information), the ceiling (for situations when the aircraft is in an inverted attitude), the sides, backs, or tops of seats, or on the walls (to locate emergency equipment). Such indicators could be located to provide a continous source of cues from any seat position to exits or emergency equipment.

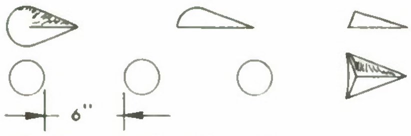
Limited research and development has been done on this concept. The idea has been advanced occasionally in the literature (<u>Aviation Week and Space Technology</u>, 1966), and description of the concept was included in the FAA evaluation of emergency evacuation concepts [Roebuck, 1966 (15)]. From this report the following tactual indicators were suggested:

(a) Wire, cord or other runners with periodic direction indicators (arrows)



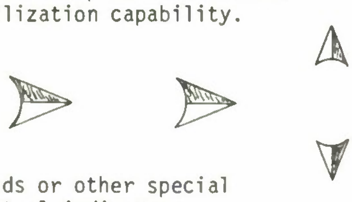
Particularly useful on ceiling where the possibility of interference with egress is minimal. Technique allows continuous and therefore very rapid use.

(b) Raised buttons or beads with pointed sides indicating direction, or periodic arrow.



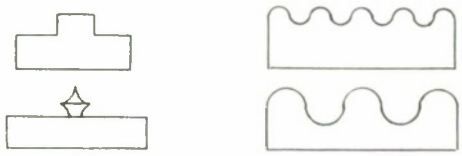
This technique is particularly useful on floor areas for crawling, or where continuous hand contact can be maintained and where minimum disturbance of surface, carpet or upholstery is required.

(c) Series of directional arrows raised to provide a tactual utilization capability.



These are similar to technique (b). Potentially, they could be combined with ultraviolet indicators, should such a system be evaluated and developed, to ensure quick, reliable utilization.

(d) Grids or other special tactual indicators.

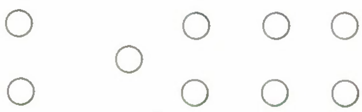


These are useful in indicating arrival at exit or equipment location - also useful on top of seat to indicate aisle with exit. These would be selected shapes which have been proven unambiguous.

(e) Raised numerical indicators.

(1)

(2)

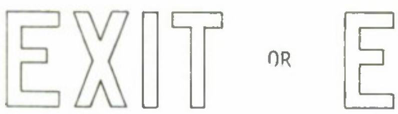


This technique could be useful to indicate number of feet, steps, or seats to equipment or exit.

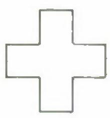
(f) Raised name, symbols, or abbreviation indicators.

This technique could be useful to indicate what is at end of series of tactual indicators.

(1)

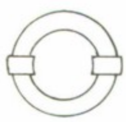


(2)



(first aid kit)

(3)



(life raft)

The tactual system would be designed as a backup system to the visual displays utilized for emergency egress. It would be most useful where visual cues are lacking, for example, at night with no emergency lighting, or in conditions of heavy smoke. Since it would be a passive system however, it is preset and could be in conflict with other than normal egress patterns when passengers must be redirected. In this particular, limited situation it might actually slow down evacuation. The concept was rated as having very good cost effectiveness and was estimated as improving chances for survivability by 50% in cases where poor visibility influences emergency egress.

The Aerospace Industries Assocation reported tests of the use of tactile aids for locating exits during adverse visual conditions. These tests were conducted by Douglas Aircraft Company in 1967 [Oden and Altman (1023)]. Fourteen subjects were tested individually under smoke conditions, using the accuracy of the direction indicated and latent response criteria to evaluate eight different tactile shapes. These forms were evaluated for two different thicknesses, 3.2 mm and 6.4 mm (1/8 and 1/4 in). Thus 16 different test conditions were evaluated. The tactile cues used in these tests are illustrated in Fig. 82a. The experimental design required the subject to place his left hand into a box that held the plywood tactile form and, by feeling this form, indicate its direction. This was done as rapidly as possible by turning a knob on a display board at the top of a box with the right hand and subsequently pressing a button to shut off the timing device. None of the tactile forms in the box were visible to the subject.

Results of these tests indicated that the teardrop-shaped (13-16) and elongated-triangle-shaped (5-8) forms were significantly better shapes with which to indicate direction. This result was evidenced by quicker response times, significantly fewer errors, and fewer reversal errors (180° out of phase). The thickness variation (3.2 mm to 6.4 mm [1/8 to 1/4 in]) made no difference, but a subject preference was indicated for larger forms. The 5 cm (2 in) elongated triangle was recommended as the best tactile form tested. However, when groups of people were tested under evacuation simulation, it was found that tactile cues were relatively ineffective. Subjects used them infrequently, preferring to hold onto the person ahead, and additional time was lost in using them.

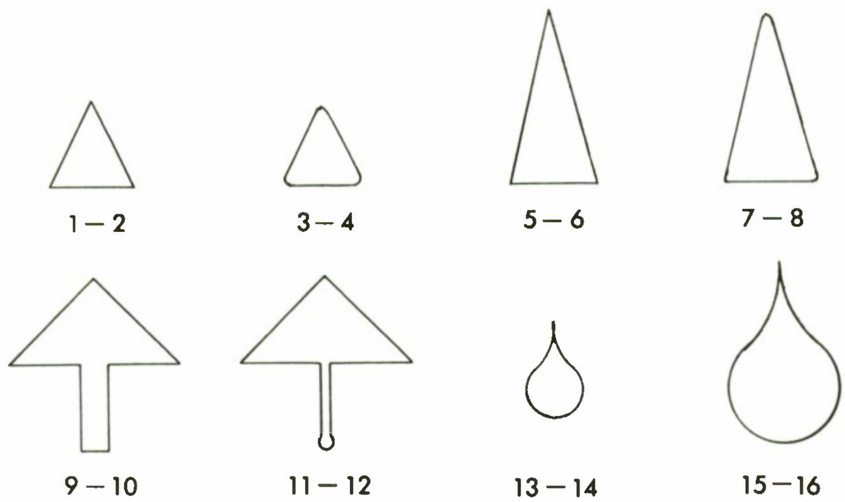


Fig. 82a. Shapes of 1/8 and 1/4 inch tactile cues used in AIA tests (1023).

5.12 Other Considerations and Requirements

In some accidents it has been found that crowding may occur, with disastrous results, when too many people try to use the same exit. This has been reported in several accidents, including the 1974 Pan American Boeing 707 accident at Pago Pago (276), the United McDonnell Douglas DC-8 accident at Denver (397, 424), and in one military Boeing C-135 accident with 11 fatalities (22). Aisle blockage has been reported to have hindered emergency egress in the 1973 Iberian McDonnell Douglas DC-10 accident at Logan Airport where 5 passengers were trapped in the rear (275), and the 1973 Delta McDonnell Douglas DC-9 crash at Chattanooga (274). It is also observed in the numerous instances where only a few of the available exits are used, such as in the McDonnell Douglas DC-8 military charter crash at Anchorage (209). Thus, directional aisle marking systems should consider the distance to the nearest exit.

In 1971 FAA standards were put into effect relative to emergency lighting under FAR, Part 25.812 (1025). This standard on emergency lighting systems requires, independent of the main lighting system, inclusion of emergency exit marking and locating signs, sources of general cabin illumination, entrance lighting in emergency exit areas, and interior emergency lighting. Each passenger exit sign and each exit locating sign must have white letters at least 2.5 cm (1 in) high on a red background at least 5.1 cm (2 in) high, which can be internally electrically illuminated, or illuminated by other than electrical means with an initial brightness of at least 160 microlamberts. The average illumination along the center line and the aisles at 101 cm (40 in) intervals must not be less than 0.05 foot-candles. The passageway floor leading to the emergency exit must be lighted.

In addition, exterior emergency lighting must be provided with illumination not less than 0.02 foot-candles at first step outside cabin, not less than 0.05 foot-candles for a .6 m (2 ft) width along 30% of the slip-restraint escape route that is farthest from the exit, illumination of at least 0.02 foot-candles on the ground surface at each overwing exit (with gear extended), and illumination of not less than 0.03 foot-candles at the ground from each non-overwing emergency exit. This FAR further specifies that the energy supply to each emergency lighting unit must provide the required level of illumination for at least 10 minutes. In case of a crash landing where the fuselage has separated, the emergency lighting system must be designed so that "after any single vertical separation" not more than 25% of all emergency lights are rendered inoperative. Emergency slide lighting is excluded from these requirements, but must serve one slide only, be independent of the main emergency lighting system, and be automatically activated (Amendments 25-28; 25 September, 1971).

The FAA at present has no aisle and evacuation path marker requirements as such for civil air carriers. However, FAR airworthiness standards for transport category airplanes [Part 25.811 (1024)] require emergency egress markings for exits which have several related items. Part 25.811(b) states that "the identity and location of each passenger emergency exit must be recognizable from a distance equal to the width of the cabin." If applied to the military Boeing C-135A, this distance would be 3.3 m (10 ft, 9 in), or little more than three rows of passenger seats. This appears to be completely inadequate, especially due to the distance between emergency exits. For example, on the left side of the passenger/cargo area of the military configuration, there is over 13.7 m (45 ft) distance between the rear-most passenger position and the left overwing escape hatch. It is very difficult at present to visually see exit signs and directions unless the passenger is seated adjacent to an exit area, or has been carefully briefed.

Society of Automotive Engineers Aeronautical Recommended Practice for emergency placarding [ARP 577A, 1963; 3.3.3 (1027)], in contrast, suggests that emergency exit "instructions should be legible from a minimum distance of 72 inches [183 cm] within a subtended angle of at least 45°...". This appears to be one of the few instances in which an SAE recommendation may be exceeded by an FAA requirement (for larger aircraft). ARP 503B (published July, 1971) (1028) relates to emergency illumination; however, civil requirements differ from those of military standards (as specified in MIL-L-6503 and MIL-A-25165).

Civil emergency exit marking is specified in FAR 25.812. Military specification MIL-A-25165 B(ASG) concerning identification of aircraft emergency escape systems does not specify a distance or visual angle at which emergency exit identification must be seen by the passenger, although letter size is specified (3.8.2) as:

"Size - 'EMERGENCY EXIT' signs inside the aircraft shall be preferably 2 inches high [5.1 cm]. The lettering of instructions shall be approximately 1 inch [2.5 cm] high where practicable, and shall in no case be less than 1/2 inch [1.2 cm]. 'EXIT RELEASE' signs on the exterior of the aircraft shall be at least 1 inch [2.5 cm] high." Types of markers mentioned in the military specification include the use of decalcomanias, radioactive luminous markers, reflective markings and emblems, but specifies that radioactive paints shall not be used.

In the Aerospace Industries study, emergency exit signs were recommended to have a brightness high-to-low contrast ratio no greater than 3 to 1 and a background-to-legend contrast ratio of at least 10 to 1. It was also found that flashing exit signs are not more effective [AIA, 1968 (1023)].

Improved aisle and evacuation markers would result in a marked improvement in passenger evacuation flow, speed egress, and reduce post-crash confusion. Some concepts would also offer a means of finding an exit where no vision is possible (tactual) or where smoke or darkness have reduced normal visual cues (directional pulsating lights). The present state-of-the-art offers several feasible and practical means for greatly improving evacuation through improved marker systems. Manufacturers of the various aisle and emergency egress illumination systems discussed in this section are listed in Appendix F.

6. PASSENGER WARNING AND PUBLIC ADDRESS SYSTEMS

6.1 Background

The primary purpose of passenger and crew warning systems is to permit either the aircraft commander or any crew member to inform all other crew members and passengers instantly and simultaneously of an existing or impending aircraft evacuation.

Alarm warning experience in civil air carriers is difficult to evaluate and has been varied. Crashes during landing or takeoff phase, when pilots are fully occupied with crew duties, often occur suddenly and preclude activating an alarm. The 1971 crash of the MAC charter McDonnell Douglas DC-8 aircraft operated by Capitol International Airways, during an attempted takeoff in freezing rain at Anchorage, Alaska is a case in point (209). More puzzling are cases where the alarm system is not used when there is adequate time for preparation. The ditching of the Dutch Antillian Airlines McDonnell Douglas DC-9 in the Caribbean Sea, for example, was anticipated by the captain far in advance of the actual event (10, 11, 12, 485). Although he instructed the purser to brief the passengers for a possible ditching 10 minutes prior to the actual impact, no further warning or alarm, visual or aural, was given prior to the ditching. This resulted not only in many unrestrained and unprepared passengers, but even the crew was unprepared, with the navigator and purser both being unrestrained at impact.

Deficiencies in the passenger warning system were evident in this St. Croix McDonnell Douglas DC-9 transport crash, and further studies have been spurred as a result. In this accident the regular public address system became inoperative prior to impact, and some passengers were still standing up while donning emergency equipment at the time of impact. Because no one-minute warning was received, many passengers undoubtedly received injuries which might have been prevented with an adequate emergency signal system.

As a result of three years' study, the FAA has adopted a new rule after an NPRM (No. 72-6) was issued in early 1972. The new regulation became effective 8 September, 1973, but gave operators two years (to 8 September, 1975) to comply [FAA, 1973 (1031)]. This regulation requires air carriers, air travel clubs, and air taxi operators to have electronic public address and interphone systems on all aircraft operated with more than 19 passenger seats. Previously there had been no FAA requirement for public address and interphone systems, nor any requirement that they be operational when installed.

Under the 1973 regulation the public address system must be accessible for immediate use by flight crew members on the flight deck and at least one flight attendant in the passenger compartment. The system must be clearly audible throughout the aircraft. The interphone must be operable independent of the public address system and must provide two-way communication between the flight deck and at least one flight attendant station. In addition, the 1973 (1975) FAA regulation requires that the interphone system on large turbojet aircraft contain an alerting system, incorporating both aural and visual signals, to notify the recipient of an impending emergency or normal call. The interphone system must also provide communication between ground personnel and at least two flight crew members and, separately, between ground personnel and at least one flight attendant. Both the public address and interphone systems must now be operational at the time of takeoff. At present both the McDonnell Douglas DC-10 and the Lockheed L-1011 have excellent evacuation signal systems.

The alarm system currently utilized in military transport aircraft is manually activated from the pilot's station. Normally this consists of a guarded toggle switch within reach of the pilot or copilot. HIAD (AFSCM 80 80-1; H. 4.3) specifies that signal lights and alarm bells be installed in Air Force aircraft according to MIL-L-6503 and international military standardization programs (A10.1.1). Standard alarm bell signals are:

(1) Immediately after takeoff: 1 long ring - brace for impact.
(2) Inflight/crash landing or ditching: 6 short rings - fasten belts securely, 1 long ring - brace for impact.
(3) Inflight/bailout: 3 short rings - don parachute, 1 long ring - bailout.
(4) On the ground: 3 short rings - prepare to abandon, 1 long ring - abandon aircraft.

Previous evaluation of this alarm system by Reagin et al. [1970 (13)], in studying emergency escape from USAF transport aircraft, concluded: "...the use of the emergency alarm bell was found to be practically worthless. In five of the accidents reviewed, the use of the alarm bell was a significant factor. It was used successfully in only one impending accident in which 30 minutes warning time was available for preparation of the landing. In two cases, the alarm bell definitely contributed to the panic of passengers. In another case, it was stated that it was used; however, the surviving passengers did not recall hearing it. And in the fifth attempted use, only two rings of the bell could be accomplished prior to impact. In the majority of the accidents where the alarm bell was not used, time and the priority of crew duties precluded its effective use."

In the 1971 study of military Boeing C-135 and Lockheed C-141 aircraft accident experience, Snyder and Robbins found that the alarm bell was utilized in only five of these C-135 accidents; however, further analysis indicates that only ten of these accidents involved a crash landing situation where an alarm bell would have been expected to be used (21, 22). Thus in Boeing C-135 accidents at least, the alarm bell has been used in approximately 50% of the cases where a crash landing and emergency egress were imminent. The major reasons for non-use, as was also found in the report of Reagin et al. [1970 (13)] were: (1) lack of sufficient warning of the impending crash event and (2) the crew's occupation with controlling the aircraft at a critical point in the flight path. In two cases where the alarm was not used, the crash occurred on landing approach and was totally unexpected by the pilots; in two cases the crash landing occurred during takeoff with insufficient warning, and a fifth case involved control problems requiring the pilot's full attention.

While these represent only a limited number of accidents involving only two types of military air transport aircraft, these cases do suggest that the alarm bell has been an effective device in the particular circumstances where used. In all five cases the alarm bell was reported to have been heard by occupants and was the primary pre-crash source of warning, even though in one case there was a communications failure.

Besides the alarm bell used by the Air Force and most civil air carriers, other techniques proposed include flashing, stroboscopic, and continuous light warning systems, while audible public address systems include warning horns, buzzers and bells, as well as verbal public address systems and bullhorns. In the event of a false alarm or averted emergency situation, or to reduce the noise and panic level once all occupants have been warned of an emergency, a signal of some kind must be available which is easily distinguishable from all other flight deck/cabin signals and which must not cause panic among passengers.

One factor which may skew the statistics relates to crew training. In a type of long-range air transport operation where accidents are rare and pilot proficiency in emergency procedures is also comparatively rare, one might expect less use of an alarm system when a critical crash emergency occurs than in another command or mission where continuous practice of engine-out landings or emergencies are simulated, under the same potential crash conditions. Most actual emergencies occur during takeoff or landing phases of flight when the crew is busiest. Thus when an emergency requiring the use of an alarm system occurs, it seems possible that prompt use or non-use during the brief time prior to impact may well vary with the particular pilot's proficiency in emergency procedures.

The author, aircraft commander of a North American B-25J (with 8 crew aboard) which sequentially lost both engines on takeoff, found sufficient time existed to warn all passengers with the bell system prior to crash landing in a farm yard. It is his personal opinion that crew training is a critical factor in ability to successfully use any emergency warning system. While one might expect greater proficiency in emergency procedures among military aircrew than among civil crews, for whom such emergencies may be less frequent, unless civil air transport crews are subjected to frequent training involving emergency procedures, accident experience shows about equal usage (or non-usage). It would be instructive to review current alarm bell usage in both civil and military transport accidents in greater detail.

Review of Federal Air Regulations (Part 25; Part 121) revealed no specific requirements for civil air transport aircraft related to emergency evacuation signal systems prior to the new regulation effective 8 September, 1975, except as related to the bullhorn (Part 121; Part 309). In regard to this equipment, the FAA only requires that there be an emergency evacuation signal system and a statement of its location. The bullhorn is a portable, battery-powered lightweight megaphone. Fig. shows a typical installation in a civil air carrier aircraft, located in the aft section at the end of the overhead storage rack.

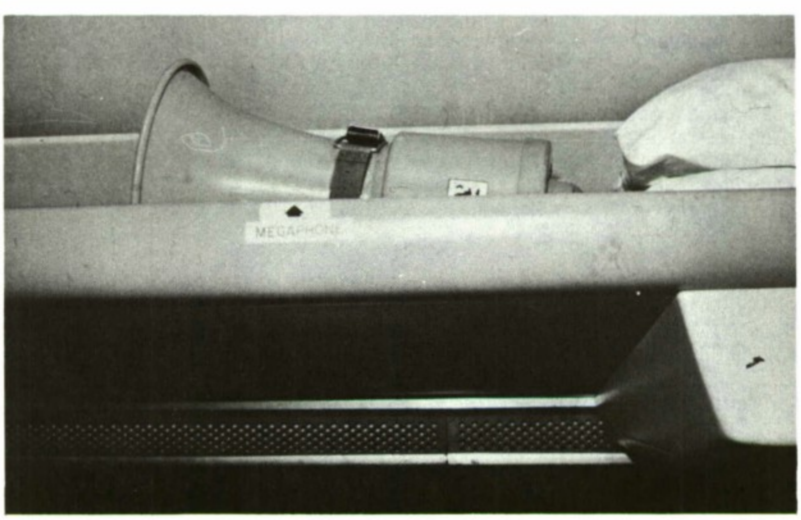


Fig. 83. Typical bullhorn emergency public address system installation in civil air transport.

However, a number of inquiries to SAE committee members, stewardesses, airline safety personnel, and crews have not resulted in identification of any case of actual emergency egress usage of the portable emergency bullhorn carried in current civil air transport aircraft; although it has been reportedly used in non-emergency, non-stress situations when the cabin communications system has failed in flight.

In Aerospace Industries Association (1968) evacuation tests involving audible horn cues, the horn was ranked as least effective (behind seat placard, voice cue, and tactile cue) in usage, and more subjects (63%) felt their way out.

6.2 Portable Solid-State Voice Amplification Devices

Review of the current state-of-the-art has not revealed any alarm system concepts which appear to offer significant improvement over the current bell alarm, inadequate as it might be in its dependence upon manual actuation. The North American Rockwell study for the FAA [Roebuck, 1968 (15)] explored several systems. One concept involved use of a miniaturized solid-state voice amplification device worn about the neck by cabin crew on takeoff. Two advantages were that it was instantly ready to provide independent communication to passengers as a lightweight replacement for the bullhorn, and it freed the hands. However, it is of no use until the individual wearing it is warned from the flight deck, thus does not solve the problem of initiating the initial alarm. A modification of this concept was the idea proposed that all crew wear miniaturized solid-state inter-communication equipment on takeoff and landing. In this concept a flip-up microphone and head set would be connected to a long cord through bulkhead jacks and control switches at intervals of 2.4 to 3.6 m (8 to 12 ft) apart. Using a battery power source this would provide high-power 15.2 cm (6 in) public address speakers at 3.6 m (12 ft) intervals.

6.3 TWA Emergency Evacuation Signal System

For several years Trans World Airlines has utilized a combination aural-visual system in all of their aircraft. The TWA Emergency Evacuation Signal System was developed by TWA and is described by Ogilvie [1968 (1032)]. Battery-powered, the audible alarm consists of 2,800 cycle tone pulses three times per second and of 90 db intensity, thus differing significantly from engine noises or other confusing sounds. The present system is dependent for activation on the pilot alone, although the original system was designed so that it could be activated by either flight deck or cabin crew. In the original version, a red light and solid-state flash provided a visual "EVAC" signal at the stewardess station to warn the stewardess of an emergency. This was to warn the stewardess but not the passengers. In case a cabin attendant initiated an evacuation the captain was warned by a flashing red light on the pilot's panel. The idea behind this was that evacuation may be initiated by either cabin or flight deck crew. However, the cabin initiation portion has been taken out of the system after several recent inadvertent evacuations have occurred; in at least one case passengers received egress injuries. Thus the current system remains a manually activated alarm similar in concept to the military type, except for the tone and intensity. Adaptation of this system might result in a more readily identifiable alarm, if in fact accident data show that the current alarm has not been heard or results in confusion in a significant number of cases.

6.4 Video Tape Presentation of Passenger Safety Information

Video tape presentations of passenger safety information normally provided by flight attendant briefing and safety cards have been found to be very successful in increasing passenger retention of vital information. Development of video techniques has primarily resulted from long-term efforts by the McDonnell Douglas Aircraft Company [Altman, 1975 (1035); Johnson, 1973 (1037); Johnson et al., 1975 (1038)]. First adopted by Chrysler Air Transportation in Grumman Gulfstream G-2 corporate operations, the system is presently used by American Airlines in a video tape cassette version of the flight attendant safety equipment demonstration on its McDonnell Douglas DC-10 equipment [Aviation Week, 1975 (1036)].

6.5 Conclusions

While no off-the-shelf device currently appears ideal, the current interest of the FAA in development of a better PA and alarm system and the new FAA standards (1973/1975) implemented, suggest that further improvements in the state-of-the-art may be forthcoming. The critical need for a public address system for evacuation using an emergency electrical power source has been previously expressed by both Air Force human factors reports related to accident investigation and civil air transport researchers. Video tape presentation of passenger safety information has resulted in better information retention than flight attendant briefings using information cards to date, and should receive widespread adoption when practical.

7. ADVANCES IN EMERGENCY EGRESS CONCEPTS

7.1 Background

Air transport accident statistics clearly indicate that improved methods and techniques for providing safe and reliable emergency egress for occupants should have priority consideration. Problems of aircraft attitude, physical condition of passengers, presence of smoke, fumes or fire, post-crash physical and mental condition of aircrew, aircrew efficiency and training, interior configuration, and structural damage in the crash impact, among other factors, are important variables affecting speed and success in emergency egress. A large number of emergency egress studies have been conducted and many reported [Dougherty, 1967 (1039); King (1041-1047); Jaglowski, 1966 (1040); see previous references cited in Section 2.2.2 - Ground Emergency Egress]. These have ranged from studies of the SST [Garner and Blethrow, 1970 (391)] and Concorde [Anstey and Brownbill, 1975 (421)] to general studies of ground vehicles under crash conditions [Sliepcevich et al., 1972 (1048)].

Development of new materials and technology, especially for the space program, has led to advances of particular importance in solution of problems of air transport safety. During the past few years there have been efforts to develop alternative systems to improve the state-of-the-art of emergency egress. The objective of the following section is to select and evaluate industry developments and advanced concepts which have application to transport aircraft. Eight different types of mechanical and inflatable slide or slide/raft systems are evaluated, as well as some less conventional systems.

Major advances have been made in the development of high energy emergency egress systems, which have been considered by the FAA, and developed and tested by the USAF to the point where all USAF Lockheed C-141 air transports will eventually be retrofitted. The ELSIE (Emergency Life-Saving Instant Exit) System, originally developed by Explosive Technology as STEN (Stored Energy) Passenger Egress System in 1967, has had continuous development and testing over the past 8 years, with considerable operational experience in a Convair C-131B test-bed aircraft, and variations installed in a Lockheed AC-130E aircraft and Lear Jet business jet. Described as "at least two orders of magnitude faster than any system in use today on cargo or passenger aircraft, either military or civilian," the ELSIE System appears to be one of the most advanced technological developments available for emergency egress.

Other aspects which will be discussed are those of ablative coating for exit areas and the use of the heat shield concept developed by NASA in Apollo research. This concept, which has been subjected to actual fuselage fire testing, would protect the passenger compartment by a fire-retardant shell able to protect the occupants from smoke, toxic fumes, or fire long enough for them to escape safely or for the fire to be extinguished. This concept is based upon development of a lightweight polyisocyanurate foam, and an intumescent paint. When exposed to heat, the intumescent paint expands to many times its original thickness and insulates the surface beneath it. The thermal-protective capabilities of these materials are based upon the charring ablative chemistry principles developed to protect astronauts during re-entry. This is effective as long as the shell remains sealed and is not compromised by fuselage breakup.

Little attention has been given to the possibility of successful egress from and survival of occupants in air transports involved in catastrophic structural failure, mid-air collision, or other situations in which there are currently no emergency alternatives to destruction of the aircraft and fatality for occupants. Of four systems evaluated, one appears to be technically possible and utilizes drogue chute technology available for helicopter application.

The following concepts represent alternative means of approaching emergency egress in air transport aircraft.

7.2 Slide Devices

Emergency egress through door exits presents slightly different problems than through overwing exits, the latter method involving off-wing egress from low-wing transports. A number of external escape concepts have been reviewed, including inflatable stairs and slides, ramps, mechanical stairways and tube slides, hand-held slides, escape ropes, rope ladders, telescope poles, and nets.

7.2.1 Inflatable Escape Slides. Inflatable escape slides represent the best current operational device in use. However, while inflatable escape slides have long been standard equipment on civil air carriers, they have been reported used on only three air transports (Lockheed C-121, Douglas C-9, and some Boeing C-135 aircraft) in the military air transport inventory. Canvas slides, rope ladders, and escape ropes still predominate operationally in military air transport operations.

7.2.1.1 Double-Lane Slide. The double-lane inflatable slide consists of two single slides side by side, utilizing a center support tube common to both sides, and inflatable tube side rails. This system is designed to provide two-abreast egress utilizing Type A doors and allowing double lines. To date, exit preparation time for arming and deployment is about 10 seconds. Egress speeds have been found to utilize slide angles of between 35 and 50 degrees while angles below 25 degrees allow the slide to be used as a walkway if the slide incorporates an inflated member as the sliding surface, rather than a fabric web type used on many current slides. Tests by AIA have shown that double-lane inflatable escape slides provide a uniform egress rate of 108 passengers per minute (1049). Stowed volume is approximately 1.4 cu m (51.1 cu ft) for a 10.4 m (34 ft) length, 45.8 kg (101 lb) weight, and 16.3 kg (36 lb) inflation system weight.

7.2.1.2 Double Escape Slide with Center Divider. This concept was proposed by McDonnell Douglas [Roebuck, 1968 (15)] and is a modification of the double escape slide described above. In this version an inflatable semi-rigid separator "fence" in the middle of the slide would in effect provide two adjacent slides, as shown in Fig. 84. The advantage of this would be to prevent persons sliding down side-by-side from getting entangled, or one passenger blocking egress from both sides. The primary purpose of the concept was to prevent hesitation caused by one passenger waiting for another beside him to get well down the slide before jumping. It would also provide an additional hand-hold. Suggested provision for chemical light along the top edge of the dividers would provide better illumination. The inflatable divider section, while increasing weight, storage bulk, and inflation capacity, would provide additional longitudinal rigidity. It was estimated that this would improve passenger flow rate by up to 10 percent; however, no tests are reported to confirm this estimate.

7.2.1.3 Combination Inflatable Slide and Life Raft. With the introduction of the wide-bodied jet transports a new concept relative to egress on land and survival at sea has been utilized. This concept relegates a dual function to the escape slide. Its primary function would remain an escape slide for rapid land evacuation of an aircraft, but an additional capability would be a flotation device or life raft for ditching at sea.

The slide/raft concept appears to offer distinct advantages from logistics and maintenance viewpoints, as explained below:

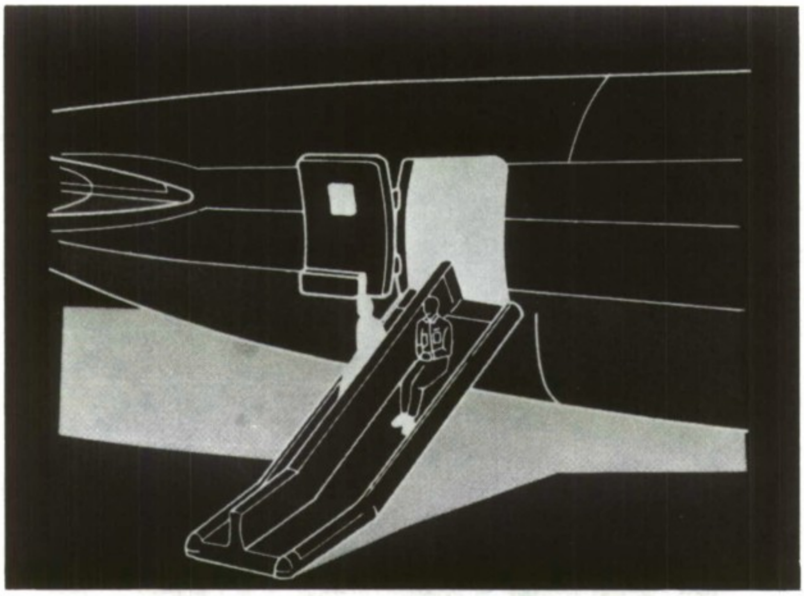


Fig. 84. Double escape slide with center divider [Roebuck, 1968 (15)].

(1) Elimination of requirements for interior life raft stowage compartments. In certain seat density configurations of the Boeing 747, for example, 20 to 23 twenty-five man life rafts are required.

(2) Reduction in weight. For the Boeing 747, this would mean elimination of some 20 twenty-five man life rafts, weighing 81.6 kg (180 lb) each, for a potential weight saving of some 1,633 kg (3,600 lb). However, some weight is gained in slide redesign and enlargement into a slide/raft configuration.

(3) The slide/raft is designed to be deployed outside the aircraft. The history of prior aircraft ditchings indicates that all too frequently survivors were unable (or failed) to remove and deploy life rafts stowed within the aircraft cabin before the aircraft sank.

(4) Maintenance and inspection of the slide/raft system only is required as compared to maintenance and inspection of both escape slides and life rafts.

There are, however, several disadvantages of the combination slide/raft concept:

(1) The number of slide/rafts is limited by the number of exits at which a slide/raft may be installed. For example, in one military Boeing C-135 configuration, there are only two main cabin or cargo doors which could accommodate a slide/raft combination. Supplementary interior stowed rafts may still be required in some instances. (On the other hand, the Lockheed L-1011 for example, has 8 exits which can be utilized.)

(2) Frequently existing slide compartments are inadequate in volume to accommodate slide/rafts and their inflation systems.

(3) Existing door hinges, structure, and exit hardware are often inadequate in design to support the added weight and volume of slide/raft combinations.

(4) Lack of mobility. Weight and volume of slide/raft combinations are frequently such that in the event that an exit is not usable, the slide/raft cannot be easily transferred to a usable exit for deployment. Management in high winds or rough seas may be difficult in raft mode.

(5) High numerical occupancy. Some large slide/rafts are designed to carry in excess of 50 survivors. The loss or malfunction of one of these slide/rafts would have the same effect as the loss of two twenty-five man rafts.

Accidents such as the ONA St. Croix, V.I. McDonnell Douglas DC-9 ditching in which none of the five life rafts aboard the aircraft were successfully deployed and some thirty-one of the survivors utilized an inflated escape slide as their primary flotation device have appeared to accelerate the application of the slide/raft concept.

Fabrication of current slide/rafts is from lightweight high strength synthetic fabrics such as nylon and dacron. The fabric is coated on both sides with an elastomeric compound, often a polyurethane, and seams are either heat-sealed or are cemented overlaps. Inflation is usually by a CO_2 system; however, to date there are no FAA requirements relative to gas emission toxicity. Inflation systems most commonly utilized are of the high ratio-air aspirator type. High pressure cylinders using nitrogen, nitrogen-CO_2, or other mixtures of gases are used to operate the aspirators. Slide/raft operating pressures vary between .1 to .25 kg/sq cm (1.5 to 3.5 psi) depending upon the design and configuration of the slide/raft. Manual or self-erecting canopies are normally an integral part of the design. Some canopies for example are connected to one of the tubes and at some later point in time following deployment small valves are opened, inflating capstans which erect the canopy. Since these capstans are of relatively small volume the pressure drop in the main tubes is not significant.

One of the larger slide/rafts designed for the McDonnell Douglas DC-10, a double lane, 7.9 m (26 ft) prototype, was evaluated in open water using larger boats to create increased wave conditions. Fig. 85 illustrates the slide/raft, designed by Pico. A usable seating area of 17.9 sq m (193 sq ft) was calculated for this configuration raft. The raft was alternately loaded with 44 subjects (.41 sq m [4.4 sq ft] per subject), 55 subjects (.33 sq m [3.6 sq ft] per subject), and 66 subjects (.27 sq m [3.0 sq ft] per subject). Under these conditions the slide/raft exhibited excellent buoyancy in all passenger loadings. Essentially rectangular in shape, slide/rafts tend to flex, bend and follow the contour of a swell. When the lower tube was deflated, freeboard was reduced and waves induced by boat action at times introduced water into the slide/raft; however, the remaining buoyancy was adequate to maintain flotation with the maximum number of occupants. When one of the two compartments is deflated the structural rigidity of the slide/raft is normally reduced with the two sides pinching inward reducing the total apparent surface area of the slide/raft.

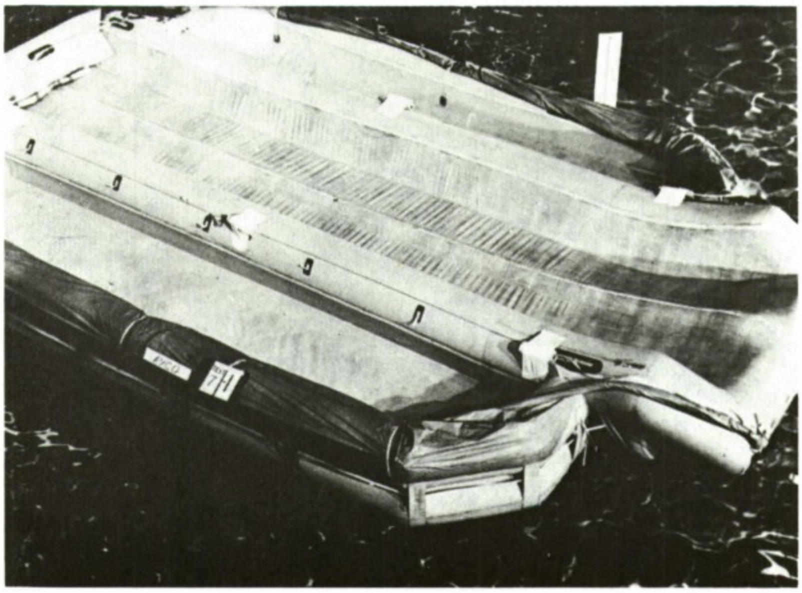


Fig. 85. Combination life raft escape slide recently certified for civil air carrier use on the McDonnell Douglas DC-10 (Photo courtesy E.B. McFadden, FAA).

On 30 November, 1972, open-sea trials were conducted by the Society of Automotive Engineers S-9 Cabin Safety Committee in response to interest in the new generation slide/raft certified for use on the McDonnell Douglas DC-10 and the Lockheed L-1011. These trials involved deployment of slide/rafts from a test fixture simulating an aircraft fuselage from the U.S. Coast Guard Buoy Tender Planetree approximately 3.2-4.8 km (2-3 mi) off the island of Oahu. The slide/rafts used in these tests were manufactured using concepts outlined in the SAE ARP 1146 "Combination Evacuation Slide/Life Raft," and in accordance with aircraft manufacturers' specifications and FAA guidelines. Tests were conducted in sea conditions with up to 1.8 m (6 ft) swells and up to 24 km/h (15 mph) winds.

Conclusions from these tests are as follows:

(1) The automatic availability of the slide/raft for immediate loading is a significant improvement in the level of safety.

(2) The slide/raft, being securely attached to the aircraft structure, greatly simplifies and expedites loading.

(3) The slide/raft installation prevents the possibility of an inverted deployment by virtue of the nature of its design.

(4) The slide/raft should be loaded to capacity while still attached to the aircraft. In certain sea conditions when the door sill height is above water level it may not be possible to load the slide/raft to rated capacity while attached to the aircraft.

(5) The slide/raft demonstrated a capability to take punishment without damage.

(6) For use in ditching, the slide/raft is a great advancement in the state-of-the-art for emergency evacuation over other conventional slide and life raft units [SAE, 1973 (1053)].

Additional recommendations were that the slide/raft be loaded while attached to the aircraft; be disconnected by the raft commander from inside the slide/raft; survival equipment be stowed next to the raft commander at the aircraft end; the sea anchor be manually deployed after drifting away from the aircraft; pictorial instructions to locate the emergency equipment be used where practical; and consideration be given to location instructions on the inside of the canopy and top of the tubes (or other surfaces not obscured by the occupants' sitting posture) where practical [SAE, 1973 (1053)]. A 1974 review of the human factors of the slide/raft combination by Sirkis et al. (1052) has discussed the improvement in the state-of-the-art represented by this device. In September, 1972 the FAA approved the 30-place Pan Avion (American Safety Flight Systems, Inc.) life raft, the largest to that date. It was subsequently retrofitted to Eastern Airlines Boeing 727 aircraft (1051). Larger 50-place systems are currently in use.

Weight is an important factor. A Lockheed L-1011, for example, utilizes 6 50-man (Type A) slide/rafts with a double lane (air cruisers), and two aft (Type I) 33-man capacity single lane slide/rafts. In an aircraft this size if slide/rafts are not used it would require 15 25-man life rafts. This weight (15 rafts @ 56.8 kg [125 lb]) each or 850 kg (1,875 lb) can be saved by utilizing the slide/raft combination. The single lane slides and slide/raft combinations range in length from approximately 4.96 to 8.84 m (13 to 29 ft), and 5.79 to 10.4 m (19 to 34 ft) for double lane models. Weight is about 2.99 to 4.46 kg/m (2 to 3 lb/ft) to which the additional weight of safety and inflation equipment must be added. To illustrate, a 10.4 m (34 ft) double lane slide weighs approximately 45.8 kg (101 lb), with a stowed volume of some .14 cu m (5.1 cu ft) and its inflation system weighs 16.3 kg (36 lb) [Sirkis et al., 1974 (1052)].

Current slides and rafts are manufactured in compliance with Technical Standard Orders (TSO) C69 and C70; however to date there is still no FAA TSO related to slide/rafts (March, 1976), although one has been in preparation for over seven years. While ARB (United Kingdom) requirements are .27 sq m (3 sq ft) per person floor area, it is probable that the U.S. standard will be .33 sq m (3.6 sq ft). The FAA published a Notice of Proposed Rule Making (NPRM 69-33, FAR 25.853[b]) in 1969 stating standards for slide/raft combinations. In this the FAA considered that the device, wet or dry, should be designed to be capable of handling evacuees at a rate of at least 60 persons/minute for single width and 120 persons/minute for double width evacuations for a duration of 70 seconds. It should be capable of operating in at least a 40.2 km/h (25 mph) wind, must be inflated in not less than 10 seconds, and 75% of initial nominal operating inflation pressure should be retained for 24 hours. In regard to flammability, the FAA is considering upgrading the present requirements of 10.2 cm (4 in) per minute horizontal burn rate. To date specific FAR requirements for slide/raft combinations have not been issued. The Society of Automotive Engineers issued an Aerospace Recommended Practice relating to combination evacuation slide/life rafts (ARP 1146) in July, 1970 (1054), and to survival kits for life rafts and slide/rafts (ARP 1282), published in July, 1973 (1055).

Current accident experience indicates that emergency egress slides do not always function to provide safe egress. Several accidents have demonstrated failure of current inflatable slide systems. In the TWA Boeing 727 accident in December, 1970 at St. Thomas, the gear collapsed on the runway and the aircraft, carrying 46 passengers, two infants, and a crew of 7, struck a hillside beyond the runway at 55.6 to 74 km/h (34.5 to 46 mph) (203). The fuselage broke into three sections. One slide was deployed but failed to reach the ground by 2 or 2.5 m (7 or 8 ft) due to the fuselage attitude. In jumping from the end of the slide there were several serious injuries. In the McDonnell Douglas DC-8 crash at Anchorage, one slide ended in a pool of burning fuel (402, 403). Movies taken of the Boeing 747 evacuation at San Francisco on 30 July, 1971 show the escape slides being blown by the high wind, again resulting in injuries (See Fig. 14) (191). In a subsequent Northwest Airlines Boeing 747 accident at Miami on 15 December, 1972 (244; 411), the two rear escape slides were unusable due to the tail-high position, and one evacuation slide failed to inflate, making that exit also unusable. In September, 1972, a Trans World Airlines Boeing 747 evacuation at John F. Kennedy International Airport, New York, resulted in 80 injuries, some being attributed to the slides (409, 411). Passengers were blown down by engine exhaust blast, piled up at the bottom of slides, and landed on a hard taxiway surface. Three of the slides were deployed near the fire.

It was previously noted (Section 2.2.2 - Ground Emergency Egress) that injuries have occurred during compliance tests of the slides, and this led to consideration by the FAA of industry proposals that evacuation compliance testing be conducted by computer simulation. An unpublished study of the Civil Aeromedical Institute, FAA, indicates that where actual crash/fire emergencies have been involved (as opposed to other emergency evacuations) current slide systems are not as reliable a means of egress as they are generally considered to be. Thus improvements in the state-of-the-art appear necessary.

7.2.1.4 Inflatable Tubular Escape Slide/Raft. A different concept of an escape slide/raft device was proposed in 1968, involving an inflatable tubular structure as shown in Fig. 86 [Roebuck, 1968 (15)]. In this version flexible joint sections of the tubular escape structure would be designed to allow slide egress in any position, including from an inverted aircraft. Completely enclosed slides have not been used previously, and some protection from smoke and flame might result. On the other hand, an enclosed slide could act as an efficient flue if fire is present, which might shorten survival time. Windows of flexible transparent plastic would provide light, with chemical light strips inside for night egress. It could be used as a ramp walkway. The floor and ceiling (identical) would be constructed of Goodyear "airmat" material with capability to inflate a 2.5 to 5.1 cm (1 to 2 in) thick stiff surface by auxiliary inflation bottles in case of a very shallow angle of egress. The attached end is extended from the aircraft by a tubular, sliding cable-restrained bellows, capable of universal flexure to some ± 25 degrees of arc, and torsion to about ± 30 degrees of arc. The bellows articulation would be a larger version of the shoulder joint in a space suit pressure garment. This concept was reported to have an estimated increase in passenger flow rate up to 50% in ditching; however, if compared to current ditching, life raft deployment requirements in aircraft such as the Lockheed C-141A would probably be considerably greater.

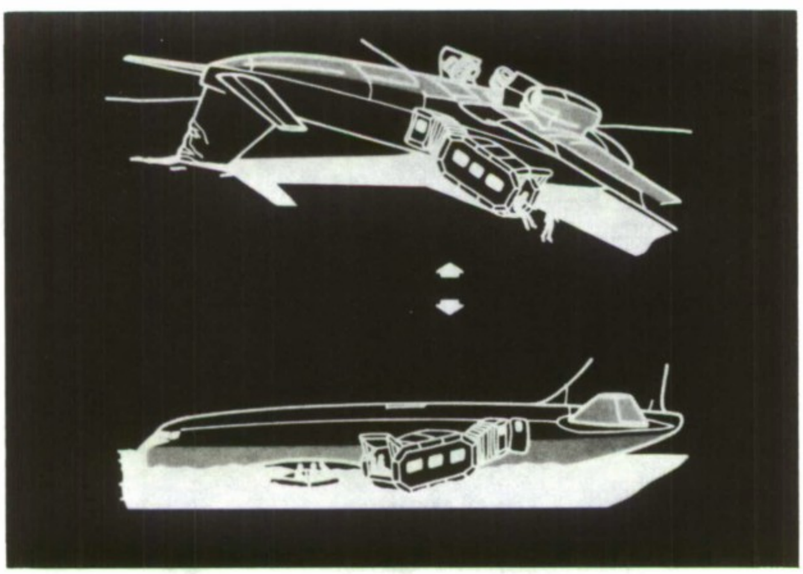


Fig. 86. Concept of a combination inflatable escape slide/life raft [Roebuck, 1968 (15)].

7.2.1.5 Exterior Platform Escape Slide Entry. The purpose of this escape slide concept (Fig. 87) is to reduce a traffic-flow bottleneck at the emergency exit caused by psychological reasons [Roebuck, 1968 (15)]. The idea here is to get the passenger out on the wing (low-wing aircraft) and then utilize conventional inflatable slides, which would be automatically deployed from the platform package. This concept is within the state-of-the-art and is a modification of some current designs.

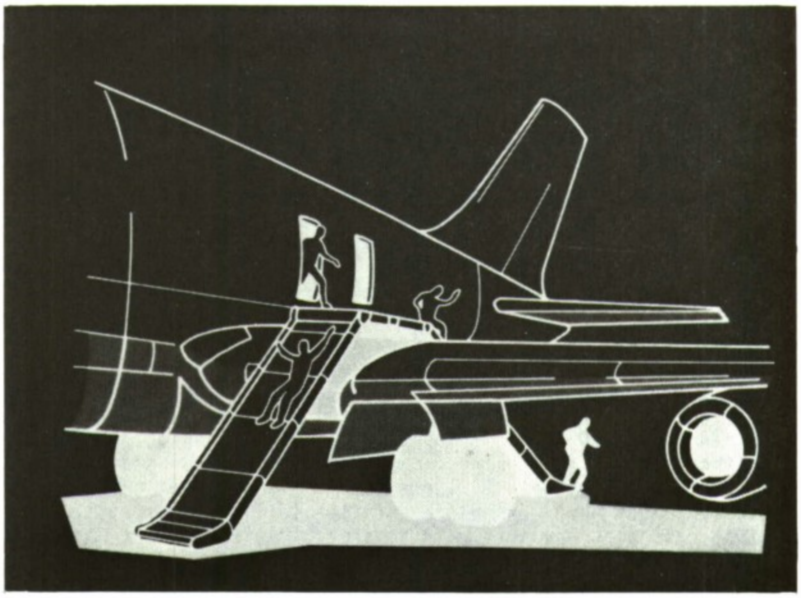


Fig. 87. Exterior platform slide entry for overwing escape [Roebuck, 1968 (15)].

7.2.2 Slide Inflation Devices. With the increasing size of these devices, particularly for aircraft such as the Boeing 747 (and Lockheed C-9), and the need for greatly increased inflation volume, rapid inflation times, increased compactness, and less weight, the need for improved inflation devices has been emphasized. Many current inflation systems utilize compressed gas stored in 211 kg/sq cm (3,000 psi) cylinders, however if used in the larger and newer systems the high-pressure gas supply would pose both storage capacity and increased weight problems. This has led to the development of cool gas generators and more efficient aspirators as the current solution to providing better inflation for the large capacity inflatable escape devices.

The conventional system of inflating escape slides is to duct high-pressure gas from a gas reservoir through an aspirator and into the slides. The aspirator contains a nozzle that expands the high-pressure gas to below ambient pressure. The aspirator casing contains doors designed to open when the pressure within the casing body falls below ambient pressure. Thus, the entering air is entrained by the expanding high-pressure gas, and the resulting mixture fills the inflatable escape slide. In the newer cool gas generator system the high-pressure gas cylinder is replaced with a solid propellant charge within a gas-generating chamber plus a coolant chamber. When ignited, this charge generates hot gas which is then cooled by one of several alternate methods when exhausted into a secondary chamber. The resulting cool gas is then directed to an improved external aspirator and subsequently into the inflatable device. Fig. 88 shows the cool gas generation system in schematic form.

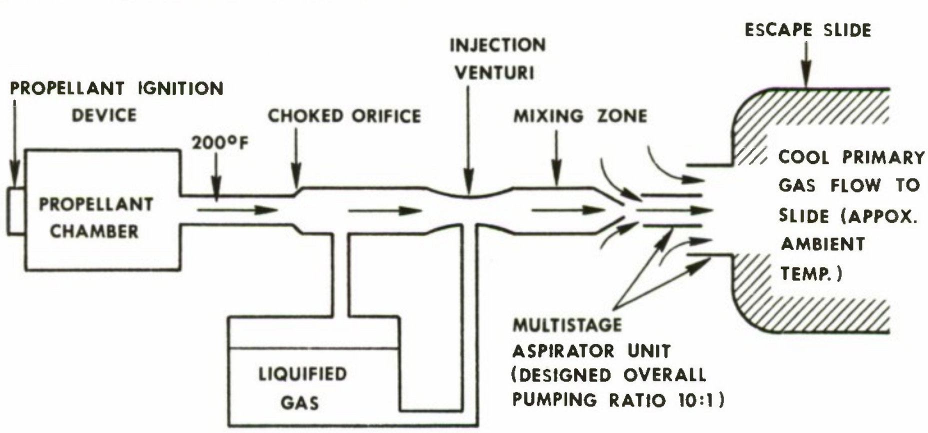


Fig. 88. Cool gas generator system for inflatable escape devices.

Three types of gas generator systems include the solid coolant-solid propellant-aspirator system, the liquid coolant-solid propellant-aspirator system, and the liquid coolant-solid propellant-aspirator system. In the solid coolant system the hot gas resulting from the solid propellant charge ignition is passed over a catalytic bed, which acts as the coolant agent, and the resulting cool gas drives the aspirator. Hardware for this concept is still in development, and problems in gas temperature control have been reported. Although it appears to be a relatively simple and easily maintained system, this cannot be determined until tested. It also may be relatively costly. In the gas coolant system, a 211 kg/sq cm (3,000 psi) gaseous nitrogen mix is the primary coolant. By mixing with the hot gases generated by the ignition of the solid propellant charge the driving gas is directed to the aspirator. It has been indicated to be effective over a temperature range of -40°C (-40°F) to +71°C (+160°F), and is capable of inflating a 4.5 cu m (160 cu ft) volume to a pressure of .09 kg/sq cm (1.4 psi) in approximately 8 seconds. Its cooling ability comes from high-pressure gas expansion, however, weight requirements for high-pressure gas cylinders may be relatively high. The third method uses a liquified gas as a coolant. The hot gas generated by the ignition of the solid propellant charge is used to provide the latent heat of vaporization required to evaporate the liquified gas coolant. It is capable of inflating an 8.2 cu m (290 cu ft) volume to a pressure of .14 kg/sq cm (2.0 psi) in less than 7 seconds, over a temperature range of -40°C to +71°C (-40°F to +160°F). A detailed analysis of inflation devices and current state-of-the-art has been previously presented in Section 4.6.11.5; however, the requirements for use with inflatable restraints and inflatable escape slides differ considerably.

7.3 Mechanical Escape Devices

7.3.1 Seat Belt Escape Harness and Egress Conveyor System. This concept envisions an integrated system utilizing the restraint system and seat cover to allow the passenger to hook onto an overhead conveyor system which would automatically carry him to an exit, as shown in Fig. 89. There is some precedence for this type of seat-mounted escape device in the current use of survival kits in the seat pack of many aircrews. This concept was proposed in the FAA study by McDonnell Douglas [Roebuck, 1968 (15)]. The seat back cushion would be designed to contain an anti-smoke and flame hood with self-contained air supply, which could be quickly deployed. The sides would contain a life vest which could be pulled out and wrapped around the body. The passenger would hook his seat belt to the back cushion system, and attach the entire system to an overhead hook on a cable. The seat cushion cover and back cover would supply a chair-like support, and the conveyor system would take the passenger to the exit, where a deployment strap would disconnect the occupant either manually or automatically.

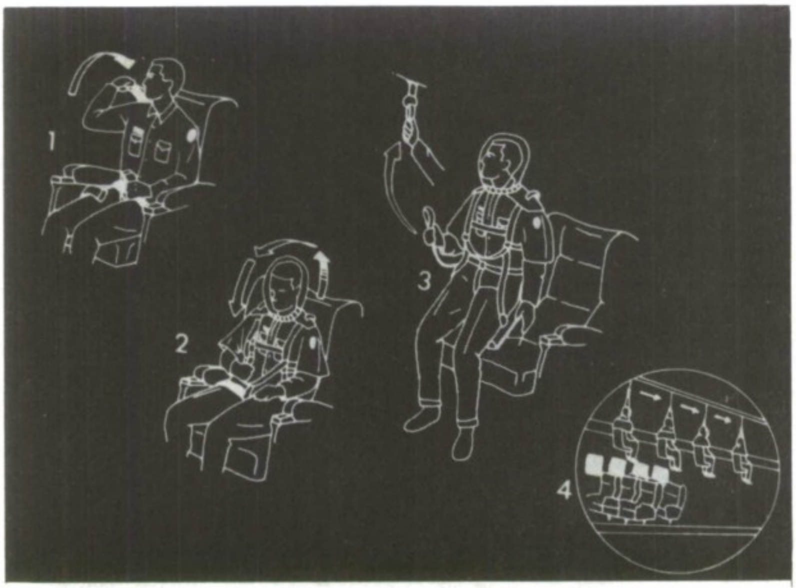


Fig. 89. In this system the passenger (1) attaches his seat belt to integrated seat-back straps, (2) hooks into an overhead hook, and (3) is automatically conveyed to an exit [Roebuck, 1968 (15)].

This is a complex system requiring a series of action by the user. It is within the state-of-the-art, however, and features a systems engineering design approach. Estimated additional weight was 1.36 kg (3 lb) per user; however, by using seat cushion cover storage, little extra volume would be required. A number of failure possibilities exist, in the deployment itself as well as in strength of parts, jamming of equipment, and failure of the power source. It would be non-usable in accidents involving significant structural intrusion or distortion. If everyone had to be hooked up before it operated it would be ineffective; yet if it operated as a continual conveyor belt system from the moment of crash-impact, some passengers might have difficulty in reaching a hook-up or might be struck down by passengers already hooked up and being conveyed out. Another hazard exists in that the passenger might be conveyed to a non-usable exit or directly into a burning area, unless there were direction control. Such a device could prove hazardous if the system failed while passengers were still attached; they would be near the ceiling where the heat, smoke and fumes would be greatest and would provide the poorest survival environment. Entanglement could be a further hazard. Also, this system might be difficult for many people psychologically to use without clear briefing and practice. It is not considered to be a reliable systems concept in this form, but could be further modified for consideration in a simpler, more automatic mode.

7.3.2 Folding Escape Slide. Actually a combination walkway and mechanical folding slide, this concept would consist of expandable pivoting structural elements which could be stored under Type I and Type II exits. It could be used as a firm ramp or evacuation slide. As shown in Fig. 90, a specially constructed, lightweight, extendable truss structure would be constructed to support stairs which can be folded down to form the surface of a slide or ramp. An advantage over inflatable devices might be that it would not puncture or tear. An analysis of mechanical versus inflatable escape devices by AIAA (1968) showed that mechanical devices require greater storage volume and heavier structural support. It was determined that a mechanical stair is more hazardous due to the quick foot movements required in descent which can lead to stumbling and falling. A fall on a stairway could seriously impede evacuation flow.

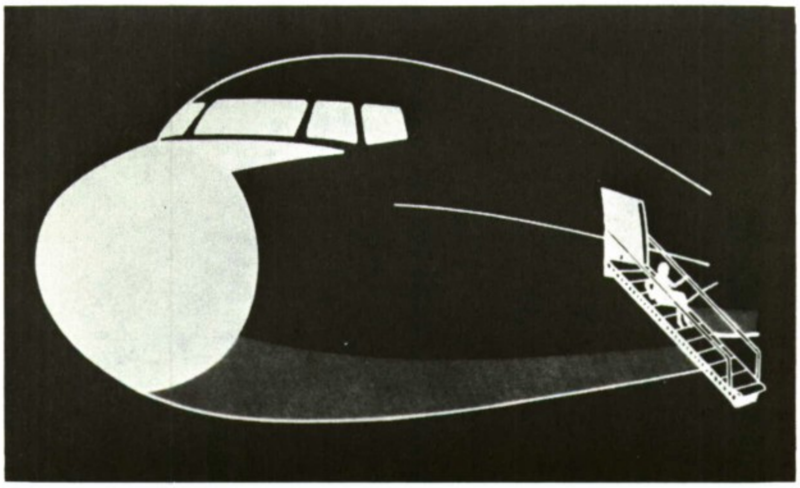


Fig. 90. Mechanical folding escape slide/stairway [Roebuck, 1968 (15)].

7.3.3 Cargo-type Emergency Egress Techniques. This concept would facilitate the evacuation of passengers by providing large openings in the nose, sides, and tail of passenger aircraft. This might be accomplished by using techniques presently in service in pressurized cabin cargo aircraft having swing-nose, clam shell or swing-tail, or large door loading capabilities. It was estimated that this system could reduce evacuation time and passenger flow rate by 90% and reduce the use of wrong exits by 10% to 20%. No data are available to validate these estimates. Fig. 91 shows a forward fuselage cargo-type exit.

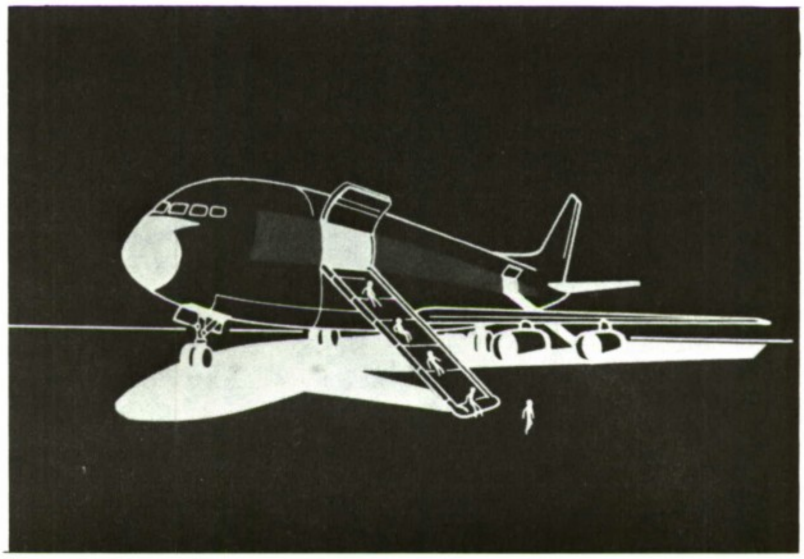


Fig. 91. Cargo-type emergency egress technique [Roebuck, 1968 (15)].

7.3.4 Conveyor Belt Concept. A number of escape system concepts have been proposed in the literature to assist in evacuation of passengers from their seats to the emergency exits. Most of these have not been considered here because of obvious technical cost, weight, or feasibility problems, although most appear to be within the state-of-the-art, and also because there are better solutions. Some of the concepts excluded involve flexible curtains, or tunnels deployed in the aisles.

The moving walkway passenger conveyor systems proposed to the FAA would consist of a forward conveyor belt intended to improve passenger evacuation time and reduce the problem of locating exits under smoke conditions [Roebuck, 1968 (15)]. An individual reaching the aisle could presumably be taken to an exit if he were incapacitated or injured. Such a system is within the state-of-the-art, but is considered to be unpractical, due to additional weight requirements, fail-safe aspects, the problem of "what if the conveyor belt is going in the wrong direction" to get to usable exits, as well as the problem of potential injury to disabled users who might get jammed against seats. This concept is illustrated in Fig. 92. However, another reason why such a concept would have limited utility is shown in Fig. 93. This photograph was taken subsequent to the FAA crash test of a Douglas DC-7 aircraft at Deer Valley, Arizona, and shows the buckling of the fuselage typical of many air transport accidents. In such instances a conveyor belt egress technique would be useless. Fig. 23 in Section 3.1.5.1 shows a recent Boeing 727 crash which also illustrates the extreme fuselage distortion which is often found.

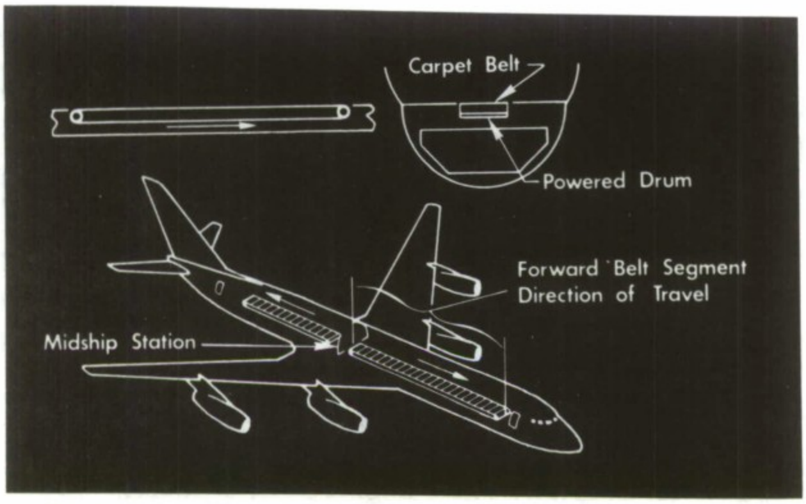


Fig. 92. Passenger egress from seat to emergency exit via conveyor belt [Roebuck, 1968 (15)].

Fig. 93. Post-crash view of Douglas DC-7 aircraft crash-tested by the FAA showing typical extreme buckling of the fuselage (Photo courtesy FAA).

7.3.5 Telescape System. The telescape system consists of an exit-mounted pole which can be extended to the ground for "fireman" type emergency exit. A major advantage is that it provides considerably more "ground reach" flexibility than standard inflatable escape slides; that is, the pole can be deployed and adjusted to the terrain condition within extreme angles and used with wide ranges of aircraft attitudes. This device was demonstrated at the Aeronautical Center, FAA, in Oklahoma City, in May, 1962, and was subsequently tested in evacuation tests of a Convair YC-131 aircraft. Development, testing, and analysis were under the direction of J.D. Garner, Chief, Emergency Escape Section, Protection and Survival Laboratories [Garner and Blethrow, 1962 (1056)]. Two group test evacuations were conducted with a mixed passenger group between 24 and 58 years of age, as well as a group of children 4 to 11 years of age, and individual tests were conducted of two different lengths of support arms.

In this system, the telescape is stored in a mounting near the top of the emergency exit. To use for an evacuation it is swung out into position (Fig. 94) and extended to a ground point (Fig. 95).

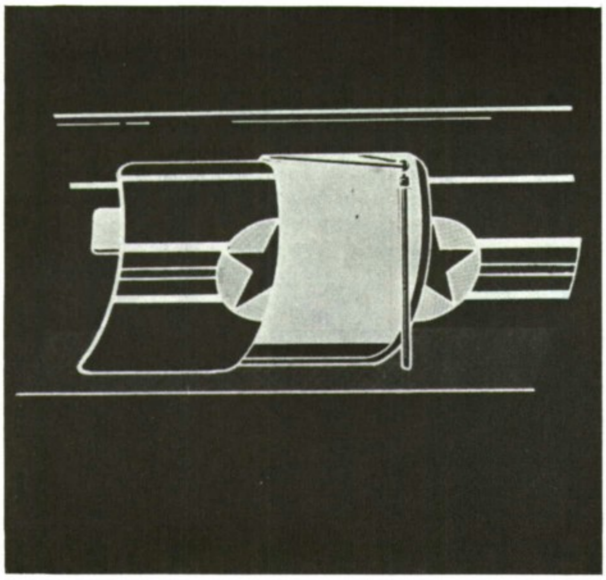
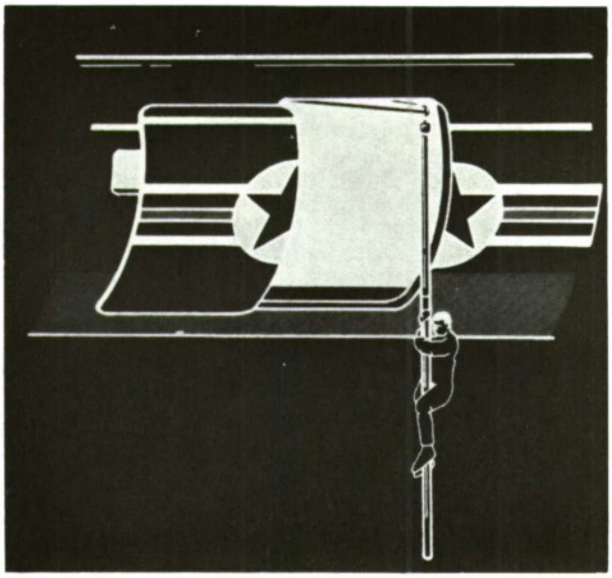


Fig. 94. Telescape swung into position for use at exit door.



95. Evacuation using fully extended telescape device [Garner and Blethrow, 1962 (1056)].

A short support arm (24.7 cm [9-3/4 in]) and a longer arm (73.1 cm [28-13/16 in]) were tested, with 45.7 cm (18 in) felt optimum. The mounting swings through 134° from the stored position against the exit bulkhead, to the out and locked position. Extension is accomplished by a CO_2 bottle providing a pressure range of 2.11 to 2.32 kg/sq cm (30 to 33 psi) at the telescope pressure inlet. Once the internally extended tube, comprised of four sections, touches the ground, a pressure of 1.4 kg/sq cm (20 psi) was found sufficient to retain pressure within the tube and hold it in place.

Test passengers were found to use various techniques for sliding down this pole, and test evacuations were conducted at an average rate of 3.61 seconds per passenger on the first test and 3.31 seconds per passenger on the second test. A polished chrome finish proved satisfactory for surface friction, although less friction was recommended to prevent burns. Rate of descent was not injurious under the conditions tested.

This concept has not had further tests conducted under darkness, smokiness, or other adverse conditions. For military or civil adaption it would only be useful at door exits and could not be used in overwing escape. It is uncertain how it could be relied upon to function after fuselage distortion. Where air evacuation litter patients are carried it would probably not be useful. Insufficient information is available to compare it with a rope egress as an escape device for military adaptation, and in civil use it would not appear feasible for many segments of the passenger population (infants, small children, elderly, infirm).

7.4 Heat Shields

7.4.1 Exit Area Ablative Coating. Severe heating from exterior fires or post-impact fires can distort exit structure and prevent opening at a later time, even if firemen have cleared a flame-free path to the exit. New, lightweight ablative coating materials applied to areas around and over the exits could form an insulative layer which also resists flame by charring and off-gassing, carrying heat away from structure. The Apollo heat shield is a composite material based on epoxy resin. Although relatively soft, such materials could be covered by a thin, glass-fiber laminate for wear resistance. The basic ablative material is stabilized by a glass-fiber laminate honeycomb bonded to the surface. For a reasonable evacuation period (2 to 5 minutes), a layer only .64 to .95 cm (1/4 to 3/8 in) thick could provide protection against fires of JP-4 or other fuels which burn cooler than spacecraft re-entry temperatures of 2200° to 2760°C (4000°to 5000°F). A typical exit area coating is illustrated in Fig. 96.

This concept would primarily protect against flame and heat damage but is included in this section since it could improve exit area integrity and identification and thus might improve egress success. Emergency egress devices such as escape slides, tubes, or raft/slide combinations could have a flexible ablative coating to protect them for a short time duration against flame damage. NASA is currently exploring the feasibility of effective flexible coatings.

For exterior usage in exit areas there may be a drag penalty which would overweigh its practical employment. Maintenance and repair require special equipment and supplies, and other problems include the increase in weight of doors and hatches on which the coatings are used, making them more difficult to handle. Combustion products could also be highly toxic and even if used only externally, the fumes could be blown inside. Advantages, however, are that the coating provides a longer time before structures to which it has been applied heat up, thereby offering a potential longer usage of emergency exits under heat and flame conditions, which presumably could reduce incidence of jamming. If an exit is heated sufficiently to distort, it may no longer be usable for egress, even if it could be opened.

Since any weight penalty is an important consideration in air carrier operation, it was estimated that an air transport having a gross weight of 181,436 kg (400,000 lb) could be protected by heat shielding by increasing weight 1.46 kg per sq m (0.3 lb per sq ft) of protected surface area. This would increase structural weight fraction from 30.0 to 30.4 percent, and total gross weight by 771 kg (1,700 lb). This system was proposed by NASA for retrofit of current air transport aircraft, but has subsequently been of less interest.

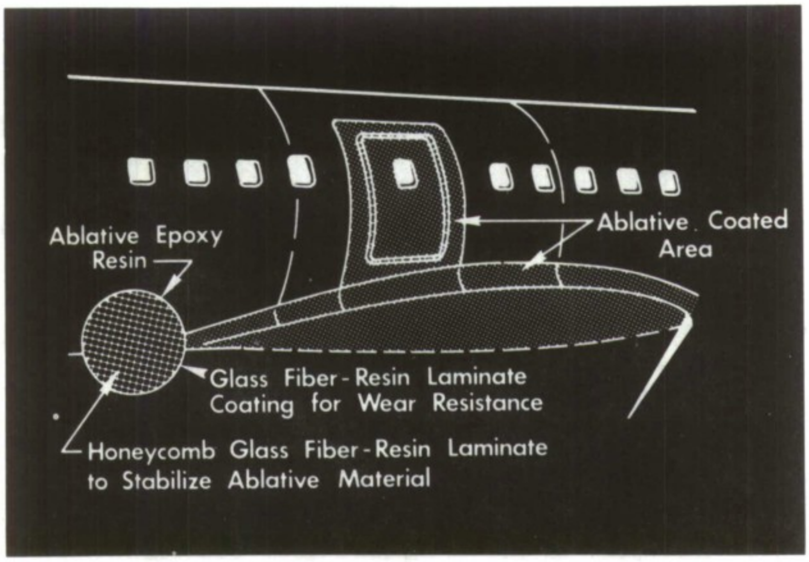


Fig. 96. Emergency exit area ablative coating [Roebuck, 1968 (15)].

7.4.2 Cabin Fire-Protective Shielding. The primary work in development of heat shielding, that is, surrounding the passenger compartment by a fire-retardant shell able to protect the occupants long enough for the fire to burn out or to be extinguished, has been conducted at NASA Ames Research Center [Neel et al., 1971 (1057)]. In tests conducted 13 August, 1970 at Otis Air Froce Base, Mass., on sections of a Douglas C-47, the major objectives considered to influence survival in a crash fire were to minimize heat penetration and prevent intrusion of smoke and toxic gases. The fire-protection system consisted of frames painted with intumescent paint .127 cm (0.05 in) thick (to expand and fill any voids caused by shrinkage of the foam as it charred), over which a layer of loosely woven fiberglass matting was bonded to the skin to reinforce the charred zone of foam. Sprayed over the matting, the polyisocyanurate foam (density of approximately 64 kg per cu m [4 lb per cu ft]) was built up to the 6.35 cm (2-1/2 in) depth of the frames and 5.1-7.6 cm (2-3 in) over the floor structure. A liner of fiberglass-epoxy laminate, similar to present air carrier decorative interior paneling, of .79 mm (1/32 in) thickness, was cemented to the foam and then riveted to the frames. The floor foam was also covered with laminate, and all joints were sealed to exclude smoke and gases.

Results of this test were impressive as to the protection heat shielding could offer. In the unprotected standard Douglas C-47 cabin section the air temperature rose to 315.5°C (600°F) in less than 2 minutes after the initiation of the fire, and the section was destroyed within 2 minutes. In contrast, the heat-shield protected section withstood 6 minutes of fire with no increase in temperature, rising to 148.8°C (300°F) as heat finally penetrated, and the fire burned out at 12 minutes. A gas sample taken 5 minutes after ignition showed no toxic gas penetration. Fig. 97 illustrates the cabin-air temperature during these tests relative to human tolerance, while Fig. 98 shows the installation of the fire-protective shielding.

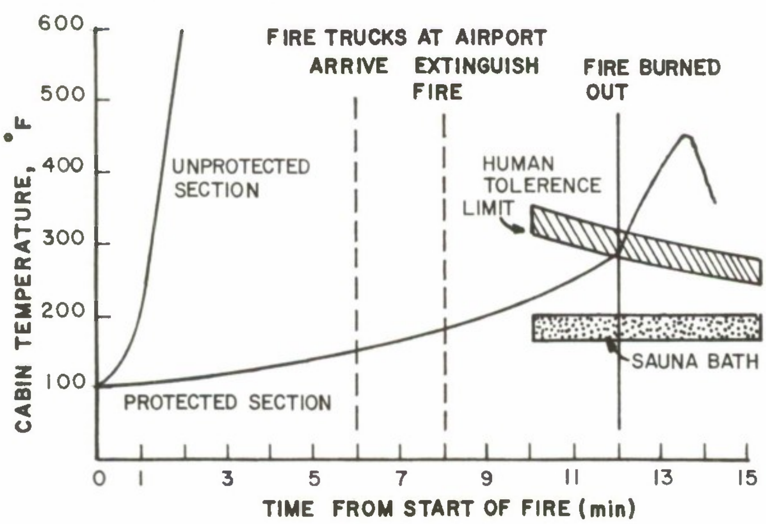


Fig. 97. Cabin air temperature in NASA C-47 cabin shield fire test [Neel et al., 1971 (1057)].

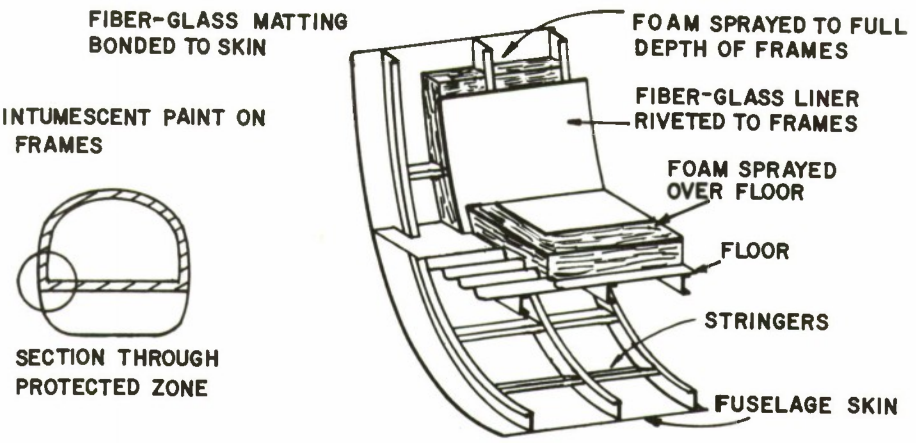


Fig. 98. Installation of fire-protective materials in NASA aircraft cabin test [Neel et al., 1971 (1057)].

7.5 High Energy Emergency Egress Systems

A major problem in emergency egress has been emphasized by a number of studies of both military and civil air transport accidents relating to the inadequacy of non-availability of emergency exits subsequent to a crash. An analysis of commercial air carrier accidents by the Flight Safety Foundation for the period 1957-1967 resulted in the estimate that 35 to 50 percent of the 794 non-survivors of survivable accidents could have been saved if adequate exits had been available. In 26 of the 34 survivable accidents occurring during that period, it was reported that of the 215 exits available, only 53 were used (24.7 percent). During emergency evacuation of 17 aircraft, 152 exits were available and only 44 (28.9 percent) were used [Caldara, 1967 (1058); 1968 (1059)]. In other cases the exits were blocked, or panicked passengers in smoke conditions could not identify exits. Examination of military air transport accidents supports the need for larger, more readily available exits which will not jam. This appears to be a particular need in aircraft such as the Boeing C-135, where the number of passengers often exceeds the critical evacuation flow capability of current exits.

7.5.1 ELSIE. A solution to this problem appears to be utilization of the ELSIE (Emergency Life Saving Instant Exits) system which uses "jet cord" flexible linear shaped charges to blow emergency exits at predetermined strategic locations in the fuselage skin, or where available exits have become jammed. Fig. 99 illustrates how this system might be applied to the Lockheed C-141 aircraft. ELSIE has been developed under contract to the Life Support System Program Office ASD/AFSC, Wright-Patterson AFB, by Explosive Technology, Fairfield, California, having evolved from their STEN (Stored Energy) concept developed in 1967 [Nicholson and Burkdoll, 1971 (1072); Burkdoll and Nicholson, 1971 (1066); Bogland, 1967 (1064); Explosive Technology, 1968 (1068); 1970 (1069)]. A similar concept has been reported by Space Ordnance Systems, Inc. of El Segundo, California, for providing "supplemental emergency exit doors" [Brown, 1967 (1065)], who had designed the crew escape module severance system for the General Dynamics F-111 aircraft and others.

This system consists of a variety of shapes and lengths of linear shaped charges (LSC) which can be routed around any existing exit (to ensure that it is instantly severed), or create a larger exit area for emergency use at any desired point. The five basic components are: a safe/arm mechanism, shielded mild detonating core lines, a flexible shaped cutting charge, an interior initiation handle, and/or exterior initiation handle. ELSIE system characteristics are reported to be that it opens emergency exits in less than 0.001 second (with smooth edges), cannot jam, always jettisons outward, cannot be inadvertently operated but is instantly operable from the interior or exterior following a crash, and requires no special structures. To initiate, the safe/arm electromechanical device is electrically armed from the flight deck, then manually initiated at an ELSIE system station by pulling either the interior or exterior handle. Detailed technical evolution and specifications are reported in Nicholson and Burkdoll [1971 (1072)] and in Burkdoll et al. [1971 (1067)].

ELSIE has been subjected to extensive ground tests and was tested in a Lockheed 130A gunship operationally [Burkdoll et al., 1971 (1067)]. Extensive flight tests were conducted in an operational Convair C-131B aircraft [Anderson and Burkdoll, 1974 (1061)]. In these tests the four over-the-wing emergency egress doors were modified to accommodate the ELSIE system. This system was armed during takeoffs and landings and disarmed during normal flight, using the normal aircraft electrical system. After 250 hours of flight tests, the ELSIE-equipped doors were removed from the aircraft and successfully subjected to a series of functional tests designed to demonstrate the capability of this system to withstand aircraft operational environments over an extended period of time without decrement.

An important proposed use of the ELSIE system would be to incorporate emergency equipment in the system so that activation would also automatically deploy slides, life rafts, or slide/raft combinations, or other devices. This would not only make available instantaneous (and larger) emergency exits, but also would save considerable time which is presently required to effectively deploy these devices.

Fig. 99. ELSIE system for instantaneous egress as might be conceived for Lockheed C-141 aircraft.

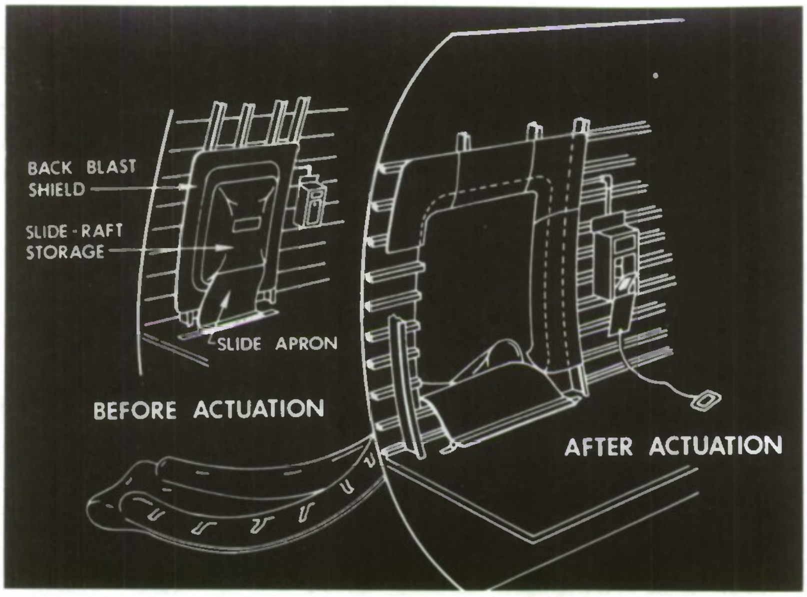


Fig. 100. Experimental high energy emergency exit configuration showing instantaneous deployment of slide/raft for subsequent emergency escape [Caldara, 1970 (4)].

Ground tests [Nicholson and Burkdoll, 1971 (1072); Anderson and Burkdoll, 1974 (1061)] consisted of 9 separate tests for vibration, operating temperature, 12.2 m (40 ft) drop, 40 G shock, structural deformation, water immersion, cook-off, fuel ignition, and inadvertent detonation by fire.

Environment tests showed that excessive vibration, operating temperatures of +93.3°C to -53.8°C (+200°F to -65°F) and 12.2 m (40 ft) drop tests did not affect operation of this system. Shock loads of 20 and 40 G for 0.10 second duration along three orthogonal axes, and bending test panels to 150° deformation were found not to influence performance. Thermal environmental testing included exposure to 218.3°C (425°F) without "cook-off" detonation. A fuel-fed fire showed that the system would not detonate "even though the skin on one test panel was burned completely through" [Anderson and Burkdoll, 1974 (1061)]. In addition, a series of 10 fuel ignition tests in which JP-4 and 115/145 grade aviation fuel were sprayed on the panels failed to inadvertently ignite the system.

The ELSIE system is designed for instantaneous operation of emergency exits, and it was found that the ground test panel was ejected at a velocity of 1.83 to 2.44 m/sec, or 8 km/h (6 to 8 ft/sec, or 5 mph), and required 0.027 sec time from remote initiation. Design goal was 0.999 reliability at 0.90 confidence level, a total life of 7 years, including an installed life of not less than 5 years. Maintenance of this system is reported to be "essentially zero" [Anderson and Burkdoll, 1974 (1061)], requiring no knowledge of explosive ordnance.

At the termination of the Convair C-131B-820 flight tests conducted during 1972 and early 1973, and after experience with a variation of the ELSIE system installed in a Lockheed AC-130E aircraft, results appeared to warrant installation in operational USAF air transport aircraft due to its ease of retrofit (minimum airframe modification is necessary), and it is planned that USAF Lockheed C-141's will be gradually modified as they require IRAN.

Features of the ELSIE system include the following:
(1) always outward opening;
(2) operable by a passenger or crew member in less than 0.027 sec when armed;
(3) maintenance-free and highly reliable;
(4) immune to the environments of a survivable crash (i.e., fire, jamming, dynamic loads);
(5) can be integrated into the aircraft without affecting the function of the aircrew or occupying usable space;
(6) does not affect the aerodynamic characteristics of the aircraft;
(7) can be controlled by the commander from the flight deck, thus making it operable only when the probability of a crash is greatest;
(8) requires only momentary power to arm or safe;
(9) can be operated from inside or outside the aircraft.

For further details of ground and flight tests the best references are Nicholson and Burkdoll [1971 (1072)] or Anderson and Burkdoll [1974 (1061)], and for most recent developmental progress, Heaton and Beers [1975 (1071)] or Burkdoll et al. [1975 (1066)].

Despite the demonstrated success of the ELSIE system as developed and tested for military air transport aircraft, several aspects may influence acceptance of this system for civil air carrier usage [Pollard, 1971 (1078)]. Although the military has extensive experience with explosive escape technology in many of its aircraft, and shielded mild detonating cord lines for the flexible linear shaped charges similar to those used in ELSIE are operational in General Dynamics F-111, Grumman F-14 and Lockheed S-3A aircraft, such explosive technology systems have not been previously utilized in civil operations. Reliability, inspection methods, testing, potential for human error, and litigation are all considerations upon which the air carrier operator may need further assurances. One problem in civil use is the means of initiation of the system. Military usage has shown that it can be initiated electrically or mechanically, and operated from the flight deck, by a passenger, or from the outside. Again, despite the options available, civil air carrier operators must be satisfied that the mechanics of the system are fool-proof. Although the purpose of this study is to evaluate the state-of-the-art of the concepts and technology, such concerns, while not directly related to the technical capabilities, may eventually play an important role in the decision process affecting application of any concept utilizing an "explosive" system.

7.5.2 Liquid Explosive Emergency Exit System. An evaluation of the liquid explosive emergency exit concept for application to civil transport aircraft has been conducted by the National Aviation Facilities Experimental Center, Atlantic City, New Jersey [Jaglowski, 1970 (1085); 1971 (1086)]. The evaluation indicates that liuqid components of nitromethane and a sensitizer can effectively create an emergency exit in a typical jet transport fuselage. However, it was found that nitromethane will freeze at -34.4°C (-30°F) and prevent subsequent detonation of the liquid-filled linear shaped explosive charge. Another limitation of this system was that "the liquid-filled linear shaped charge will operate satisfactorily following simulated crash impact conditions where no severe fuselage structural damage or deformation of the linear tubing occurs" [Jaglowski, 1971 (1086)].

Thus the solid explosive charge of the ELSIE system, which can operate at temperatures below -53.8°C (-65°F) and is not affected by fuselage deformation, appears to be considerably more reliable than the liquid charge approach as evaluated by the FAA.

7.6 Emergency Inflight Egress

Little attention has been given to the problem of emergency inflight evacuation from air transport aircraft other than standard bail-out techniques. Yet, test flight crews have often had emergency escape devices in prototype air transports subjected to initial test flights. Such aircraft as the Fokker F-27, the Concorde, the Boeing 747, 727, and 707, and the McDonnell Douglas DC-8, for example, had escape chutes installed on the flight deck for inflight emergency escape of flight test crews. The Aeritalia G222 twin turbo-proo military transport also has utilized escape chutes constructed in the bottom of the flight deck in the prototype aircraft. The Concorde prototype utilized floor emergency escape chutes in three locations; one at the right rear of the flight deck, one in the main cabin, and one in the rear of the aircraft. The military Boeing C-135 transport has an entry chute spoiler at the primary inflight flight deck exit, to protect the crewmen in bail-out from striking structure due to windblast. When all passengers and crew are equioped with parachutes, bail-out can be accomplished successfully, provided airspeeds are not too high and there is sufficient altitude and time. However, at high-speed, high-altitude conditions, even well-equipped flight crew may have difficulty. Uninitiated passengers, female, child, or infant passengers, and litter-cases cannot be expected to bail out successfully, particularly under adverse conditions.

Close examination of current accident experience shows that inflight structural failure as a result of extreme turbulence, mid-air collision, or other emergency such as fire, decompression, or explosion (Appendices A-D) does occur all too frequently. In cases where catastrophic inflight structural failure occurs, there presently is no way to save the occupants.

It is interesting to note that the concept of inflight recovery of aircraft and passengers is not new. In 1928 the War Department (Air Corps) developed an experimental parachute 25.6 m (84 ft) in diameter "and sufficient to support the weight of an airplane and its passengers, bearing them safely to earth" [Winters, 1928 (1106)]. Design of this early device was attributed to Major E.L. Hoffman, who was responsible for development of the U.S. Army Standard 7.3 m (24 ft) parachute. Some appreciation of the technical difficulties and problems apparently unsolved in this design of nearly 50 years ago may be observed in the following description of the test evaluation with a 725.7 kg (1,600 lb) weight: "The preliminary tests with this high parasol, resembling such when its mammoth billows of silk unfold, were beset with difficulties. This Goliath of all parachutes, with its great lift and enormous strength, demonstrated a disinclination to deflate upon landing, and it was equally unresponsive to efforts to halt its racing proclivities across an open field. Singularly amusing must have been the use of an automobile for chasing the errant parachute. The aviator, upon overtaking it, alighted from the automobile and grabbed at the shroud lines of the parachute. His strength, pitted against such a Samson-like structure, was utterly futile and, unfortunately, he became enmeshed in the billows of silk," finally just avoiding being dispatched by the 1,600 lb weight [Winters, 1928 (110)].

In recent years much attention has been given to the problem of safe recovery of passengers or crew from disabled helicopters, with at least nine primary concepts proposed, and some developed and tested. Detailed discussion of these techniques has been presented in two recent AGARD reports: Escape Problems and Manoeuvres in Combat Aircraft [1974 (1091)] and Escape Measures for Combat Helicopter Crews [1973 (1087)]. The techniques consist of: (1) manual bail-out escape, (2) upward ejection seat escape concept (first explosively separating the rotors), (3) downward ejection seat escape concept, (4) sideward ejection seat escape concept, (5) L-shaped ejection seat escape concept, (6) upward extraction escape concept, (7) sideward extraction escape concept, (8) total aircraft recovery concept, and (9) capsule recovery concept. The Working Group sponsored by the Flight Mechanics Panel of AGARD concluded (1) that manual bail-out or sideward extraction systems were the only systems which could be retrofitted in an absolute minimum of development time and which did not require major changes to the helicopter (although neither are very effective at low altitude); (2) that upward extraction (or ejection) or sideward ejection with L-shaped trajectory are the best approaches for helicopters that have been conceived but not yet designed in detail and fabricated (although a major disadvantage of upward extraction or ejection is the need for disposing of the rotor); and (3) that the best candidate for helicopters that have not yet been conceived ("far-term") would be an escape capsule [1973 (1087)]. AGARD recommended that all future helicopters incorporate inflight escape systems from conception.

Two of the systems which have been considered for helicopters may have application to commercial air carriers, those of capsule escape and total aircraft escape. Thus the evaluations given for use of these concepts in helicopters should be considered. In the total recovery concept, a cluster of parachutes would be deployed to slowly lower the helicopter to the ground (Fig. 101). In addition, shock absorption techniques such as inflatable bags and/or retrorockets might be required to reduce final impact loads. Problems include mounting of parachute containers, effect on helicopter flight dynamics and stability, long deployment times (precluding survival below 91.4 m [300 ft], weight (6-10% of the helicopter's gross weight, which might be as great as 50% of other available payload), and the technical complexities involved. Total aircraft recovery was not considered a promising concept for helicopter inflight escape by the AGARD Working Group, although the big advantages offered are that of effecting recovery of all of the occupants through a single system, and the possibility of repair and reuse of the vehicle.

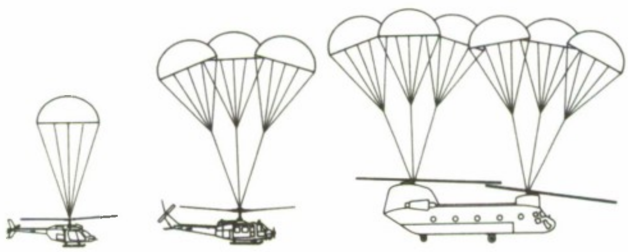


Fig. 101. Total aircraft recovery concept for helicopters [AGARD, 1973 (1087)].

For multi-place helicopters, especially those carrying passengers, the modular recovery concept in which the entire occupied section of the cabin is recovered "appears to be the only practical possibility for escape" (1087). Although this concept is essentially the same as for total aircraft recovery, the module weight is minimized. The occupied compartment would be separated by explosively severing airframe appendages, propulsion systems, tail cones, etc. A cluster of ballistically deployed and spread parachutes would be used for recovery, and would have to lower the module at a survivable descent rate of less than 9.1 m/sec (30ft/sec) [AGARD, 1973 (1087)]. Small explosive cutting charges can sever the tail boom assembly and rotor blades;within 0.1 second of the severance of these structural components, a "drogue gun" fires a nylon line attached to a parachute deployment package directly overhead, deploying the main descent recovery parachute which then lowers the fuselage module. The parachute is reportedly deployed in less than 0.5 second from the activating signal, and is designed to bring down the helicopter at a rate of about 10 m/sec (33 ft/sec) or less. The components have been tested at the U.S. Navy's Weapon Laboratory, Dahlgren, Virginia, and tested at El Centro Naval Air Facility, and may be considered within the state-of-the-art [Arnold and Pollard, 1968 (1088); Teledyne McCormick Selph (1104)]. Studies have also been performed at the U.S. Naval Air Development Center which have demonstrated the feasibility of a helicopter capsule escape system by Vertol Division of the Boeing Company [Millington and Thompson, 1966 (1101); Boeing Company, 1968 (1102); 1969 (1105)].

Several concepts, based upon current state-of-the-art technology have been advanced to provide emergency egress inflight. Snyder and Stapp [1969 (1103)] outlined physiological tolerance factors necessary for survival, and evaluated current inflight egress techniques, including ejection, encapsulated seats, and separable compartment systems. Escape from helicopters has had considerable attention, and several concepts for rotorcraft or V/STOL emergency egress might be applied to air carrier aircraft [AGARD, 1973 (1087); Arnold and Pollard, 1967 (1088); Law, 1974 (1092); Ogden and Davis, 1974 (1093)]. Use of ejection seats in air transports does not appear feasible, since passengers would not normally be equipped to face temperatures to -55°C (-67°F), deceleration windblast to 20 G, and oxygen deficiency in a 9144 m (30,000 ft) initial ejection environment. The structural modification necessary to eject 150 or so separate passengers would present unreasonable structural weight and cost penalties, and this technique was not felt feasible.

Capsule proposals have also been advanced [Dobbek, n.d. (1090); Wilkes, 1952 (1097)]. The following sections briefly survey several of the concepts proposed for inflight emergency egress of air transport occupants.

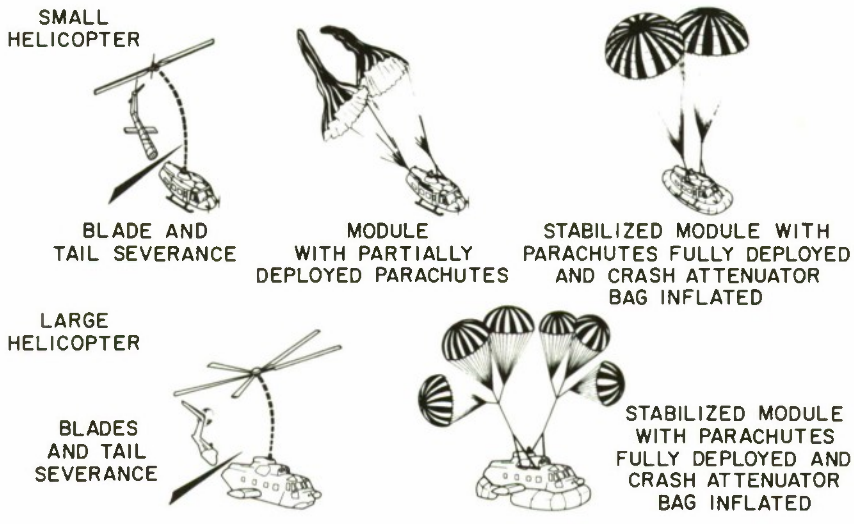


Fig. 102. Capsule recovery concept for helicopters [AGARD, 1973 (1087)].

7.6.1 Tail Evacuation. To avoid the problems of multiple fuselage exits, one technique would be to mount specially modified seats on rails in the floor which would be oriented from front to rear of the cabin. In case of inflight evacuation emergency, the seats would be sequentially fired toward the tail, which would be separated to allow sufficient exit space, much as cargo is sometimes dropped from transports in combat. The seated occupant could then be automatically lowered to the ground by parachute. This method also presents timing problems in evacuation, in balancing the necessity to evacuate a large number of persons rapidly with their ability to tolerate the evacuation, and might not be feasible in aircraft having engines located at the tail. An alternative concept was recommended to Tactical Air Command in 1963 by Stapp for deployment of airborne troops in low-level operations (below 61 m [200 ft] msl), using static lines on an accordion pleated, rip-stitched overhead webbing on guides. The webbing would be towed out by a large drogue chute catapulted at 45° upward from the open rear of the fuselage, ripping the stitches as it evacuated the attached cargo and paratroopers 6.1 m (20 ft) apart. Their chutes would be deployed by a hook as they emerged through the rear opening. For ease in assembly at night, they would remain attached to the webbing.

7.6.2 Paracone Concept. Modification of the current operational technique of aerial delivery of cargo has been proposed by Kendall [1970 (1098)] utilizing the paracone technique. In this system the aircraft would be constructed as a shell with each floor made with rollers and hardware required in present USAF airborne cargo drops. All passenger seats would be mounted on pallets up to 7.3 m (24 ft) long (9' x 24' x 436L pallet) holding 24 passengers. The paracone device and its inflation system would be packaged under the floor. Deployment would be identical to the current military airborne drop except that rather than open doors, the tail section would be blown off. Pallets would be propelled out the rear on rollers, the first pallet deploying an extraction chute to provide for deployment of the succeeding pallet. This concept would have the extracting chute stabilize the pallet while the paracone deployed in approximately 4-5 seconds, as is shown in Figs. 103 and 104. The paracone escape and recovery system would be self-sufficient, having rafts and survival equipment self-contained. Kendall has proposed the use of inflatable air bags for the pallet passengers to protect them from initial airblast during deployment.

The paracone consists of a cone-shaped expandable and pneumatically inflatable structure that utilizes the advantages of the parachute. It is constructed of expandable material which is lightweight and can be packaged readily and is reportedly more effective than the parachute as an aerodynamic decelerator. It is cone-shaped with an open end and the payload, rather than being suspended as with a parachute, is located inside the open end of the cone with the inflated structure surrounding and supporting it. Between the impact attenuation floor and the payload is an inflation gas distribution plenum chamber which doubles as the flotation chamber in case of water landing. The paracone has been extensively tested with systems analysis and subsonic development by McDonnell Douglas. Drag co-efficients of from 0.6 to 1.2 were reported, and impact velocities of 8.5 to 15.2 m/sec (28 to 50 ft/sec) (27 to 30 G) for a time duration of 0.1 second were measured. Kendall's analysis [1970 (1098)] indicated that the paracone can be successfully dropped at very low altitude (61 to 106 m [200 to 350 ft]) and high velocity (482 to 965 km/h [300 to 600 mph]). Application studies have been conducted for space booster recovery, emergency astronaut escape and recovery from orbit, vehicle recovery from orbit at velocities over 10,668 m/sec (35,000 ft/sec), vehicle landings on planets, zero velocity-zero altitude, supersonic and hypersonic ejection, airborne cargo drops, paratroop, and emergency bail-out. This concept has been considered for application to the McDonnell Douglas DC-10 transport aircraft.

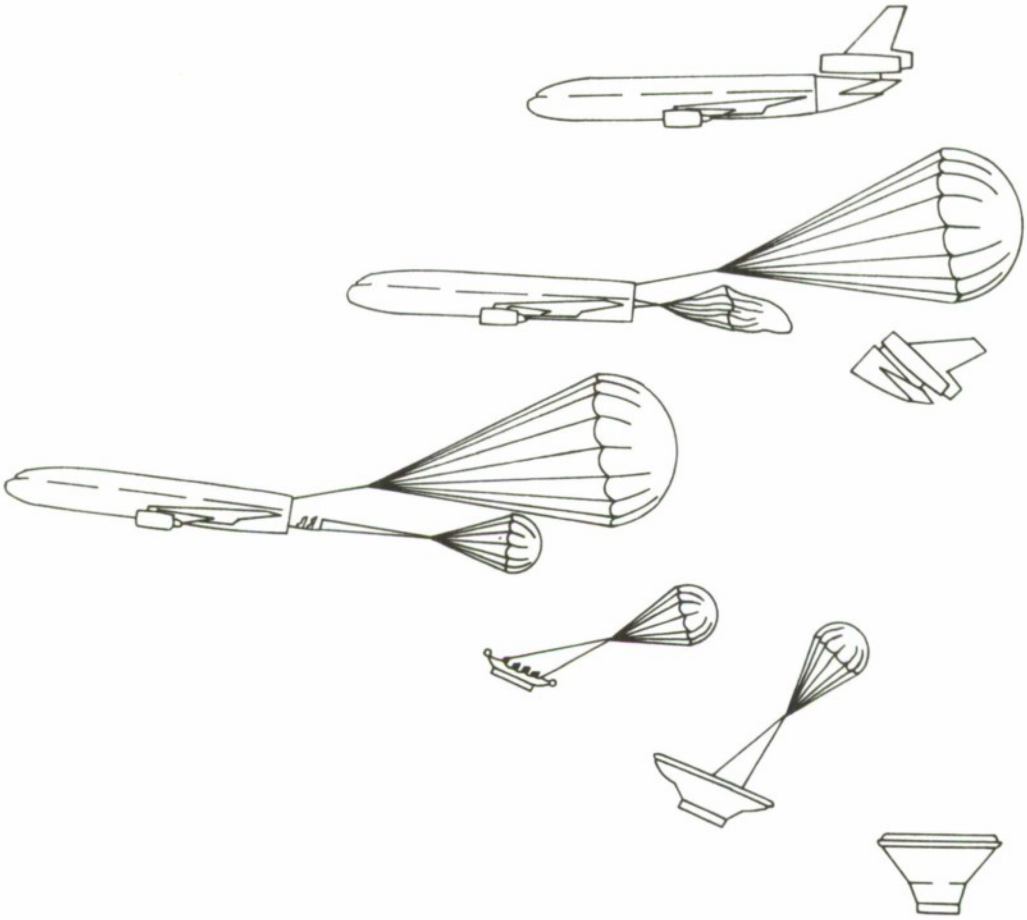


Fig. 103. Paracone emergency inflight egress concept [Kendall, 1970 (1098)].

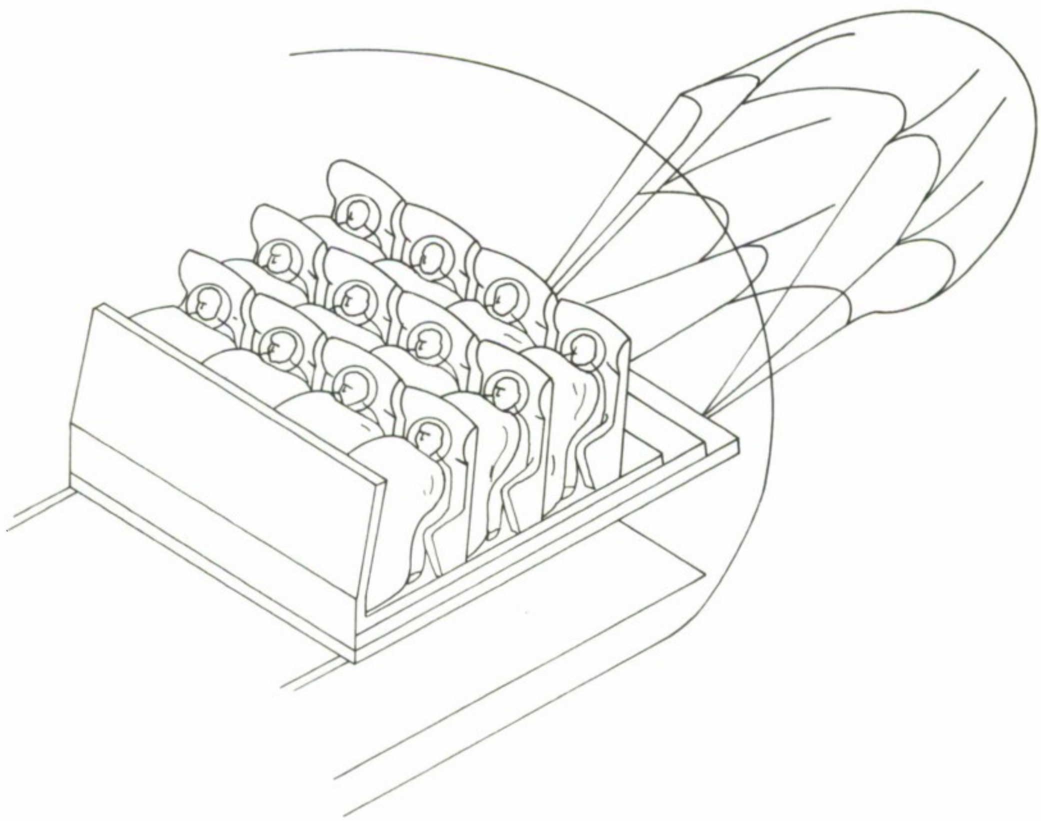


Fig. 104. Pallet passenger packaging at initiation of inflight emergency escape by paracone concept [Kendall, 1970 (1098)].

7.6.3 Rapidjet. To provide fast inflight egress for passengers or crew without the necessity of donning flight clothes or parachutes, and when "the presence of fire, smoke, poor visibility, aircraft maneuvers, decompression, injuries, hypoxia, panic, or confusion impairs the ability" of the occupants to put on their equipment, the rapidjet concept was proposed [McIntyre, 1970 (1099)]. The rapidjet installation would consist of an escape slide with power operated inner and outer doors, a series of individual crew escape modules, and the power drive unit required for module advance and release. The escape module for each passenger consists of an encapsulation bag of "cocoon" and a parachute pack. The open end of the cocoon is stretched across the escape slide entrance so that the crewman enters the cocoon as he jumps into the slide. Upon reaching the bottom of the cocoon, a sequenced release mechanism is triggered. This closes the open end and the cocoon and parachute pack are then released from the aircraft. The release of the escape module from the aircraft triggers an oxygen supply to a mask within the cocoon, and this activates an automatic parachute recovery system. As soon as one module is released, the remaining modules are power indexed toward the slide and another cocoon is positioned in the slide ready to receive the next passenger. This sequence is estimated to require 6 seconds.

As the escape module is released, a 1.2 m (4 ft) diameter Hemisflo drogue chute is deployed to provide immediate stability, deceleration, and controlled descent from high altitude. When descent is made to 4,572 m (15,000 ft) altitude, an aneroid-controlled actuator opens the main parachute pack, and the 9 m (29.7 ft) diameter "skysail" parachute is deployed by the drogue, utilizing the sleeve principle (4% reefing is used for 1 second to maintain opening shocks under 10 G's). In egress below 4,572 m (15,000 ft) a 3-second time delay is employed. The egress sequence and cocoon containment system is illustrated in Fig. 105. This concept is passive in the sense that the only action necessary from the occupant, once he has jumped into the slide, is to use a control handle to release the parachute after the cocoon has landed. This system would not appear to be usable in a case where the aircraft was violently thrown about, or ended up in an unusual attitude, which would prevent passengers from reaching the escape slides. There might also be a reluctance for uninitiated individuals to "trust" jumping into any opening not knowing whether there would in fact be a chute to catch them or not. Also, at the given rate of 10 individual "bail-outs" per minute per slide, it would take considerable total time to evacuate a loaded aircraft, under conditions in which little time would presumably be available.

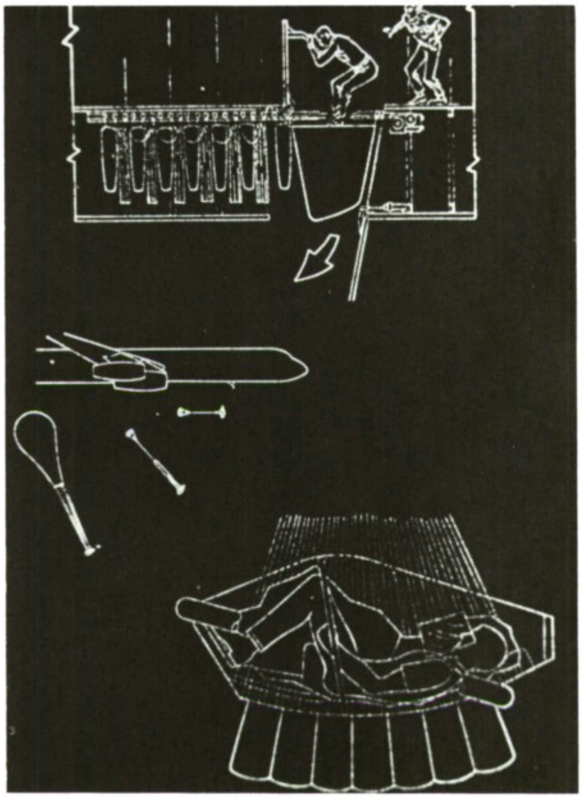


Fig. 105. Rapidjet emergency inflight egress system, deployment, and passenger cocoon container [McIntyre, 1969 (1099)].

7.6.4 Parachute Lowering of Fuselage. Ordnance techniques have developed to the point where it is possible for the pilot to increase survivability by jettisoning under exact control various parts of the aircraft, such as an engine, the complete baggage compartment or large sections of the fuselage for fast passenger egress under very extreme conditions [Sipes, 1967 (1079)]. In adapting this technique to inflight evacuation the module could consist of a section of seats which would be separately encapsulated and ejected as a unit, or jettisoned from the fuselage in separate compartments. However, the effects of flight dynamics on jettisoned sections could compromise a safe deployment in some environments.

In 1969 Snyder and Stapp (1103) proposed several concepts for inflight emergency egress, presenting the aeromedical aspects of a survival envelope necessary for salvage of a disabled air transport at sonic speeds and high altitudes. Fig. 106 shows the concept of inflight ejection of encapsulated compartments of a disabled aircraft. Such a system could not be retrofitted and would have to be designed into a future aircraft. However, while such a system is utilized in military aircraft having a small number of highly trained crew members, such as the B-1 [Beers, 1974 (848)] or F-111 [Shaffer and Brinkley, 1974 (17)], it probably would not be practical for air transport consideration, even though technically within the state-of-the-art.

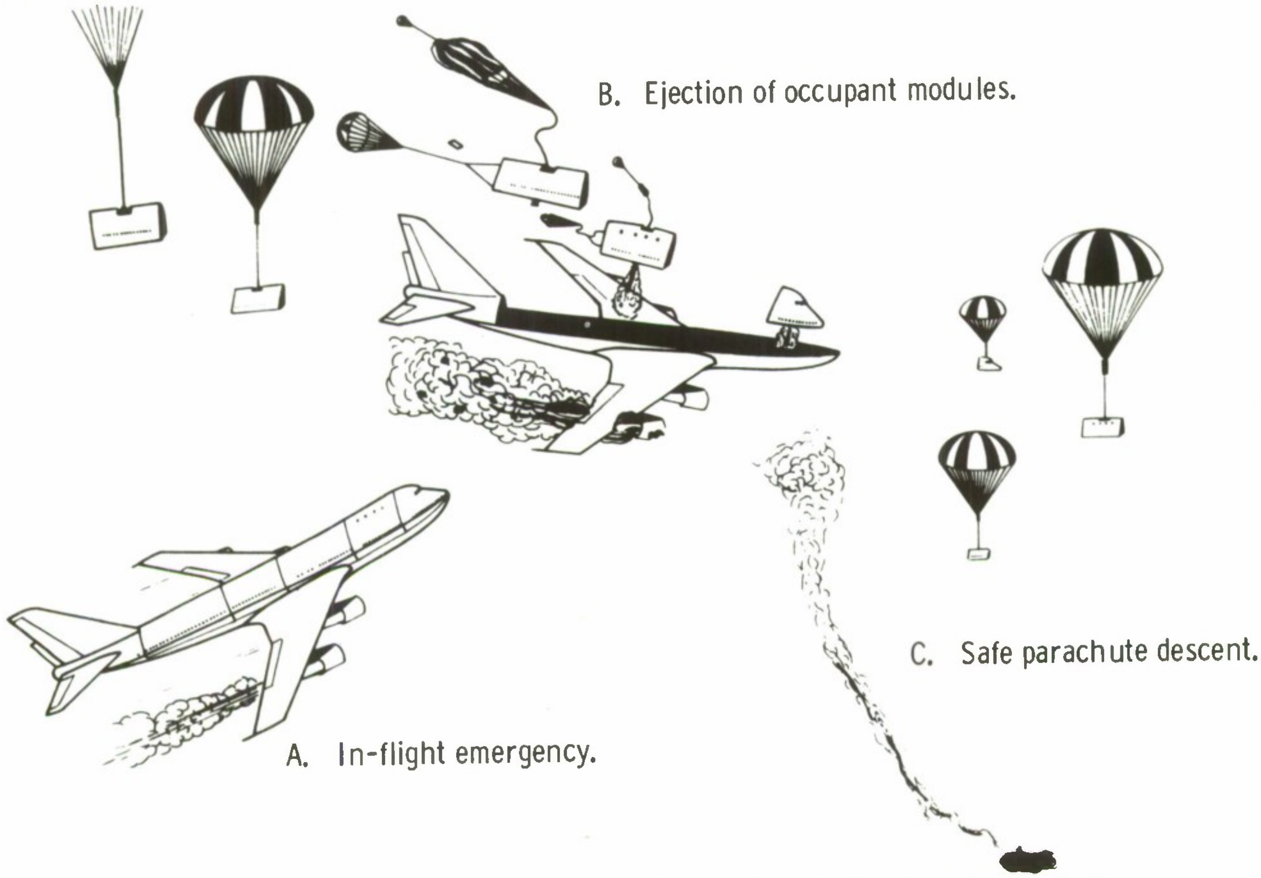


Fig. 106. Inflight ejection of encapsulated compartments from disabled airliner [Snyder and Stapp, 1969 (1103)].

Yet another concept resulting from studies conducted for NASA, combining tail evacuation and capsule-pod emergency escape, is illustrated in Fig. 107 [Yost et al., 1970 (789)].

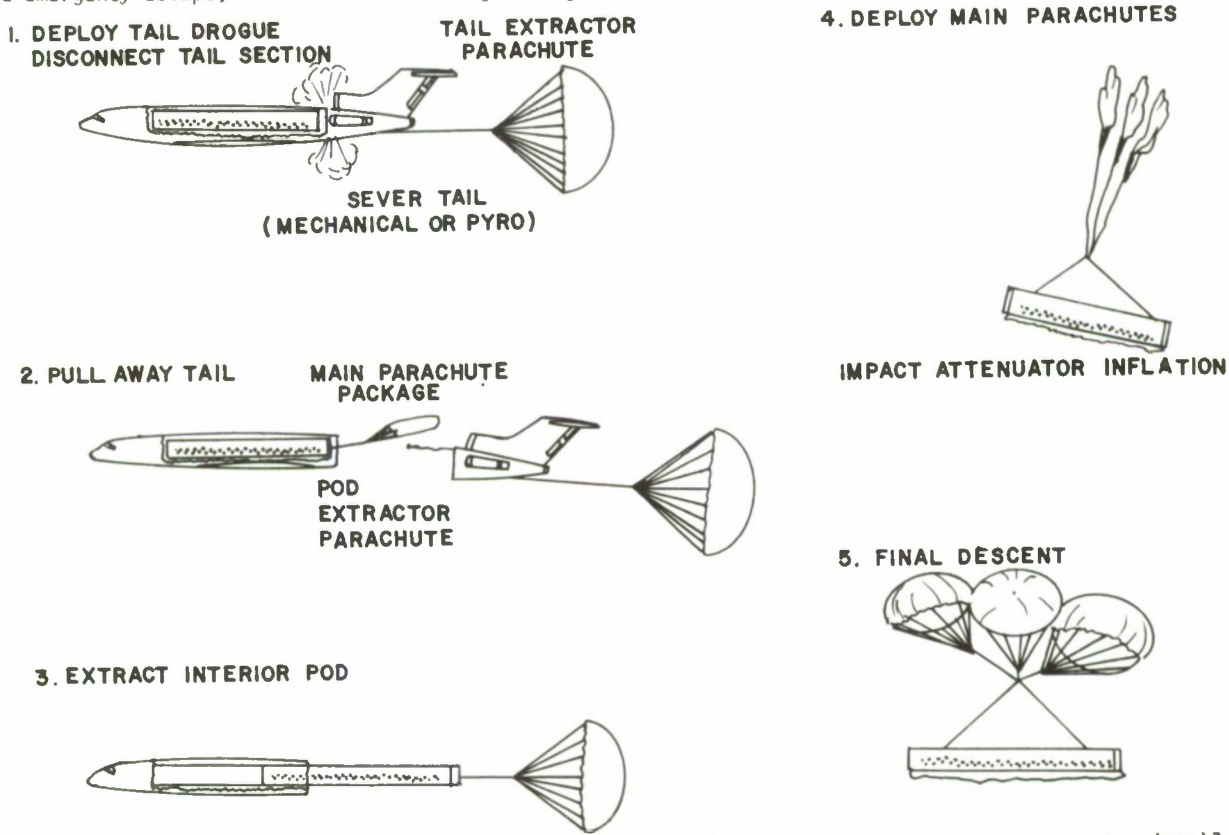


Fig. 107. Emergency inflight escape of passengers utilizing pod concept [Yost et al., 1970 (789)].

Still another concept is illustrated in Fig. 108. In this scheme the wings (or engines) and tail are separated by explosive technology (developed for military aircraft), drogue chutes then deploy to slow the velocity of the fuselage, and finally parachutes (probably multiple canopies) lower the fuselage to the ground (as with a space vehicle). The objective in this case is to salvage the occupants by keeping them as intact as possible in their own environment.

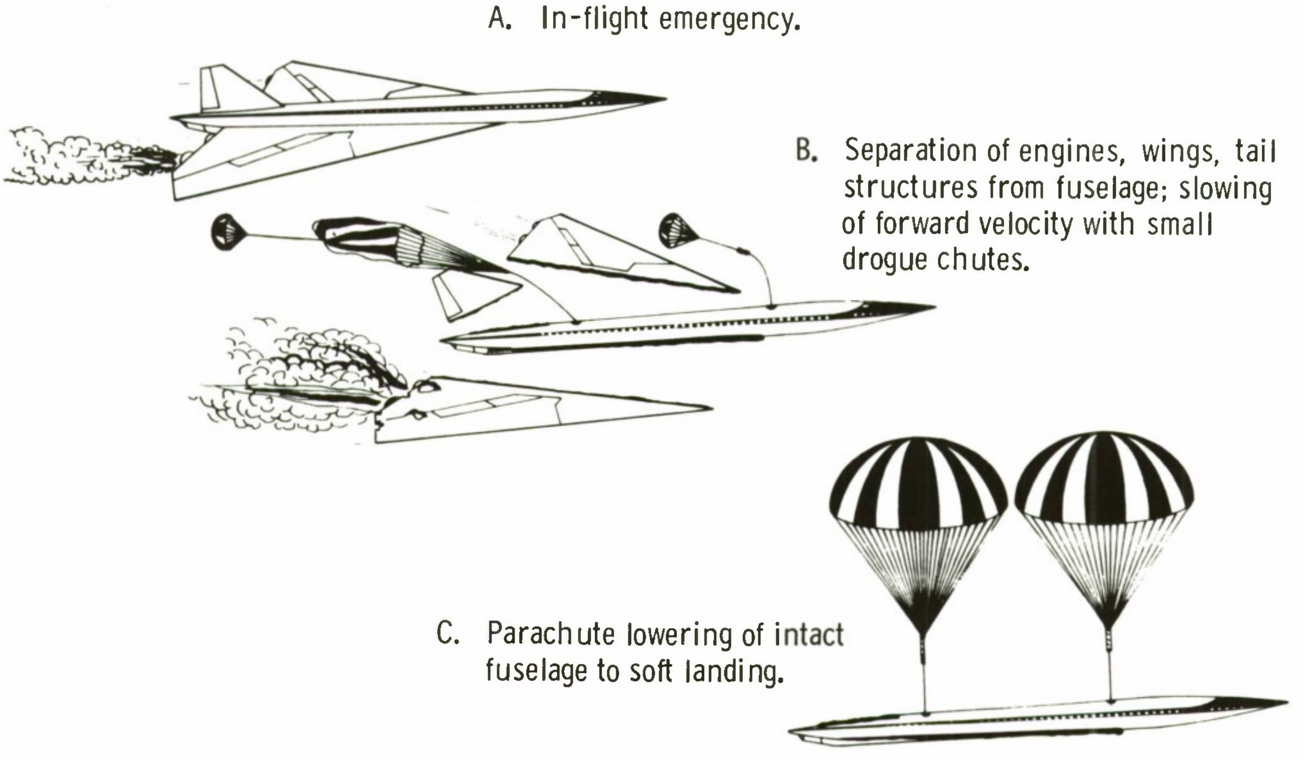


Fig. 108. Concept of safe parachute lowering of passengers and crew in fuselage of air transport following major structural failure in flight [Snyder and Stapp, 1969 (1103)].

Among many problems which would be anticipated in the development and testing of such a concept are the fundamental ones of how to ensure that the separation, braking and parachute deployment systems would be intact and reliable after an inflight structural failure and how to prevent (with 100% reliability) inadvertent activation of any of these systems. Other very fundamental considerations are cost of structural modifications, and weight (increased fuel usage) penalties. While the concept of lowering the passengers to the ground within tolerable impact velocities, using the aircraft emergency oxygen system, and keeping the thermal environment within tolerable limits may be possible under favorable environments, the complexity of accomplishing these objectives in future aircraft would require considerable effort to develop and evaluate. A similar technique has been previously considered in solving the problem of saving helicopter crews and passengers from otherwise fatal mid-air emergencies [Arnold and Pollard, 1968 (1088); Teledyne McCormick Selph, n.d. (1104)].

While the foregoing concepts are only unproven ideas, the fact remains that the area of emergency inflight egress for occupants of air transport aircraft has been largely ignored. This is in contrast to research relating to advanced inflight egress for aircrews and spacecraft, which has made considerable progress. The systems described in this section are within the state-of-the-art technically, however, until research programs are conducted to seriously test and assess an entire system it is not possible to determine at this time just how feasible these or other concepts may be. It would be unfortunate if the impetus for such research is the result of an inflight collision of two commercial air transports, as nearly occurred twice within 9 days in November, 1975, although the standard solution in such a case would be to increase the complexity of the avionics and airways system. On the other hand, each of the inflight emergency egress concepts examined to date (including the author's) may well involve a higher probability of hazard created by the proposed solutions, as indicated. The distinction between "practical" and "technically feasible" is often fine, but certainly this is an area where further study might be beneficial.

8. CONCLUSIONS

Analysis of current civil and military air transport aircraft accidents suggests that many injuries and fatalities that occur in otherwise survivable accidents could have been prevented or reduced. Since all accidents cannot be prevented, considerable benefits in terms of lives saved could be achieved by more fully utilizing advanced protective systems, devices, or concepts currently available as state-of-the-art technology. The objective of this study has been to gather and review those concepts which might have application to improving air transport crash impact and emergency egress survivability. The following steps were followed to accomplish this objective:

First, a review of future design trends was conducted.

Second, NATO member air carrier accident experience was analyzed to determine what impact and egress problems exist and to identify those areas where there is the greatest need for improvement. Besides the need for greater occupant protection against post-crash fire, smoke, toxic fumes, and impact (seating/restraint), a number of deficiencies were observed and have been pointed out in emergency lighting, passenger warning systems, and aisle and evacuation markers.

Third, using the background of accident experience as a basis, approximately 150 state-of-the-art techniques, devices, and concepts available through advanced technology were evaluated which may have application to both civil and military air transports. To provide an objective means of evaluation, a systems analysis approach was utilized to determine the most promising concepts.

The principal conclusions may be summarized as follows:

A. Accident Experience

1. In-Flight Accidents

Medical and human factors aspects of air transport accidents have had limited investigation and reporting, with the result that it is not possible to precisely determine the cause of occupant trauma nor the emergency egress problems in many cases. In-flight hazards of mid-air collision, turbulence, bird strikes, explosion, fire or structural failure, takeoff and landing crashes, ditching, and emergency egress experience were examined primarily for the period 1964-1975. From the comparatively limited data available it was found that fatalities and trauma (in otherwise survivable crashes) may be primarily attributed to smoke, fire and toxic fumes, followed secondarily by impact trauma.

. Mid-Air Collisions Reported from 1964 through 1971 included 12 U.S. air carriers, with 239 fatalities. In one year (1968) 2,230 near misses were reported, including 317 in which the miss was "critical" (only due to chance there was no collision) and during the first ten months of 1975 there were 207 officially reported "Hazardous" near-misses, suggesting that fatalities from mid-air collisions in the future could take a significant jump.

. Turbulence often has resulted in serious injury, 95 stewardesses and 241 passengers were injured in 70 air carrier turbulence accidents between 1968-1971 alone (116 serious), while 15 were injured in a single accident in 1974, and 17 injuries have been reported for a portion of 1975.

. Bird Strikes have been attributed as the cause of 63 accidents, 17 involving air carriers between 1964-1973. Two fatal crashes occurring in 1960 and 1962 resulted in 75 fatalities, and in 1975 a McDonnell Douglas DC-10 crash was also identified as a bird strike.

. In-Flight Explosions have been reported world-wide for 18 air transport catastrophies, and have included two NATO member Boeing 707's and a McDonnell Douglas DC-9. A recent Boeing 720 destruction was also attributed to this cause, although the investigation is not complete. These four accidents resulted in 242 fatalities. In-flight fire is not rare but has not been identified as a significant cause of major passenger-carrying accidents. Structural failure also has generally been the result of explosive decompression, collision, explosion, fire, or other primary cause.

. Explosive Decompression is required to be reported to the FAA only when related to "mechanical reliability reports," so the actual number of rapid or explosive decompressions (as well as inadvertent deployment and failure of emergency oxygen systems) is not known. Between mid-1968 and mid-1970, 253 cases were reported. Rapid decompression has been responsible for 175 fatalities (of 330 occupants) in a 1975 USAF Lockheed C-5A crash, for 345 fatalities in (the worst crash in history) a McDonnell Douglas DC-10 in 1974, and for ten passengers seriously injured and subsequently hospitalized in a 1975 DC-10 decompression.

2. Emergency Ground Egress

Most injuries and fatalities may be attributed to crash impacts which occur in take-off or landing phases of flight. Review of accident experience to date indicates an alarming number of injuries occurring during emergency ground egress, indicating that improvement is needed.

Contributing factors found include:

. Narrow aisle widths in coach sections (often 40% less than in first class) which restricts emergency evacuation capability.

. Blockage of aisles and exits by falling ceiling panels, failure of galley doors, overhead baggage doors, stowed emergency equipment, and hat racks spilling contents in aisles. Net restraints or improved door retension capabilities are necessary.

. Inability to use exits, because they are jammed, blocked, can't be opened, or due to fire.

. Lack of emergency exterior lighting.

. Inadequate warning or briefing of passengers prior to crash or ditching (the "bull horn" has not been reported as used in any emergency).

. Failure due to functional or environmental causes of emergency equipment, rafts, slides (did not inflate, punctured, too high off ground, too steep attitude, into fire, wind carried). Serious injuries to volunteer subjects in certification compliance tests are common from these causes, even though carried out under optimum conditions).

. Failure of the seat restraint system (seats, belts, anchorages) is a major cause of injuries and fatalities. The impact of the passenger or crew member with rigid non-yielding structure such as seat back trays also contributes.

. Lack of any occupant protection whatever in emergency egress during flame, smoke, or toxic fume conditions appears to be a primary cause of fatalities and trauma.

3. Ditchings

Since 1964 there has only been one intentional ditching of a jet transport aircraft and three unintentional water landings which could be classed as ditchings. These involved inadvertent ditching on takeoff of a Lockheed C-141A with fatalities to 7 of 9 crew, and of two McDonnell Douglas DC-8 transports: a Japan Air Lines flight that landed in the ocean 3-1/2 miles short of San Francisco in 1968, with 107 occupants, and a Scandinavian Airlines landing in Santa Monica Bay, California, short of the runway, in which of 45 aboard, 12 passengers and three cabin attendants were drowned or received fatal injuries, 11 passengers and six crew were injured, and only 13 passengers escaped injury. Studies have shown that high-wing air transports flood in the passenger compartment up to wing level within 5-30 seconds. Aircraft such as the Lockheed C-141 require an average of 7-1/2 minutes to evacuate a full load of passengers. While air carrier ditchings are rare it is apparent that high-wing aircraft may not be expected to ditch with the success of comparable low wing transports.

The intentional ditching of an ONA (operating as ALM) McDonnell Douglass DC-9 near St. Croix, Virgin Islands, in 1970 is the only known case of an intentional ditching of a scheduled jet air transport aircraft to date. Of 63 aboard there were 23 fatalities. A large number of adverse contributing factors were found to influence survival, including incomplete briefing and failure of crew to warn of impact. Injuries and fatalities were due to unrestrained passengers thrown forward at impact (some while standing in aisles), to at least seven failures of seat belts (metal to fabric) with slippage of others, to contents of galley blocking one emergency exit, and to the loss of all life rafts. This ditching impact left the fuselage intact, which floated for 5-6 minutes. All survivors egressed within 2-3 minutes, but the loss of life rafts pointed to the need for improved emergency egress devices, along with retension of galley and hat-rack baggage stowage, improved seating, restraint systems, and crew training.

B. Advanced Technology

1. Smoke Hood

The need for post-crash protection of passengers and crew from disabling and fatal effects of toxic fumes, smoke, and flame has been well documented. Some 17 protective smokehood concepts or developments were evaluated in this study. At present, although a production smokehood is used in the President's aircraft, many FAA and corporate aircraft, and by knowledgeable individual travelers, there is no FAA requirement to provide this protection to air carrier passengers and crew. In January 1969 an FAA NPRM to require that protective smokehoods be carried in all civil air carriers was initiated but withdrawn nine months later. Several protective hood devices developed for non-aviation-related purposes offer a self-generating air supply for up to 15 minutes. However, the increased complexity of use, and increased cost, do not make them as practical as a rebreathing device at this time. Civil air carriers are required by FAA to demonstrate that all passengers can be evacuated within 90 seconds, but FAA burn tests have demonstrated that after three minutes, heat may preclude survival in current aircraft interiors. Thus a requirement for extended breathing time is not realistic. The Sheldahl septal seal (type S) smokehood, is a current production rebreathing device which can offer significant protection to 1472°F. This device is constructed of metalized polyimide film (Kapton), offers 4-6 minutes rebreathing time, (about 20 liter vol.), and has been subjected to extensive FAA testing since 1965. A potential hazard related to time exposure beyond critical rebreathing (3-6 minutes) is far outweighed by the survival benefits provided. It is highly recommended that a smokehood be made immediately available to passengers and crew of all civil and military air transport aircraft.

2. Passenger Seating and Restraint Systems.

The state-of-the-art in occupant protection and passenger seating has greatly exceeded current air transport requirements (which have not significantly changed since established a generation ago). Considerable documentation from accident investigation has cited seat and restraint failure as a major cause of fatality and injury in a large number of otherwise survivable accidents. Although there are no FAA standards dealing with occupant protection above a "minor" crash landing, review of human tolerance research overwhelmingly has documented the adequately restrained individual's ability to withstand accelerative forces considerably greater than the forces generated in most air carrier crashes. This is most simply expressed, as cited in the text of nearly a decade ago, that we have 40G people riding in 20G airplanes and sitting in 9G seats and restraint systems. Technology has been available for some time to provide passenger protection far above that currently available.

. Rearward-Facing Passenger Seating. In comparison with forward (or sideward) body orientations, rearward facing passenger seating provides the maximum protection from impact forces. The major advantages are that crash loads are distributed over a larger portion of the body and the head is better protected. Such seating is used in RAF transports and has been the predominant passenger orientation in USAF transports for 25 years (The USAF adopted in 1951 a 250 lb. occupant criteria ∴ 4,000 lb (1,814 Kg) ultimate load in a 16G seat, vs. the 1976 FAA requirement of 1,530 lb (694 Kg) ultimate load for a 170 lb (77 Kg) occupant in a 9G seat.) The USAF 16G rearward facing seat was 15 lb (6.8 Kg) lighter than the 6G forward facing seat it replaced, and has been found to offer effective impact protection.) One accident study has shown seven times less injury to rear-facing passengers when compared to frontal seated occupants. Although requiring stronger seats, anchorages, and seat backs, current technology can provide rear-ward facing seats of lighter weight as well as greater strength.

. The NASA Ames Integral aircraft passenger seat is a prime example of the system approach and NASA's expertise in aerospace technology combined to conceive, design, test, and develop from scratch a seat specifically for new-generation air transport use. Based upon study of the failings of current seats, it has had extensive development and dynamic testing (to $21+G_x$ $45+G_z$), or a demonstrated protective capability of 2 to 10 times current seats. The inertia-reel-integral double-upper-torso restraint provides additional protection against jackknifing or head and upper torso injury, and is comfortable to use. Weight has not increased. The NASA integrated seat, operationally used only in part to date on NASA's Convair 990 air transport, represents the state-of-the-art. As a considerable advance over current generation seats it must be highly recommended for current or future air transport use.

. Advanced active and passive (requiring no effort from the occupant) restraint systems were evaluated in this study. Passive restraints included over 65 concepts or devices, such as webbing belt restraints which are automatically locked in place when the individual sits in the seat, deployable net, blanket, and air bag systems, transparent shields, cushions, arms and barriers, static/capsule, and deployable head restraints. Inverted Y-yoke and integrated seat-restraint harnesses, which retract into the seat and incorporate inertia reels, offer increased occupant protection for the passenger over conventional lap belts. However, they also require stronger seat backs and anchorages to be an effective system. Although a number of concepts were found to be technically feasible several were especially promising, including the Allied Chemical inflaband, which combines a three-point upper torso belt with the advantage of a passive inflatable system, integrated/inflatable systems developed by HSRI for NHTSA, and inflatable air bag systems.

. Inflatable air bag passive restraint received particularly comprehensive attention in this study due to the major development and testing previously conducted for motor vehicles relative to proposed federal standards. Only very limited study relative to aircraft has been conducted, although adaptations have been used in the American Rockwell B-1 capsule landing shock attenuators and the General Dynamics F-111 for side-impact energy attenuation. The state-of-the-art relative to development, components, design, crash sensors, inflation energy sources, diffusers, human volunteer tests, aspects of noise and toxicity, and accident experience have been reviewed. Major problems which must be resolved include determination of a crash envelope, including critical closing rates and collision object definition for use with proximity sensors; definition of crash G-loads anticipated in aircraft accidents with sufficient accuracy that hard landing or air turbulence can be distringuished from impact events; the level of hazard with respect to toxicological or other occupant physical/physiological hazards and with respect to effect on occupant egress; reliability and cost effectiveness problems, such as possible structural changes in the aircraft, penalty for increased weight (could be 1 to 2t. in 300-500 passenger aircraft),-redesigns of seats, maintenance, longevity, cost in comparison with other systems. One major problem involves crash sensing, and although there are now acoustic, optical, radar, radar-impact switch combination, proximity, mechanically extended probes, electro-mechanical, chemical, and electromagnetic systems and numerous additional subsystems under development, they have not been tested for use in aircraft crash environments, nor is the effect of some of these systems known relative to airborne avionics systems.

Results of extensive air bag tests, accident data, and human volunteer testing to date clearly indicate that the air bag restraint system is capable of offering excellent occupant protection in a frontal mode, although it must be combined with a lap belt (active system) to provide adequate lateral protection. The Diamond air bag system is the only such concept developed to date for the back of air carrier seats, but even this is in prototype stage requiring further tests and is at present manually operated. It is concluded that at this point in the state-of-the-art, that the NASA Ames air transport seat, and the rearward facing seat, as well as several integral restraint systems, offer better all-round crash protection for the air transport passenger than passive inflatable air bag systems.

3. Aisle and Evacuation Path Markers

A number of interior aisle and pathmarker illumination systems and concepts are available which could offer significant improvement for passenger egress, but none have had adequate research for this specific application in a crash environment.

. Reflective tapes require illumination for effective utilization, while phosphorescent or ultra-violet markers require either pre-illumination exposure or a special light source for activation.

. Self-luminous sources such as Tritium markers presently provide relatively low levels of illumination without exceeding allowable radioactive levels.

. Electro-illuminescence offers another means, but requires a relatively high level of electric current for activation.

. A promising technique for providing adequate pathway illumination, signs, and directional markers involves chemo-illuminescence (either exposure to air or to a second chemical). This could be achieved by initiation upon impact.

. Adequate emergency aisle markers, evacuation markers, and egress sign illumination could be provided by a gaseous discharge system using Xenon strobe lights, which would be most effective in a smoke-filled dark cabin and would require only small battery units for initiation.

. Tactile markers could provide a means of emergency egress in the absence of light; however, they have been found ineffective in limited group evacuation testing and require further development.

. Directional pulsating lights, using incandescent illumination, appear to be a good concept but have not been tested in this application.

. Floor-level lighting can be utilized by application of present incandescent techniques.

. Aisle width, especially in coach class seating configurations, should be reassessed and made wider in future air transports because of accident findings of difficulty in reaching egress, and slower evacuation time. The 15 inch (38 cm) aisle width is estimated to be exceeded in hip breadth by up to 10% of the population. Addition of from 2.54-12.7 cm (1-5 in) would assist.

4. Passenger Warning and Public Address Systems.

Electronic public address systems were not required until September, 1975 by the FAA. The TWA battery-powered audio/visual system with solid-state audible pulsed alarm is designed for crew communication only and provides no alarm warning for passengers; however, it could provide an effective emergency communication link between the military pilot and loadmaster or cabin crew. The same function could be improved through a solid-state portable communications device, offering greater flexibility. In cases of main communications failure, the battery-powered portable bull-horn is effective if within reach of a crew member but has not yet proven useful in actual crash evacuation. The present military air transport bell alarm system is relatively ineffective (50% in cases studied) because there is often insufficient time for manual activation. Passenger warning and public address systems appear to be areas where great improvement is needed. A more reliable means of automatically communicating warnings to passengers in crash or emergency egress situations, as well as post crash communication, should receive further attention.

5. Advances in Emergency Egress Concepts

. Slide Devices. The current-generation double-aisle slide/raft escape device offers reasonable evacuation capability for cabin doors, and in ditchings can save considerable time in deploying rafts. However, operational problems found include non-deployment, cost and time in inadvertent deployment, and injuries resulting from unusual aircraft positions beyond the capabilities of the slide to reach the terrain. The possibility of employing cargo type doors and/or swing-tail or swing-nose concepts for mass evacuation of future extra-wide body air transports is worthy of further study.

. The ELSIE high-energy emergency egress system, developed and tested by the USAF in C-130 aircraft, represents the most advanced and potentially most significant technical improvement currently available to instantaneously provide emergency egress for passengers post-crash and may also serve a function of deploying survival equipment such as slides, rafts, slide/rafts, beacon markers, and survival kits. This system can be retrofitted into existing aircraft, as is being initiated for USAF Lockheed C-141 transports. Despite the demonstrated military success with ELSIE, application of explosive escape technology to civil air transports will require further consideration for means of initiation, potential for human error, inspection methods, and reliability.

. Heat Shielding of air transport cabins has been indicated in NASA tests (where the fuselage is intact post-crash) to be accomplished by utilizing intumescent paint, a technique similar to that used to protect Apollo astronauts. Significant protection has been reported against smoke, toxic gases (at least 5 minutes), and heat/flame (for about 12 minutes), for a weight penalty of 0.3 lb per sq ft of protected surface area (1700 lb for 400,000 lb gross weight air transport).

. Ablative coating for overwing exit areas appears also feasible. NASA is presently exploring feasibility of effective flexible coatings. Emergency egress devices such as escape slides or raft/slide combinations could use a flexible ablative coating to protect them for a short time duration against flame damage.

. Emergency In-flight Egress. At present there is no way to survive a major in-flight accident, although emergency in-flight egress has long been provided for test flight crews of the same air transport aircraft by means of escape chutes installed in the flight deck of prototype models. Of four techniques reviewed, drogue-parachute deployment to slow and lower the intact-disabled cabin, after separation of the engines wings, and empannage to reduce weight, appears to be most promising. This concept is one of several being developed for large passenger-carrying helicopter recovery. However, while this and other concepts appear to be technically feasible, further study is necessary to evaluate weight (fuel/range) penalties, cost, and other aspects of the entire environmental system. To date there has been no clear requirement, based upon past accident experience, for future in-flight emergency egress; however this may only have been a matter of chance as documented by the volume of past near-miss incidents on record.

. Trends in next-generation air transports beyond present supersonic and subsonic wide-bodied aircraft are being influenced by concerns for energy conservation, with advanced designed proposed for exotic liquid-hydrogen-fueled and laminarized-flow aircraft. Very large 1000-passenger transports and cargo aircraft have been conceived, such as the 375-ft (114.3 m) 2,400-t span-loaded flying wing with six times the payload of the Boeing 747F and utilizing air cushion landing systems, the Dornier 1000-t capacity, and the very wide body (five 90 ft (27m) bays) cargo transports. STOL and V/STOL air carrier development may also be an important projection. However, historically air transport design and standards have not incorporated state-of-the-art techniques or devices relative to occupant crash impact protection and emergency egress.

It is concluded that the present rate of fatalities and injuries incurred in otherwise survivable accidents in current air carrier aircraft could be significantly reduced by use of a smokehood, and use of either the NASA Ames Integrated airline seat or rear-facing seating. Cabin heat shielding and ablative flexible coatings utilizing intumescent paint, also appear promising. Other improvements are needed in the slide/raft, in emergency illumination, in passenger warning devices, and in aisle and pathway path-markers which could utilize xeon gaseous discharge, chemo-illuminescence or floor level and pulsating incandescent techniques. Some concepts such as the ELSIE high-energy emergency egress system technologically offer a significant advance in emergency escape capability, and should be considered for future air transport design, although requiring further study before the feasibility of adaptation to civil air carrier operation can be determined. In view of the rapidly expanding technological base, to achieve optimum occupant crash protection and survival will require much greater emphasis upon research in those areas and in insuring that the state-of-the-art be considered in future air transport design.

REFERENCES

I. INTRODUCTION

1.1 Background

1. Aerospace Industries Association of America, Inc. Crashworthiness Development Program, Technical Group Report. Report No. AIA CDP-1-4, July, 1968.

2. Black, D.O. Facilities and Methods Used in Full-Scale Airplace Crash-Fire Investigation. National Advisory Committee for Aeronautics, Lewis Flight Propulsion Laboratory, Cleveland, NACA RM ESIL06, March, 1952 (declassified 3 April, 1953).

3. Brown, C.L. Emergency Ground Egress from USAF Passenger-Carrying Aircraft. Presented Seventh National SAFE Symposium, Las Vegas, Nevada, October, 1969.

4. Caldara, J.D. "Commercial and Military Aircraft Emergency Egress Systems." Proceedings, Eighth Annual Symposium, The Survival and Flight Equipment Association, Vol. 1, September, 1971, pp. 295-333.

5. Carr, R. Helicopter Troop 1 Passenger Restraint Systems Design Criteria Evaluation. Prepared for Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, Report No. USAAMDL-TR-75-10, June, 1975.

6. Carr, R. and S. Desjardins. Aircrew Restraint System - Design Criteria Evaluation. Prepared for Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, Report No. USAAMRDL-TR-75-2, February, 1975.

7. Clarke, T.D. Daisy Track Baboon Lethal Tolerance Tests. 6571 AMRL, Department of Transportation Final Report, Holloman AFB, New Mexico, 1970.

8. Kubokawa, C. "The NASA Ames Integral Aircraft Passenger Seat Concept - A Human Engineering Approach." SAFE Journal, Vol. 4, No. 4, 1974, pp. 18-23.

9. National Highway Traffic Safety Administration. "Occupant Crash Protection." Federal Register Docket 74-14, Notice 4.40(157):33977, August, 1975.

10. National Transportation Safety Board. Aircraft Accident Preliminary Report. ALM Dutch Antillian Airlines DC-9-33F, N953F, Caribbean Sea, 29 Miles ENE of St. Croix, V.I. VOR, May 2, 1970, 1549 EDT. Safety Information Report, SB70-49, 29 June, 1970.

11. National Transportation Safety Board. Aircraft Accident Report. Overseas National Airways, Inc., Douglas DC-9, N935F, Operating as Antilliaanse Luchtvaart Maatschappiji Flight 980, Near St. Croix, Virgin Islands, May 2, 1970. Washington, D.C., Report No. NTSB-AAR-71-8, 31 March, 1971.

12. National Transportation Safety Board. Special Study. Passenger Survival in Turbojet Ditchings (A Critical Case Review). Washington, D.C., Report No. NTSB-AAS-72-2, 5 April, 1972.

13. Reagin, J.L., C.L. Brown, P.A. Land, and B.P. Chesterfield. Combat Egress: A Study of Emergency Escape and Survival Criteria for USAF Transport Aircraft. Prepared by Combat Egress Working Group, in Coordination with Life Support and Electronic Systems Management Division, Directorate of Material Management, Kelly Air Force Base, Texas, USAF Directorate OT & E/AFLC/69-8, 14 March, 1969.

14. Robbins, D.H. and R.G. Snyder. A Systems Engineering Evaluation of Passive Restraint Systems for Crash-Impact Attenuation in Air Transport Aircraft. Society of Automotive Engineers, Inc., New York, New York, Paper No. 740044, February, 1974.

15. Roebuck, J.A., Jr. New Concepts for Emergency Evacuation of Transport Aircraft Following Survivable Accidents. Prepared for Aircraft Development Service, Federal Aviation Administration, Department of Transportation, Washington, D.C. by Aerospace and System Group North American Rockwell Corp., Los Angeles, California, FAA Report No. DS-69-2, January, 1968.

16. Sawyer, C.H. USAF Cargo/Transport Crash Experience - Limiting Factors in Crash Survival and Escape in Land Accidents, 1 January, 1962-30 June, 1967. Department of the Air Force, Headquarters, United States Air Force, Washington, D.C., 1967.

17. Shaffer, J.T., and J.W. Brinkley. Lateral (-Gy) Impact Tests with Inflatable Restraint Systems for Air Force Crew Escape Module Applications. Society of Automotive Engineers, Inc., New York, New York, Paper No. 740043, 25 February, 1974.

18. Sommers, J. "Airbag Restraint for General Aviation Aircraft." Proceedings of the Institute of Environmental Sciences 18th Annual Technical Meeting, New York, New York, May, 1972.

19. Snyder, R.G. Passenger Protection and Crashworthiness in the Coming Decade. Proceedings, XIX International Congress on Aeronautics and Space Medicine, Tel Aviv, Israel, 25 October, 1971.

20. Snyder, R.G. "Advanced Concepts in Crash Impact Protection and Emergency Egress Techniques for Air Transport Aircraft." Preprints, Aerospace Medical Association. 1975 Annual Scientific Meeting, April, 1975, pp. 91-92.

21. Snyder, R.G., and D.H. Robbins. "Crash Egress Experience in C-141 and C-135 Military Air Transport Aircraft" (unpublished paper). 1972.

22. Snyder, R.G., and D.H. Robbins. Crash Impact and Escape Study. Final Report prepared for Air Force Systems Command, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, under contract No. F-33657-71-C-10709, University of Michigan Report No. ORA-71-1380-KB1, December, 1971.

23. USAF-Industry Life Support Conference. Directorate of Aerospace Safety, Norton AFB, California, - Las Vegas, Nevada, 28 November - 1 December, 1967.

1.2 Scope and Objectives

24. Department of Defense. Human Engineering Design Criteria for Military Systems, Equipment and Facilities. MIL-STD-1472A, Washington, D.C., 15 May, 1970.

25. Department of Defense. Reliability Program for Systems and Equipment Development and Production. MIL-STD-785A, Washington, D.C., 28 March, 1969.

26. Department of Defense. Maintainability Program Requirements. MIL-STD-470, Washington, D.C.,

27. Department of Defense. System Safety Program for Systems and Associated Subsystems and Equipment. MIL-STD-882, Washington, D.C., 15 July, 1969.

1.3 Future Trends

28. Aviation Week and Space Technology. "Next Generation Transports Will Emphasize Fuel Savings." 28 October, 1975, pp. 48-51, 55, 63.

29. Aviation Week and Space Technology. "Tomorrow's Transport Technology." Special Report, 10 November, 1975, p. 40.

30. Aviation Week and Space Technology. "Airlines Weigh NASA Technology Studies." 10 November, 1975, pp. 83-87.

31. Aviation Week and Space Technology. "Boeing 7X7 Development Stresses Costs, Fuel." 10 November, 1975, pp. 48-52.

32. Aviation Week and Space Technology. "Advanced Airborne Command Post Design." 12 August, 1974, p. 58.

33. Aviation Week and Space Technology. "Boeing YC-14. The Jet That Could Land in the Grand Canyon with a 27,000 Pound Payload." 3 November, 1975, pp. 40-41.

34. Automotive Engineering. "New Concepts for Air Transports." Vol. 83, No. 5, May, 1975, pp. 31-35.

35. Boullioun, E.H. "Report on Future Transport Trends." Presentation at World Transport Conference, London, Editorial. Aviation Week and Space Technology, 3 June, 1974, p. 7.

36. Civil Aviation Research and Development (CARD) Policy Study. Joint Report. Department of Transportation and National Aeronautics and Space Administration, DOT TST-10-4; NASA SP-265, March, 1971.

37. Civil Aviation Research and Development Policy Study. Supporting Papers. Department of Transportation and National Aeronautics and Space Administration, DOT TST-10-5; NASA SP-266, March, 1971.

38. Carline, A.J.K. Future Hydrogen Fueled Commercial Transports. Society of Automotive Engineers, Inc., New York, New York, Paper No. 750615, 1975.

39. Cook, G. Weird and Wonderful Aircraft. Enterprise Books, Secausus, New Jersey, 1975, p. 43.

40. Dornier AG. "The DO231 V-Jet." VSTOL is the Answer to the Transportation Needs of Tomorrow, Friedrichshafen, 1974.

41. Dornier, C. "Future Tasks for European Aircraft Industry." Dornier Post, Vols. 1-2, No. 75, February, 1975, pp. 4-7.

42. Elson, B.M. "Short-Haul Designs Include Trade-offs." Aviation Week and Space Technology, 10 November, 1975, pp. 73-78.

43. Federal Aviation Administration. Aviation Forecasts Fiscal Years 1971-1982. Department of Transportation, Office of Aviation Economics, Aviation Forecast Division, January, 1971.

44. Federal Aviation Administration. The National Aviation System Plan: Fiscal Years 1976-1985. Department of Transportation, Washington, D.C., No. 1000.27, March, 1975.

45. Fink, D.E. "New Wide-Body Transport Plan Evolving (Part I)." Aviation Week and Space Technology, 13 October, 1975, pp. 22-29.

46. Fink, D.E. "DC-X-200 Melds DC-10, New Technology (Part II)." Aviation Week and Space Technology, 20 October, 1975, pp. 35-37.

47. Fink, D.E. "Builders Vie for Short/Medium Market." Aviation Week and Space Technology, 10 November, 1975, pp. 43-51.

48. Geratherwohl, S.J., S.R. Mohler and P.V. Siegel. Medical and Psychological Aspects of Mass Air Transportation. FAA Office of Aviation Medicine, Washington, D.C., Report. No. FAA-AM-71-10, March, 1971.

49. Goodmanson, L.T. "Transonic Transports." Astronautics and Aeronautics, November, 1971, pp. 46-57.

50. Haley, J.L., Jr. "Air Force STOL Crashworthy Features." Paper presented at Air Force Advanced Medium STOL Transport (AMST) Meeting, Wright-Patterson AFB, Ohio, 27 January, 1976.

51. Hofton, A. "Commercial Aircraft of the World." Flight International, Vol. 108, No. 3476, October, 1975, pp. 609-638.

52. Industry Observer. "NASA is Studying a Huge Span-Loaded Flying Wing Design as a Future Fuel Efficient Air Freighter." Aviation Week and Space Technology, 21 October, 1974, p. 11.

53. Lange, R.H. The Spanloader Advanced Transport Concept, Lockheed Georgia Co., Marietta; Society of Automotive Engineers Inc., New York, New York, Paper No. 750616, 1975.

54. Marks, M. McDonnell Douglas AMST Program quotes as cited in Kocivar, B., "Super STOL." Popular Science, Vol. 208, No. 2, February, 1976, pp. 84-86, 136.

55. Mohler, S.R. "Advanced Aviation Medicine - Supersonic Transportation and Other Exotic Aircraft." Texas Reports of Biology and Medicine 24(Suppl.), June, 1956, pp. 392-401.

56. Newman, R. Personal Communication. Ministry of Transport, CATA STOL Project, Ottawa, 6 February, 1976.

57. O'Lone, R.G. "Cost-Saving Cargo Transport Studied." Aviation Week and Space Technology, 14 October, 1974, p. 28.

58. Ropelewski, R.R. "French Studies Poised for Market Thrust." Aviation Week and Space Technology, 10 November, 1975, pp. 63-67.

59. Schaffer, J. Why are We Flying More but Enjoying it Less? Thirteenth Annual Symposium of the Society of Experimental Test Pilots, Los Angeles, California, 25 September, 1969.

60. Schmidt, C.F. "Pointing the Way for Air Transport Technology." Astronautics and Aeronautics, Vol. 9, No. 10, October, 1971, pp. 63-67

61. Schneider, C. "Rockwell Proposes VTOL C-130 Version." Aviation Week and Space Technology, Aeronautical Engineering Section, 6 October, 1975, pp. 34-39.

62. Schriever, B.A. and W.W. Seifert. Air Transportation 1975 and Beyond: A Systems Approach. MIT Press, Cambridge, Mass., 1968.

63. Schumann, W.A. "Limited SST Use Gets Initial Approval." Aviation Week and Space Technology, 10 March, 1975, p. 28.

64. Taylor, J.W.R., ed. Jane's All the World's Aircraft 1974-75. Jane's Yearbooks, London, 1974, p. 20.

65. Taylor, J.W.R., ed. Jane's All the World's Aircraft 1975-1976. Jane's Yearbooks, London, 1975, pp. 23, 291.

66. Tryckare, T. "Breguet Br 941." The Lore of Flight, Gothenburg, Sweden, 1970, p. 314.

67. Ward, E.J. The Impact of New Transportation on Future Living Patterns. Society of Automotive Engineers, Inc., New York, New York, Paper No. 710054, January, 1971.

68. Wells, E.C. Potentials for Advanced Civil Transport Aircraft. The Third William Littlewood Memorial Lecture, Society of Automotive Engineers, Inc., New York, New York, Publication SP-385, 1973.

69. Wetmore, W.C. "Fuel Outlook Dictating Technical Transport Research." Aviation Week and Space Technology, 28 October, 1976, pp. 52-63.

2. AIR TRANSPORT ACCIDENT EXPERIENCE

2.1 Sources and Limitations of Data

70. Aerospace Industries Association of America, Inc. Aerospace Facts and Figures 1974/75. Published by Aviation Week and Space Technology, New York, New York, 1975, pp. 76-77.

71. Aerospace Industries Association of America, Inc. Aerospace Facts and Figures 1975/76. Published by Aviation Week and Space Technology, New York, New York, 1976, pp. 70-78.

72. Air Registration Board. International Register of Civil Aircraft. Bureau veretas, Registro Aeronautico Italiano Joint Publication, Edition G., London, 1969.

73. Air Saftey Investigation Branch. Accident Investigation Report. Pan-American World Airways, Inc., Boeing 707-321B Aircraft N892PA at Sydney (Kingsford Smith) Airport, Australia on 1st December, 1969. Department of Civil Aviation, Australia, Special Investigation Report 69-1, August, 1970.

74. Aviation Week and Space Technology. "Board in Massachusetts Reports on Logan Airport." Safety Section, 4 March, 1974, pp. 52-54.

75. Aviation Week and Space Technology. "Letters to the Editor - Airline Accidents." 4 March, 1974, p.58.

76. Aviation Week and Space Technology. 1975 International Aerospace Specification Tables. McGraw-Hall, Inc., New York, New York, 1975.

77. Aviation Week and Space Technology. "Controllers Claim Safe Altitude was 727 Crew's Responsibility." 10 February, 1975, pp. 39-40.

78. Aviation Week and Space Technology. "Wind Factor Studied in Iberia Crash." Safety Section, 14 April, 1975, pp. 53-56.

79. Aviation Week and Space Technology. "Board Details Engine Overspeed Accident." Safety Section, 21 April, 1975, pp. 63-66.

80. Aviation Week and Space Technology. "NTSB Studies Fan Section Disintegration." Safety Section, 5 May, 1975, pp. 64-69.

81. Aviation Week and Space Technology. "NTSB Finds Descent Error Caused Crash." Safety Section, 26 May, 1975, pp. 56-57.

82. Aviation Week and Space Technology. "NTSB Assays L-382 Crash in Illinois." Safety Section, 4 August, 1975, pp. 52-54.

83. Aviation Week and Space Technology. "NTSB Studies Eastern DC-9 Accident." Safety Section, 13 October, 1975, pp. 58-61.

84. Aviation Week and Space Technology. "Eastern DC-9 Accident Causes Detailed." Safety Section, 20 October, 1975, pp. 58-59.

85. Civil Aeronautics Board. Report of Crash/Injury and Evacuation Accident Involving Allegheny Airlines Convair 440, Flight 604, N8415H, Williamsport, Pennsylvania, July 23, 1965. Washington, D.C., 5 October, 1965.

86. Civil Aeronautics Board. Aircraft Accident Report. Bonanza Air Lines, Inc., Fairchild F-27A, N745L, Las Vegas, Nevada. November 15, 1964. Washington, D.C., 19 November, 1965.

87. Civil Aeronautics Board. Aircraft Accident Report. The Flying Tiger Line, Inc., L-10494, N6915C, San Francisco International Airport, San Francisco, California, December 24, 1964. Washington, D.C., 8 June, 1966.

88. Civil Aeronautics Board. Aircraft Accident Report. United Air Lines, Inc., Vickers Viscount 745D, N7405, Near Parrottsville, Tennessee, July 9, 1964. Washington, D.C., 9 June, 1966.

89. Civil Aeronautics Board. Aircraft Accident Report. Eastern Air Lines, Inc., Douglas DC-8, N8708, New Orleans, Louisiana, February 25, 1964. Washington, D.C., 1 July, 1966.

90. Civil Aeronautics Board. Aircraft Accident Report. Continental Air Lines, Inc., B-707, N70773, Kansas City Municipal Airport, Kansas City, Missouri, July 1, 1965. Washington, D.C., 24 June, 1966.

91. Civil Aeronautics Board. Aircraft Accident Report. Pan American World Airways, Inc., B-707-321B, N761PA, San Francisco, California, June 28, 1965. Washington, D.C., 5 October, 1966.

92. Civil Aeronautics Board. Aircraft Accident Report. American Airlines, Inc., Boeing 727, N1996, Near the Greater Cincinnati Airport, Constance, Kentucky, November 8, 1965. Washington, D.C., 7 October, 1966.

93. Civil Aeronautics Board. Aircraft Accident Report. Aaxico Airlines, Inc., Douglas DC-6A, N6579C, Whiteman Air Force Base, Knob Noster, Missouri, May 18, 1965. Washington, D.C., 27 October, 1966.

94. Civil Aeronautics Board. Aircraft Accident Report. United Air Lines, Inc., Boeing 727, N7D3DU, Salt Lake City, Utah, November 11, 1965. Washington, D.C., 7 June, 1966.

95. Civil Aeronautics Board. Aircraft Accident Report. TWA B-7D7, N748TW and EAL Lockheed Connie N6218C, Carmel, New York, December 4, 1965. Washington, D.C., 20 December, 1966.

96. Civil Aeronautics Board. Aircraft Accident Report. Aaxico Airlines, Inc., Douglas DC-6A, N6541C, West Slope of Mt. Rainier, Washington, April 23, 1965. Washington, D.C., 16 March, 1967.

97. Civil Aeronautics Board. Aircraft Accident Report. American Flyers Airline Corporation, L-188C, N183H, near Ardmore Municipal Airport, Ardmore, Oklahoma, April 22, 1966. Washington, D.C., 4 April, 1967.

98. Civil Aviation Authority. World Airline Accident Summary. Greville House, Cheltenham, England, 1974.

99. Civil Aviation Authority. World Airline Accident Summary. Supplement No. 25, period 1 January, 1975 to June, 1975. July, 1975.

100. Civil Aviation Authority. World Airline Accident Summary. Supplement No. 24, period 1 January, 1974 to 31 December, 1974. February, 1975.

101. Dean, D.W., ed. World Aviation Directory. Ziff-Davis Publishing Co., Washington, D.C., Fall, 1975.

1D2. Federal Aviation Administration. FAA Statistical Handbook of Aviation. Washington, D.C., 197D.

103. Federal Aviation Administration. "Accidents, Fatalities, Rates, U.S. General Aviation 1964-1974." FAA Aviation News, March, 1975, p. 14.

104. Federal Aviation Administration. Engineering and Development Program Plan-Aircraft Safety. Office of Systems Engineering, Washington, D.C., Report No. FAA-ED-18-1, April, 1973.

1D5. Federal Aviation Administration. Census of U.S. Civil Aircraft. Calendar Year 1973. Washington, D.C., 1974.

1D6. Federal Aviation Administration. FAA Statistical Handbook of Aviation. Calendar Year 1973. U.S. Department of Transportation, Washington, D.C., 1974.

1D7. Federal Aviation Administration. Statistical Handbook of Civil Aviation. 1975.

1D8. Information Canada. Report of the Board of Inquiry into the Accident at Toronto International Airport, Malton, Ontario, to Air Canada DC8-CF-TIW Aircraft on July 5, 197D, held before the Honorable Mr. Justice Hugh F. Gibson, Commissioner. Ottawa, Canada, 1971.

109. International Civil Aviation Drganization. Aircraft Accident Digest. Montreal, Duebec, No. 20, 1974, p. 35.

11D. Ministry of Transport. Accident Report. Lockheed L188C, DF-PAB, 3D October, 1974, Rea Point, Melville Is NWT. Aviation Safety Investigation Division, 1974.

111. Ministry of Transport. Accident Report. Air Canada, Douglas DC8F-54, CF-TJM, Ottawa International Airport, May 2D, 1967. Ottawa, Canada,

112. Ministry of Transport. Report of the Board of Inquiry Regarding the Crash of a Douglas C54B-DC Aircraft, Registration of CF-MCF, near Issoudun, Quebec, on the 11th of August, 1957. Montreal, Canada, 19 January, 1959.

113. Ministry of Transport. Aircraft Accident Report. Boeing 707-321 CF-PWZ, Edmonton International Airport, 2 January, 1973. Ottawa, Canada, n.d.

114. Ministry of Transport. Aircraft Accident Report. Douglas DC8/41, CF-TJC, 40 Nautical Miles NW of Kleinberg, 2 March, 1971. Ottawa, Canada, n.d.

115. Ministry of Transport. Report of an Aircraft Accident to Sabreliner CF-BRL, 27 February, 1974 at Frobisher Bay, NWT Ottawa, Canada, n.d.

116. Ministry of Transport. Aircraft Accidents, Canada, 1969. A Statistical Summary. Aircraft Accident Investigation Division, Ottawa, Canada, 1972.

117. Ministry of Transport. Aircraft Accidents, Canada, 1971. A Statistical Summary. Aircraft Accident Investigation Division, Ottawa, Canada, 1973.

118. Ministry of Transport. Aircraft Accidents, Canada, 1972. A Statistical Summary. Dttawa, Canada, 1975.

119. National Transportation Safety Board. General Aviation Accidents. A Statistical Review, Calendar Year 1965. Washington, D.C., 1966.

120. National Transportation Safety Board. Aircraft Accident Report. Delta Airlines, Inc., DC-8, N802E, Kenner, Louisiana, March 30, 1967. Washington, D.C., 20 December, 1967.

121. National Transportation Safety Board. Briefs of Accidents, U.S. Civil Aviation 1966 Accidents. Washington, D.C., June, 1967.

122. National Transportation Safety Board. Aircraft Design-Induced Pilot Error. Department of Transportation, Washington, D.C., Report PB-175629, July, 1967.

123. National Transportation Safety Board. Aircraft Accident Report. Japan Air Lines, Ltd., Douglas DC-8-33, JA-8006, San Francisco, California, December 25, 1965. Washington, D.C., 15 July, 1967.

124. National Transportation Safety Board. Annual Review of U.S. General Aviation Accidents Occurring in Calendar Year 1966. Washington, D.C., November, 1967.

125. National Transportation Safety Board. Aircraft Accident Report. West Coast Airlines, Inc., DC-9, N9101, Near Wemma, Oregon, October 1, 1966. Washington, D.C., 11 December, 1967.

126. National Transportation Safety Board. Aircraft Accident Report. United Air Lines, Inc., B-727, N7036U, In Lake Michigan, August 16, 1965. Washington, D.C., 19 December, 1967.

127. National Transportation Safety Board. Briefs of Accidents Supplemental Issue. 1967 Accidents. Washington, D.C., 1968.

128. National Transportation Safety Board. Aircraft Accident Report. Lake Central Airlines, Inc., Allison Prop Jet Convair 340, N73130 Near Marseilles, Ohio, March 5, 1967. Washington, D.C., Report No. PB 177-339, 26 February, 1968.

129. National Transportation Safety Board. Aircraft Accident Report. West Coast Airlines, Inc., Fairchild F-27, N2712, Near Klamath Falls, Oregon, March 10, 1967. Washington, D.C., Report No. PB 177 339-3, 6 March, 1968.

130. National Transportation Safety Board. Aircraft Accident Report. Lexington Air Taxi, Inc., Beech C-45H, N3727G, Near Blue Grass Field, Lexington, Kentucky, April 3, 1967. Washington, D.C., Report No. PB 177 339-2, 13 March, 1968.

131. National Transportation Safety Board. Aircraft Accident Report. Frontier Airlines, Inc., Douglas DC-3C, N65276, Stapleton International Airport, Denver, Colorado, December 21, 1967. Washington, D.C., Report No. PB 177 339-4, 20 March, 1968.

132. National Transportation Safety Board. Aircraft Accident Report. Braniff Airways, Inc., BAC 1-11, N1553, Near Falls City, Nebraska, August 6, 1966. Washington, D.C., Report No. PB 177-339-5, 18 April, 1968.

133. National Transportation Safety Board. Aircraft Accident Report. Mohawk Airlines, Inc., BAC 1-11, N1116J, Near Blossberg, Pennsylvania, June 23, 1967. Washington, D.C., Report No. PB 177 339-6, 18 April, 1968.

134. National Transportation Safety Board. Pan American World Airways, Inc., Boeing 727, N317PA, Near Berlin, Germany, November 15, 1966. Washington, D.C., Report No. PB 177-339-7, 5 June, 1968.

135. National Transportation Safety Board. Aircraft Accident Report. Trans World Airlines, Inc., B-707, N742TW, Near the Greater Cincinnati Airport, Erlanger, Kentucky, November 6, 1967. Washington, D.C., Report No. PB 177-339-11, 11 September, 1968.

136. National Transportation Safety Board. Annual Review of U.S. General Aviation Accidents Occurring in Calendar Year 1967. Washington, D.C., October, 1968.

137. National Transportation Safety Board. Annual Review of U.S. Air Carrier Accidents Occurring in Calendar Year 1967. Washington, D.C., December, 1968.

138. National Transportation Safety Board. An Analysis of Aircraft Accident Data. U.S. Air Carrier Operations 1967. Department of Transportation, Washington, D.C., 31 December, 1968.

139. National Transportation Safety Board. Aircraft Accident Report. Braniff Airways, Inc., Lockheed L-188, N9707C, Near Dawson, Texas, May 3, 1968. Washington, D.C., Report No. NTSB-AAR-69-3, 19 June, 1969.

140. National Transportation Safety Board. Aircraft Accident Report. Los Angeles Airways, Inc., 6-61L Helicopter, N300Y, Compton, California, August 14, 1968. Washington, D.C., Report No. NTSB-AAR-69-7, 14 August, 1969.

141. National Transportation Safety Board. Aircraft Accident Report. Piedmont Airlines, Fairchild Hiller 227B, N712U, Charleston, West Virginia, August 10, 1968. Washington, D.C., Report No. NTSB-AAR-69-6, 21 August, 1969.

142. National Transportation Safety Board. Aircraft Accident Report. Trans World Airlines, Inc., Convair 880, N821TW, Constance, Kentucky, November 20, 1967. Washington, D.C., Report No. NTSB-AAR-69-5, 27 August, 1969.

143. National Transportation Safety Board. Aircraft Accident Report. Los Angeles Airways, Inc., Sikorsky S-61L, N303Y, Paramount, California, May 22, 1968. Washington, D.C., Report No. NTSB-AAR-70-1, 18 December, 1969.

144. National Transportation Safety Board. Annual Review of U.S. General Aviation Accidents Occurring in Calendar Year 1968. Washington, D.C., 1 September, 1969.

145. National Transportation Safety Board. Aircraft Accident Report. Pan American World Airways, Inc., Boeing 707-321C, N799PA, Elmendorf Air Force Base, Anchorage, Alaska, December 26, 1968. Washington, D.C., Report No. NTSB-AAR-69-8, 19 November, 1969.

146. National Transportation Safety Board. Aircraft Accident Report. Japan Air Lines, Co., Ltd., DC-8-62, JA 8032, San Francisco Bay, San Francisco, California, November 22, 1968. Washington, D.C., Report No. NTSB-AAR-70-2, 31 December, 1969.

147. National Transportation Safety Board. Aircraft Accident Reports. Brief Format. Supplemental Issue 1968 Accidents. Washington, D.C., Report No. NTSB-BA-70-5, 1970.

148. National Transportation Safety Board. A Preliminary Analysis of Aircraft Accident Data, U.S. Civil Aviation, 1969. Washington, D.C., 1970.

149. National Transportation Safety Board. Aircraft Accident Reports. Brief Format, U.S. Civilian Aviation 1969 Accidents, Issues 1-5 plus Supplement. Washington, D.C., Report Nos. NTSB-BA-70-1,2,3,4,6 and 71-2, 1970.

150. National Transportation Safety Board. Aircraft Incident Report. Boeing 747, N732PA, Renton Airport, Renton, Washington, December 13, 1969. Bureau of Aviation Safety, Washington, D.C., Report No. NTSB-AAR-70-19, 1970.

151. National Transportation Safety Board. Aircraft Accident Report. Douglas DC-3, N142D, New Orleans International Airport (Moisant Field), New Orleans, Louisiana, March 20, 1969. Washington, D.C., Report No. NTSB-AAR-70-3, 14 January, 1970.

152. National Transportation Safety Board. Aircraft Accident Report. Allegheny Airlines, Inc., Convair 580, N5802, Near the Bradford Regional Airport, December 24, 1968. Washington, D.C., Report No. NTSB-AAR-70-4, 28 January, 1970.

153. National Transportation Safety Board. Aircraft Accident Report. Northeast Airlines, Inc., Fairchild Hiller FH-227C, N380NE, Near Hanover, New Hampshire, October 25, 1968. Washington, D.C. Report No. NTSB-AAR-70-7, 1 April, 1970.

154. National Transportation Safety Board. Aircraft Accident Report. Mineral County Airlines, d.b.a. Hawthorne Nevada Airlines, DC-3, N15570, Near Lone Pine, California, February 18, 1969. Washington, D.C., Report No. NTSB-AAR-70-5, 4 February, 1970.

155. National Transportation Safety Board. Aircraft Accident Report. United Air Lines, Inc., Boeing 727-22C, N7434U, Near Los Angeles, California, January 18, 1969. Washington, D.C., Report No. NTSB-AAR-70-6, 18 March, 1970.

156. National Transportation Safety Board. Aircraft Accident Report. Puerto Rico International Airlines, Inc., De Havilland Heron 114-2, N563PR, Sierra De Luquillo, San Juan, Puerto Rico, March 5, 1969. Washington, D.C., Report No. NTSB-AAR-70-9, 24 April, 1970.

157. National Transportation Safety Board. Aircraft Accident Report. Allegheny Airlines, Inc., Allison Prop Jet Convair 440, N5825, Near Bradford, Pennsylvania, January 6, 1969. Washington, D.C., Report No. NTSB-AAR-70-10, 27 May, 1970.

158. National Transportation Safety Board. Aircraft Accident Report. Japan Air Lines Company, Ltd., Convair 880, Model 22M, JA8028, Grant County Airport, Moses Lake, Washington, June 24, 1969. Washington, D.C., Report No. NTSB-AAR-70-11, 17 June, 1970.

159. National Transportation Safety Board. Aircraft Accident Report. Mohawk Airlines, Inc., Fairchild Hiller FH-227B, N7811M, Near Glens Falls, New York, November 19, 1969. Washington, D.C., Report No. NTSB-AAR-70-12, 25 June, 1970.

160. National Transportation Safety Board. Aircraft Accident Report. Cessna 310N, N4111Q, Near Upland, California, April 12, 1969. Washington, D.C., Report No. NTSB-AAR-70-13, 25 June, 1970.

161. National Transportation Safety Board. Aircraft Accident Report. Scandinavian (Norwegian Registry) in Santa Monica Bay Near Los Angeles, California, January 13, 1969. Bureau of Aviation Safety, Washington, D.C., Report No. NTSB-AAR-70-14, 1 July, 1970.

162. National Transportation Safety Board. Aircraft Accident Report. Wien Consolidated Airlines, Inc., Fairchild F-27B, N4905, Pedro Bay, Alaska, December 2, 1968. Washington, D.C., Report No. NTSB-AAR-70-16, 22 July, 1970.

163. National Transportation Safety Board. Aircraft Accident Report. Trans World Airlines, Inc., Boeing 707-331C, N787TW, National Aviation Facilities Experimental Center, Atlantic City Airport, Pomona, New Jersey, July 26, 1969. Washington, D.C.

164. National Transportation Safety Board. Aircraft Incident Report. Boeing 747, N732PA, Renton Airport, Renton, Washington, December 13, 1969. Washington, D.C., Report No. NTSB-AAR-70-19, 26 August, 1970.

165. National Transportation Safety Board. Aircraft Accident Report. Air South, Inc., Beechcraft B-99, N844NS, Near Monroe, Georgia, July 6, 1969. Washington, D.C., Report No. NTSB-AAR-70-18, 26 August, 1970.

166. National Transportation Safety Board. Aircraft Accident Report. Ozark Air Lines, Inc., Douglas DC-9-15, N974Z, Sioux City Airport, Sioux City, Iowa, December 27, 1968. Washington, D.C., Report No. NTSB-AAR-70-20, 2 September, 1970.

167. National Transportation Safety Board. Aircraft Accident Report. Caribbean Atlantic Airlines, Inc., Douglas DC-9-31, N938PR, Harry S. Truman Airport, Charlotte Amalie, St. Thomas, Virgin Islands, August 12, 1969. Washington, D.C., Report No. NTSB-AAR-70-23, 16 September, 1970.

168. National Transportation Safety Board. Aircraft Accident Report. Seaboard World Airlines, Inc., Douglas DC-8-63F, N8634, Stockton Metropolitan Airport, Stockton, California, October 16, 1969. Washington, D.C., Report No. NTSB-AAR-70-24, 30 September, 1970.

169. National Transportation Safety Board. Aircraft Incident Report. Air France, Boeing 747-128, F-BPVD, St. Jean, P.Q., Canada, August 17, 1970. Washington, D.C., Report No. NTSB-AAR-70-26, 7 October, 1970.

170. National Transportation Safety Board. Aircraft Accident Report. North Central Airlines, Inc., Convair 580, N2045, O'Hare International Airport, Chicago, Illinois, December 27, 1968. Washington, D.C., Report No. NTSB-AAR-70-27, 12 November, 1970.

171. National Transportation Safety Board. Aircraft Accident Report. Texas International Airlines, Inc., Douglas DC-9, N1308T, Harlingen, Texas, January 11, 1970. Washington, D.C., Report No. NTSB-AAR-70-28, 2 December, 1970.

172. National Transportation Safety Board. Aircraft Accident Report Compania Ecuatoriana de Aviacion, Douglas C-540, Republic of Ecuador, HC-AON, Miami International Airport, Miami, Florida, April 14, 1970. Washington, D.C., Report No. NTSB-AAR-71-2, 16 December, 1970.

173. National Transportation Safety Board. Aircraft Accident Report. Lear Jet L23A, N434EJ, Near the Emmet County Airport, Pellston, Michigan, May 9, 1970. Washington, D.C., Report No. NTSB-AAR-71-3, 22 December, 1970.

174. National Transportation Safety Board. Aircraft Accident Report. Martin 404, N464M, 8 Statute Miles West of Silver Plume, Colorado, October 2, 1970. Washington, D.C., Report No. NTSB-AAR-71-4, 24 December, 1970.

175. National Transportation Safety Board. Annual Review of Aircraft Accident Data. U.S. General Aviation, Calendar Year 1969. Washington, D.C., Report No. NTSB-ARG-71-1, 1971.

176. National Transportation Safety Board. Aircraft Accident Reports. Brief Format, U.S. Civil Aviation 1970 Accidents, Issue I. Washington, D.C., Report No. NTSB-BA-71-1, 1971.

177. National Transportation Safety Board. Briefs of Accidents Involving Corporate/Executive Aircraft, U.S. General Aviation 1967. Washington, D.C., 1971.

178. National Transportation Safety Board. A Preliminary Analysis of Aircraft Accident Data. U.S. Civilian Aviation 1970. Washington, D.C., Report No. NTSB-APA-71-1, 1971.

179. National Transportation Safety Board. Aircraft Accident Report. Rocky Mountain Airways, Inc., Aero Commander 680V, N63590, Aspen, Colorado, January 22, 1970. Washington, D.C., Report No. NTSB-AAR-72-1, 29 December, 1971.

180. National Transportation Safety Board. Preliminary Accident Resume Report (Delta Airlines, Inc., Douglas DC-9, January 11, 1971, Jackson, Mississippi). Bureau of Safety, Washington, D.C., 1971.

181. National Transportation Safety Board. Aircraft Accident Report. Jetco Aviation, Incorporated, Short Brothers of Harland, Ltd., Sylvan Series 3(SC-7), N21CK, Washington National Airport, Washington, D.C., July 2, 1970. Washington, D.C., Report No. NTSB-AAR-71-6, 13 January, 1971.

182. National Transportation Safety Board. Aircraft Accident Report. Pilgrim Aviation and Airlines, Inc., De Havilland Turbo Prop DHC-6, N124PM, In Long Island Sound, Near Waterford, Connecticut, February 10, 1970. Washington, D.C., Report No. NTSB-AAR-71-1, 27 January, 1971.

183. National Transportation Safety Board. Aircraft Accident Report. Tag Airlines, Inc., De Havilland Dove (DH-104), N2300H, In Lake Erie, January 28, 1970. Washington, D.C., Report No. NTSB-AAR-71-5, 6 January, 1971.

184. National Transportation Safety Board. Aircraft Incident Report. American Airlines, Inc., Boeing 747-121, N743PA, San Francisco, California, September 18, 1970. Washington, D.C., Report No. NTSB-AAR-71-7, 3 February, 1971.

185. National Transportation Safety Board. Annual Report to Congress 1970. Washington, D.C., 17 March, 1971.

186. National Transportation Safety Board. Preliminary Accident Resume Report (Trans World Airlines, Inc., Boeing 727, April 1, 1971). O'Hare International Airport, Chicago, Illinois. Bureau of Safety, Washington, D.C., 1971.

187. National Transportation Safety Board. Aircraft Accident Report. Alitalia Airlines, McDonnell Douglas DC-8-62, I-DIWZ (Italian Registry), John F. Kennedy International Airport, Jamacia, New York, September 15, 1970. Washington, D.C., Report No. NTSB-AAR-71-9, 28 April, 1971.

188. National Transportation Safety Board. Aircraft Accident Report. Mississippi Valley Airways, Inc., De Havilland DHC-6, N9565M, La Crosse, Wisconsin, November 9, 1970. Washington, D.C., Report No. NTSB-AAR-71-10, 5 May, 1971.

189. National Transportation Safety Board. Preliminary Incident Resume Report (Piedmont Airlines, Boeing 737, May 7, 1971, Charlotte, North Carolina). Bureau of Safety, Washington, D.C., 1971.

190. National Transportation Safety Board. Preliminary Accident Resume Report (United Airlines, Inc., Douglas DC-8, May 15, 1971, San Francisco International Airport, California). Bureau of Safety, Washington, D.C., 1971.

191. National Transportation Safety Board. Aircraft Accident Report. Pan American World Airways, Inc., Boeing 747, N747PA, Flight 845, San Francisco, California, July 30, 1971. Washington, D.C., Report No. NTSB-AAR-72-17, 24 May, 1972.

192. National Transportation Safety Board. Aircraft Accident Report. Federal Aviation Administration, Douglas DC-3C, N7, Laguardia Airport, New York, January 4, 1971. Washington, D.C., Report No. NTSB-AAR-71-11, 3 June, 1971.

193. National Transportation Safety Board. Briefs of Accidents Involving Corporate/Executive Aircraft, U.S. General Aviation, 1968. Washington, D.C., Report No. NTSB-AMM-71-3, June, 1971.

194. National Transportation Safety Board. Aircraft Accident Report. Trans International Airlines Corp., Ferry Flight 863, Douglas DC-8-63F, N4863T, J.F. Kennedy International Airport, New York, September 8, 1970. Washington, D.C., Report No. NTSB-AAR-71-12, 18 August, 1971.

195. National Transportation Safety Board. Aircraft Accident Report. Commuter Airlines, Inc., Beechcraft C-45H (Infinite II), N497DM, Broome County Airport, Binghamton, New York, March 22, 1970. Washington, D.C., Report No. NTSB-AAR-71-13, 26 August, 1971.

196. National Transportation Safety Board. Aircraft Accident Report. Southern Airways, Inc., Douglas DC-9-15, N925, Gulfport, Mississippi, February 17, 1971. Washington, D.C., Report No. NTSB-AAR-71-14, 1 September, 1971.

197. National Transportation Safety Board. Aircraft Accident Report. Delta Air Lines, Inc., Douglas DC-9-32, N3329L, Louisville, Kentucky, September 8, 1970. Washington, D.C., Report No. NTSB-AAR-71-15, 17 November, 1971.

198. National Transportation Safety Board. Aircraft Incident Report. Northwest Airlines, Inc., Boeing 747-151, N607US, Honolulu, Hawaii, May 13, 1971. Washington, D.C., Report No. NTSB-AAR-71-16, 15 December, 1971.

199. National Transportation Safety Board. Aircraft Accident Report. United Airlines, Inc., Boeing 737-222, N9005U, Philadelphia International Airport, Philadelphia, Pennsylvania, July 19, 1970. Washington, D.C., Report No. NTSB-AAR-72-9, 29 December, 1971.

200. National Transportation Safety Board. Aircraft Incident Report. Northeast Airlines, Inc., McDonnell Douglas DC-9-31, N98ZNE, Martha's Vineyard, Massachusetts, June 22, 1971. Washington, D.C., Report No. NTSB-AAR-72-4, 29 December, 1971.

201. National Transportation Safety Board. Aircraft Accident Report. Downeast Airlines, Scheduled Air Taxi, Piper PA-31, N595DE, Augusta State Airport, Augusta, Maine, August 19, 1971. Washington, D.C., Report No. NTSB-AAR-72-6, 29 December, 1971.

202. National Transportation Safety Board. Aircraft Accident Report. Flying Tiger Line, Inc., Douglas DC-8-63F, N785FT, Naha Air Base, Okinawa, Ryukyu Islands, July 27, 1970. Washington, D.C. Report No. NTSB-AAR-72-10, 29 December, 1971.

203. National Transportation Safety Board. Aircraft Accident Report. Trans Cribbean Airways, Inc., Boeing 727-200, N8790R, Harry S. Truman Airport, Charlotte Amalie, St. Thomas, Virgin Islands, December 28, 1970. Washington, D.C., Report No. NTSB-AAR-72-8, 29 December, 1971.

204. National Transportation Safety Board. Aircraft Accident Report. Aloha Airlines, Inc., Vickers Viscount Model 7450, N7415, Honolulu International Airport, Honolulu, Hawaii, August 8, 1971. Washington, D.C., Report No. NTSB-AAR-72-2, 29 December, 1971.

205. National Transportation Safety Board. Aircraft Accident Report. Monmouth Airlines, Inc., Scheduled Air Taxi, Beech 99, N-986 MA, Allentown, Bethlehem-Easton Airport, Allentown, Pennsylvania, October 24, 1971. Washington, D.C., Report No. NTSB-AAR-72-3, 29 December, 1971.

206. National Transportation Safety Board. Aircraft Accident Reports. Brief Format. U.S. Civilian Aviation. 1971 Accidents. Issues Nos. 1, 2, 3, 4, 5 and Supplement. Washington, D.C., Report Nos. NTSB-BA-72-4, 6, 7, 73-1, 5, 1972.

207. National Transportation Safety Board. A Preliminary Analysis of Aircraft Accident Data. U.S. Civil Aviation 1971. Washington, D.C., Report No. NTSB-APA-72-1, 15 March, 1972.

208. National Transportation Safety Board. Aircraft Accident Report. Western Air Lines, Inc., Boeing 720-047B, N3166, Ontario International Airport, Ontario, California, March 31, 1971. Washington, D.C., Report No. NTSB-AAR-72-18, 1972.

209. National Transportation Safety Board. Aircraft Accident Report. Capitol International Airways, Inc., DC-8-63F, N4909C, Anchorage, Alaska, November 27, 1970. Washington, D.C., Report No. NTSB-72-12, 29 March, 1972.

210. National Transportation Safety Board. Aircraft Accident Report. Southern Airways, Inc., DC-9, N97S, Tri State Airport, Huntington, West Virginia, November 14, 1970. Washington, D.C., Report No. NTSB-AAR-72-11, 14 April, 1972.

211. National Transportation Safety Board. Aircraft Accident Report. Chicago and Southern Airways, Inc., Beech E18S (ATECO Westwind II) N51CS, Peoria, Illinois, October 21, 1971. Washington, D.C., Report No. NTSB-AAR-72-15, 19 April, 1972.

212. National Transportation Safety Board. Aircraft Accident Report. Pan American World Airways, Inc., Boeing 747-121, N739PA, Near Nantucket, Massachusetts, November 4, 1970. Washington, D.C., Report No. NTSB-AAR-72-14, 3 May, 1972.

213. National Transportation Safety Board. A Study of U.S. Air Carrier Accidents 1964-1969. Washington, D.C., Report No. NTSB-AAS-72-5, 10 May, 1972.

214. National Transportation Safety Board. Aircraft Accident Report. Pan American World Airways, Inc., Boeing, N747PA, Flight 845, San Francisco, California, July 30, 1971. Washington, D.C., Report No. NTSB-AAB-72-17, 24 May, 1972.

215. National Transportation Safety Board. Aircraft Accident Report. Apache Airlines, Inc., De Havilland DH-104-7AXC, N4922V, Coolidge, Arizona, May 6, 1971. Washington, D.C., Report No. NTSB-AAR-72-19, 1 June, 1972.

216. National Transportation Safety Board. Aircraft Accident Report. Allegheny Airlines, Inc., Allison Prop Jet Convair 340/440, N5832, New Haven, Connecticut, June 7, 1971. Washington, D.C., Report No. NTSB-AAR-72-20, 1 June, 1972.

217. National Transportation Safety Board. Aircraft Accident Report. Aero Taxi, Beech E18S, N42A, Cleveland, Ohio, June 22, 1972. Washington, D.C., Report No. ATSB-AAR-72-33, 20 December, 1972.

218. National Transportation Safety Board. Aircraft Accident Report. National Airlines, Inc., Boeing 747-135, N77772, Near Lake Charles, Louisiana, January 4, 1972. Washington, D.C., Report No. NTSB-AAR-72-21, 12 July, 1972.

219. National Transportation Safety Board. Aircraft Incident Report. Eastern Air Lines, Inc., Boeing 727-100, N8168G, Flight 9701, Atlanta, Georgia, December 21, 1971. Washington, D.C., Report No. NTSB-AAR-72-22, 26 July, 1972.

220. National Transportation Safety Board. Aircraft Accident Report. Alii Air Hawaii, Inc., Beech D18S, N5642V, Kalohi Channel, Hawaiian Islands, February 22, 1972. Washington, D.C., Report No. NTSB-AAR-72-23, 26 July, 1972.

221. National Transportation Safety Board. Aircraft Accident Report. Sun Valley Airlines, Inc., Beech 65B-80, N1027C, Fairfield, Idaho, February 20, 1972. Washington, D.C., Report No. NTSB-AAR-72-25, 30 August. 1972.

222. National Transportation Safety Board. Aircraft Accident Report. Northwest Airlines, Inc., Boeing 747-151, N606 U.S., Over the North Pacific Ocean, 105 Nautical Miles West of 150° East Longitude at 36° North Latitude, April 12, 1972. Washington, D.C., Report No. NTSB-AAR-72-27, 4 October, 1972.

223. National Transportation Safety Board. Aircraft Accident Report. Alaska Airlines, Inc., Boeing 727, N2969G, Near Juneau, Alaska, September 4, 1971. Washington, D.C., Report No. NTSB-AAR-72-28, 13 October, 1972.

224. National Transportation Safety Board. Aircraft Incident Report. Continental Airlines, Inc., McDonnell Douglas DC-10, N68041, Tucson, Arizona, May 2, 1972. Washington, D.C., Report No. NTSB-AAR-72-29, 18 October, 1972.

225. National Transportation Safety Board. Aircraft Accident Report. Eastern Airlines, Inc., DC-9-31, N8961E, Fort Lauderdale, Florida, May 18, 1972. Washington, D.C., Report No. NTSB-AAR-72-31, 13 December, 1972.

226. National Transportation Safety Board. Aircraft Accident Report. Puerto Rico International Airlines (PRINAIR), Inc., De Havilland DH-114, N554PR, Ponce, Puerto Rico, June 24, 1972. Washington, D.C., Report No. NTSB-AAR-72-34, 20 December, 1972.

227. National Transportation Safety Board. Aircraft Accident Report. Eastern Air Lines, Inc., L-1011, N310EA, Miami, Florida, December 29, 1972. Washington, D.C., Report No. NTSB-AAR-73-14, 14 June, 1973.

228. National Transportation Safety Board. Aircraft Accident Reports. Brief Format, U.S. Civilian Aviation. Issues Number 2-5 and Supplemental Issue of 1973 Accidents. Washington, D.C., Report Nos. NTSB-BA-73-9, 74-1, 2, 3, and 5, 1973.

229. National Transportation Safety Board. Aircraft Accident Reports. Brief Format. U.S. Civil Aviation. Issues No. 1, 2, and 3 and Supplement of 1972 Accidents. Washington, D.C., Reports Nos. NTSB-BA-73-2, 3, 4, 10, 1973.

230. National Transportation Safety Board. Aircraft Accident Report. Pan Alaska Airways, Ltd., Cessna 310C, N1812H, Missing between Anchorage and Juneau, Alaska, October 16, 1972. Washington, D.C., Report No. NTSB-AAR-72-1, 31 January, 1973.

231. National Transportation Safety Board. Aircraft Accident Report. American Airlines, Inc., McDonnell Douglas DC-10-10, N103AA, Near Windsor, Ontario, Canada, June 12, 1972. Washington, D.C., Report No. NTSB-AAR-73-2, 28 February, 1973.

232. National Transportation Safety Board. Aircraft Accident Report. Delta Air Lines, Inc., McDonnell Douglas DC-9-14, N3305L, Greater Southwest International Airport, Fort Worth, Texas, May 30, 1972. Washington, D.C., Report No. NTSB-AAR-73-3, 13 March, 1973.

233. National Transportation Safety Board. Aircraft Accident Report. Trans World Airlines, Inc., Boeing 707-331C, N15712 San Francisco International Airport, San Francisco, California, September 13, 1972. Washington, D.C., Report No. NTSB-AAR-73-4, 14 March, 1973.

234. National Transportation Safety Board. Aircraft Accident Report. North American Rockwell, Inc., Turbo Commander 690, N1NR, Wellsburg, West Virginia, August 14, 1972. Washington, D.C., Report No. NTSB-AAR-73-5, 21 March, 1973.

235. National Transportation Safety Board. Factual Report of Investigation. Delta Airlines, McDonnell Douglas DC-8-61, N1302L, Near Las Vegas, Nevada, February 28, 1973. Washington, D.C., Report No. OAK-73-A-P025, 25 March, 1973.

236. National Transportation Safety Board. Aircraft Accident Report. Spectrum Air, Inc., Sabre Mark 5, N275X, Sacramento Executive Airport, Sacramento, California, September 24, 1972. Washington, D.C. Report No. NTSB-AAR-73-6, 28 March, 1973.

237. National Transportation Safety Board. Aircraft Accident Report. Jugoslovenski Aerotransport (JAT), Boeing 707-321, YU-AGA, John F. Kennedy International Airport, Jamaica, New York, August 13, 1972. Washington, D.C., Report No. NTSB-AAR-73-7, 4 April, 1973.

238. National Transportation Safety Board. Aircraft Accident Report. Mohawk Airlines, Inc., Fairchild Hiller FH-227B, N7818M, Albany, New York, March 3, 1972. Washington, D.C., Report No. NTSB-AAR-73-8, 11 April, 1973.

239. National Transportation Safety Board. Aircraft Accident Report. Cessna 182, N70586, Duluth International Airport, Duluth, Minnesota, November 8, 1972. Washington, D.C., Report No. NTSB-AAR-73-10, 26 April, 1973.

240. National Transportation Safety Board. Aircraft Accident Report. Trans World Airlines, Inc., Boeing 707-331C, N788TW, John F. Kennedy International Airport, Jamaica, New York, December 12, 1972. Washington, D.C., Report No. NTSB-AAR-73-11, 2 May, 1973.

241. National Transportation Safety Board. Factual Report of Investigation. United Airlines, Boeing 727, N7002, Near Harrisburg, Pennsylvania, March 17, 1973. Washington, D.C., Report No. NYC-73-A-N123, 8 May, 1973.

242. National Transportation Safety Board. Factual Report of Investigation. Northwest Airlines, Inc., Boeing 747, N601US, Near Tallahassee, Florida, April 26, 1973. Washington, D.C., Report No. MIA-73-A-M050, 24 May, 1973.

243. National Transportation Safety Board. Aircraft Accident Report. Machinery Buyers Corporation, Learjet Model 24, N454RN, Atlanta, Georgia, February 26, 1973. Washington, D.C., Report No. NTSB-AAR-73-12, 30 May, 1973.

244. National Transportation Safety Board. Aircraft Accident Report. Northwest Airlines, Inc., Boeing 747-151, N602US, Miami, Florida, December 15, 1972. Washington, D.C., Report No. NTSB-AAR-73-13, 30 May, 1973.

245. National Transportation Safety Board. Factual Report of Investigation. Delta Air Lines, Douglas DC-9-32, N33247, Enroute New York, New York to Atlanta, Georgia, April 1, 1973. Washington, D.C., Report No. MIA-73-A-M095, 12 June, 1973.

246. National Transportation Safety Board. Western Air Lines, Inc., Boeing 737, N4508W, Flight 415, Near West Yellowstone, Montana, June 29, 1973. Washington, D.C., Statements of Pilot and Other Crew Members, 6 July, 1973.

247. National Transportation Safety Board. Aircraft Accident Report. United Air Lines, Inc., Boeing 737, N903IU, Chicago Midway Airport, Chicago, Illinois, December 8, 1972. Washington, D.C., Report No. NTSB-AAR-73-16, 29 August, 1973.

248. National Transportation Safety Board. Aircraft Accident Report. Eastern Air Lines, Inc., Boeing 727-225, N8843E, Toledo, Ohio, April 10, 1973. Washington, D.C., Report No. NTSB-AAR-73-17, 27 September, 1973.

249. National Transportation Safety Board. Aircraft Accident Report. Frontier Airlines, Inc., Boeing 737-200, N7370F, St. Louis, Missouri, July 24, 1973. Washington, D.C., Report No. DEN-74-A-D004, 29 September, 1973.

250. National Transportation Safety Board. Aircraft Accident Report. Air Iowa, Inc., Beech E18S, N310WA Davenport, Iowa, April 19, 1973. Washington, D.C., Report No. NTSB-AAR-73-18, 3 October, 1973.

251. National Transportation Safety Board. Factual Report of Investigation. National Airlines, Douglas DC-10-10, N67NA, Enroute New Orleans, Louisiana to Miami, Florida, August 10, 1973. Washington, D.C., Report No. MIA-74-A-Mo13, 24 October, 1973.

252. National Transportation Safety Board. Aircraft Accident Report. Continental Airlines, Saberliner Model NA-265-60, N743R, Montrose, Colorado, April 13, 1973. Washington, D.C., Report No. NTSB-AAR-73-19, 7 November, 1973.

253. National Transportation Safety Board. Aircraft Accident Report. Lofteidir Icelandic Airlines, Inc., Douglas DC-8-61, John F. Kennedy International Airport, Jamaica, New York, June 23, 1973. Washington, D.C., Report No. NTSB-AAR-73-20, 5 December, 1973.

254. National Transportation Safety Board. Aircraft Accident Reports. Brief Format, U.S. Civilian Aviation. Issues Number 1-4 of 1974 Accidents. Washington, D.C., Report Nos. NTSB-BA-74-4, 6, 7, and 75-1, 1974.

255. National Transportation Safety Board. Aircraft Accident Report. National Airlines, Inc., DC-10-10, N60NA, Near Albuquerque, New Mexico, November 3, 1973. Washington, D.C., Report No. NTSB-AAR-75-2, 15 January, 1975.

256. National Transportation Safety Board. Factual Report of Investigation. Delta Airlines, Douglas DC-9-32, N3338L, Near Lebanon, New Hampshire, December 21, 1973. Washington, D.C., Report No. NYC-74-A-N060, 18 January, 1974.

257. National Transportation Safety Board. Aircraft Accident Report. Overseas National Airways, Inc., McDonnell Douglas DC-8-63, N863F, Bangor, Maine, June 20, 1973. Washington, D.C., Report No. NTSB-AAR-74-1, 7 February, 1974.

258. National Transportation Safety Board. Aircraft Accident Report. Eastern Air Lines, Inc., Douglas DC-9-31, N8962E, Near Meridian, Mississippi. Washington, D.C., 15 February, 1974.

259. National Transportation Safety Board. Aircraft Accident Report. Skyways International, Inc., Douglas DC-7C, N296, Near the Miami International Airport, Dade County, Florida, June 21, 1973. Washington, D.C., Report No. NTSB-AAR-74-2, 27 February, 1974.

260. National Transportation Safety Board. Aircraft Accident Report. Delta Air Lines, Inc., Douglas DC-9-31, N975NE, Boston, Massachusetts, July 31, 1973. Washington, D.C., Report No. NTSB-AAR-74-3, 7 March, 1974.

261. National Transportation Safety Board. Annual Reviews of Aircraft Accident Data. U.S. Air Carrier Operations 1970-1972. Washington, D.C., Report No. NTSB-ARC-74-1, 11 April, 1974.

262. National Transportation Safety Board. Aircraft Accident Report. Texas International, Inc., Convair 600, N94230, Mena, Arkansas, September 27, 1973. Washington, D.C., Report No. NTSB-AAR-74-4, 11 April, 1974.

263. National Transportation Safety Board. Aircraft Accident Report. Ozark Air Lines, Inc., Fairchild Hiller FH-227B, N4215, Near the Lambert-St. Louis International Airport, St. Louis, Missouri, July 23, 1973. Washington, D.C., Report No. NTSB-AAR-74-5, 24 April, 1974.

264. National Transportation Safety Board. Factual Report of Investigation. American Airlines, Boeing 727-023, N2914, Detroit Metropolitan Airport, Detroit, Michigan. December 22, 1973. Washington, D.C., Report No. CHI-74-A-C006, 25 April, 1974.

265. National Transportation Safety Board. Aircraft Accident Report. World Airways, Inc., DC-8-63F, N802WA, King Cove, Alaska, September 8, 1973. Washington, D.C., Report No. NTSB-AAR-74-6, 8 May, 1974.

266. National Transportation Safety Board. Aircraft Accident Report. Piedmont Airlines, Boeing 737, N751N, Greensboro, N.C., October 28, 1973. Washington, D.C., Report No. NTSB-AAR-74-7, 22 May, 1974.

267. National Transportation Safety Board. Factual Report of Investigation. Eastern Air Lines, Inc., Lockheed L-1011, N321EA, Near Ft. Lauderdale, Florida, March 21, 1974. Washington, D.C., Report No. MIA-74-A-M083, 7 June, 1974.

268. National Transportation Safety Board. Aircraft Accident Report. Trans World Airlines, Inc., Boeing 707-331B, N8705T, Los Angeles, California, August 28, 1973. Washington, D.C., Report No. NTSB-AAR-74-8, 10 July, 1974.

269. National Transportation Safety Board. Aircraft Accident Report. National Airlines, Inc., McDonnell Douglas DC-10-10, N60NA, Near Tampa, Florida, July 8, 1974. Washington, D.C., Report No. NTSB-AAR-74-9, 24 July, 1974.

270. National Transportation Safety Board. Aircraft Accident Report. Trans World Airlines, Inc., Boeing 707-131B, N757TW, Los Angeles International Airport, Los Angeles, California, January 16, 1974. Washington, D.C., Report No. NTSB-AAR-74-10, 14 August, 1974.

271. National Transportation Safety Board. Aircraft Accident Report. Aircraft Pool Leasing Corporation, Lockheed Super Constellation, L-1049H, N6917C, Miami, Florida, December 15, 1973. Washington, D.C. Report No. NTSB-AAR-74-11, 11 September, 1974.

272. National Transportation Safety Board. Annual Reviews of Aircraft Accident Data, U.S. Air Carrier Operations, 1973. Washington, D.C., Report No. NTSB-ARC-74-2, 24 October, 1974.

273. National Transportation Safety Board. Aircraft Accident Report. Eastern Air Lines, Inc., McDonnell Douglas DC-9-31, N8967E, Akron-Canton Regional Airport, North Canton, Ohio, November 27, 1973. Washington, D.C., Report No. NTSB-AAR-74-12, 5 November, 1974.

274. National Transportation Safety Board. Aircraft Accident Report. Delta Air Lines, Inc., McDonnell Douglas DC-9-32, N3323L, Chattanooga Municipal Airport, Chattanooga, Tennessee, November 27, 1973. Washington, D.C., Report No. NTSB-AAR-74-13, 8 November, 1974.

275. National Transportation Safety Board. Aircraft Accident Report. Iberian Airlines, McDonnell Douglas DC-10-30, EC CBN, Logan International Airport, Boston, Massachusetts, December 17, 1973. Washington, D.C., Report No. NTSB-AAR-74-14, 8 November, 1974.

276. National Transportation Safety Board. Aircraft Accident Report. Pan American World Airways, Inc., Boeing 707-321B, N454PA, Pago Pago, American Samoa, January 30, 1974. Washington, D.C., Report No. NTSB-AAR-74-15, 8 November, 1974.

277. National Transportation Safety Board. Factual Report of Investigation. Pan American World Airways, Boeing 727/200, N6818, O'Hare International Airport, Chicago, Illinois, July 10, 1974. Washington, D.C., Report No. CHI-75-A-C003, 13 November, 1974.

278. National Transportation Safety Board. Factual Report of Investigation. Delta Air Lines, Inc., Douglas DC-8, N815E, Flight 889, Enroute Detroit, Michigan to Tampa, Florida. Washington, D.C., Report No. MIA-75-A-M026, 27 November, 1974.

279. National Transportation Safety Board. Aircraft Accident Report. Pan American World Airways, Inc., Boeing 707-321C, N458PA, Boston, Massachusetts, November 3, 1973. Washington, D.C., Report No. NTSB-AAR-74-16, 2 December, 1974.

280. National Transportation Safety Board. Annual Report to Congress 1974. Washington, D.C., 1975.

281. National Transportation Safety Board. Aircraft Accident Report. Sierra Pacific Airlines, Inc., Convair 340/440, N4819C, Near Bishop, California, March 13, 1974. Washington, D.C., Report No. NTSB-AAR-75-1, 10 January, 1975.

282. National Transportation Safety Board. Aircraft Accident Report. Air France, Boeing 707-B-328B, FBLCA, Near O'Neill, Nebraska, May 13, 1974. Washington, D.C., Report No. NTSB-AAR-75-4, 15 January, 1975.

283. National Transportation Safety Board. Aircraft Accident Report. Air East Inc., Beechcraft 99A, N125AE, Johnstown-Cambia County Airport, Johnstown, Pennsylvania, January 6, 1974. Washington, D.C., Report No. NTSB-AAR-75-3, 15 January, 1975.

284. National Transportation Safety Board. Aircraft Accident Report. Saturn Airways, Inc., Lockheed L-382, N14ST, Springfield, Illinois, May 23, 1974. Washington, D.C., Report No. NTSB-AAR-75-5, 22 January, 1975.

285. National Transportation Safety Board. Aircraft Accident Report. Eastern Air Lines, Inc., Douglas DC-9-31, N8984E, Charlotte, North Carolina, September 11, 1974. Washington, D.C., Report No. NTSB-AAR-75-9, 23 May, 1975.

286. National Transportation Safety Board. Aircraft Accident Report. Federal Aviation Administration. Douglas DC-3C, N6, Dubois, Pennsylvania, March 27, 1975. Washington, D.C., Report No. NTSB-AAR-75-11, 25 June, 1975.

287. National Transportation Safety Board. Aircraft Accident Report. Montana Power Company. Rockwell Turbo Commander 690A, N40MP and USAF F-111A, 77-055, Near Kingston, Utah, November 12, 1974. Washington, D.C., Report No. NTSB-AAR-75-12, 1 August, 1975.

288. National Transportation Safety Board. Aircraft Accident Report. Northwest Airlines, Inc., Boeing 727-251, N274US, Near Thiells, New York, December 1, 1974. Washington, D.C., Report No. NTSB-AAR-75-13, 13 August, 1975.

289. Snyder, R.G. Crashworthiness Investigation of General Aviation Accidents. Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, Paper No. 750537, April, 1975, p. 3.

290. Stroud, J. European Transport Aircraft Since 1910. Putnam Aeronautical Library, London, 1966.

291. Taylor, J.W.R., ed. Jane's All the World's Aircraft 1959-60. Jane's Yearbooks, London, 1960.

292. Taylor, J.W.R. and K. Munson. Jane's Pocket Book of Commercial Transport Aircraft. MacDonald and Jane's, St. Giles House, London, 1973.

293. The Flight Safety Committee. Flight Safety Focus. London, U.K., (January to December), 1970-1975.

294. Time. "The Great DC-10 Mystery." Economy and Business Section, 8 April, 1974, p. 71.

295. United States Air Force. Summary and Evaluation of Aircraft Accidents and Fatalities, 1 January, 1957 through 31 December, 1961. Norton Air Force Base, California, 12 March, 1961.

296. United States Air Force. Safety, Aircraft Accident and Incident Classification Elements and Factors (IGDM 127-1), 1 November, 1970.

297. United States Air Force. Air Force Manual (AFM 127-2), Safety USAF Accident/Incident Reporting, 7 June, 1971.

298. United States Air Force. Design Handbook. Headquarters, Air Force Systems Command and National Aeronautics and Space Administration. Series 1-10, General, AFSC DH1-6, Systems Safety, Fourth Edition, 20 July, 1974.

299. Zay, E. "Aircraft Accidents Involving Passenger Fatalities on Scheduled Air Services During 1954-1974." International Civil Aviation Organization, Personal Communication, 12 March, 1975.

2.2.1.1. Mid-Air Collisions

300. Aviation Week and Space Technology. "French Board Analyzes Midair Collision." Safety Section, 28 July, 1975, pp. 57-58.

301. Aviation Week and Space Technology. "NTSB Analyzes Air France Incident." Vol. 103, No. 7, 18 August, 1975, pp. 48-49.

302. Associated Press. "Another TWA Airliner Has A Near Miss." The Ann Arbor News, Vol. 304, 6 December, 1975, p. 1.

303. Business and Commercial Aviation. "Aviation Intelligence." February, 1976, p. 21.

304. Committee on Commerce. Collision Avoidance and Pilot Warning Indicator Systems. Hearings Before the Subcommittee on Aviation of the Committee on Commerce, United States Senate, Ninety-Second Congress Second Session on S. 2264, Washington, D.C., Serial No. 92-94, January, 1972.

305. Department of Transportation 1969 Report of the DOT Air Traffic Control Advisory Committee. Volumes 1 and 2, December, 1969.

306. Federal Aviation Administration. Terminal Area Forecast, 1973-1983. Washington, D.C., December, 1971.

307. Federal Aviation Administration. "Termination of Policy Regarding Reports of Near Midair Collisions," (Docket No. 8555). Department of Transportation News, Washington, D.C., 3 November, 1971.

308. Gibbs-Smith, C.W. The Aeroplane - An Historical Survey. London: HMSO, 1960.

309. McLucas, J.L., Administrator of the Federal Aviation Administration. Testimony Before the Sub-Committee on Government Activities and Transportation of the House Committee on Government Operations on Near Midair Collisions, 16 December, 1975. Including Appendix "1975 Near Midair Collisions as Reported on FAA Form 3018 to AFS-50," Prepared 9 December, 1975.

310. National Transportation Safety Board. Briefs of Accidents Involving Midair Collisions, 1962-1968. U.S. General Aviation, 1968.

311. National Transportation Safety Board. Aircraft Accident Report. Piedmont Aviation, Inc., Piedmont Airlines Division, Boeing 727, N68650, Lanseair Inc., Cessna 310, N3121S Midair Collision, Hendersonville, North Carolina, July 19, 1967. Washington, D.C., Report No. PB 177-399-10, 5 September, 1968.

312. National Transportation Safety Board. Aircraft Accident Report. North Central Airlines, Inc., Convair 580, N4634S, Home Airmotive, Inc., Cessna 150, N87425, Midair Collision Near Milwaukee, Wisconsin, August 4, 1968. Washington, D.C., Report No. NTSB-AAR-69-4, 8 July, 1969.

313. National Transportation Safety Board. Midair Collisions in U.S. Civil Aviation - 1968. A Special Accident Prevention Study. Washington, D.C., July, 1969.

314. National Transportation Safety Board. Aircraft Accident Report. Ozark Air Lines, Inc., DC-9, N970Z and Interstate Airmotive, Inc., Cessna 1JOF, N8669G, St. Louis, Missouri, March 27, 1968. Washington, D.C., Report No. NTSB-AAR-69-2, 30 June, 1969.

315. National Transportation Safety Board. Aircraft Accident Report. Allegheny Airlines, Inc., DC-9, N988VJ and A, Fourth Corporation, Piper PA-28, M7374J, Near Fairland, Indiana, September 3, 1969. Washington, D.C., Report No. NTSB-AAR-70-15, 15 July, 1970.

316. National Transportation Safety Board. Aircraft Incident Report. Trans World Airlines, Boeing 707, N6729TW, and American Airlines, Boeing 707, N8432, Near Phillipsburg, Pennsylvania, June 11, 1971. Washington, D.C., Report No. NTSB-AAR-72-7, 29 December, 1971.

317. National Transportation Safety Board. Aircraft Accident Report. Eastern Air Lines, Inc., McDonnell Douglas DC-9-31, N8943E, and a Cessna Model 206, N2110F, Raleigh-Durham Airport, Raleigh, North Carolina, December 4, 1971. Washington, D.C., Report No. NTSB-AAR-72-13, 4 December, 1971.

318. National Transportation Safety Board. Aircraft Accident Report. Continental Air Lines, Inc., Boeing 707-320C, N47330, Floyd Flying Service Cessna 150J, N61011, Compton, California, August 4, 1971. Washington, D.C., Report No. NTSB-AAR-72-5, 29 December, 1971.

319. National Transportation Safety Board. Aircraft Accident Report. Hughes Air West DC-9, N9345, and U.S. Marine Corps F-4B, 151458, Near Duarte, California, June 6, 1971. Washington, D.C., Report No. NTSB-AAR-72-26, 30 August, 1972.

320. National Transportation Safety Board. Aircraft Accident Report. American Air Lines, Inc., Boeing 707-323, N7595A, and a Lenden Flight Service, Inc., Cessna 150, N60942, Over Edison, New Jersey, January 9, 1971. Washington, D.C., Report No. NTSB-AAR-72-16, 10 May, 1972.

321. National Transportation Safety Board. Aircraft Incident Report. Near Midair Collision Vicinity of Front Royal, Virginia. Northwest Air Lines, Boeing 720 B, N736VS, Lockheed Aircraft Corporation, Convair 240, N737Z, April 26, 1972. Washington, D.C., Report No. NTSB-AAR-72-30, 26 October, 1972.

322. National Transportation Safety Board. Aircraft Accident Report. North Central Airlines, Inc., Allison Convair 340/440 (DV-580), N90858, and Air Wisconsin, Inc., DHC-6, N4043B, Near Appleton, Wisconsin, June 29, 1972. Washington, D.C., Report No. NTSB-AAR-73-9, 25 April, 1973.

323. National Transportation Safety Board. Aircraft Accident Report. North Central Airlines, Inc., McDonnell Douglas DC-9-31, N-54N and Delta Air Lines, Inc., Convair CV-880, N8807E, O'Hare International Airport, Chicago, Illinois, December 20, 1972. Washington, D.C., Report No. NTSB-AAR-73-15, 5 July, 1973.

324. National Transportation Safety Board. Preliminary Accident Resume Report (American Air Lines, Inc., Boeing 707 Descending into Phoenix, December 10, 1974). 19 December, 1974.

325. National Transportation Safety Board. Aircraft Accident Report. New Jersey Air National Guard, Convair F106, 59-0044, Piper PA 24-250, N6876P, Midair Collision Near Saxis, Virginia, October 11, 1974. Washington, D.C., Report No. NTSB-AAR-75-6, 29 January, 1975.

326. National Transportation Safety Board. Aircraft Accident Report. United States Air Force Convair VT-29D (CV-340) and Cessna 150H, N50430, Newport News, Virginia, January 9, 1975. Washington, D.C., Report No. NTSB-AAR-75-10, 18 June, 1975.

327. National Transportation Safety Board. Aircraft Accident Report. Golden West Air Lines, Inc., De Havilland DHC-6, N6383, and Cessnair Aviation, Inc., Cessna 150, N11421, Whittier, California, January 9, 1975. Washington, D.C., Report No. NTSB-AAR-75-14, 7 August, 1975.

328. National Transportation Safety Board. Preliminary Accident Resume Report (Douglas DC-10-10, N124, About 30 NM West of Carleton VOR [Michigan], November 26, 1975, 1924 EST). 1975.

329. National Transportation Safety Board. 1976 Computer Printout of "Collision with Aircraft - Both in Flight." For Years 1964 - 1974, University of Michigan MTS System, January, 1976.

330. Simpson, T.R., R.A. Rucker, and J.P. Murray. Civil Aviation Midair Collisions Analysis. January 1964 - December 1971. Department of Transportation, Federal Aviation Administration, Office of Systems Engineering Management, Washington, D.C., Report No. FAA-EM-73-8, May, 1973.

2.2.1.2 Turbulence

331. National Transportation Safety Board. Special Study. In-Flight Safety of Passengers and Flight Attendants Aboard Air Carrier Aircraft. Report No. NTSB-AAS-73-1, 14 March, 1973.

332. National Transportation Safety Board. Preliminary Accident Resume Report (Flying Tiger Line McDonnell Douglas DC-8-63F, Las Vegas, Nevada, 21 March, 1975).

333. National Transportation Safety Board. Preliminary Accident Resume Report (Frontier Airlines Convair 580 War Gunison, 20 May, 1975).

334. National Transportation Safety Board. Preliminary Accident Resume Report (Trans World Air Lines Boeing 707, 12 July, 1975).

335. National Transportation Safety Board. Preliminary Accident Resume Report (Air France Boeing 707 Approximately 435 NM SE of New York, 28 July, 1975).

336. National Transportation Safety Board. Preliminary Incident Resume Report (Delta Air Lines McDonnell Douglas DC-9 at Flight Level 270, Near Buffalo, N.Y., 3 August, 1975).

337. National Transportation Safety Board. Preliminary Accident Resume Report (Delta Air Lines McDonnell Douglas DC-8-51 at Flight Level 370 Vicinity of Wilmington, Delaware, 8 August, 1975).

338. National Transportation Safety Board. Preliminary Accident Resume Report (Pan American World Airways Boeing 747, Near Puerto Rico, 15 September, 1975).

339. National Transportation Safety Board. Preliminary Accident Resume Report (Delta Air Lines McDonnell Douglas DC-8-51, Texico, Texas, 22 September, 1975).

340. National Transportation Safety Board. Preliminary Accident Resume Report (Trans International Air Lines McDonnell Douglas DC-10, 5 NM West Calgary, Alberta, Canada, 3 November, 1975).

2.2.1.3 Bird Strikes

341. Associated Press. "Bird Hazard at Tokyo Airport." 13 November, 1975.

342. Aviation Week and Space Technology. "Overseas National Airways McDonnell Douglas DC-10-30CF Crash at Kennedy After Ingestion of Seagulls." 15 November, 1975, p. 24.

343. Australian Air Safety Investigation Branch. Report of Pan American Boeing 707 Takeoff Accident at Sydney, Australia, Subsequent to Running into a Flock of Birds. 1969.

344. Dodds, L.H. "Bird Hazard in New Zealand Airports." Proceedings, Flight Safety Foundation, 19th Annual International Air Safety Seminar, Madrid, Spain, November 15-18, 1966, pp. 243-250.

345. Khan, M.A. "Bird Menace." Proceedings, Flight Safety Foundation, 19th Annual International Air Safety Seminar, Madrid, Spain, November 15-18, 1966, pp. 233-242.

346. National Transportation Safety Board. Preliminary Accident Resume Report (Overseas National Airways McDonnell Douglas DC-10-10-30 Bird Strike and Accident at John F. Kennedy International Airport, 12 November, 1975).

347. National Transportation Safety Board. Preliminary Incident Report (Federal Aviation Administration Lockheed L-1329, N1, Bird Strike at North Philadelphia on 20 November, 1975).

348. Shearer, L. "Birds and Accidents." Parade Intelligence Report, 1975.

349. Swearingen, J.J. and S.R. Mohler. Sonotropic Effects of Commercial Air Transport Sound on Birds. Federal Aviation Agency, Civil Aeromedical Research Institute, Oklahoma City, Report 62-4, March.

350. van Messel, G. "Bird Strikes." Proceedings, Flight Safety Foundation, 13th Annual International Air Safety Seminar, Chandler, Arizona, 14-18 November, 1960, pp. 87-90.

2.2.1.4 Explosion, Fire, or Structural Failure

351. Aviation Week and Space Technology. "U.K. Investigators Cite Bomb in Crash of Trans World 707." 11 November, 1974, p. 29.

352. Aviation Week and Space Technology. "NTSB Links Ionian Sea Crash to Bomb." Safety Section, 9 June, 1975, pp. 71-74.

353. Aviation Week and Space Technology. "Bomb Tests in Ionian Sea Crash Detailed." Safety Section, 16 June, 1975, pp. 72-73.

354. Aviation Week and Space Technology. "NTSB Studies Fan Section Disintegration." 5 May, 1975, pp. 64-67.

355. Aviation Week and Space Technology. "MEA 720B Crash Investigated." 12 January, 1976, p. 26.

356. Dille, J.R. and A.H. Hasbrook. "Injuries Due to Explosion, Decompression and Impact of a Jet Transport." Aerospace Medicine, Vol. 37, No. 1, January, 1966, pp. 5-11.

357. National Transportation Safety Board. Aircraft Accident Report. Trans World Airlines, Inc. Boeing 707-331B, N8734 in the Ionian Sea·September 8, 1974. Report No. NTSB-AAR-75-7, 26 March, 1975.

358. National Transportation Safety Board. Preliminary Incident Resume Report (Boeing 747 25 Miles West of Honolulu, Hawaii, November 17, 1974), 24 November, 1974.

359. National Transportation Safety Board. Preliminary Incident Resume Report (Allegheny Air Lines Douglas DC-9-31, Boston, Mass., 5 November, 1974). 23 December, 1974.

360. National Transportation Safety Board. Preliminary Incident Resume Report (American Air Lines Boeing 727, Los Angeles International Airport, 24 July, 1975).

361. National Transportation Safety Board. Preliminary Accident/Incident Resume Report (Continental Air Lines Douglas DC-10-10, Seattle, 25 July, 1975).

362. National Transportation Safety Board. Preliminary Incident Resume Report (United Air Lines Boeing 747, enroute San Francisco to Honolulu, 24 August, 1975).

363. National Transportation Safety Board. Preliminary Accident/Incident Resume Report (American Air Lines Boeing 747-123, San Juan, Puerto Rico, 8 September, 1975).

364. National Transportation Safety Board. Preliminary Accident Resume Report (Trans World Air Lines Boeing 747, London, 11 September, 1975).

365. National Transportation Safety Board. Preliminary Incident Resume Report (Trans World Air Lines Boeing 707-131B, Edwardsville, Illinois, 14 September, 1975).

366. Snyder, R.G. "In-Flight Structural Failures Involving General Aviation Aircraft." Aerospace Medicine, Vol. 43, No. 10, October, 1972, pp. 1132-1140.

367. Vulovic, V. "Airline Stewardess Who Fell 6 Miles and Lived Tells Her Amazing Story," as quoted in National Enquirer, Vol. 47, No. 7, 15 October, 1972, p. 17.

2.2.1.5 Explosive Decompression

368. Federal Aviation Administration. Summary of Cabin Pressure Loss Incidents. Turbine Power Category Aircraft. U.S. Registry. January, 1968 - January, 1970. Flight Standards Service, FS-130, Washington, D.C., March, 1971.

369. Federal Aviation Administration. Civil Aeromedical Institute, Aeronautical Center, Oklahoma City, Oklahoma, Personal Communication, February, 1976.

370. Mohler, S.R. Physiologically Tolerable Decompression Profiles for Supersonic Transport Type Certification. Department of Transportation, Federal Aviation Administration, Office of Aviation Medicine, Washington, D.C., Report AM 70-12, July, 1970.

371. National Transportation Safety Board. Aircraft Accident Report. American Air Lines, Inc. McDonnell Douglas DC-10-10, N103AA, Near Windsor, Ontario, Canada June 12, 1972. Washington, D.C., Report No. NTSB-AAR-73-2, 28 February, 1973.

372. National Transportation Safety Board. Aircraft Accident Report. National Air Lines, Inc., DC-10-10, N60NA Near Albuquerque, New Mexico, November 3, 1973. 15 January, 1975.

373. National Transportation Safety Board. Preliminary Accident Resume Report (Capitol Airways International McDonnell Douglas DC-10, West of Oakland, California, 27 December, 1975).

2.2.1.6 Takeoff and Landings

374. Newman, R.L. Airport Related Accidents: Takeoff and Climb. Canadian Air Transportation Administration, STOL Project, Ottawa, Canada, Report No. CPS-75-2, December, 1975.

375. Foxworth, T.G. and H.F. Marthinsen. "Another Look at Accelerate - Stop Criteria." AIAA, July, 1969, pp. 69-72.

376. Kennard, J.R.D. "Approach Criteria." Journal of the Royal Aeronautical Society, Vol. 67, 1962, pp. 552-557.

377. Kirchner, O.E. Critical Factors in Approach and Landing Accidents. Part I - Statistics. Flight Safety Foundation, Inc., 31 December, 1960.

378. International Civil Aviation Organization. "Strip Characteristics." 5th ICAO Air Navigation Conference, Montreal, Report AN/Conf. - WP/44, 1967.

379. United States Air Force. Summary of USAF Aircraft Accidents in Vicinity of Airfields 5 Mile Zone. Directorate of Aerospace Safety, Norton AFB, California, Report No. NR-21-65, 1965.

380. White, L.C. "Safety in the Accident Prone Phases of Takeoff, Approach, and Landing." Outlook on Safety, British Air Line Pilots Association: London, 1972.

2.2.2 Ground Emergency Egress

381. Bergman, J. "Crashes: The Illusion of Safety." ABC Closeup, Television Documentary, New York, 28 December, 1974, (Ibid., 1975).

382. Bruggink, G.M. Impact Survival in Air Transport Accidents. Aviation Crash Injury Research, Flight Safety Foundation, Inc., Phoenix, Report No. AVCIR-8-CSS-129, 20 January, 1961.

383. Burgin, R.E. Human Factors Group Chairman's Factual Report. (Pago Pago Pan American Boeing 707 Accident, 30 January, 1974). National Transportation Safety Board, File No. 1-000-1, Docket No. SA-444, Exhibit 6A, 1974.

384. Chesterfield, B.P. Emergency Evacuation Tests of the C-9A Aeromedical Aircraft. Aeronautical Systems Division, Wright-Patterson AFB, Ohio, Report ASD-TR-69-4, March, 1969.

385. Carroll, J. A Review of U.S. Air Carrier Accidents in Which Fatalities Resulted from Fire Following Impact, 1952-1961. Civil Aeronautics Board, Washington, D.C., June, 1962.

386. Department of Public Health and Preventive Medicine. Crash-Injury Study of the Northeast Airlines-Convair 240 Accident at Laguardia Airport on January 14, 1952. Cornell University Medical College, New York, New York, August, 1952.

387. Dougherty, J.E. Status Report on FAA Task Force for Crashworthiness and Evacuation. Presentation at FAA Flight Standards Service Conference, Washington, D.C., 29 March, 1966.

388. Doyle, B.C. Civil Air Carrier Crash Experience - Limiting Factors in Crash Survival and Escape. Paper Presented to USAF - Industry Life Support Conference, 1967.

389. Flight Safety Foundation, Inc. Study of Failure in Aircraft Emergency Evacuation Systems. New York, New York, 1968.

390. Garner, J.D. and J.G. Blethrow. Emergency Evacuation Tests of a Crashed L-1649. Office of Aviation Medicine, Federal Aviation Agency, Washington, D.C., Report AM-66-42, August, 1966.

391. Garner, J.D. and J.G. Blethrow. Evacuation Tests From an SST Mock-Up. Office of Aviation Medicine, Federal Aviation Administration, Department of Transportation, Washington, D.C., Report No. AM-70-19, December, 1970.

392. Gembo, B. and B.M. Conklin. "Safety Proposals Drawn from Denver Crash Study." With the Flight Attendants, Recommendations, Denver Council No. 9, Steward and Stewardess Division, 12 September, 1961, p. 19. January, 1962.

393. Godson, J. Runway-Anatomy of a Major Crash. Mayflower Books, Ltd., St. Albans, U.K., 1974.

394. Halacy, D.S., Jr. America's Major Air Disasters. Monarch Books, Inc., Derby, Conn., 1961.

395. Haley, J.L. et al. Floor Accelerations and Passenger Injuries in Transport Aircraft Accidents (Appendix I. Civil Transport Accidents in which Survival was Possible [42 Cases]; Appendix II. Military Transport Accidents in which Survival was Possible). U.S. Army Aviation Medical Laboratories, Fort Eustis, Va., Report No. USAAVLABS-67-16, May, 1967.

396. Hasbrook, A.H. Gross Pattern of Injury of 109 Survivors of Five Transport Accidents. Aviation Crash Injury Research of Cornell University, Phoenix, Arizona, July, 1958.

397. Hasbrook, A.H., J.D. Garner, and C.C. Snow. Evacuation Pattern Analysis of a Survivable Commercial Aircraft Crash. Aviation Medical Service, Research Division, Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma, Report 62-9, May, 1962.

398. Henneberger, H.G.C., H.F. Roegner, and L. Cambeis. Synthesis of Aircraft (Crash) Fire, Rescue, and Evacuation Technology. Federal Aviation Agency, July, 1964.

399. Hoffman, P.E., K.N. Beers, and R.G. Snyder. "Considerations for Improving Survivability in Air Transport/Aircraft Crashes." (Paper for Presentation, 1976 Annual Meeting, SAFE), 1976.

400. IATA Safety Information Exchange. B-707/345C, July 11, 1973, Rio/Paris, Approaching Orly. Inflight Cabin Fire. IATA, Montreal, No. 1517, 2 November, 1973.

401. Joensen, H.D., and H.D. Joensen. "Aircraft Accident in the Faroe Islands in 1970: Observations from a Medical Point of View, with Special Reference to Spinal Fractures." Aerospace Medicine, June, 1972, pp. 665-670.

402. LeRoy, C.H. Human Factors Group Chairman's Factual Report of Investigation (Capitol International Airways, Inc., McDonnell Douglas DC-8-63F, Anchorage International Airport, November 27, 1970). National Transportation Safety Board, Bureau of Aviation Safety, Washington, D.C., SA-423, Exhibit No. 6A, January, 1971.

403. LeRoy, C.H. "The Anchorage, Alaska, Crash Fire." National Transportation Safety Board, Washington, D.C., Paper Presented at 75th Annual Meeting, National Fire Protection Association, San Francisco, California, 17 May, 1971.

404. Lowell, V.W. Airline Safety is a Myth. Bartholomew House, U.S.A., 1967.

405. McClement, F. It Doesn't Matter Where You Sit. The Unsolved Problems of the Jet Age. McClelland and Stewart Limited, Toronto, 1966.

406. McIntire, G.V. "A Study of Emergency Evacuation From A High-Wing Transport Aircraft Under Simulated Ditching Conditions." SEG-TR-67-42 Systems Engineering Group, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, November, 1967.

407. Mohler, S.R., J.J. Swearingen, E.B. McFadden, and J.D. Garner. Human Factors of Emergency Evacuation. Office of Aviation Medicine, Federal Aviation Agency, Oklahoma City, Oklahoma, Report AM-65-7, 27 September, 1964.

408. Pollard, F., (Moderator). Emergency Egress from Transport Aircraft. Panel Discussion, Ninth Annual Symposium, The Survival and Flight Equipment Association, Las Vegas, Nevada, 30 September, 1971.

409. National Transportation Safety Board. Aircraft Accident Report. Trans World Air Lines Boeing 747, John F. Kennedy International Airport, New York, 1 September, 1972. Report No. NYC-73-A-N040, 1973.

410. National Transportation Safety Board. Special Study. In-Flight Safety of Passengers and Flight Attendants Aboard Air Carrier Aircraft. Washington, D.C., Report No. NTSB-AAS-73-1, 14 March, 1973.

411. National Transportation Safety Board. Special Study. Safety Aspects of Emergency Evacuation from Air Carrier Aircraft. Washington, D.C., Report No. NTSB-AAS-73-3, 13 November, 1974.

412. National Transportation Safety Board. Aircraft Accident Report. Westair Air Lines, Inc., Boeing 737-200, N4527W, Casper, Wyoming, March 31, 1975. Report No. NTSB-AAR-75-15, 30 October, 1975.

413. National Transportation Safety Board. Aircraft Accident Reports. Brief Format, U.S. Civil Aviation Issue Number 1 of 1975 Accidents. Washington, D.C., Report No. NTSB-BA-75-4, 4 September, 1975.

414. National Transportation Safety Board. Preliminary Incident Resume Report (Southeast Air Lines, Martin 404, Key West, Florida, 16 June, 1975).

415. National Transportation Safety Board. Preliminary Accident Resume Report (Trans World Air Lines Lockheed L-1011, Los Angeles, California, 14 June, 1975.

416. National Transportation Safety Board. Preliminary Accident/Incident Resume (Continental Air Lines Boeing 727, Denver, Colorado, 7 August, 1975).

417. National Transportation Safety Board. Preliminary Accident Resume Report (American Air Lines Boeing 727, Buffalo, New York, 23 August, 1975).

418. National Transportation Safety Board. Preliminary Incident Resume Report (American Air Lines Boeing 727-023, Dulles International Airport, Washington, D.C., 11 October, 1975).

419. National Transportation Safety Board. Preliminary Accident/Incident Resume Report (United Air Lines McDonnell Douglas DC-10-10, Seattle, Washington, 16 October, 1975).

420. National Transportation Safety Board. Preliminary Accident/Incident Resume Report (Eastern Air Lines, Boeing 727-200, Raleigh-Durham Airport, North Carolina, 12 November, 1975).

421. Anstey, J.R., and H. Brownbill. Concorde Type Certification Emergency Evacuation Demonstration. British Aircraft Corporation, Ltd., Commercial Aircraft Division, Final Report No. SST/B42/JRA/9282, 1975.

422. Serling, R.J. Loud and Clear. Dell Publishing Co., Inc., New York, 1969.

423. Shuckburgh, J.S. "Accident Statistics and the Human-Factor Element." Aviation, Space, and Environmental Medicine, Clinical Medicine Section, January, 1975, pp. 76-79.

424. Snow, C.C., J.J. Carroll, and M.A. Allgood. Survival in Emergency Escape from Passenger Aircraft: The Experiment Perilous. Office of Aviation Medicine, Federal Aviation Administration, Department of Transportation, Washington, D.C., May, 1970.

425. Snyder, R.G. "Analysis of Cause of Occupant Trauma in Air Transport Accidents." Reprint, Aviation, Space and Environmental Medicine, (abstract in press), 1976.

426. Tillman, J.M. Some Safety Considerations for Interior Cabin Design of New Aircraft. United Air Lines, Flight Safety Department, San Francisco, 10 September, 1956.

427. United States Air Force. C-5A Emergency Ground and Ditching Egress Test Report. Systems Command, Wright-Patterson AFB, Ohio (Unpublished), 1970.

428. Walhout, G.J. Human Factors Group Chairman's Factual Report (Overseas National Airways, Douglas DC-9-33F, Approximately 28 Miles ENE of St. Croix, V.I., May 2, 1970). National Transportation Safety Board, Washington, D.C., Docket No. SA-420, Exhibit No. 6A, June, 1970.

429. Walhout, G.J. Human Factors Group Chairman's Factual Report of Investigation (Trans Caribbean Airways, Boeing 727-200, N8790R, Harry S. Truman Airport, St. Thomas, Virgin Islands, December 28, 1970). National Transportation Safety Board, Washington, D.C., 1 March, 1971.

2.2.2.1 1973-1974 Accidents

430. National Transportation Safety Board. Aircraft Accident Report. Air East, Inc., Beechcraft 99A, N125AE, Johnstown - Cambria County Airport, Johnstown, Pennsylvania, January 6, 1974. Report No. NTSB-AAR-75-3, 1975.

431. National Transportation Safety Board. Preliminary Accident/Incident Resume Report (United Air Lines Boeing 727, Tampa, Florida, 4 January, 1974).

432. National Transportation Safety Board. Aircraft Accident Report. Eastern Air Lines, Inc., Douglas DC-9-31, N8984E, Charlotte, North Carolina, September 11, 1974. Report No. NTSB-AAR-75-9, 23 May, 1975.

433. National Transportation Safety Board. Preliminary Accident Resume Report (Continental Airlines, Boeing 727, Stapleton International Airport, Denver, Colorado, 7 August, 1975).

434. National Transportation Safety Board. Preliminary Accident Resume Report (United Airlines, McDonnell Douglas DC-8, San Francisco International Airport, California, 15 May, 1971).

435. National Transportation Safety Board. Preliminary Accident Resume Report (Trans World Airlines, Boeing 727, O'Hare International Airport, Chicago, 1 April, 1971).

2.3 Military Air Transport Experience

2.3.1 USAF Boeing C-135 Low-Wing Transport

436. United States Air Force. C-135 A&B Flight Manual. USAF Series Aircraft, T.O. IC-135A-1, 15 April, 1971 (15 November, 1964).

437. United States Air Force. C-141A Flight Manual. USAF Series Aircraft, T.O. IC-141A-1, 15 July, 1971 (13 September, 1967).

438. Headquarters Strategic Air Command. Use of Personal Equipment by Aircrew Members and Passengers Flying in SAC Aircraft. Offutt Air Force Base, Nebraska, SAC Regulation No. 60-8, 1964.

2.4 Air Transport Ditchings

439. Adams, F.D. "Ditchings." National Aeronautics and Space Administration Aeronautical Dictionary, 1959, p. 5.

440. Aviation Week and Space Technology. "AM-56 Wreckage Studied for Cause of Crash in Sea." Vol. 90, 12 May, p. 38.

441. Aviation Week and Space Technology. "News Digest." 26 January, 1976, p. 35.

442. Aviation Week and Space Technology. "CAB Accident Investigation Report: Similar Failures Indicate Ditching Course." Vol. 67, 12 August, 1956, p. 117.

443. Aviation Week and Space Technology. "Crash Spurs Ditching Recommendations: Flying Tiger Flight." Vol. 80, 23 September, 1964, pp. 96-105.

444. Aviation Week and Space Technology. "U.S. Probes Ditching of Tiger Constellation." Vol. 72, 1 October, 1962, p. 30.

445. Aviation Week and Space Technology. "Northwest DC-7C Crashes Into Pacific, 3 June, 1963." Vol. 81, 10 August, 1964, pp. 82-84.

446. Brean. H. "Agony and Enigma in a Dark River; Prop Jet Crash in East River." Life, Vol. 46, 16 February, 1959, pp. 37-40.

447. Bruggink, G. "Emergency Landing and Ditching Techniques in Helicopters." The United States Army Board for Aviation Accident Prevention, Ft. Rucker, Alabama, January, 1968.

448. Bruggink, G.M. Special Study. Emergency Landing Techniques in Small Fixed-Wing Aircraft. Report No. NTSB-AAS-72-3, National Transportation Safety Board, Washington, D.C., 5 April, 1972.

449. Craig, P.E. "Physical and Psychological Aspects of Ditching." Air Surgeons Bulletin, Vol. 2, February, 1945, p. 41.

450. Davidson, A.F. "Investigation of Ditching Accidents." Aerospace Medicine, Vol. 36, No. 7, July, 1965, pp. 646-648.

451. Departments of the Army, Navy, Air Force and Transportation. Aircraft Emergency Procedures Over Water. Report No. FM 20-151; OPNAV INST 3730.4A: AFM 64-6; CG 306, November, 1968.

452. Department of Trade and Industry. Piper PA 23-235 G-ASKW, Report on the Accident in the Sea 18 Nautical Miles Southeast of Southwold, Suffolk on 25 February, 1971. London, England, 17 December, 1971.

453. Department of Trade and Industry. Model DR 1050 Ambassador G-AYEA, Report on the Accident in Bridgewater Bay, Somerset on 25 March, 1972. London, England, 4 April, 1973.

454. Department of Trade and Industry. Cessna F172H G-AVHI, Report on the Accident in the Sea, 44 Nautical Miles East of Wick, Scotland on 11 December, 1962. London, England, 29 May, 1964.

455. Dodd, K.N. "Rate of Cockpit Flooding in a Sinking Aircraft." Tech. Note Math, 103, Royal Aircraft Establishment (Farnborough), Ministry of Aircraft, London, September, 1963.

456. Doyle, B.C. "Civil Air Carrier Crash Experience - Limiting Factors in Crash Survival and Escape." Paper Presented to USAF - Industry Life Support Conference by National Transportation Safety Board, November, 1967.

457. Doyle, B.C., and R.A. Roepe. "A Study of United States Air Carrier Water Accidents, July 1954 - June 1964." Aerospace Medicine, Vol. 36, No. 7, June, 1965, pp. 648-658.

458. Fisher, L.J., and E.L. Hoffman. Model Ditching Investigation of the Douglas DC-4 and DC-6 Airplanes. NACA Research Memorandum, Report No. RML9K02A, 4 May, 1950.

459. Flight. "Text-Book Ditching." Vol. 69, 3 February, 1956, pp. 142-143.

460. Fokker-VFW B.V. F.28 Ditching Certificate (LV-28-118). Schiphol-Oost. Netherlands. 7 August, 1973.

461. Foley, P.A. "We Ditched at Sea: Ordeal of Flying Tiger 1923." Saturday Evening Post, Vol. 235, 17 November, 1962, pp. 97-101.

462. Gelfan, D. "Blown Out to Sea." FAA Aviation News, Vol. 12, Nos. 11-12, March/April, 1974, pp. 7-9.

463. Gelfan, D. "Island Hopping." FAA Aviation News, Vol. 13, No. 5, September, 1974, pp. 8-9.

464. Gelfan, D. "Island Hopping II." FAA Aviation News, Vol. 13, No. 7, November, 1974, pp. 6-7.

465. Hardingham, R.E. "Aircraft Accidents: Can Chances of Survival Be Increased?" Royal Aeronautical Society, Vol. 52, No. 451, July, 1948, p. 480.

466. Hunt, V.A.M. "The Recovery of Aircraft from Under the Sea - 'Walrus.'" Society of Air Safety Investigators Forum, Spring Edition, 1974, pp. 16-17.

467. Ice, J., R.G. Snyder, A.D. Hyde, and S. Leverett. Biomedical Research Studies in Acceleration, Impact, Weightlessness, Vibration, and Emergency Escape and Restraint Systems: A Comprehensive Bibliography. Supplement One, Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, September, 1966.

468. Keating, C. "Final Progress Report - 40 G Ditching Seats." Engr. Report No. 664, Bureau of Aeronautics, Department of the Navy, Virginia, May, 1954.

469. King, B.E., and M.C. Richardson. "An Experimental Study of Escape Survival in Aircraft Ditching." Civil Aeronautics Administration, Washington, D.C., Paper Presented at Flight Safety International Air Safety Seminar, Palo Alto, California, November, 1957.

470. Kysor, H.D. Aircraft in Distress. Chilton Co., Inc., Philadelphia, 1961, pp. 299-356.

471. Ogg, R. "Pilot Describes Stratocruiser Ditching, October 16, 1956." Aviation Week and Space Technology, Vol. 66, 25 March, 1957, pp. 133-134.

472. National Transportation Safety Board. Aircraft Accident Report. Japan Air Lines Co., Ltd., DC-8-62, JA8032, San Francisco Bay, San Francisco, California, November 22, 1968. Report No. NTSB-AAR-70-2, 31 December, 1969.

473. National Transportation Safety Board. Manual of Code Classifications: Aircraft Accidents and Incidents. Third Edition. Department of Transportation, Washington, D.C., June, 1970, p. 41.

474. National Transportation Safety Board. Preliminary Accident Resume Report (Britten Norman BN2-8 Ditching Near St. Thomas, Virgin Islands, 12 December, 1975).

475. Simpson, J.M. "Ditching of a Jet Transport." Proceedings of the Seventh Annual Symposium. Survival and Flight Equipment Association, Vol. 1., October, 1969, pp. 23-28.

476. Snyder, R.G. "U.S. Experience in Water Ditching of Civil Aircraft." Proceedings, XXIInd International Congress of Aviation and Space Medicine, Beirut, Lebanon, October, 1974.

477. Snyder, R.G. "Crashworthiness in General Aviation Ditching." Aircraft Crashworthiness, The University of Virginia Press, October, 1975.

478. Snyder, R.G. "U.S. Experience in Water Ditching of Civil Aircraft." Arab Wings, Bulletin of the Arab Air Carriers Organization, Beirut, Lebanon, Vol. 25, March/April, 1975, pp. 10-11.

479. Snyder, R.G., H. Gibbons, and J. Widiker. "Emergency Ditching of General Aviation Aircraft." Proceedings, SAFE, September, 1974.

480. Snyder, R.G., J. Ice, J.C. Duncan, A.S. Hyde, and S. Leverett. Biomedical Research Studies in Acceleration, Impact, Weightlessness, Vibration, and Emergency Escape and Restraint Systems: A Comprehensive Bibliography. Report 63-30, Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, December, 1963.

481. Time. "Riders to the Sea; KLM Flight 607E." Vol. 72, 25 August, 1958, pp. 21-22.

482. Time. "Rescue at Sea; Chartered Flying Tiger Transport." Vol. 80, 5 October, 1962, p. 28.

483. Townshend, B.W. Safety in Over Water Flight, A Study of Ten Years Losses of Aircraft Over Water, January 1952 - December 1962. R.F.D. Company, Ltd., Godalming, Surrey, England, March, 1963.

484. Townshend, B.W. "Ditching the Air Bus: A Matter of Self Preservation." The Central, Vol. 136, January, 1968, pp. 3-8.

485. Walhout, G.J. Human Factors Group Chairman's Factual Report (Overseas National Airways, Douglas DC-9-33F, Approximately 28 Miles ENE of St. Croix, Virgin Islands, May 2, 1970). National Transportation Safety Board, Washington, D.C., Docket No. SA-420, Exhibit No. 6A, June, 1970.

486. White, C.B., P.J. Johnson, and H.T.E. Hertzberg. "Review of Escape Hatch Sizes for Bailout and Ditching." OTE WCRD 52-81, Wright Air Development Center, Air Research and Development Command, Wright-Patterson Air Force Base, Ohio, September, 1952.

487. Woerden, J.V. Survival of Aircraft - Accidents and Shipwrecks - Bibliography. Netherlands Armed Services Technical Documentation and Information Center, The Hague, 1961, pp. 10-31.

3.0 Smoke Hood and Other Mask Protective Devices

488. Aerospace Industries Association. Fire Suppression and Smoke and Fume Protection. Crashworthiness Development Program, Technical Group Report, AIA CDP-2, July, 1968.

489. Aerospace Industries Association. Evacuation. Crashworthiness Development Program, Technical Group Report, AIA CDP-4, July, 1968.

490. Aerospace Industries Association. Smoke Protective Device (Smoke Mask) Development. Crashworthiness Study Program, Phase VI (1967-1968), 1969.

491. Air Force Systems Command. "Nomex Flying Suits." Aerospace Safety, June, 1971, p. 23.

492. Aviation Week and Space Technology. "Smoke Evacuation Tests," (Boeing 707-321C). 10 March, 1975, pp. 47-51.

493. Aviation Week and Space Technology. "NTSB Analyzes Pan Am Freighter Crash." 10 March, 1975, pp. 47-51.

494. Blockley, W.V., and C.L. Taylor. "Studies in Human Tolerance for Extreme Heat." Tech. Report 5831, U.S. Air Force, February, 1950.

495. Brown, C.L. Emergency Ground Egress from USAF Passenger-Carrying Aircraft. Seventh National SAFE Symposium, Las Vegas, Nevada, 26-30 October, 1969.

496. Buettner, K. "Effects of Extreme Heat on Man." JAMA, Vol. 144, October, 1950, pp. 732-738.

497. Carroll, J.J. Investigating the Human Factors in Aircraft Accidents. National Fire Protection Association, Aviation Bulletin No. 292, June, 1962.

498. Connell, J.F. Research in Burns, Proceedings of the First International Congress on Research in Burns, Bethesda, Md., September 19, 1960.

499. Craig, A.B., Jr. "Underwater Swimming and Loss of Consciousness." JAMA, Vol. 176, 1961, pp. 255-258.

500. Dyer, R.F., and V.H. Esch. "Polyvinyl Chloride Toxicity in Fires." JAMA, Vol. 236, No. 4, 26 January, 1976, pp. 393-397.

501. Einhorn, I.N. Physio-Chemical Study of Smoke Emission by Aircraft Interior Materials - Part I: Physiological and Toxicological Aspects of Smoke During Fire Exposure. Dept. of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, D.C., FAA Report No. FAA-NA-73-70, I; National Technical Information Service, Springfield, Va., Report No. AD-763602, July, 1973.

502. Einhorn, I.N., M.D. Kanokia, and J.D. Seader. Physio-Chemical Study of Smoke Emission by Aircraft Interior Materials - Part II: Rigid and Flexible Urethane Foams. Dept. of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, D.C., Report No. FAA-RD-73-50, II; National Technical Information Service, Springfield, Va., Report No. AD-763935, July, 1973.

503. Erhart, F.J. Airworthiness Department, Fokker-V.F.W. B.V., Schiphol-Oost. Personal Communication, October, 1974.

504. Federal Aviation Administration. Demonstration of Emergency Evacuation Procedures. Federal Aviation Regulations, Part 121.291, Appendix D. Criteria for Demonstration of Emergency Evacuation Procedures under Part 121.291, n.d.

505. Federal Aviation Administration. Emergency Evacuation. Airworthiness Standards: Transport Category Airplanes, Part 25.803, Amendments 25-15, Crashworthiness and Passenger Evacuation Standards; Transport Category Airplanes, 1967.

506. Federal Aviation Administration. Smoke Hook Evaluation Program. Aeronautical Center, Flight Standards Technical Division. Special Project Report, Project No. 01271, March, 1968.

507. Federal Aviation Administration. Notice of Proposed Rule Making, "Protective Smoke Hoods for Emergency Use by Passengers and Crew Members." Docket No. 9344, Notice 69-2, Federal Register, Vol. 34, No. 8, 11 January, 1969, pp. 465-466.

508. Federal Aviation Administration. Engineering and Development Program Plan - Aircraft Safety. Aircraft and Noise Abatement Division, FAA Report FAA-ARD-500; National Technical Information Service, Springfield, Va., Report No. AD-765009, April, 1973.

509. Federal Aviation Administration. Advance Notice of Proposed Rule Making, "Compartment Interior Materials Toxic Gas Emission." Federal Register, 39 F.R. 45044, 30 December, 1974.

510. Federal Aviation Administration. Notice of Proposed Rule Making, "Transport Category Airplanes. Smoke Emission from Compartment Interior Materials." Federal Register, 40 F.R. 6506, 12 February, 1975.

511. Federal Aviation Administration. Advance Notice of Proposed Rule Making, "Flight Attendant Clothing." Federal Register, 40(50):11737, 13 March, 1975.

512. Finney, L.D. Special Subcommittee on Investigations of the Committee on Interstate and Foreign Commerce, Congress of the United States. Personal Communication, 20 September, 1974.

513. Fish, R.H. "The Performance of Lightweight Plastic Foams Developed for Fire Safety." Proceedings of the NASA Conference on Materials for Improved Fire Safety. May, 1970, pp. 11-1 to 11-20.

514. Flight Safety Foundation. A Statistical Analysis of Jet Transport Aircraft Accidents Relating to Fire Suppression and Passenger Evacuation. Flight Safety Foundation, Inc., New York, 1967.

515. Flight Surgeon's Manual. Air Force Manual No. 161-1, Department of the Air Force, Washington, D.C. 1962,

516. Fohlen, G.M., J.A. Parker, S.R. Riccitiello, and P.M. Sawko. "Intumescence: An In Situ Approach to Thermal Protection." Proceedings of the NASA Conference on Materials for Improved Fire Safety, May, 1970, pp. 12-1 to 12-20.

517. Fourn, P. "Problems du Feu a Bord." Proceedings, XXIInd International Congress of Aviation and Space Medicine, Beirut, Lebanon, 10 October, 1974.

518. Gross, D., J.J. Loftus, T.G. Lee, and V.E. Gray. "Smoke and Gases Produced by Burning Aircraft Interior Materials." Fire Research Section, Washington, D.C., Report No. NA-68-36 (DS-68-16), Contract FA66NF-AP-7, Project No. 510-001-11x, June, 1969.

519. G.T. Schjeldahl Company. Safety Hood. Advanced Programs Division, Northfield, Minnesota, Technical Bulletin No. 45-21, 1971.

520. G.T. Schjeldahl Company. The Schjeldahl Safety Hood. Materials Group, Northfield, Minnesota, 1971.

521. G.T. Schjeldahl Company. Miner's Protective Hood - For Use with Rebreather. Northfield, Minnesota, 1971.

522. Heine, D. ALPA Cleveland Fire Test Results. Presented at the Thirteenth ALPA Air Safety Forum, October 4, 1966.

523. Henderson, Y., and H.W. Haggard. "Noxious Gases and the Principles of Respiration Influencing Their Action." 2nd Ed., Reinhold Publishing Corp., New York, 1943.

524. Higgins, E.A., V. Fiorica, A.A. Thomas, and H.V. Oavis. The Acute Toxicity of Brief Exposures to HF, HCL, NO_2 and HCN, Singly and in Combination with CO. Federal Aviation Administration, Civil Aeromedical Institute, Oklahoma City, Report No. FAA-AM-71-41, 1971.

525. Klass, P.J. "FAA Approach to Flammability Protested." Aviation Week and Space Technology, 24 November, 1975, pp. 35-36.

526. Kourtides, D., and T.A. Parker. Chemical Research Projects Office: Functions, Accomplishments and Programs. National Aeronautics and Space Administration, NASA TMX-62, 186, September, 1972.

527. Kuchta, J.M. Fire and Explosion Manual for Aircraft Accident Investigators. Bureau of Mines, PMSRC Ret. No. 4193; USAF Rept. AFAPL-TR-73-74, Wright-Patterson AFB, Ohio; National Technical Information Service, Springfield, Va., Rept. AD-771191. August, 1973.

528. Lewis, M.F. "Vision Through Smoke Hoods." Protective Smook Hood Studies (E.B. McFadden and R.C. Smith, eds.), Federal Aviation Administration, Office of Aviation Medicine, Report No. AM70-20, Oecember, 1970, pp. 19-22.

529. Lopez, E.L. Study of Smoke Emission from Burning Cabin Materials and the Effect of Visibility in Wide Body Jet Transports. Lockheed Aircraft Corporation, Rept. RO-73-127, 1973.

530. March, J.F. A Study of Air Transport Passenger Cabin Fires and Materials. Federal Aviation Administration, Report No. FAA ADS-44, Oecember, 1965.

531. Marcy, J.F., E.B. Nichols, and J.E. Oemargee. Flammability and Smoke Characteristics of Aircraft Interior Materials. Federal Aviation Administration, Systems Research and Oevelopment Service, Technical Report No. AOS-3, January, 1964.

532. Marcy, J.F. A Study of Air Transport Passenger Cabin Fires and Materials. National Aviation Facilities Experimental Center, Federal Aviation Administration, Report No. FAA-AOS-44, December, 1965.

533. McFadden, E.B. Smoke and Flame Protective Hood. Oisclosure of Invention, FAA Form 3522, 13 December, 1966.

534. McFadden, E.B. "Evacuation Testing Using Oense Theatrical Smoke." Protective Smoke Hood Studies (E.B. McFadden and R.C. Smith, eds.), Federal Aviation Administration, Office of Aviation Medicine Report No. AM-70-20, Oecember, 1970, pp. 31-33.

535. McFadden, E.B. Civil Aeromedical Institute, Federal Aviation Administration, Oklahoma City, Personal Communication, 14 November, 1975.

536. McFadden, E.B., and H.L. Gibbons. "Smoke Hood Effectiveness in a Toxic Environment." Protective Smoke Hood Studies (E.B. McFadden and R.C. Smith, eds.), Federal Aviation Administration, Office of Aviation Medicine, Report No. 70-20, Oecember, 1970, pp. 17-18.

537. McFadden, E.B., H.I. Reynolds, and G.E. Funkhouser. "Protective Passenger Smoke Hood." Aerospace Medicine, Vol. 39, No. 2, February, 1968, pp. 177-181.

538. McFadden, E.B., H.I. Reynolds, and G.E. Funkhouser. A Protective Passenger Smoke Hood. Federal Aviation Administration, Office of Aviation Medicine, Report No. AM 67-4, April, 1967.

539. McFadden, E.B., and R.C. Smith, eds. Protective Smoke Hood Studies. Federal Aviation Administration, Office of Aviation Medicine, Report No. AM 70-20, December, 1970.

540. Maxey, E.S. "Airline Safety" (NO_2). Aviation Week and Space Technology, 9 June, 1975.

541. McKenzie, J.M., E.B. McFadden, J.M. Simpson, and P.R. Fowler. "Evaluation of Leakage in Protective Smoke Hoods." Protective Smoke Hood Studies (E.B. McFadden and R.C. Smith, eds.), Federal Aviation Administration, Office of Aviation Medicine, Report No. AM 70-20, December, 1970, pp. 3-16.

542. Mohler, S.R. "Air Crash Survival: Injuries and Evacuation Toxic Hazards." Aviation, Space, and Environmental Medicine, Vol. 46, No. 1, January, 1975, pp. 86-88.

543. National Bureau of Standards. "Test Method for Measuring the Smoke Generation Characteristics of Solid Material" (Appendix II). Inter-laboratory Evaluation of Smoke Oensity Chamber, NBS Technical Note No. 708, September, 1971.

544. National Transportation Safety Board. Aircraft Accident Report. Capitol International Airways, Inc., McDonnell Douglas DC-8-63F, Anchorage International Airport, November 27, 1970. Report No. NTSB-AAR-72-12, 1971.

545. National Transportation Safety Board. Aircraft Accident Report. North Central Airlines, McDonnell Oouglas DC-9-31, N954N and Oelta Air Lines Convair CV-880, N8807E, O'Hare International Airport, Chicago, Illinois, December 20, 1972. Report No. NTSB-AAR-73-15, 5 July, 1973.

546. National Transportation Safety Board. Aircraft Accident Report. Pan American World Airways, Inc., Boeing 707-321C, N458PA, Boston, Massachusetts, November 3, 1973. Report No. NTSB-AAR-74-16, 2 December, 1974.

547. Oden, J.R., and H.B. Altman. Demonstration Tests of the Audibility and Visibility of Two Prototype Smoke Hoods for Use in Commercial Aircraft Evacuation. Douglas Aircraft Company, Inc., Long Beach, California, Report No. DAC-33965, September, 1967.

548. Origer, T.F. Neck Closure for Protective Hood Device. U.S. Patent Office #3,562,813, Assigned to G.T. Schjeldahl Co., Northfield, Minn., Filed 3 July, 1969, Patented 16 February, 1971.

549. Paabo, M., and J.J. Comeford. A Study of the Decomposition Products of Polyurethane Foam Related to Aircraft Cabin Flash Fires. U.S. Dept. of Commerce, National Bureau of Standards for National Aviation Facilities Experimental Center, Atlantic City, N.J., FAA Rept. No. FAA-NA-73-69; National Technical Information Service, Springfield, Va., Report AD-763 327, 1973.

550. Parker, J.A., G.M. Fohlen, P.M. Sawko, and R.N. Griffin. "The Use of a Salt of p-nitroaniline as a Component for Intumescent Coatings." Sampe J., August/September, 1968.

551. Parker, J.A., S.R. Riccitiello, W.J. Gilwee, and R.H. Fish. "Development of Polyurethane for Controlling Fuel Fires in Aircraft Structures." Sampe J., April/May, 1969.

552. Pesman, G.J. Appraisal of Hazards to Human Survival in Airplane Crash Fires. Lewis Flight Propulsion Laboratory, Cleveland, Ohio, NACA Rept. TN2996, September, 1953.

553. Peterson, I. "Recommendations for Accident Survival." Proceedings, SAFE, 1970, pp. 163-170.

554. Phillips, A.W., and O. Cope. Research in Burns, Proceedings of the First International Congress on Research in Burns, Bethesda, Md., September, 1960.

555. Pinkel, I.I. "Crash-Fire Research with Jet Aircraft." Aeronaut. Eng. Rev., Vol. 15, No. 1, January, 1956, pp. 53-57.

556. Pinkel, I.I., and G.M. Preston. Mechanism of Start and Development of Aircraft Crash Fires. Lewis Flight Propulsion Laboratory, Cleveland, Ohio, NACA Rept. RM E52F06, 28 August, 1952.

557. Reynolds, H.I. Heat and Smoke Protective Hoods. U.S. Patent Office #3,521,629, Assigned to G.T. Schjeldahl Co., Northfield, Minn., Filed 18 September, 1967, Patented 28 July, 1970.

558. Reynolds, H.I. Technical Report on Protective Hoods. G.T. Schjeldahl Company, Northfield, Minn., September, 1966.

559. Riccitiello, S.R., R.H. Fish, J.A. Parker, and E.J. Gustafson. "Development and Evaluation of Modified Polyisocyanurate Foams for Low-Heating-Rate Thermal Protection." J. Cell. Plast., Vol. 7, No. 2, March/April, 1971, pp. 91-96.

560. Riley, R.L., and S. Permutt. "Report to Air Transport Association of America on Protective Smoke Hoods for Emergency Use by Passengers and Crewmembers." Submitted for Air Transport Association of America to Department of Transportation, Federal Aviation Administration, in response to Docket No. 9344, Notice 69-2, Appendix 9, 1969.

561. Roepe, R.A. A Study of United States Air Carrier Accidents Involving Fire 1955-1964. Civil Aeronautics Board, Bureau of Safety, Report No. BOSP-7-6-3, 1965.

562. Sawko, P.M., and S.R. Riccitiello. "Intumescent Coatings for Improved Fuel-Fire Protection of Sensitive Articles." Paper Presented at 161st National Meeting of American Chemical Society, Los Angeles, California, March/April, 1971.

563. Simpson, C.G. Interrelationship of FAA-DOT-NASA Programs Relating to Aircraft Cabin Materials Fire. National Technical Information Service, Springfield, Va., Report No. AD-768 845, September, 1973.

564. Smith, R.C. "Effects of Variations in Safety Briefings Upon Use of Protective Smoke Hoods." Protective Smoke Hood Studies (E.B. McFadden and R.C. Smith, eds.), Federal Aviation Administration, Office of Aviation Medicine, Report No. AM 70-20, December, 1970, pp. 75-30.

565. Solt, G.A. Comments and Recommendations Relative to KC-135A Accident. Recovery and Crew Station Branch, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, 3 March, 1969.

566. Stewart, R.D., R.S. Stewart, W. Stamm, and R.P. Seelew. "Rapid Estimation of Carboxyhemoglobin Level in Fire Fighters." JAMA, Vol. 235, No. 4, 26 January, 1976, pp. 390-392.

567. Time. "Of Mice and Men: Alarm Over Plastics." 14 October, 1975, p. 52.

568. Tobias, J.V. "Smoke Hood Tests: Acoustic Attenuation." Protective Smoke Hood Studies (E.B. McFadden and R.C. Smith, eds.), Federal Aviation Administration, Office of Aviation Medicine, Report No. AM 70-20, December, 1970, pp. 23-24.

569. United Air Lines, Inc., Boeing 727, N-7030U, Salt Lake City, Utah, November 11, 1965. Civil Aeronautics Board Aircraft Accident Report, SA 338, File No. 1-0032, Washington, D.C., 7 June, 1966.

570. Webb, Paul. "Pain Limited Heat Exposures." Temperature -- Its Measurement and Control in Science and Industry, Vol. 3, Pt. 3, Reinhold Pub. Corp., 1962, pp. 245-250.

571. White, C.S., J.H. Humm, E.D. Armstrong, and N.P.V. Lundgren. "Human Tolerance to Acute Exposure to Carbon Dioxide." Journal of Aviation Medicine, Vol. 23, October, 1952, pp. 439-455.

572. Wright, J.C. (Chairman). Hearings, Special Subcommittee on Investigations of the Committee on Public Works and Transportation, Congress of the United States, 2-6 February, 1976.

3.1 Smoke, Flame, Toxic Fumes and Smoke Hoods

573. Advisory Group for Aeronautical Research and Development. Aircraft Fire Safety. Conference Proceedings No. 166, North Atlantic Treaty Organization, October, 1975.

574. Ansarf, F. Moyens de sauvetage et de lutte contre les incendies d'aeronefs. Ecole Nationale de l'Aviation civile. Toulouse, ENAC, 1974.

575. BOPI. Dispositif de sauvetage pour les occupants d'un aeronef. Societe de construction des avions Hurel-Dubois. 16° An., n° 26 (27.06.75), p. 7757.

576. BOPI. Dispositif de container largable se fixant a Z'exterieur sous la voilure des aeronefs. Services auxiliaires de Z'armement, S.A., 16° An., n° 03 (17/1/75) p. 661.

577. BOPI. Disposition d'evacuation individuelle des occupants d'un aeronef. Societe de construction des avions Hurel-Dubois. 16° An., n° 05 (31/01/75), p. 1376.

578. Bureau of Mines. Coal Mine Rescue and Survival System. Contract H0101262, Westinghouse Electric Corp. (Unpublished), 1971.

579. Enders, J. National Aeronautics and Space Administration, Washington, D.C., Personal Communication, December, 1975.

580. Federal Aviation Administration. Final Project Report on the Disposition of Notice of Proposed Rule Making 69-2 on Smoke Hoods (Unpublished Report). September, 1969.

581. L'Armement. "Les essais d'inflammabilite des materiaux de cabines d'avions au Centre d'Essais Aeronautique de TOULOUSE." N° 35, (4/75), pp. 75-77.

582. Lopez, R. "Protection contre l'incendie a bord des aeronefs de transport public. Amenagement des cabines." Bulletin Technique Bureau Veritas, N° 4 (4/75), pp. 86-91.

583. Mouton, L., and G. Armand. Test of Fireproof Anti-Smoke Hoods, Paris (Unpublished Report). 14 October, 1969.

584. Newsweek. "A Survivable Crash." 11 March, 1968, p. 69.

585. Timbal, J., et J. Colin. "Essai d'un moyen de protection individuel contre l'incendie : la cagoule anti-fumee." Revue de Medecine Aeronautique et Spatiale, 9 (35), 131-134, 1970.

3.1.1 Effects of Fire, Heat, CO_2 on Man

586. Buettner, K. "Effects of Extreme Heat on Man." JAMA, Vol. 144, October, 1950, pp. 732-740.

587. Coleman, E.H. "Physiological Effects of Some Gases Which May Occur in Fires." Plastics, Vol. 24, No. 10, 1959, pp. 416-418.

588. Connell, J.F. "Research in Burns." Proceedings of the First International Congress on Research in Burns, Bethesda, Maryland, September, 1960.

589. Cooper, A.G. "Carbon Monoxide: A Bibliography with Abstracts." U.S. Public Health Service, Washington, D.C., PHS Publication No. 1503, 1966.

590. Darmer, Kenneth I. Short Term Animal Exposure to Carbon Monoxide and Hydrogen Cyanide Singly and in Combination. Report FAA-AM-73-15, December, 1972.

591. Finck, P.A. "Exposure to Carbon Monoxide: Review of the Literature and 567 Autopsies." Military Medicine, Vol. 131, No. 12, December, 1966, pp. 1513-1539.

592. Forbes, W.H., et al. "The Rate of Carbon Monoxide Uptake By Normal Men." American J. Physiol., Vol. 143, April, 1945.

593. Forlano, G. "The Effect of Ambient and Body Temperatures Upon Reaction Time." U.S. Navy Special Devices Center, SPECDEVCEN 151 1 13, Contract No. N6-ORI-151-01, March 15, 1948.

594. Gorodinskii, S.M., et al. "Heat Stress Dynamics and Limits of Heat Tolerance in Man." Environmental Space Science, Vol. 2, No. 1, 1968, pp. 66-73.

595. Gross, D., et al. "Smoke and Gases Produced by Burning Aircraft Interior Materials." Fire Journal, (FAA Rept. No. NA-68-36), July, 1969, pp. 23-25, 30.

596. Harter, M.R., and R.W. Lansing. "Effects of Carbon Dioxide on the EEG and Reaction Time in Humans." Paper, Western EEG Society, San Francisco, March 2-4, 1966; Abstract in Electro-enceph. Clin. Neurophysiol., Vol. 22, March, 1967, p. 294.

597. Henderson, Y., and H.W. Haggard. Noxious Gases and the Principles of Respiration Influencing Their Action. Second Edition, Reinhold Publishing Corporation, New York, New York, 1943.

598. Johnson, N.B., et al. "An Appraisal of the Postcrash Fire Environment." U.S. Army Natick, Mass., Report 70-22-CE, September, 1969, AD 699 826.

599. Jones, J., and P. Sarkos. Design Calculations for a Halon 1301 Distribution Tube for an Aircraft Cabin Fire Extinguishing System. Report FAA-RD-73-32, April, 1973.

600. Jones, R.H., et al. "The Relationship Between Alveolar and Blood Concentrations During Breath-Holding." J. Lab. Clin. Med., Vol. 51, 1958, p. 553.

601. Miller, H.S. "A Review of the Literature on Burns and Trauma September 1961 to August 1962." Medical Services Journal, Canada, Vol. 19, March, 1963, pp. 141-171.

602. Moritz, A.R., et al. "An Exploration of the Casualty Producing Attributes on Conflagrations; Local and Systemic Effects of General Cutaneous Exposure to Excessive Heat of Varying Duration and Intensity." Arch. Pathol., Vol. 43, 1947, pp. 466-502.

603. National Fire Protection Association. "A Method of Measuring Smoke Density." Quarterly of the National Fire Protection Association, Vol. 57, 1964, pp. 276-287.

604. New York Academy of Medicine. "Conference on Burns and Flame-Retardant Fabrics, New York Academy of Medicine." Bulletin of the New York Academy of Medicine, Vol. 43, No. 8, August, 1967.

605. Phillips, A.W., and O. Cope. "Research in Burns." Proceedings of the First International Congress on Research in Burns, Bethesda, Maryland, September, 1960.

606. Pryor, A.J., and C.H. Yuill. "Mass Fire Life Hazard." Southwest Research Institute, San Antonio, Texas, September, 1966, AD 642 790.

607. Pryor, A.J., et al. "Mass Fire Life Hazard." Southwest Research Institute, San Antonio, Texas, Final Report, Contract No. N00228-67-C00838, OCD Work Unit 2537A, March, 1968.

608. Rasbash, D.J. "Smoke and Toxic Gas." Fire, September, 1966, pp. 175-179.

609. Ray, A.M., and T.H. Rockwell. "An Exploratory Study of Automobile Driving Performance Under the Influence of Low Levels of Carboxyhemoglobin." Ohio State University, Department of Industrial Engineering, Columbus, Ohio, 1967.

610. Roth, E.M. "Supplementary Bibliography on Fire and Blast. A. Combustion Studies. B. Secondary Effects." Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico, NASA NASR 115, February, 1966.

611. Slater, K. "The Detection and Measurement of Dangerous Quantities of Carbon Monoxide Gas." J. Scien. Inst., Vol. 44, No. 8, 1967, p. 642.

612. Society of Automotive Engineers, Inc., "Carbon Monoxide Concentration Test Procedure." SAE Technical Report J989, January, 1968.

613. Stoll, A.M., et al. "Burn Production and Prevention in Convective and Radiant Heat Transfer." Aerospace Med., Vol. 39, October, 1968, pp. 1097-1100.

614. Strouse, D.F., and J.R. Westaby, eds. "Accident Research: Vol. I. Fire and Burn Injury." Accident Control Graduate Program, Department of Health Administration, School of Public Health, University of North Carolina, Chapel Hill, North Carolina, 1968.

615. Sunshine, I., et al. "Drugs and Carbon Monoxide in Fatal Accidents." Postgrad. Med., Vol. 43, March, 1968, pp. 152-155.

616. Iampietro, P.F. Use of Skin Temperature to Predict Tolerance to Thermal Environments. Prepared for Department of Transportation, Federal Aviation Administration, Office of Aviation Medicine, Washington, D.C., Report No. FAA-AM-71-4, January, 1971.

617. Waters, W. Reid. "A Review of the Literature on Burns and Trauma, September 1964 to August 1965." Medical Services Journal, Canada, Vol. 22, No. 2, February, 1966, pp. 99-141.

618. Yuill, Calvin, H. "Smoke and Toxic Fume Problems." Building Research, Vol. 2, No. 4, July/August, 1965.

619. Zapp, J.A., Jr. "The Toxicology of Fire." U.S. Army Chemical Corps, Medical Division, Army Chemical Center, Maryland, Special Report No. 4, April, 1951, AD 104 487.

3.1.2 Material Flammability

620. Albright, J.D., F.S. Knox, III, D.R. Dubois, and G.M. Keiser. The Testino of Thermal Protective Clothing in a Reproducible Fuel Fire Environment, A Feasibility Study. U.S. Army Aeromedical Research Laboratory, Ft. Rucker, Alabama, USAARL Report No. 71-24, June, 1971.

621. Berry, G.T., and B.P. Botteri. "Research and Technology for Aircraft Fire Protection." Aircraft Fluids Fire Hazards Symposium, Cornell-Guggenheim Aviation Safety Center, Ft. Monroe, Virginia, AFAPL-CONF-66-5, June, 1966, AD 635 066.

622. Buhnke, W.P., and R.E. Seaman. "Development of Clothino for Protection from Convective Heat." Fire Technology, Vol. 2, No. 3, August, 1966, pp. 219-225.

623. Blease, R.A. "Flame Resistance and Textiles." Fire, Vol. 59, No. 732, 1966, pp. 37-39.

624. Blease, R.A. "Flame Resistance and Textiles." Trans. J. Plastics Inst., January, 1967, pp. 79-83.

625. Cornell University, Daniel and Florence Guggenheim Aviation Safety Center. Aircraft Fluids Fire Hazard Symposium - 1966 Proceedings. New York, N.Y., Guggenheim Aviation Safety Center, Cornell University, 1966.

626. Einhorn, I.N., J.D. Seader, C.M. Mihlfeith, and W.O. Drake. Flammability and Toxicological Characteristics of Isocyanurate Foams, Instumescent Coatings and Fluorel. University of Utah, NASA NA52-6063, March, 1971.

627. Epstein, F., et al. "Materials for Space Cabins: The Fire Hazard and Atmosphere Contaminant Control Problems." Aerospace Corporation, El Segundo, California, USAF Report No. SAMSO-TR-67-76, October, 1967, AD 663 418.

628. Federal Aviation Administration. Compartment Interior Materials Gas Emission Draft Advance Notice of Proposed Rulemaking 14 CFR Part 25,

629. Federal Aviation Administration. Smoke Emission from Compartment Interior Materials In Transport Category Airplanes. 14 CFR Part 25, Docket No. 9611

630. Fire Journal. "Flaming and Self-Extinguishment Characteristics of Aircraft Cabin Interior Materials." May, 1969.

631. Gassman, J. Characteristics of Fire in Large Cargo Aircraft (Phase II). Federal Aviation Administration, Washington, D.C., Report FAA-RD-70-42, September, 1970.

632. Gassman, J. Characteristics of Fire in Large Cargo Aircraft. Federal Aviation Administration, Washington, D.C., Technical Report ADS-73, March, 1966.

633. Goldsmith, A. "Flammability Characteristics of Vehicle Interior Materials." U.S. Department of Transportation, Washington, D.C., Final Report, Contract FH-11-6892, Project J6152, PB 189 653, May, 1969.

634. Grenneman, J.J., and D.A. Heine. "The Cleveland Aircraft Fire Tests." Fire Technology, Vol. 4, No. 1, February, 1963, pp. 5-16.

635. Gross, D., J.J. Loftus, T.G. Lee, and V.E. Gray. Smoke and Gasses Produced by Burning Aircraft Interior Materials. National Bureau of Standards, Report NA-68-36, June, 1968.

636. Hendrix, J.E., et al. "Flammability Measurements and Thermal Decomposition of Textiles." Journal of Fire and Flammability, Vol. 1, 1970, p. 107.

637. Industrial Research. "Flame-Resistant Urethane Smothers Fire." Vol. 11, No. 11, November, 1969, p. 83.

638. Johnson, R., and M.I. Radnofsky. "Nonflammable Clothino Development Program." Fire Technology, Vol. 4, 1968, p. 88.

639. Jones, R.B., et al. "An Engineering Study of Aircraft Crash-Fire Prevention." USAF Wright Air Development Center, Wright-Patterson A.F.B., Ohio, WADC TR-57-370, June, 1958.

640. Kourtides, D.A., and T.A. Parker. Chemical Research Projects Office: Functions, Accomplishments and Programs. NASA TM X-62, 186, September, 1972.

641. Klein, Howard A. "The Effects of Cabin Atmosphere on Combustion of Some Flammable Aircraft Materials." USAF, Wright Air Development Center, Wright-Patterson A.F.B., Ohio, WADC TR 59-456, April, 1960, AD 238 367.

642. Lodge, J.E. "Crashed Aircraft Fires." Fire, November, 1966, pp. 289-293.

643. Marcy, J.F. "Interior Material Finishes." Fire Technology, Vol. 2, 1966, p. 263.

644. Marcy, J.F., et al. "A Symposium: Research to Advance Aircraft Fire Safety." Fire Technology, Vol. 2, No. 4, November, 1966, pp. 263-278.

645. Marcy, J.F., and R. Johnson. "Flaming and Self-Extinguishing Characteristics of Aircraft Cabin Interior Materials." Department of Transportation, Federal Aviation Administration, NAFEC, Atlantic City, N.J., Final Report NA-68-30, July, 1968, Project No. 510-D01-11X. AD 673 084.

646. Marcy, John F. Air Transport Cabin Mockup Fire Experiments. Report FAA-RD-70-81, December, 1970.

647. Meade, J.P. "Flammability in Cockpit/Cabin Environments." Proceedings, Seventh National Flight Safety, Survival and Personal Equipment Symposium. Las Vegas, Vol. II, October, 1969, p. 588.

648. Miller, J. Melvin. Crash Fire-Fuel Survey Involving Turbine Powered Airplanes. Report No. AFS-14D-73-3, June, 1973.

649. National Aeronautics and Space Administration. Non-metallic Material Design Guidelines and Test Data Handbook. NASA-MSC-02681, May 29, 1970.

650. National Bureau of Standards. "The Flammable Fabrics Program, 1968-1969." National Bureau of Standards, Washington, D.C., Report No. NBS-TN-525, April, 1970.

651. National Highway Safety Bureau. "Flammability of Interior Materials; Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses." Notice of Proposed Motor Vehicle Safety Standard No. 302, Federal Register 34(249):20434, December, 1969.

652. National Safety Council. "Flammability of Wearing Apparel." Safety Education, Vol. 39, No. 2, October, 1959, pp. 13-17.

653. Nessley, P.M., and T.L. Heid. "Structural Design for Fuel Containment Under Survivable Crash Conditions." General Dynamics/Convair, San Diego, Calif., GD/C 64-222, FAA Aircraft Development Service ADS-19, August, 1964.

654. Nichols, O.D., et al. "Flames and Flame Properties -- A Report Bibliography." Defense Documentation Center, Alexandria, Va., January, 1964, AD 422 075.

655. Pacidrek, K.L., R.H. Fratzer, and J. Kaufman. Fundamental Ignition Study for Material Fire Safety Improvement. Dynamic Science Corp., NASA CR 114402, May, 1972.

656. Parker, J.A., et al. "Development of Polyurethane for Controlling Fuel Fires in Aircraft Structures." SAMPE Journal, Vol. 5, No. 41, April/May, 1969.

657. Ranney, M.W. Flame Retardant Textiles. Park Ridge, New Jersey: Noyes Data Corp., 1970.

658. Roberts, B. "Flammability Standards and Textiles: Advantages of Nylon for Apparel Fabrics." The Textile Weekly, August, 196D, pp. 345-346, 349.

659. Rubber and Plastics Age. "The Future for Plastics in Cars." Vol. 49, No. 8, August, 1968, pp. 724-725, 727.

66D. Sarkos, C.P. Small Scale Fire Tests of High Temperature Cabin Pressure Sealant and Insulating Materials. Federal Aviation Administration, Report FAA-RD-71-67, November, 1971.

661. Sayers, L.W. "The Flammability of Fibers, Fabrics, and Garments." The Textile Institute and Industry, July, 1965, pp. 168-171.

662. Schaffer, E.L., and H.W. Eickner. "Corridor Wall Linings - Effect on Fire Performance." Fire Technology, Vol. 1, No. 4, November, 1965, pp. 243-255.

663. Smith, S. "Nomex." Car and Driver, March, 1966

664. U.S. Army Natick Labs. "Summary of Specification Requirements for Military Fabrics." U.S. Army Natick Labs, Textile Research and Engineering Division, Natick, Mass., USA-NLABS-TR-69-41, Dctober, 1968, AD 68D 231.

665. U.S. Department of Commerce. "Flammability of Clothing Textiles, Commercial Standard 191-53 (Revised)." U.S. Dept. of Commerce, Washington, D.C., January 3D, 1953.

666. U.S. Department of Commerce. "Bibliographies on Fabric Flammability." U.S. Dept. of Commerce, National Bureau of Standards, Washington, D.C., NBS Technical Note 498, February, 1970.

4. Advanced Dccupant Restraint Systems

4.1. Current Air Transport Restraint Systems

667. British Civil Airworthiness Requirements. Chapter K4-4, Seats, Safety Belts and Harnesses. Civil Aviation Authority, London, Paper 647, Issue 1, 28 March, 1975.

668. Carroll, J.J. Consolidated Notes on Aircraft Safety (Covering 1943-1963). Falls Church, Virginia.

669. Federal Aviation Administration. (Notice of Proposed Rule Making 69-33), "Transport Category Airplanes; Crashworthiness and Passenger Evacuation," 1969.

670. Federal Aviation Regulations. Emergency Landing Conditions. Part 25. Airworthiness Standards: Transport Category Airplanes. Department of Transportation, Federal Aviation Administration, 25.561(b) (3), June, 1974.

671. Hawkins, F. "Ergonomic Aspects of Crew Seats in Transport Aircraft." Clinical Aviation and Aerospace Medicine, Aerospace Medicine, Vol. 45, No. 2, 1974, pp. 196-203.

672. International Organization for Standardization. Draft Proposals by USSR for Passenger Seats in Aircraft. ISO/TC 20, British Standards Institution, London, April, 1968.

673. Mohler, S.R. "Crash Protection in Survivable Accidents." Memorandum, Staff Study, Office of Aviation Medicine, Federal Aviation Administration, Washington, D.C., 4 February, 1969.

674. National Transportation Safety Board. Status of Safety Board Recommendations 1967 through 1973. Washington, D.C., 1974.

675. Siegel, P.V. NPRM 69-33, "Transport Category Airplanes; Crashworthiness and Passenger Evacuation." Federal Aviation Administration, Office of Aviation Medicine, Memorandum, 6 October, 1969.

676. Society of Automotive Engineers. Aerospace Recommended Practice. Passenger Seat Design. New York, N.Y., ARP 750A issued 20 April, 1965; revised 18 June, 1971; revised January, 1974.

677. Society of Automotive Engineers. Aerospace Recommended Practice. Occupant Restraint Systems (Active) for General Aviation Aircraft. ARP 1226, proposed 11 June, 1971.

678. Society of Automotive Engineers. Aerospace Recommended Practice. Safety Lap Belts. Transport Aircraft. ARP 682A

679. Society of Automotive Engineers. Aerospace Recommended Practice. Impact Protective Design of Occupant Environment. Transport Aircraft. ARP 767

680. "Tu-144 Crash Investigation Ends." Aviation Week and Space Technology. 5 August, 1974.

681. Turnbow, J.W., et al. Aircraft Passenger-Seat-System Response to Impulsive Loads. U.S. Army Aviation Materials Laboratories, Fort Eustis, Virginia, USAAVLABS Technical Report No. 67-17, August, 1967.

682. Yost, C.A., and R.W. Oates. Human Survival in Aircraft Emergencies. National Aeronautics and Space Administration, Report No. NASA CR-1262, Washington, D.C., January, 1969.

4.2 Human Tolerance Design Limits

683. Air Force Systems Command AFSC Design Handbook. DN3024.4, Section 30 Crash Protection and Escape/Survival Systems. Chapter 3, Aerospace Vehicle Safety Design, 20 July, 1969.

684. Barnes, A.C., Jr., J.J. Carroll, and L.W. Gregg. "Handbook for Aircraft Accident Investigators Cooperating in Crash Injury Research." Aviation Crash Injury Research, Flight Safety Foundation, Inc., Phoenix, Arizona.

685. Beeding, E.L., Jr. "Human Forward Facing Impact Tolerance." Aerospace Medicine, Vol. 32, No. 3, March, 1961, p. 220.

686. Beeding, E.L., Jr., and R. Hessberg, Jr. "Daisy Track Tests 271-337." Rept. AFMDC TR 28-8, Runs 4 February - 9 May, 1958.

687. Beeding, E.L., Jr., and J.D. Mosely. Human Deceleration Tests. Rept. AFMDC-TN-60-2, Air Force Missile Development Center, Hollman AFB, New Mexico, January, 1960.

688. Carroll, D.F., J.A. Collins, J.L. Haley, Jr., and J.W. Turnbow. "Crashworthiness Study for Passenger Seat Design -- Analysis and Testing of Aircraft Seats." Aviation Safety Engineering and Research, Phoenix, Arizona, AVSER Report No. 67-4, May, 1967.

689. Chandler, R.F. Lateral Impact Data. Unpublished summary, 6571st Aeromedical Field Lab, Holloman Air Force Base, New Mexico, 10 January, 1966.

690. Dynamic Science Engineering Operations. "Crash Survival Design Guide." Prepared by Marshall Industries, Phoenix, Arizona, for Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Va., Dynamic Science Report No. 1500-71-6; USAAMRDL Technical Report 71-22, revised, October, 1971.

691. Ewing, C.L., D.J. Thomas, G.W. Beeler, Jr., L.M. Patrick, and D.B. Gillis. Dynamic Response of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration." Proceedings of the Twelfth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, 1968, pp. 424-439.

692. Ewing, C.L., D.J. Thomas, L.L. Lustick, E. Becker, G. Williams, and W.M. Muzzy, III. "The Effect of the Initial Position of the Head and Neck on the Synamic Response of the Human Head and Neck to -G_x Impact Acceleration." Proceedings, Nineteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, 1975, pp. 487-512.

693. Greer, D.L., J.D. Breeden, and T.L. Heid. "Crashworthy Design Principles." General Dynamics/ Convair, San Diego, California, Federal Aviation Agency Technical Report FAA ADS-24, September, 1964.

694. Hasbrook, H. Design of Passenger "Tie-Down," Some Factors for Consideration in the Crash-Survival of Passenger Seats in Transport Aircraft. Aviation Crash Injury Research of Cornell University, Flushing, N.Y., September, 1956.

695. Huelke, D.F. "The Second Collision." Traffic Safety Magazine, National Safety Council, 1966, pp. 18-21.

696. King, A.I. "Survey of the State of the Art of Human Biodynamic Response." Aircraft Crashworthiness (K. Saczalski, G.T. Sengley, W.D. Pilkey, and R.L. Huston, eds.), University Press of Virginia, Charlottesville, Va., 1975, pp. 83-120.

697. Laanaen, D. Development of a Scientific Basis for Analysis of Aircraft Seating Systems. Prepared for U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., Report No. FAA-RD-74-130, January, 1975.

698. Latham, L. "Linear Deceleration Studies and Human Tolerance." Flying Personnel Research Committee, Great Britain, FDRC Report No. 1012, June, 1957.

699. Latham, L., and F. Howard. "Mechanism of Injury During Whole Body Linear Deceleration." RAF Institute of Aviation Medicine, Farnborough, FPRC Memo. Report No. 100, September, 1958.

700. Lewis, S.T., and J.P. Stapp. "Experiments Conducted on a Swing Device for Determining Human Tolerance to Lap Belt Type Decelerations." 6571st Aeromedical Research Laboratory, Holloman AFB, New Mexico, Report ARMDC TN-57-1, 1957.

701. Patrick, L.M., C.K. Kroell, and H.J. Mertz, Jr. "Forces on the Human Body in Simulated Crashes." Proceedings, Ninth Stapp Car Crash Conference, University of Minnesota, Minneapolis, M.K. Cragun, ed., (1965) 1966.

702. Pennybaker, A.L., J.W. Ross, Jr., and G.L. Wilson. "A Summary of Crashworthiness Information for Small Airplanes." Federal Aviation Administration, Aeronautical Center Flight Standards Technical Division, Oklahoma City, Oklahoma, Report No. FS-70-592-120A, February, 1973.

703. Rothstein, J.D., and W.K. Brown. "Feasibility Study: Lateral Impace with Standard Aircraft Harness Configuration." 6571st Aeromedical Research Laboratory, Holloman AFB, New Mexico, Report ARL-TR-66-3, 1966.

704. Snyder, R.G. "Physiological Effects of Impact: Man and Other Mammals." Environmental Biology, Federation of American Societies for Experimental Biology, (P.L. Altman and D.S. Dittmer, eds.), 1966, pp. 231-242.

705. Snyder, R.G. State-of-the-Art-Human Impact Tolerance. Society of Automotive Engineers, New York, SAE Paper No. 700398, revised August, 1970; reprinted May, 1970 from 1970 International Automobile Safety Conference Compendium, Publication SAE P-30; reprinted October, 1972.

706. Snyder, R.G. Occupant Impact Injury Tolerances for Aircraft Crashworthiness Design. SAE National Business Aircraft Meeting, Wichita, Kansas, March 26; Society of Automotive Engineers, Inc., New York, N.Y., Technical Paper No. 710406, 1971.

707. Snyder, R.G. "Impact." Bioastronautics Data Book, Chapter 6, pp. 221-296, 2nd Ed., National Aeronautics and Space Administration, NASA SP-3006, (J.F. Parker and V.R. West, eds.), Washington, D.C., 1973.

708. Snyder, R.G., C.C. Snow, J.W. Young, G.T. Price, and P. Hanson. "Experimental Comparison of Trauma in Lateral (+G_y), Rearward Facing (+G_x), and Forward Facing (-G_x) Body Orientations When Restrained by Lap Belt Only." Aerospace Medicine, Vol. 38, No. 9, September, 1967.

709. Society of Automotive Engineers, Inc., "Human Tolerance to Impact Conditions as Related to Motor Vehicle Design." New York, SAE J-885a, 1966.

710. Sonntag, R. Unpublished test data with human volunteers, 6571st Aerospace Medical Laboratory, Holloman Air Force Base, New Mexico, 1966.

711. Stapp, J.P. "Human Exposure to Linear Deceleration. Part I. Preliminary Survey of Alt-Facing Seated Position." AF Tech. Rept. 5915, June, 1949.

712. Stapp, J.P. "Human Exposure to Linear Deceleration. Part II. The Forward-Facing Position and the Development of a Crash Harness." December, 1951.

713. Stapp, J.P. "Human Exposure to Linear Decelerative Forces in the Backward Facing Seated Position." Military Surgeon, Vol. 109, 1951, pp. 106-108.

714. Stapp, J.P. "Human and Chimpanzee Tolerance to Linear Decelerative Force." Conference on Problems of Emergency Escape in High-Speed Flight, Wright-Air Development Center, Wright-Patterson Air Force Base, Ohio, September 29, 30, 1952.

715. Stapp, J.P. "Effects of Mechanical Force on Living Tissues, I. Abrupt Deceleration and Windblast." J. Aviation Med., Vol. 26, No. 4, August, 1955, pp. 268-288.

716. Stapp, J.P. "Tolerance to Abrupt Deceleration." Collected Papers on Aviation Medicine, AGARD, Butterworths Scientific Publications, London, 1955, pp. 122-139.

717. Stapp, J.P. "Human Tolerance to Severe, Abrupt Acceleration." Gravitational Stress in Aerospace Medicine, (O.H. Gauer and G.D. Zuidema, eds.), Little, Brown and Co., Boston, 1961, pp. 165-188.

718. Stapp, J.P. "Whole Body Tolerance to Impact. Part I. Effects of Position: Man. Part II. Effects of Seat Belts: Man. Part III. Effects of Orientation: Man." In Environmental Biology, (P.L. Altman and D.S. Dittmer, eds.), Federation of American Societies for Experimental Biology, Bethesda, Maryland, 1966.

719. Stapp, J.P. "The Problem: Biomechanics of Injury." In The Prevention of Highway Injury, Highway Safety Research Institute, The University of Michigan, Ann Arbor, 1967, pp. 159-164.

720. Stapp, J.P. "Human Factors and Design Aspects of Transportation Safety." Paper presented at American Association for the Advancement of Science, 134th Meeting, New York, N.Y., 30 December, 1967.

721. Stapp, J.P. "Voluntary Human Tolerance Levels." Impact Injury and Crash Protection, (E.S. Gurdjian, W.A. Lange, L.M. Patrick, and L.M. Thomas, eds.), Charles C. Thomas, Springfield, Illinois, 1970, pp. 308-349.

722. Stapp, J.P., J.D. Mosely, C.F. Lombard, and G.A. Nelson. "Part I. Biodynamics of Maximal Decelerations. Part II. Dynamic Response of Restrained Subject During Abrupt Deceleration." Analyzed and Biodynamics of Selected Rocket-Sled Experiments, USAF School of Aerospace Medicine, July, 1964.

723. Stapp, J.P., E.R. Taylor, and R. Chandler. "Effects of Pitch Angle on Impact Tolerance." Proceedings, 7th Stapp Car Crash Conference, Charles C. Thomas, 1965.

724. Swearingen, J.J. Evaluation of Head and Face Injury Potentials of Current Airline Seats During Crash Decelerations. Federal Aviation Agency, Office of Aviation Medicine, Report No. AM66-18, June, 1966.

725. Swearingen, J.J., J.D. Garner, E.B. McFadden, and J.G. Blethrow. "Human Voluntary Tolerance to Vertical Impact." Aerospace Medicine, Vol. 31, No. 12, 1960, p. 989.

726. Swearingen, J.J., A.H. Hasbrook, R.G. Snyder, and E.B. McFadden. Kinematic Behavior of the Human Body During Deceleration. Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Report No. 62-13, June, 1962.

727. Turnbow, J.W., D.F. Carroll, J.L. Haley, Jr., and S.H. Robertson. "Crash Survival Design Guide." US Army Aviation Material Laboratories, Ft. Eustis, Va., Prepared by AVSER, Phoenix, Arizona, USAAVLABS Tech. Report 70-22, August, 1969.

728. U.S. Army Board for Aviation Accident Research. "Handbook of Inadequate Aircraft Design." Fort Rucker, Alabama, USA BAAR Unnumbered Report, n.d. (1964).

729. Zaborowski, A.V. "Human Tolerance to Lateral Impact With Lap Belt Only." 8th Stapp Car Crash and Field Demonstration Conference, Wayne State University Press, Detroit, 1966, pp. 34-69.

730. Zaborowski, A.V., J.D. Rothstein, and W.K. Brown. "Investigations in Human Tolerance to Lateral Impact." Paper presented, 36th Annual Meeting, Aerospace Medical Association, New York, 26-29 April, 1965.

4.3 Principles of Restraint

731. Robbins, D.H., R.O. Bennett, A.W. Henke, and N.M. Alem. "Prediction of Mathematical Models Compared with Impact Sled Tests Using Anthropomorphic Dummies." Proceedings, Fourteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y., 1970, pp. 299-328.

732. Robbins, D.H., A.W. Henke, and V.L. Roberts. Child Seat and Restraint Systems Test Results. Final Report, National Highway Safety Bureau, Report No. BIO-M-70-2, 31 October, 1970.

733. Robbins, D.H., and V.L. Roberts. "Maximizing Occupant Protection Using Integrated Seat-Restraint System Design Concepts." Proceedings, Third Triennial Congress on Medical and Related Aspects of Motor Vehicle Accidents, New York, N.Y., 1971, pp. 196-199.

4.4 Rear Facing Seats

734. Beck, A. Flugmedizinesches Institut der Luftwaffe, Furstenfeldbruck, Germany. Personal Communication, 10, 24 November, 1975.

735. Campbell, H.E. "Rearward Seated Urged for Airline Use." Aviation Week, 1956, pp. 65-74.

736. Covault, C. "Presidential Wing Maintenance Unusual" (Part I and Part II). Aviation Week and Space Technology, 30 July, 1974, p. 40; 20 August, 1974, pp. 57-59.

737. De Haven, H. "Crash Research from the Point of View of Cabin Design." Aeronautical Engineering Review, Vol. 5, 1946, pp. 11-17.

738. De Haven, H. Protective Design in Forward and Rearward Facing Seats in Transport Aircraft. Proceedings, SAE Annual Meeting, Detroit, January 12, 1953.

739. De Haven, H. "Rearward and Forward - Facing Seats." Aeronautical Engineering Review, Vol. 12, 1953.

740. Department of Defense. Military Specification, Seat, Passenger, Aft-facing, Transport Aircraft, MIL-S-26688 (USAF), March, 1957, revised 1 June, 1970.

741. Dudgeon, A.G. "The Case of the Backward Facing Seat." The Aeroplane, Vol. 72, 1947, p. 131.

742. Dudgeon, A.G. "Passengers Face Aft." Air Clues, Vol. 14, 1960, pp. 99-103.

743. Flight. "On Going Forwards Backwards." Vol. 66, 16 July, 1954, pp. 91-92.

744. Fryer, D.I. Aircraft Passenger-Seat Design and Crash Survival. Flying Personnel Research Committee Royal Air Force Institute of Aviation Medicine, Farnborough, Report No. FPRC 1055, August, 1958.

745. Fryer, D.I. "Passenger Survival in Aircraft Crashes." Aeronautics, Vol. 40, 1959, pp. 31-37.

746. Fryer, D.I. "RAF Experience with Safety Harnesses." Am. Occup. Hyg., Vol. 5, 1962, pp. 113-127.

747. Gronow, D.G.C. Backward Facing Seats in Aircraft for Increased Passenger Safety. Flying Personnel Research Committee, Royal Air Force Institute of Aviation Medicine, Farnborough, Report No. FPRC 870(a), March, 1954.

748. Hasbrook, A.H., and J. Earley. Failure of Rearward Facing Seat Backs and Resulting Injuries in a Survivable Transport Accident. Federal Aviation Agency, Civil Aeromedical Research Institute, Oklahoma City, Oklahoma, Report No. 62-7, April, 1962.

749. Hasbrook, A.H., and J.C. Earley. "Armrest Installation as Related to Seat-Back Failure in Rearward Facing Weber Aircraft Seats in C-131 Convair Incident." Unpublished CARI Alert Report, Federal Aviation Agency, Oklahoma City, 19 February, 1962.

750. Hawthorne, R. "Are Aft Facing Seats Safe? What the Evidence Shows." Aviation Age, October, 1953, pp. 31-43.

751. Lombard, C.F. "How Much Force Can the Body Withstand?" Aviation Week and Space Technology, Vol. 50, No. 3, 1949, p. 20.

752. McFarland, R.A. Human Factors in Air Transportation. McGraw-Hill, 1953, p. 561.

753. Moseley, H.G., F.M. Townsend, and V.A. Stembridge. "Prevention of Death and Injury in Aircraft Accident." A.M.A. Archives of Industrial Health, Vol. 17, February, 1958, pp. 111-117.

754. Myers, H.M. "Reverse Seating on Air Transport Command Aircraft." Memo to Commanding General, Air Material Command, Wright Field, Ohio, May 5, 1947.

755. Noble, H., and L.P. Domzalski. Project TED NAM AE-6303.1. Evaluation of Human Subject Reaction in the Forward and Aft Facing Seated Positions. Naval Air Material Center, Philadelphia, Report No. NAMC-ACEL-424, 9 February, 1961.

756. Pekarek, Z. Royal Aircraft Establishment, Structural and Mechanical Engineering Department, Note No. 17, 1941.

757. Peterson, R.L. "Fixed Seat and Restraint System Criteria." Presented to USAF Industry Life Support Conference, Unassisted Egress Panel, Directorate of Aerospace Safety, Las Vegas, Nevada, November, 1967.

758. Pinkel, I.I. "Aircraft Seating. Forward Facing? ...Or Rearward?" Mechanical Engineering, Vol. 82, No. 2, February, 1960, pp. 60-63.

759. Pinkel, I.I., and E.G. Rosenberg. Seat Design For Crash Worthiness. National Advisory Committee for Aeronautics, Lewis Flight Propulsion Laboratory, Cleveland, Technical Note 3777, October, 1956.

760. Preston, G.M., and G.J. Pesman. Acceleration in Transport Airplane Crashes. NACA, Lewis Flight Propulsion Laboratory, Cleveland, Report TN 4158, February, 1958.

761. Ruff, S. "Brief Acceleration: Less Than One Second." German Aviation Medicine in World War II, Vol. 1, 1950, p. 584.

762. Shea, F. "CIR Calls for Stronger Cabins." Aviation Week, October, 19, 1953, pp. 98-99.

763. Smith, H. "Crash Worthiness." The Technical Instructor, June, 1951, pp. 3-6.

764. Stanfield, R.I. "USAF Reports Rearward Seating Safer." Aviation Week, 11 February, 1957, pp. 91-95.

765. Stapp, J.P. "Crash Protection in Air Transports." Aeronautical Engineering Review, Vol. 12, April, 1953, pp. 71-78.

766. Stapp, J.P. "Design Criteria for Occupant Restraint Systems." Proceedings, Seminar on Design Aspects of Occupant Survivability in Aircraft, Flight Standards Service, FAA, Oklahoma City, February, 1963, pp. 1-4.

767. Staff Study. Backward Seating Experiment for Passenger Transport Aircraft. Conducted by the Air Transport Command, Traffic Division, U.S. Army Air Force, April, 1947.

768. Staff Study. Crash Protection in Survivable Accidents. Staff Report, Office of Aviation Medicine, Federal Aviation Administration, Washington, D.C., 1968.

769. Swearingen, J.J. Cockpit Design for Impact Survival. Federal Aviation Agency, Office of Aviation Medicine, Civil Aeromedical Research Institute, Oklahoma City, Oklahoma, Report No. AM 66-3, February, 1966.

770. Turnbow, J.W., D.F. Carroll, J.L. Haley, W.H. Reed, S.H. Robertson, and L.W.T. Weinberg. Crash Survival Design Guide. U.S. Army Aviation Material Laboratories, Fort Eustis, Virginia, USAAVLABS Technical Report 67-22, July, 1967.

771. Turnbow, J.W., et al. "Plane - Crash Research Leads Way to Lower Life Loss." SAE Journal, Vol. 73, No. 6, June, 1965, pp. 38-44.

772. Tye, W. "Backward-Facing Seats and Safety Belts." The Aeroplane, Vol. 81, 1951, p. 5970.

773. U.S. Air Force. Design Handbook. Series 1 - 0, General, AFSC DH 1-6, System Safety, Design Note 302; 2. "Crew and Passenger Seats," Headquarters, Air Force Systems Command, in cooperation with the National Aeronautics and Space Administration, Fourth Edition, 20 July, 1974.

774. United States Army Air Force. "A Backward Facing Seat, Investigation." Air Transport Commands Traffic Division, Vol. 22, 1950, pp. 372-373.

775. U.S. Air Force Pamphlet, AFP160-10-4, "Physiology of Flight." Chapter 13, January, 1961.

776. von Beckh, H.J. "I. Linear Accelerations." Fisiologia del Vuelo, Editorial Alfa, Buenos Aires, 1955.

777. von Beckh, H.J. The Advantages of Rearward Facing Seats During Post Decompression Emergency Descent of Multi Mach/High Altitude Transport Aircraft. 6571st Aeromedical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Holloman Air Force Base, New Mexico, Report No. ARL-TR-69-15, July, 1969.

778. Stapp, J.P., and S.T. Lewis. "Effects of Mechanical Force on Living Tissues. IV. Time Motion Studies on Escape from Air Transport Following Exposure to Crash Forces." Journal of Aviation Medicine, Vol. 27, No. 1, April, 1956, p. 173.

779. Wilson, K.G., and H.F. Helmholtz. Safety Advantage of Rearward Seating in Passenger Aircraft. Consolidated Vultee Aircraft Corporation, San Diego, California, Appended to Staff Study Conducted by the Air Transport Command, April, 1947.

4.5 Advanced Active Systems

780. Federal Aviation Regulations. Part 25. Airworthiness Standards: Transport Category Airplanes. Sections 25.561 and 25.785, Department of Transportation, Federal Aviation Administration, June, 1974.

781. Federal Register. Notice of Proposed Rule Making, "Crashworthiness for Small Airplanes." Federal Aviation Administration, Department of Transportation, 38 F.R. 2985, 31 January, 1973.

782. Federal Register. "Motor Vehicle Safety Standard No. 208, Occupant Crash Protection in Passenger Cars, Multi-purpose Passenger Vehicles, Trucks and Buses." Docket No. 69-7, Notice No. 9, revised 31 January, 1974.

783. Leveau, M.G. "Bretelles Protectrices Pour Voitures Automobiles et Autres." Republique Francaise, Office National de la Propriete Industrielle, No. 331 926, May 11, 1903.

784. Robbins, D.H., V.L Roberts, A.W. Henke, B.F. Raney, R.O. Bennett, and J.H. McElhaney. Development and Testing of Integrated Seat Restraint Systems. Highway Safety Research Institute, University of Michigan, Ann Arbor, Michigan, Contract No. FH-11-6962, Final Report; Prepared for U.S. Dept. of Transportation, National Highway Traffic Safety Administration, Washington, D.C., Final Report No. DOT HS-800 528, June, 1971.

785. Snyder, R.G. A Survey of Automotive Occupant Restraint Systems: Where We've Been, Where We Are and Our Current Problems. Society of Automotive Engineers, Inc., New York, N.Y., Publication No. 690243, January, 1969.

4.5.1.1 NASA Ames Integrated System

786. Ball, R.S., W.J. Goodman, and W.H. Kennish. Design of An Improved Aircraft Seat. An Engineering Case Study. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California. University of California, Davis, June, 1972.

787. Dynamic Science. Crashworthy Test Evaluation of an Experimental Aircraft Seat. Interim Report 1560-70-15 for NASA, Phoenix, Arizona, June, 1970.

788. Oates, R.W., and N.J. Bentzen. Study of a Seat Design for Human Survival in Aircraft, Emergencies. NASA-Ames Research Center, Calif., Report NAS 2-5101 Mod. 6, NASA CR 114455, 8 March, 1972.

789. Yost, C.A., R.W. Oates, and N.J. Bentzen. Study of a Seat Design for Human Survival in Aircraft Emergencies. Stencel Aero Engineering Corporation, Asheville, North Carolina, December, 1970.

4.5.2 Y-Yoke Inertia Reel System

790. Barecki, C.J. Auto Crash Safety Research Leading to Optimum Protection for Automobile Occupants. American Seating Company, Grand Rapids, 1957.

791. Snyder, R.G., J.W. Young, and C.C. Snow. Experimental Protection with Advanced Automotive Restraint Systems: Preliminary Primate Tests with Air Bag and Inertia Reel/Inverted-Y-Yoke Torso Harness. Society of Automotive Engineers, Inc., New York, N.Y., Publication P-20, 1969, pp. 271-285.

792. Snyder, R.G. "Occupant Restraint Systems of Automotive, Aircraft, and Manual Space Vehicles: An Evaluation of the State-of-the-Art and Future Concepts." In Impact Injury and Crash Protection (E.S. Gurdjian, W.A. Lange, L.M. Patrick, and L.M. Thomas, eds.), Charles C. Thomas, Springfield, Illinois, Chapter XXII, 1970, pp. 496-561.

4.5.3 Safety Energy Absorbing Devices

793. Avery, J.P. Cargo Restraint Concepts for Crash Resistance. Aviation Safety and Research, Phoenix, Arizona, Report AVSER-64-13, USAAML-TR-65-30, 1965.

794. Bennett, J.B. "Hammock-Type Plane Seat May Prove Crash Safety Aid." Technical Data Digest, Vol. 16, No. 3, 1951, pp. 11-12.

795. Bergeman, P.C., and A.I. King. "The Effect of Variable Load Energy Absorbers on the Biodynamic Response of Cadavers." Nineteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, Paper No. 751168, 1975, pp. 787-806.

796. Desjardins, S.P., and G.T. Singley. "Development of Design Criteria for Crashworthy Armored Aircrew Seats." Aircraft Crashworthiness (K. Saczalski, G.T. Singley, W.D. Pilkey, and R.L. Huston, eds.), University of Virginia Press, Charlottesville, Va., 1975, pp. 401-446.

797. Hart, G. "Designing Aircraft Seats to Save Lives." American Aviation, 28 July, 1958, pp. 29-30.

798. Hawthorne, R. "Energy Absorption Applied to Seat Design." Space/Aeronautics, October, 1958.

799. Kroell, C.K. "A Simple, Efficient, One-shot Energy Absorber." Shock, Vibration and Associated Environments, Bulletin No. 30, Part III, February, 1962.

800. Mazelsky, B. The ARA Inc. Crashworthy Armored Helicopter Seat. Aerospace Research Associates, West Covina, California, 1975.

801. McGhee, J.R. A Preliminary Experimental Investigation of an Energy-Absorption Process Employing Frangible Metal Tubing. NASA Publication TN D-1477, 1962.

802. Russo, A. Aircraft Cargo Restraint System. All American Engineering Company, Wilmington, Delaware, USAAVLABS Technical Report No. 66-50, 1966.

803. University of Denver. Program for the Exploitation of Unused NASA Patents. Second Annual Report (4/1/69 - 5/31/70), 1970.

4.6 Passive Systems

804. Phillips, N.S. Alternative Passive Occupant Restraint Development. Beta Industries, Dayton, Ohio; Final Report to U.S. Department of Transportation, National Highway Traffic Safety Administration, Under Contract No. DOT-HS-220-2-375, 24 January, 1973.

805. Phillips, N.S. "Fully Passive Restraint Systems: Alternatives to Inflatable Systems." Proceedings of the Seventeenth Conference of the American Association for Automotive Medicine, University of Oklahoma, Oklahoma City, 1973, pp. 31-51.

4.6.1 Passive Belt Systems

806. Baxter, R.S. Passenger Car Occupant Restraint Alternatives Demonstration and Display: A Consumer Research Study. 2nd International Conference on Passive Restraints, Detroit, Michigan; Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720430, May, 1972.

807. Bradford, G.M., J. Broughton, and H. Jakob. Design Approach and Crash Performance of Automatic Seat Belt Systems. 2nd International Conference on Passive Restraints, Detroit, Michigan; Society of Automotive Engineers, Inc., New York, N.Y., Publication No. 720436, May, 1972.

808. Coenen, M.J.W. How to Turn a 3-point Inertia Belt Into a Passive Seat Belt System. 2nd International Conference on Passive Restraints, Detroit, Michigan; Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720523, May, 1972.

809. Hellriegel, E., and A. Rauthmann. A New Full Passive Safety Belt System. Proceedings, 5th ESV Conference, London, 3 June, 1972, pp. 682-686.

810. Johannessen, H.G., and G.A. Yates. Passive and Semi-Passive Seat Belts for Increased Occupant Safety. 2nd International Conference on Passive Restraints, Detroit, Michigan; Society of Automotive Engineers, Inc., New York, N.Y., Publication No. 720438, May, 1972.

811. Pilhall, S., and N. Bohlin. A Passive Safety Belt System. 2nd International Conference on Passive Restraints, Detroit, Michigan; Society of Automotive Engineers, Inc., New York, N.Y., Publication No. 720440, May, 1972.

812. Powell, R.B. Engineering Development and Design of Operator Restraint Systems for Post Office Vehicles. All American Engineering Company, Wilmington, Delaware; Submitted as report of Work Group B on Contract RE 38-67, Post Office Department, Bureau of Research and Engineering Washington, D.C., Report No. M-1147, February, 1968.

813. Schimkat, H., R. Weissner, and G. Schmidt. "A Comparison Between Volkswagen Automatic Restraint and Three-Point Automatic Belt on the Basis of Dummy and Cadaver Tests." Eighteenth Stapp Car Conference, Society of Automotive Engineers, Inc., Warrendale, Pa., 1974, pp. 293-302.

814. Seiffert, V.W., E. Carbon, and H. Ristau. Three-Point Energy-Absorbing Seat Belt System with Combined Vehicle-and-Webbing-Sensitive Emergency Retractor. 2nd International Conference on Passive Restraints, Detroit, Michigan; Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720434, May, 1972.

815. Seiffert, V., K. Oehm, and H. Paitula. Description of the Volkswagen Restraint Automatic (VW-RA) used in a Fleet Test Program. Society of Automotive Engineers, Inc., New York, N.Y., February, 1974.

816. Swedish Trade Commissioner, U.S. Demonstration of "AUTOLIV" Safety Inventions. 1969.

817. Takada, J. Seat Belt Type Passive Restraint System. 2nd International Conference on Passive Restraints, Detroit, Michigan; Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720680, May, 1972.

818. Willumeit, H.P. Passive Preloaded Energy-Absorbing Seat Belt System. 2nd International Conference on Passive Restraints, Detroit, Michigan; Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720433, May, 1972.

4.6.2 Passive Net Restraint

819. Maki, S., H. Uchiyama, K. Oyama, and A. Shimano. "Automatic Falling Occupant Protecting Net Preliminary Study." Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 700452, May, 1970.

4.6.3 Inflatable Belt Systems

820. Burkes, J.M., J.R. Cromack, and T.H. Glenn. "Human Volunteer Testing of the Inflatable Belt Restraint." Proceedings of Nineteenth Conference of the American Association for Automotive Medicine, October, 1975.

821. Fitzpatrick, M., and T. Egbert. Inflatable Belt Development for Subcompact Car Passengers. Minicars, Inc., Galeta, Calif., Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C., Final Report DOT-HS-801720, September, 1975.

4.6.4 Transparent Shields

822. Brown, A.M. Daytona Beach, Florida, September, 1972. [Cited by Phillips, 1973 (804)].

823. Calati, M.I., and W.L. Lehle. Patent No. 3,643,972. 22 February, 1972. [Cited by Phillips, 1973 (804)].

824. Wohn-Machowski, M. Windsor, Ontario, Patent No. 3,663,037. 16 May, 1972. [Cited by Phillips, 1973 (804)].

4.6.5 Blankets

825. Huber, R.L. Flexible Blanket, Garden City, Michigan, Patent No. 3,633,936. 11 January, 1972. [Cited by Phillips, 1973 (804)].

4.6.6 Cushions

826. Sobkow, W. Automotive Safety Research Center, Ford Motor Company, Dearborn, Michigan, Patent No. 3,614,128. 19 October, 1971

4.6.7 Arms and Blankets

827. DeLavenne, H.Y. Fixed Arm Barrier Cushion, Patent No. 3,524,678, Automobiles Peugot, Paris, France, 18 August, 1970. [Cited by Phillips, 1973 (804)].

828. Doehler, E.J. Vehicle Safety Guard, Buffalo, New York, Patent No. 3,640,572. 16 December, 1969. [Cited by Phillips, 1973 (804)].

829. Friedman, D., et al. Improved Air Bag Restraints for Front Seat Compact Car Occupants. Vol. II, Final Program Report, Minicars, Inc., Goleta, California, Contract No. DOT-HS-113-1-163, National Highway Traffic Safety Administration, Department of Transportation, Report No. DOT-HS-800712, July, 1972.

830. Graham, P. Pittsburgh, Pennsylvania, Patent No. 3,545,789. 8 December, 1970. [Cited by Phillips, 1973 (804)].

831. Grime, G. The Automatic Cushion Restraint -- A New Passive Safety System. Britax, Ltd., Surrey; Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720439, May, 1972.

832. Kilronski, R. Arm Restraint System. Naval Underwater Systems Center, Newport, Rhode Island, Patent applied for. [Cited by Phillips, 1973 (804)].

833. Lymar, W. Winged Bar, Patent No. 3,441,103. 17 July, 1967. [Cited by Phillips, 1973 (804)].

834. Wycech, C.E. Automatic Crash Pad, Patent No. 3,630,542. 28 December, 1971. [Cited by Phillips, 1973 (804)].

4.6.8 Static/Capsule Passive Restraint

835. Egglestone, W., and G.D. Suthurst. "Occupant Protection in Frontal Impacts: A Static, Passive Restraint System." Ford Motor Company, Ltd., Report on the Fifth International Technical Conference on Experimental Safety Vehicles, U.S. Department of Transportation, National Highway Traffic Safety Administration, London, England, June, 1974, pp. 748-759.

836. Snyder, R.G. "Concepts in Automotive Occupant Crash Protection." Highway Safety: Anatomy of a Problem, North Carolina Symposium on Highway Safety, Chapel Hill, North Carolina, Vol. I, Fall, 1969, pp. 36-89.

4.6.9 Deployable Head Restraints

837. Brinkley, J.W. Occupant Impact Protection Benefits Attributable to Seat Headrests. Interagency Communication to USAMRDL, Ft. Eustis, Virginia, 21 December, 1973.

838. Hilyard, J.F., J.W. Melvin, and J.H. McElhaney. Deployable Head Restraints. Highway Safety Research Institute, The University of Michigan, Ann Arbor, Mich., Contract HS-031-2-281, National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, D.C., Report No. DOT-HS-800-802, 31 January, 1973.

839. Melvin, J.W., and J.H. McElhaney. Deployable Head Restraints. Highway Safety Research Institute, The University of Michigan, Ann Arbor, Mich., Contract FH-11-7612, National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, D.C., Report No. DOT-HS-800-515, 1971.

840. Melvin, J.W., J.H. McElhaney, V.L. Roberts, and H.D. Portnoy. "Deployable Head Restraints -- A Feasibility Study." Proceedings of the Fifteenth Stapp Car Crash Conference. Society of Automotive Engineers, Inc., New York, N.Y., 1971, pp. 158-189.

841. Motor Vehicle Safety Standard No. 202. Head Restraints. Passenger Cars. Federal Motor Vehicle Safety Standards and Regulations, U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C., Docket No. 8, Part 571, S 202-PRE5. 33 F.R. 2945, Effective 1 January, 1969. 14 February, 1968.

4.6.10 Integrated Passive Restraints

842. Block, B. Protect-O-Matic Seat System, Ford Motor Company, Dearborn, Michigan; Evaluation, 1967.

843. Capener, E.L. Integral Arms About Torso, Stanford Research Institute, Patent No. 3,623,768 30 November, 1971.

844. Kerner, F.G. Safety Seat, Patent No. 3,409,326. 5 November, 1968. [Cited by Phillips, 1973 (804)].

845. Simon, L.B. Life-Net Seat, Patent No. 3,591,232. 6 July, 1971. [Cited by Phillips, 1973 (804)].

846. Simon, L.B. Barrier Seat, Patent No. 3,556,585. 19 January, 1971. [Cited by Phillips, 1973 (804)].

4.6.11 Inflatable (Airbag) Passive Restraint Systems

4.6.11.1 History and Background of Development

847. Aldman, B., and A. Anderson, and O. Saxmark. "Possible Effects of Airbag Inflation on a Standing Child." Proceedings of the Eighteenth Conference of the American Association for Automotive Medicine, Toronto, Canada, 1974, pp. 15-29.

848. Beers, K.N., W.L. Benson, and O.W. Sepp. "The B-1 Crew Module: An Integrated Life Support System for a 6-Man Shirt-Sleeve Aircrew." Proceedings, Annual Scientific Meeting, Aerospace Medical Association, Washington, D.C., 1975, pp. 180-181.

849. Bertrand, H.A. United States Patent 2,834,606, Filed in October, 1955 and Granted May 13, 1958.

850. Blechschmidt, C., C. Clark, and F. Gordon. "Impact Protection by the Airstop Restraint System." Proceedings, 36th Annual Meeting of the Aerospace Medical Association, New York, 1965, pp. 25-26.

851. Campbell, D.D. "Air Cushion Restraint Systems Development and Vehicle Application." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720407, May, 1972.

852. Carr, R.W., and N.S. Phillips. Inflatable Restraint Concept for General Aviation Aircraft. Prepared for Federal Aviation Administration by Beta Industries, Inc., Dayton, Ohio, Report No. FAA-RD-73-3, May, 1973.

853. Carter, R.L. Passive Protection at 50 mph. Society of Automotive Engineers, Inc., New York, N.Y., Publication No. 720445, May, 1972.

854. Clark, C., et al. "Technical Proposal for a Universal Couch Restraint System Concept Development." Engineering Report 1243P, Martin Company, Baltimore, Maryland, May, 1962.

855. Clark, C.C., and R.F. Gray. "A Discussion on Restraint and Protection of the Human Experiencing the Smooth and the Oscillating Accelerations of Proposed Space Vehicles." Bio-Assay Techniques for Human Centrifuges and Physiological Effects of Acceleration, Pergamon Press, 1961.

856. Clark, C., C. Blechschmidt, and F. Gordon. Pilot Compartment Airbag Restraint Program. Final Report, Martin Company, Baltimore, Maryland, Report No. ER 13551, July, 1964.

857. Clark, C., and C. Blechschmidt. "Passenger Transportation Applications of the Airstop Restraint System." Engineering Report No. 13962, Martin Company, Baltimore, Maryland, 1964.

858. Clark, C., and C. Blechschmidt. Passenger Transportation Applications of the Airstop Restraint System. Final Report, Aircraft Applications Addenda to NASA Contract NASw-877, December, 1965.

859. Clark, C., and C. Blechschmidt. "Human Vibration and Impact Protection by Airbag Restraint Systems." American Institute for Aeronautics and Astronautics, Paper 64-220 and Engineering Report 13539, Martin Company, Baltimore, Maryland, June, 1964.

860. Clark, C., et al. "The Analytical Performance of an Airstop Restraint System in an Automobile Crash." Engineering Report 14005, Martin Company, Baltimore, Maryland, October, 1965.

861. Clark, C., and C. Blechschmidt. "Human Transportation Fatalities and Protection Against Rear and Side Crash Loads by the Airstop Restraint." Ninth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y., 1965, pp. 19-64.

862. Clark, C., and C. Blechschmidt. "The Analytical Performance of an Airstop Restraint System in an Automobile Crash." Engineering Report No. 14005, Martin Company, Baltimore, Md., October, 1965.

863. Clark, C., C. Blechschmidt, and F. Gordon. "Impact Protection with the 'Airstop' Restraint System". Eighth Annual Stapp Car Crash Conference, Society of Automotive Engineers Inc., New York, N.Y., 1966, pp. 79-113. (Also available as Engineering Report 13670, Martin Company, Baltimore, October 1964.)

864. Cooper, B., et al. "Human Vibration and Impact Isolation with a Full Length Airbag Restraint System." Research Memorandum 146, Martin Company, Baltimore, Maryland, March, 1963.

865. Committee on Commerce. Hearing Before the Committee on Commerce. United States Senate. Ninety-Third Congress. First Session on Air Bag Development and Technology. Serial No. 93-43, U.S. Government Printing Office, Washington, D.C., 1 August, 1973.

866. Cornell Aeronautical Laboratory. "Advanced Inflatable Occupant Restraint Development." D.O.T. Contract FH-11-7574; 1971.

867. Cornell Aeronautical Laboratory. "Preliminary Vehicle Tests - Inflatable Occupant Restraint Systems." 5 Vols., Contract FH-11-7621; 1971.

868. Daniel, R.P. Explosive Charge Activation of Air Bag. Patent Disclosure, 25 January, 1960.

869. Defeammes, M., and R. Quincy. "Efficiency Comparison Between Three-Point and Air Bag in a Subcompact Vehicle." Fifteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y., 1975, pp. 25-44.

870. Fitzpatrick, M. Development of an Advanced Passive Restraint System for Subcompact Car Drivers. U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C., Report No. DOT-HS-801 592, May, 1975.

871. Fukuda, S., O. Katsuji, O. Takashi, and A. Tsuryoshi. "Study on Air Bag Systems for Small-Sized Cars." Nissan Technical Review, Vol. 10, 1975.

872. Frey, S.M. "History of Air Bag Development." Presentation at NATO International Automotive Passive Restraints Conference, May 11, 1970.

873. Fumiyuki, A. and S. Satoh. "Study on Air Bag Systems for Nissan Small-Sized Cars." Proceedings, 3rd International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, N.Y., July, 1974, pp. 189-211.

874. Gates, Howard P. Review and Critique of National Highway Safety Administration's Revised Restraint System Cost Benefit Analysis. 1 May, 1975.

875. Hammond, R.A. "Digital Simulation of an Inflatable Safety Restraint." SAE Paper No. 710019, January, 1971.

876. Hetrick, J.W. United States Patent 2,649,311, Filed on August 5, 1952 and Granted August 18, 1953.

877. Howe, J.T. "Theory of High-Speed-Impact Attenuation by Gas Bags." NASA TN-D-1298, April, 1962.

878. Irish, F.J., et al. "Modeling Tools for Design of Air Cushion Restraint Systems." SAE Paper No. 710015, January, 1971.

879. John Z. DeLorean Corporation. Automotive Occupant Protective Safety Air Cushion Expenditure/Benefit Study. Prepared for The Allstate Insurance Study Company, Northbrook, Illinois, August, 1975.

880. Jordanoff, A. "The Jordanoff Air Bag Restraint Design." C.C. Clark and C. Blechschmidt, Ninth Stapp Car Crash Conference, 1952, pp. 24-25.

881. Keiller, I.L. Pekarek Safety Cell MD. IB. For Airborne Lifeboat MK.II. Flying Personnel Research Committee, July, 1944.

882. Kemmerer, R.M. Air Bag Passenger Restraint System. Ford Motor Co., Impact Dynamics Dept., Automotive Safety Office, Dearborn, Michigan, Report S-67-3; 23 February, 1967.

883. Kemmerer, R.M., R. Chute, D.P. Hass, and W.K. Slack. "Automatic Inflatable Occupant Restraint System." Parts I and II, SAE Paper No. 680033, January, 1968.

884. Kemmerer, R.M., et al. "Tests Show Vehicle Passengers Have Best Chance of Survival with Inflatable Air Bag Restraint." SAE Journal, Vol. 77, No. 1, January, 1969, pp. 58-61.

885. King, A.I., et al. "Mathematical Model of an Airbag Restraint System for Automobile Drivers." SAE Paper No. 720036, 1972.

886. Klove, E.H., and R.N. Oglesby. "Special Problems and Considerations in the Development of Air Cushion Restraint Systems." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720411, 1972.

887. Kohn, W.A. Proposed Air Cushion Applications. Disclosure, January 29, 1957.

888. Kowalick, J.F., and W. White. "A Critique on the Problem of Pressure Loss in the XM18 Pad One-Man Life Raft System." Report M66-7-1, Frankford Arsenal, n.d.

889. Lamm Aircraft Company, Inc. "The Air Bag Seat for Passenger Aircraft." Report No. 200, Oakland, California, July, 1961.

890. Leis, R.D., C.W. Hamilton, and E.S. Cheaney. "Design of Field and Crash Test Programs for Inflatable Occupant Restraint Systems." Department of Transportation HS-800-395, PB 197617; 1970.

891. Mackay, G.M. "An Assessment of Active and Passive Restraints in Serious Injury European Car Occupant Collisions." Proceedings, AGARD Conference on Linear Acceleration (Impact Type), AGARD CPP88; 23 June 1971.

892. Martin, J.F., and D.J. Romeo. "Preliminary Vehicle Tests-Inflatable Occupant Restraint Systems." Fifteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y., 1971, pp. 518-551.

893. Martin, D.E., and L.C. Lundstrom. Analysis of Occupant Restraint Systems. Society of Automotive Engineers, Inc., New York, N.Y., SAE 750396, 24 February, 1975.

894. McElhaney, J.H., et al. "Car Crash Tests." HSRI Report No. HSRI-71-122, Submitted to NHTSA under Contract No. FH-11-t962, July, 1971, p.57.

895. McElhaney, J.H., et al. "Ford High Speed Air Bag Development Program Sled Tests, Phase I." HSRI Report No. Bio-M-71-2, March, 1971.

896. Mindlin, R.D. "Dynamics of Package Cushioning." Bell System Technical Journal, 1941, pp. 353-461.

897. Mosely Float-On-Air. Patent, "Pneumatic Upholstery." 1918.

898. National Highway Traffic Safety Administration. Docket No. 69-7, Notice 9, Occupant Crash Protection - 49 CFR 571, 36 F.R. 4600; Notice 16, Occupant Crash Protection - 49 CFR 571, 37 F.R. 3911, 1972.

899. North Atlantic Treaty Organization. International Automotive Passive Restraints Conference, Held at General Motors Proving Ground, 11-12 May, 1970. Sponsored by North Atlantic Treaty Organization, U.S. Department of Transportation, and U.S. Automotive Industry; National Technical Information Service, Springfield, Virginia, Publication No. PD1940 27; 1970.

900. Office of Science and Technology. Cumulative Regulatory Effects on the Cost of Automotive Transportation (RECAT). Chapter II-3, Final Report of the Ad Hoc Committee, NTIS Report No. PB 207713; 28 February, 1972.

901. Patrick, L.M., et al. "Air Bag Restraints for Automobile Drivers." DOT Contract FH-11-7607, Wayne State University, 1970. 1971.

902. Patrick, L.M., G. W. Nyquist, and K.R. Trosien. "Safety Performance of Shaped Steering Assembly Airbag." Sixteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y., 1972, pp. 4340471.

903. Pekarek, Z. "Improvements in or Relating to Devices for the Safety of Flying Personnel During Crash Landing of an Aircraft." Patent Specification No. 14079; 1 November, 1941.

904. Pekarek, Z. "Remarks on the Safety of the Crew (Excluding Pilots) in Crash Landing of an Aircraft." Royal Aircraft Establishment, Farnborough, U.K., Technical Note No. SME 56, February, 1942.

905. Pekarek, Z. "Remarks on Pekarek Safety Cells." Royal Aircraft Establishment, Farnborough, U.K., Technical Note No. SME 176, November, 1943.

906. Pekarek, Z. "Safety Device for Pilots of Aircraft and Drivers of Vehicles." Patent Specification No. 4245; 16 March, 1943.

907. Pekarek, Z. "Further Comments on the Safety of the Crew in Crash Landings of Bombers." Royal Aircraft Establishment, Farnborough, U.K., Technical Note No. SME 187, November, 1943.

908. Pflug, J.A. "Air Cushion Systems for Full-Sized Cars." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720408, May, 1972.

909. Robbins, D.H., A.W. Henke, and V.L. Roberts. Impact Sled Studies of Right Front Passenger Inflating Restraint Systems. Highway Safety Research Institute, The University of Michigan, Ann Arbor, Report No. BIO-M-71-2, Sponsored by National Highway Traffic Safety Administration, Washington, D.C., Contract No. FH-11-6962, NTIS No. PB-201 264, 15 May, 1971.

910. Romeo, O.J., and R.A. Rose. "Rear Seat Inflatable Occupant Restraint System." Sixteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y., 1972, pp. 412-433.

911. Romeo, O. "Front Passenger Passive Restraint for Small Car, High Speed, Frontal Impacts." Proceedings, Nineteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, Paper No. 751170, 1975, pp. 821-848.

912. Seiffert, V.W., and G.H. Borenius. "Development Problems with Inflatable Restraints in Small Passenger Vehicles." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720409, May, 1972.

913. Shoemaker, N.E., and O.J. Biss. "The Oevelopment of an Airbag on Collapsible Dashpanel Restraint System for Right Front Seat Occupants." Proceedings, 3rd International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, N.Y., July, 1974, pp. 168-187.

914. Slack, W.K. "Automatic Inflatable Occupant Restraint System, Part II." SAE Paper No. 680033, January, 1968.

915. Smith, R.A., and C.A. Moffatt. "Accident Experience in Airbag-Equipped Cars." Proceedings of the Nineteenth Conference of the American Association for Automotive Medicine, Lake Bluff, Illinois, 1975, pp. 60-79.

916. Snyder, R.G. Design and Fabrication of a Restraint System for Advanced Manned Flight. Proposal to AMC Aeronautical Systems Center, Wright Air Development Center, Applied Research Laboratory, College of Engineering, University of Arizona, Tucson, Ariz., PR 96126, University of Arizona No. 60-Q-8, 1 February, 1960.

917. Society of Automotive Engineers, Inc. Proceedings, 2nd International Conference on Passive Restraints. Sponsored by SAE, NHTSA and Committee on the Challenges of Modern Society, North Atlantic Treaty Organization; Detroit, Michigan, 22-25 May, 1972.

918. Society of Automotive Engineers, Inc. Proceedings, 3rd International Conference on Occupant Protection. Passenger Protection Committee, SAE Passenger Car Activity; Troy, Michigan, 10-12 July, 1974.

919. Sommers, J. A Comparison of General Aviation Occupant Restraint Systems. Federal Aviation Administration, Systems Research and Development Service, Washington, D.C., Report No. FAA-RD-73-114; 1973.

920. Strother, C.C., and R.M. Morgan. "The Efforts of the National Highway Traffic Safety Administration in the Oevelopment of Advanced Passive Protection Systems and Child Restraint Systems." Proceedings, 3rd International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, N.Y., July, 1974, pp. 246-267.

921. Tarriere, C., G. Mauron, and P. Ventre. "French Oevelopments in Original Oeployable Systems." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720410, May, 1972.

922. "The Auto-Ceptor Occupant Restraint System." Eaton, Yale & Towne, Inc., Southfield, Michigan, 1969.

923. Trosien, K.R., and L.M. Patrick. "Collision Performance of Air Cushion Restraint Systems." SAE Paper No. 710020; 1971.

924. Vital Facts Concerning the Air Cushion System. U.S. Department of Transportation, Washington, D.C., 24 January, 1972.

925. Warner, C., M. Withers, and R. Peterson. "Societal Priorities in Occupant Crash Protection." Fourth International Conference on Automotive Safety, San Francisco, California, 14-16 July, 1975.

4.6.11.2 Inflating Occupant Restraint System Components

4.6.11.3 Air Bag Design

926. Streed, D.D.M., and C.B. Rodenback. "Materials, Fabrications and Packs for Air Cushions." SAE Paper No. 710018, January, 1971.

4.6.11.4 Crash Sensors

927. Bell, L.E. "Crash Detector Development." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., May, 1972.

928. Hass, D.P. "Air Pillow Occupant Restraint System - Automatic and Effective." Thirteenth AAAM, 1969, pp. 221-237.

929. Hopkins, J.B., et al. "Oevelopment of Anticipatory Automobile Crash Sensors." Transportation Systems Center Report No. DOT-TSC-NHTSA 71-3, July, 1971.

930. Hopkins, J.B. Automobile Crash Sensor Development. Progress/Status Report No. 2, 1971.

931. Horner, J.L. "Occupant Motion Sensors." DOT-TSC-NHSB-71-1, 1971.

932. Hopkins, J.B., F.R. Holmstrom, M.E. Hazel, E. White, and T. Newfell. "A Microwave Anticipatory Crash Sensor for Automobiles." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., May, 1972.

933. Ikeda, S., K. Nonaka, and M. Fukushima. "Fluid Crash Sensor." Proceedings, 3rd International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, N.Y., July, 1974, pp. 153-167.

934. Jones, T.O., et al. Crash Sensor Development. Society of Automotive Engineers, Inc., New York, N.Y., Publication No. 710016, January, 1971.

935. Jones, T.O., and O.T. McCarter. "Crash Sensor Basic Requirements." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720419, May, 1972.

936. Jones, T.O., D.M. Grimes, and R.A. Dork. "A Critical Review of Radar as a Predictive Crash Sensor." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., May, 1972.

937. Pudjdowski, E. "Crash Sensors for Inflatable Occupant Restraint Systems." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720420, May, 1972.

938. Ross, G.F. "BARBI, a New Radar Concept for Precollision Sensing." Proceedings, 3rd International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, N.Y., July, 1974, pp. 141-152.

939. Takahashi, T., T. Makino, and K. Sato. "Development of a Radar Sensor for Inflatable Occupant Restraint Systems." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., May, 1972.

940. Termaat, K.B., and K. Freeman. "Development of the Crash Sensor/Vehicle Interface." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., May, 1972.

4.6.11.5 Inflation Energy (Gas) Sources

941. Abe, F., and S. Satoh. "Study on Air Bag Systems for Nissan Small-Sized Cars." 3rd International Conference on Occupant Protection. Society of Automotive Engineers, Inc., New York, N.Y., 1974, pp. 189-211.

942. Carey, W.R., T.J. Wissing, R.G. Gehig, G.W. Goetz, and D.A. Larson. "Energy Management in IORS." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720418, May, 1972.

943. Jacobsson, D., and S. Thoren. Rapid Inflation of a Fabric Bag by Solid Fuel Gases. Forsvarets Forskning Sanstalt (Research Institute of National Defense), Sundbyberg, Sweden, Report No. E1446-F1, March, 1972.

944. Johnson, J.P., R.E. McComb, T.F. McDonnell, and D.R. Trowbridge. "Energy Source Selection." Society of Automotive Engineers, Inc., New York, N.Y., Publication No. 710017, January, 1971.

945. Jones, T.O., et al. Comparative Analysis of Crash Sensors. Society of Automotive Engineers, Inc., New York, N.Y., Publication No. 720035, 1972.

946. Hayosh, R.J., and A.L. Gutherie. "Requirements for Air Bag Restraint Energy Sources. Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720412, May, 1972.

947. Lane, G.A., T.E. Dergazarian, and G.R. Staudacher. "Compact, All-Solid Gas Generators." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720417, May, 1972.

948. Lawwil, R.C. "The Anatomy of an Inflator for Air Cushion Occupant Systems." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720416, May, 1972.

949. McCullough, F., W.F. Thorn, B.L. Kotter, and E.W. Schmidt. "Gas Generator and Aspirator for Automatic Occupant Restraint Systems" Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720413, May, 1972.

950. Meranshain, G. "Development of Cool Gas Generators for Inflating the PK-2 and Mark 20 Life Rafts." Report R-1805, Frankford Arsenal, n.d.

951. Rocket Research Corporation. Development of Improved Inflation Techniques. Prepared for the U.S. Department of Transportation, Washington, D.C., Report No. DOT-HS-801 724, September, 1975.

952. Sutter, C. "Development of the XM19 Cool Gas Generator." Report R-1822, Frankford Arsenal, n.d.

953. Thiokol Chemical Corporation. Preliminary Performance Requirements and Goals. Gas Generator for the Inflatable Restraint Systems for Passenger Cars. Wasatch Division, Brigham City, Utah, Report No. TWR-3897, Rev. 1, n.d.

954. Tolley, C.P., and B.K. Hamilton. "Energy Requirements - Correlation Between Occupant, Bag and Inflator." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Paper No. 720415, May, 1972.

4.6.11.6 Diffuser Design

4.6.11.7 Human Volunteer Tests

955. Bendixen, C.D. Department of Transportation Daisy Track Human Tolerance Tests. Bio-Effects Division 6571st Aeromedical Research Lab, Aerospace Medical Division, Holloman AFB, New Mexico, June, 1970, in a cooperative effort between NHTSA and the USAF.

956. Brinkley, J., G. Mohr, H. Russell, S. Coopter, and J. Shaffer. Impact Test of a Near-Production Air Cushion Restraint. U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C., Final Report, April, 1974.

957. Buschman, D.L., and H.C. Russell. Dynamic Investigation of the Injury-Attenuation Potential of the GMC Production Air Cushion. 6571st Aerospace Medical Research Lab, Holloman AFB, New Mexico (unpublished protocol), June, 1972.

958. Clark, C.C. "Airbag Restraints and Airlitter Systems for the Alleviation of Highway Injury." The Prevention of Highway Injury Symposium, Highway Safety Research Institute, The University of Michigan, Ann Arbor, Mich., 1967, pp. 221-237.

959. Clarke, T.D., J.F. Sprouffske, E.M. Trout, C.D. Gragg, W.H. Muzzy, and H.S. Klopfenstein. "Baboon Tolerance to Linear Deceleration ($-G_x$): Airbag Restraint." Proceedings, 14th Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y., November, 1970, pp. 263-278.

960. Clarke, T.D., et al. "Human Head Angular Acceleration During Impact." Proceedings, 15th Stapp Car Crash Conference, SAE Paper No. 710857, 1971.

961. Department of Transportation. "Report on Static Air-Bag Tests with Human Subjects at Holloman Air Force Base." NHTSA Docket 69-7, General Reference No. 95, 1971, 6 p.

962. Glenn, T.H. "Anthropomorphic Dummy and Human Volunteer Tests of Advanced and/or Passive Belt Restraint Systems." Proceedings, 3rd International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, N.Y., July, 1974, pp. 227-245.

963. Gragg, C.D., C.D. Bendixen, T.D. Clarke, H.S. Klopfenstein, and J.F. Sprouffske. "Evaluation of the Lap Belt, Air Bag, and Air Force Restraint Systems During Impact with Living Human Sled Subjects." Proceedings, 14th Stapp Car Crash Conference, Society of Automotive Engineers, Inc., New York, N.Y., SAE 700904, 1970, pp. 241-298.

964. Gragg, C.D., et al. "Evaluation of the Lap Belt and Pre-Inflated Air Bag during Impact with Human Sled Subjects." SAFE Symposium Proceedings, Vol. 1, 1970, pp. 27-44.

965. Greer, C.R. "Dynamic Testing of a Prototype Air Bag with Human Volunteers - Serum Enzyme Determinations, Observed Trauma and Subjective Response Descriptions." Proceedings of the Seventeenth Conference of the American Association for Automotive Medicine, University of Oklahoma, Oklahoma City, 1973, pp. 21-30.

966. Greer, C.R., and C.D. Gragg. "Experimental Evaluation of the Deployment of an Airbag Restraint Using Human Subjects." Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio (unpublished), Report to National Highway Traffic Safety Administration, Washington, D.C., December, 1971.

967. Greer, C.R., and H.C. Russell. "Impact Tests of Human Subjects Using a Prototype Air Bag Restraint System." Air Force Systems Command, Aerospace Medical Division, Wright-Patterson AFB, Ohio; Prepared for U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C., Final Report, DOT-HS-805, September, 1972.

968. Hendler, E., J. O'Rourke, M. Schulman, M. Katzeff, L. Domzalski, and S. Rodgers. "Effect of Head and Body Position and Muscular Tensing on Response to Impact." Proceedings, Eighteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1974, pp. 303-337.

969. McElhaney, J.H., et al. "Analysis of Daisy Track Human Tolerance Tests." HSRI Report No. Bio-M-71-1, Submitted to NHTSA under Contract No. FH-11-6962; FTIS No. DOT-HS-800498, March, 1971.

970. Patrick, L.M. "Static Air Bag Experiments (Animal), Progress Report No. 1." Submitted to General Motors Corporation, Research Laboratories, Warren, Michigan, 1971.

971. Smith, G.R., S.S. Hurite, A.J. Yanik, and C.R. Greer. "Human Volunteer Testing of GM Air Cushions." Proceedings, 2nd International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, N.Y., Publication No. 720443, 1972.

972. Smith, G.R., E.C. Gulash, and R.G. Baker. "Human Volunteer and Anthropomorphic Dummy Tests of General Motors Driver Air Cushion System." Proceedings, 3rd International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, N.Y., July, 1974, pp. 212-226.

973. Smith, G.R., E.C. Gulash, and R.G. Baker. "Human Volunteer and Anthropomorphic Dummy Tests of Driver Air Cushion System." Clinics in Plastic Surgery, W.B. Saunders Company, Philadelphia, Pa., Vol. 2, No. 1, 1975, pp. 35-45.

4.6.11.8 Noise

974. "Acceptable Noise Exposures." Sound and Vibration, November, 1967.

975. Allen, C.H., R.D. Bruce, C.W. Dietrich, and K.S. Pearsons. "Noise and Inflatable Restraint Systems." Bolt, Beranek and Newman, Inc., Report No. 2020, September, 1970.

976. American Standards Association. "The Relations of Hearing Loss to Noise Exposure." (Report of Subcommittee Z24-X-Z), 10 E. 40th St., New York, N.Y., 1954.

977. Cohen, A., B. Kylin, and P.J. LaBenz. "Temporary Threshold Shifts in Hearing From Exposure to Combined Impact/Steady-State Noise Conditions." J. Acoust. Soc. Amer., Vol. 40, 1966, pp. 1371-1380.

978. Coles, R.R., et al. "Hazardous Exposure to Impulse Noise." JASA, Vol. 43, No. 2, 1963, pp. 336-343.

979. Garinther, G.R., and K.D. Kryter. "Auditory and Acoustical Evaluation of Several Shoulder-Rifles." Technical Memorandum 1-65, U.S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, 1965.

980. Garinther, G.R., and J.B. Moreland. "Transducer Techniques for Measuring the Effect of Small Arms' Noise on Hearing." Technical Memorandum 11-65, U.S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, 1965.

981. General Motors Corporation. "Air Restraint Program Acoustic Impulse Test Procedure." 1970.

982. Gjaevenes, K. "Damage-Risk Criteria for the Impulsive Noise of Toys." JASA, Vol. 42, No. 1, 1967, p. 268.

983. Glass, D.R., P.O. Hays, and J.A. Nicholls. A Study of the Noise Aspects of Automobile Air Bag Safety Systems. University of Michigan, Noise Dynamics Laboratory, Ann Arbor, Mich., December, 1970.

984. Glorig, A., W.D. Ward, and J. Nixon. "Damage-Risk Criteria and Noise-Induced Hearing Loss." Arch. Otolaryngol., Vol. 74, 1961, pp. 413-423.

985. "Guide for Conservation of Hearing in Noise." A Supplement to the Transactions of the American Academy of Ophthalmology and Otolaryngology (Damage-Risk Criteria), 1964.

986. Harbold, G.J., and J.W. Greene. "A Study of the Effect of Gunfire and Other Infantry Combat Training Noises on the Hearing Acuity of U.S. Marine Corps Recruits." Project MR005, 13-2005, Subtask 1, Report No. 10, U.S. Naval School of Aviation Medicine, Pensacola, Fla., 1961.

987. Hickling, R. "An Investigation of the Noise and Overpressure Generated by the Safety Air Cushion." General Motors Corporation, Research Laboratories Warren, Michigan, 1974.

988. Nicholls, J.A., et al. "Preliminary Study of the Noise Aspects of Automobile Air Bag Safety Systems." Department of Aerospace Engineering, The University of Michigan, July, 1970.

989. Nixon, C.W. "Human Auditory Response to an Air Bag Inflation Noise." Biological Acoustics Branch, 6570th Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio; Report Prepared for National Highway Traffic Safety Bureau, March, 1969.

990. Richter, H.J., R.L. Stalnaker, and J.E. Pugh. "Otologic Hazards of Airbag Restraint System." Proceedings, Eighteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., Warrendale, Pa., Report No. 741185, December, 1974, pp. 339-349.

991. U.S. Air Force, Medical Service. "Hazardous Noise Exposure." Air Force Reg. No. 160-3, Washington, D.C., 1956.

992. Van Wagoner, W.T. "Air Bag Versus Interior Pressure." Ford Motor Co. Intra-Company Communication, April 19, 1967.

993. Ward, W.D., R.E. Fleer, and A. Glorig. "Characteristics of Hearing Losses Produced by Gunfire and by Steady Noise." J. Auditory Res., Vol. 1, 1962, pp. 325-356.

994. Zepler, E.E., and J.R.P. Harel. "The Loudness of Sonic Booms and Other Impulsive Sounds." J. Sound Vib., Vol. 2, 1965, pp. 249-256.

4.6.11.9 Toxicity

995. Halstead, A.M. "A Study of Selected Propellant Actuated Devices to Eliminate or Minimize Toxic Propellant Gases." SEG-TR-65-27, Wright-Patterson AFB, Ohio, 1965.

996. McDonnell, T.F. "Toxicity Considerations for Air Cushion Inflation Gases." Olin Research Center Library, November, 1971.

997. Schmidt, E.W. Toxicity Evaluation of Gas Generator Effluents for Crash Restraint Bag Inflation. Rocket Research Corporation, Redmond, Washington, Engineering Study No. 71-ES-73, Rev. A., 29 February, 1972.

998. Schmidt, E.W. "Toxicity Evaluation of Crash Restraint Gas Generators." Proceedings of the Sixteenth Conference of American Association for Automotive Medicine, Society of Automotive Engineers, Inc., New York, N.Y. 1972, pp. 398-414.

999. Mackay, G. M. "Airbag Effectiveness - a Case for the Compulsory Use of Seat Belts." Proceedings, FISITA Conference, London, June, 1972.

1000. O'Day, J., and L.L. Morgan. "The First Thousand Airbags." HIT Lab Reports, Highway Safety Research Institute, the University of Michigan, Ann Arbor, March, 1972.

1001. Smith, G.R. "Field Testing 1000 Air Cushion Equipped Automobiles." Proceedings of the 17th Conference of the American Association for Automotive Medicine, Society of Automotive Engineers, Inc., New York, N.Y. 1973, pp. 443-464.

1002. Yost, C.D. "Investigation Report of the First Air-Bag Deployment in a 'Real-World' Accident." Proceedings if Sixteenth Conference of the American Association for Automotive Medicine, Society of Automotive Engineers, Inc., New York, N.Y., 1972, pp. 124-128.

1003. Yost, C.P. "Third 'Real-World' Air Bag Crash. Fourth Air-Bag Crash. Fifth 'Real-World' Air-Bag Crash." American Association for Automotive Medicine Quarterly, June, 1973, pp. 12, 13.

4.6.11.11 Air Transport Application

1004. Brown, P.J. "Automotive Restraint Systems." Cumulative Regulatory Effects on the Cost of Automotive Transportation (RECAT), Office of Science and Technology, Washington, D. C., Appendix II-D, 1972, pp. II-D1 - LL-D27.

1005. Diamond, F.L. F.L. Diamond Corporation, Granada Hills, California. Personal Communication, 9 March, 1976.

1006. U.S. Department of Transportation. Air Bag Restraint Systems. National Highway Traffic Safety Administration, Washington D.C., Special Bibliography No. 5, Report No. DOT HS 801 033, October, 1973.

5. Aisle and Evacuation Markers

5.1 Aisle Width

1007. Alexander, M., J.W. Garrett, and J.C. Robinette. "Role of Anthropometry in Air Force Systems." Aerospace Medicine, Vol. 4, No. 4, April, 1971, pp. 388-393.

1008. Clauser, C. 1967 Anthropometric Survey of USAF Flying Personnel. Wright Patterson AFB, Ohio, (unpublished data), 1971.

1009. Damon, A., W.W. Stoudt, and R.A. McFarland. The Human Body in Equipment Design. Harvard University Press, Cambridge, Mass., (2nd printing), 1971.

1010. Federal Aviation Regulations. "Width of Aisle." Part 25, Airworthiness Standards: Transport Category Airplanes, Department of Transportation, 25.815, June, 1974.

1012. Flight Safety Focus. "Narrow Aisle Stretchers." The Flight Safety Committee, London, No. 5, June, 1971, p. 5.

1013. King, B.G. Aircraft Emergency Evacuation: A Method of Evaluating Devices, Procedures and Exit Provisions. Civil Aeronautics Administration, Washington, D.C., April, 1951.

1014. Knapp, S.C. "Operational Problems and the Role of Human Factors in Tactical Deployments." Paper presented XIX International Congress of Aviation and Space Medicine, Tel Aviv, Israel, 26 October, 1971.

1015. Mohler, S.R., J.J. Swearingen, E.B. McFadden, and J.D. Garner. Human Factors of Emergency Evacuation. Office of Aviation Medicine, Federal Aviation Agency, Report AM65-7, September, 1964.

1016. United States Air Force. "Cargo Compartment Dimensions and Zoning." C-135A and B Flight Manual, T.O. 10-135A-1, Figure 4-58, Section IV, 1971, pp. 4-112.

5.2 Chemo-Illuminenscence

1017. Strongin, O. "Luminescence and Air Safety." Proceedings, Seventh National Flight Safety, Survival and Personal Equipment Symposium, Las Vegas, Nevada, Vol. 1, October, 1969, pp. 169-178.

1018. General Aviation News. "Liqui-Light," New Product, 22 July, 1974, p. 20.

5.3 Electro-Illuminescence

5.4 Ultraviolet Activated Pathway Systems

5.5 Self-Luminous Sources (Tritium)

1019. Atomic Energy Commission. Licensing of Byproduct Material. Title 10, Chapter I, Part 30, Published in Federal Register 2393, 14 March, 1962.

1020. McFadden, E.B., J.D. Garner, and R.A. Mosler. "Development of a Tritium Self-Luminous Life Raft Light Source." Aerospace Medicine, Vol. 36, No. 6, June 1965, pp. 548-551.

5.6 Phosphorescent Markers

5.7 Incandescent Sources

5.8 Gaseous Discharge Systems

1021. Braunstein, M.L., and M.H. Piazza. "Preparation for Evacuation Tests of a Crashed L1649." Federal Aviation Agency, Washington, D.C., Report TRL FAA-ADS-48, June, 1965.

1022. Garner, J.D., and J.G. Blethrow. Emergency Evacuation Tests of a Crashed L-1649. Office of Aviation Medicine, Federal Aviation Agency, Oklahoma City, Oklahoma, Report AM66-42, August, 1966.

5.9 Floor-Level Lighting

5.10 Directional Aisle and Evacuation On-Off Lights

5.11 Tactile Aisle Markers

1023. Oden, J.R., and H.B. Altman. Aircraft Emergency Evacuation Systems: Tactile Cue Directionality. Douglas Aircraft Company, Long Beach, Calif., Report No. DAC 33967, September, 1967.

5.12 Other Considerations and Requirements

1024. Federal Air Regulations. "Emergency Exit Marking." Part 25, Airworthiness Standards: Transport Category Airplanes, Department of Transportation, 25.811, June, 1974.

1025. Federal Air Regulations. "Emergency Lighting." Part 25, Airworthiness Standards: Transport Category Airplanes, Department of Transportation, 25.812, June, 1974.

1026. Department of the Air Force. Military Specification. Aircraft Emergency Escape System, Identification of. MIL-A-25165B (ASG), 5 October, 1964.

1027. Society of Automotive Engineers, Inc. Emergency Placarding-Internal and External. Aerospace Recommended Practice, ARP 577, Revised 15 October, 1962.

1028 Society of Automotive Engineers, Inc. Emergency Illumination. Aerospace Recommended Practice, ARP 503A, Revised 15 August, 1962, ARP-503B, July, 1971.

6. Passenger Warning and Public Address Systems

1029. Altman, H.B. "Corporate/Executive Aircraft Passenger Safety: An Educational Approach." SAFE Journal, Vol. 5, No. 1, Spring, 1975, pp. 7-11.

1030. Federal Aviation Administration. Federal Air Regulations, Part 121.309, 1970.

1031. Federal Aviation Administration "New FAA Safety Rule Requires Improved Communications on Commercial Transports." Department of Transportation News, FAA 73-141, 13 August, 1973.

1032. Ogilvie, A.W., III. Emergency Evacuation Signal System for Airplanes. Trans World Airlines. Society of Automotive Engineers, A-20 Aircraft Lighting Symposium, Wichita, Kansas, 2 April, 1968.

1033. Society of Automotive Engineers, Inc. Flight Deck Visual, Audible and Tactual Signals. ARP 450B, New York, N.Y., 1971.

1034. Society of Automotive Engineers, Inc. Aircraft Evacuation Signal System. Proposed Aerospace Recommended Practice, ARP 1178, New York, Y.Y., 1971.

6.4 Video Tape Presentation of Passenger Safety Information

1035. Altman, H.B. "Corporate/Executive Aircraft Passenger Safety: An Educational Approach." SAFE Journal, Vol. 5, No. 1, Spring Quarter, 1975, pp. 7-11.

1036. Aviation Week and Space Technology. "Airline Safety." Letters to the Editor, 24 November, 1965, p. 62.

1037. Johnson, D.A. "Effectiveness of Video Instructions on Life Jacket Donning." Proceedings, Human Factors Society, Seventeenth Annual Meeting, (Douglas Aircraft Company Report No. MDCJ5936 and Paper No. 6175), 1973, pp. 223-228.

1038. Johnson, D.A., D.I. Blom and H.B. Altman. "Video Tape Presentation of Passenger Safety Information." Proceedings, Human Factors Society, Nineteenth Annual Meeting, October 14, 1975, pp. 102-107.

7. Advances in Emergency Egress Concepts

7.1 Background

1039. Dougherty, J.E. FAA Airframe Egress Standards and Demonstration Practices for Air Carrier Aircraft. Presentation, USAF Industry Life Science Support Conference, Las Vegas, Nevada, 28 November, 1967.

1040. Jaglowski, J.J. "Improving Emergency Egress." Fire Technology, Vol. 2, No. 4, 1966, pp. 274-275.

1041. King, B.G. Aircraft Emergency Evacuation: A Method of Evaluation Devices, Procedures and Exit Provisions. Civil Aeronautics Administration, Washington, D.C., April, 1951.

1042. King, B.G. Elimination of Some Time Losses in Emergency Evacuation of Passengers from Airplanes. Civil Aeronautics Administration, Washington, D.C., 1952.

1043. King, B.G. Aircraft Emergency Evacuation Operating Experience and Industrial Trials. Civil Aeronautics Administration, Washington, D.C., Report No. 2, May, 1952.

1044. King, B.G. Aircraft Emergency: Convair 240, Experimental Trials of Emergency Escape of American Airlines, Inc. Civil Aeronautics Administration, Washington, D.C., Report No. 3, August, 1952.

1045. King, B.G. Aircraft Evacuation Under Fire Conditions. Civil Aeronautics Administration, Washington, D.C., May, 1954.

1046. King, B.G. Emergency Escape Procedures. Air Research and Development Command, Washington, D.C., August, 1954.

1047. King, B.G. Some Survival Lessons Learned from Recent Accidents. Civil Aeronautics Administration, Washington, D.C., November, 1954.

1048. Sliepcevich, C.M., W.D. Steen, J.L. Purswell, R.F. Krenek, and R.G. Rein. Escape Worthiness of Vehicles for Occupancy Survivals and Crashes. First Part: Reaearch Program. University of Oklahoma, Norman, Oklahoma, Report No. DOT HS-800 736, (NTIS PB 213 201), July, 1972.

7.2 Slide Devices

7.2.1 Inflatable Escape Slides

7.2.1.1 Double Lane Slides

1049. Aerospace Industries Association of America, Inc. Evacuation. Crashworthiness Development Program, Technical Group Report, Washington, D.C., Report No. AIA CDP-4, July, 1968.

1050. British Aircraft Corporation. "Extract from the Equipment Technical Specification 'Concorde Combined Escaped Slide/Slide Raft.'" Ref. BES/SST/FURN/2003. 17 December, 1973.

7.2.1.2 Double Escape Slide with Center Divider

7.2.1.3 Combination Inflatable Slide and Life Raft

1051. Pan Avion. TSO C12C Aircraft Rafts. American Safety Flight Systems, Miami, Florida, Data Sheet AR.1116. 1971.

1052. Sirkis, J.A., S.R. Mohler, and E. Podolak. "Human Factors of Aircraft Slide/Raft Combinations." Aerospace Medicine, May, 1974, pp. 553-558.

1053. Society of Automotive Engineers, Inc. SAE S-9 Committee Slide/Raft Open-Sea Tests Oahu, Hawaii - November 1972. Final Report, 1973.

1054. Society of Automotive Engineers, Inc. Combination Evacuation Slide/Life Raft, ARP-1282, Issued 15 July, 1970.

1055. Society of Automotive Engineers, Inc. Survival Kit-Life Rafts and Slide/Rafts. ARP-1282, Issued July, 1973.

7.2.1.4 Inflatable Tubular Escape Device Slide/Raft

7.2.1.5. Exterior Platform Escape Slide Entry

7.2.2 Slide Inflation Devices

7.3 Mechanical Escape Devices

7.3.1 Seat Belt Escape Harness and Egress Conveyor System

7.3.2 Folding Escape Slide

7.3.3 Cargo-type Emergency Egress Techniques

7.3.4 Conveyor Belt Concept

7.3.5 Telescape System

1056. Garner, J.D. and J.G. Blethrow. "Evaluation Test on the Telescape System for Emergency Evacuation from Aircraft." Federal Aviation Agency, Civil Aeromedical Research Institute, Oklahoma City, Oklahoma, Report No. 1 (Unpublished), October, 1962.

7.4 Heat Shields

7.4.1 Exit Area Ablative Coating

7.4.2 Cabin Fire - Protective Shielding

1057. Neel, C.B., J.A. Parker, and R.H. Fish. "Heat Shields for Aircraft: A New Concept to Save Lives in Crash Fires." Astronautics and Aeronautics, (AIAA), November, 1971.

7.5 High Energy Emergency Egress Systems

1058. Caldara, J.D. "Implications of Design and Its Effects on Emergency Egress." Parks Air College, 11 May, 1965.

1059. Caldara, J.D. "Explosive Emergency Exits for Crashed Aircraft as Part of Flight Safety Research." 6th Annual Symposium, The Survival and Flight Equipment Association. 1 October, 1968.

1060. Caldara, J.D. "High Energy Technology for Fail-Safe Emergency Egress." ALPA Air Safety Forum, 1970.

7.5.1 ELSIE

1061. Anderson, M.C., and F.B. Burkdoll. An Emergency Life-Saving Instant Exit System for Cargo, Cargo-Transport and Passenger Aircraft. Life Support System Program Office, Air Force Systems Command, Wright-Patterson AFB, Ohio, Technical Report ASD-Tr-71-41, Vol. II, February, 1974.

1062. "Big Jets May Blast Away Escape Doors." Machine Design, 17 August, 1967.

1063. Bennett, H.I. "High Energy Technology for Emergency Egress." Teledyne McCormick Selph, Presented to 22nd Annual International Flight Safety Seminar of the Flight Safety Foundation, Inc., Montreux, Switzerland, 30 October, 1969.

1064. Bogland, J.L. "Explosive Release of Emergency Exit Hatches, Explosive-Technology." Ducommun, Inc., 5th National Flight Safety, Survival and Personal Equipment Symposium, 25-28 September, 1967.

1065. Brown, C.K. "Design and Application Parameters - Ordnance Actuated Aircraft Emergency Evacuation Systems." Space Ordnance Systems, Inc., El Segundo, Calif., 5th National Flight Safety, Survival and Personal Equipment Symposium, 25-26 September, 1967.

1066. Burkdoll, F.Bl, D.E. Nicholson, and B. Chesterfield. "ELSIE - A Progress Report." Proceedings, Ninth Annual Symposium, SAFE, 30 September, 1975.

1067. Burkdoll, F.B., D.E. Nicholson, and B. Chesterfield. "ELSIE - A Progress Report." Proceedings, Ninth Annual Symposium, The Survival and Flight Equipment Association, 30 September, 1971.

1068. Explosive Technology. The STEN passenger Egress System. Fairfield, California, Report No. 4066 (01)SR, May, 1968.

1069. Explosive Technology. Design Study Report. Fairfield, California, Report No. 2802(01)TR, August, 1970.

1070. "Explosives Blow Out Plane Doors to Save Airline Passengers." Product Engineering, 23 November, 1970, p. 14.

1071. Heaton, R.L., and K.N. Beers. "An Emergency Life-Saving Instant Exit System for Cargo, Cargo-Transport, and Passenger Aircraft." Proceedings, 46th Annual Scientific Meeting, Aerospace Medical Association, San Francisco, Calif., 1 May, 1975.

1072. Nicholson, D.E., and F.B. Burkdoll. An Emergency Life-Saving Instant Exit System for Cargo, Cargo-Transport and Passenger Aircraft. Life Support System Program Office Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, Technical Report No. ASD-TR-71-41, (Volume I), June, 1971.

1073. Nuttall, J.B. "Emergency Escape from Aircraft and Spacecraft." In Aerospace Medicine, Second Edition (H.W. Randel, ed.), William and Wilkins Co., Baltimore, Md., 1971, pp. 367-417.

1074. Patent 2,797,884. "Emergency Release for Cabin Door." (Peed), 2 May, 1957.

1075. Patent 2,942,813. "Combined Speed Brake Escape Hatch." (English), 14 February, 1958.

1076. Patent 3,201,169. "Safety Door for Vehicles." (Scott), 12 July, 1963.

1077. Patent 3,331,571. "Emergency Exit Arrangements in Aircraft." (Lawrence, et al.), 22 April, 1964.

1078. Pollard, F.(Moderator). Emergency Egress from Transport Aircraft. Panel presentation and discussion, Ninth Annual Symposium, The Survival and Flight Equipment Association, 30 September, 1971.

1079. Sipes, W.J. "Emergency Escape and Inflight Safety Systems." Teledyne McCormick-Selph, 5th National Flight Safety, Survival and Personal Equipment Symposium, 26-28 September, 1967.

1080. Teledyne McCormick Selph. High Energy Power Systems for Use in Emergency Egress from Transport Aircraft. Report No. AS-201. 15 December, 1969.

1081. Teledyne McCormick Selph. Aircraft Safety Study. Phase I. Report on Cutting Tests on Aircraft Canopies. 1969.

1082. Teledyne McCormick Selph. Aircraft Safety Study. Phase II. Report on Canopy Removal System for T-38 Aircraft. No. 482-51-800. 9 February, 1970.

1083. Teledyne McCormick Selph. External Emergency Egress System and Emergency Access System. Proposal No. 482-70-345. 1970.

1084. Teledyne McCormick Selph. Aircraft Safety Systems. Hollister, California, 1971.

7.5.2 Liquid Explosive Emergency Exit System

1085. Jaglowski, J.J., Jr. Feasibility Study and Initiating System Development of Explosive Exit Concept for Civil Transport Aircraft. Department of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, D.C., Technical Report No. FAA-DS-70-8, April, 1970.

1086. Jaglowski, J.J., Jr. Development and Test of the Explosive Exit Concept for Civil Transport Aircraft. Department of Transportation, Federal Aviation Administration, Systems Research and Development Services, Washington, D.C., Technical Report No. FAA-RD-71-33, July, 1971, AD727 348.

7.6 Emergency In-Flight Egress

1087. AGARD. Escape Measures for Combat Helicopter Crews. Advisory Report No. AR-62 NATO (AGARD-AR-62), August, 1973.

1088. Arnold, J.H., and F.B. Pollard. "Emergency Helicopter Crew, Passenger and Vehicle Survival and Recovery Techniques." Proceedings, Fifth National Flight Safety, Survival and Personal Equipment Symposium, September, 1967, pp. B1-B11.

1089. Christy, R.L. "A Survey of Present Techniques for Emergency Escape from Aircraft." Physics and Medicine of the Upper Atmosphere, (C.S. White & O.O. Benson, Jr., Eds.), The University of New Mexico Press, Albuquerque, N. Mex., 1952, pp. 509-515.

1090. Dobbek, R.F. The Separable Crew Compartment Capsule for Emergency Escape. Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, pp. 205-222, n.d.

1091. Jones, W.L., (Ed.). Escaped Problems and Manoeuvers in Combat Aircraft. AGARD Conference Proceedings No. 134, AGARD-CP-134), February, 1974.

1092. Law, W.G. "Advanced Concepts for Rotary Wing and V/STOL Aircraft Escape Systems." Escape Problems and Manoeuvers in Combat Aircraft, (W.L. Jones, Ed.), AGARD Conference Proceedings, No. 134 (AGARD-CP-134), February, 1974.

1093. Ogden, W., and G. Davis. "In-Flight Escape System for Heavy Helicopters." Escape Problems and Manoeuvers in Combat Aircraft, (W.L. Jones, Ed.), AGARD Conference Proceedings, No. 134 (AGARD -CP-134), February, 1974.

1094. Pengelly, C.D. Model Testing Techniques for Investigating Jettisoning of Evacuation Capsules from Supersonic Aircraft. Paper presented at Symposium on the Problems of Emergency Escape in High Speed Flight, Wright Field, Ohio, 29 September, 1952.

1095. Product Engineering. "Safety Experts Propose Systems to Eject Airline Passengers." 2 February, 1970, p. 11.

1096. Sipes, W.J. "Emergency Escape and Inflight Safety Systems." Proceedings, Fifth National Flight Safety, Survival and Personal Equipment Symposium, September, 1967, pp. B49-B59.

1097. Wilkes, W.H. Escape from Multiplace Supersonic Aircraft. Paper presented at Symposium on the Problems of Emergency Escape in High Speed Flight, Wright Field, Ohio, 29 September, 1952.

7.6.1 Tail Evacuation

7.6.2 Paracone Concept

1098. Kendall, R.T. "The Paracone Airborne Drop." Ordnance, 1970.

7.6.3 Rapid Jet

1099. McIntyre, R.G. "Rapid Jet - A New Concept in Aircrew Escape for Large Multiplace Military Aircraft." Proceedings, Seventh National Flight Safety, Survival and Personal Equipment Symposium, Vol. 1, October, 1969, pp. 179-190.

7.6.4 Parachute Lowering of Fuselage

1100. "Airliner in Trouble May Parachute Down." Machine Design, Vol. 42, No. 2, January, 1970, p. 43.

1101. Millington, R., and D.F. Thompson. "Development of a Helicopter Capsule Escape System, Final Report." Boeing Co., Vertol Division Report. D8-0444, Oct., 1966.

1102. "Preliminary Design and Applicability Study of a Personnel Survival System." Boeing Co., Vertol Division, Vol. 1, Final Report, and Vol. 2, Final Report, May, 1968.

1103. Snyder, R.G., and J.P. Stapp. "Emergency In-Flight Evacuation from Future Commercial Air Transport Aircraft." Proceedings, Seventh National Flight Safety, Survival and Personal Equipment Symposium, Vol. 1, October, 1969, pp. 214-233.

1104. Teledyne McCormick Selph. "High Energy Helicopter Recovery System." Hollister, California, Preliminary Report No. 20-282, n.d.

1105. "Trade-Off Study of Component Jettison and System Severance for Helicopter Survival System." Boeing Co., Vertol Division, Dec., 1969.

1106. Winters, S.R. "A Plane-Size Parachute." Popular Aviation (Chicago), As reported in The Literary Digest, 27 October, 1928, p. 28.

ACKNOWLEDGEMENTS

This study was accomplished through the cooperation and assistance of many organizations and individuals during the past 30 months. The author wishes to acknowledge with gratitude the contributions of several in particular.

Appreciation is extended to Dr. Walton L. Jones, Director of Life Sciences, NASA Office of Manned Space Flight, and Chairman, AGARD Aerospace Medical Panel Biodynamics Committee, who encouraged the initiation of this study.

Assistance with aircraft accident files and data was provided by Gerard M. Bruggink, David Kelly, James Constantine, Gerrit J. Walhout, and Matthew M. McCormick of the Bureau of Aviation Safety, National Transportation Safety Board, Washington, D.C.; for Canada by D.J. Douglass, Supt., Aviation Safety Research Division, and Richard L. Newman, CATA STOL Project, Canadian Air Transportation Administration, Ottawa; for world data by Emily Zay, ICAO, Montreal; for the U.K. and world data by Laurence S. Edwards, Civil Aviation Authority, Liaison Officer, North America, British Embassy and R.S. Perry, Civil Aviation Authority, London.

Col. Kenneth Beers, Life Support System Office, Air Force Systems Command, Wright Patterson Air Force Base, Dayton, Ohio, provided valued technical assistance related to ELSIE, as did Ernest B. McFadden, Chief, Survival Equipment Research, Protection and Survival Laboratories, CAMI, Federal Aviation Administration, Oklahoma City, who gave generously of his time with regard to the smoke hood, emergency lighting, and emergency egress technical developments and evaluation.

Courteous consultation was provided relative to the A300B and Concorde developments by Jean-Luc Bersat, Bureau d'Etudes, by Paul Ducassé, Chief Engineer, A300B, and by C. Lenseigne, Head, Safety and Reliability Dept., S.N.l Aerospatiale, Toulouse, France.

Expert technical consultation on U.K. technology was provided by Squadron Leader David Reader, Wing Commander David Glaister, and Dr. J.G. Fitzgerald, Royal Air Force Institute of Aviation Medicine, Farnborough; and by Squadron Leader S.A. Cullen, Department of Aviation and Forensic Pathology and Tropical Medicine, Aylesbury.

Professional review of U.K. and NATO restraint developments was provided by K.J.B. Teesdale, Manager Safety Concepts, Ford Moter Company Research and Engineering Center, Basildon; and Dr. G. Murray MacKay, Department of Transportation and Environmental Planning, The University of Birmingham, England.

Particular thanks are due to Victor C. Pavey, Head, Interior Layout Group, Commercial Aircraft Division, British Aircraft Corporation, Ltd., Bristol, England, with regard to the Concorde and emergency evacuation; and to Harry Brownbill, Jerry Sascomb, regarding systems analysis; and Kenneth Dunn with respect to restraint systems and flight deck seating of the Concorde.

At Aeritalia, I. Ivaldi, Director of Ground Testing, M. Priolo, G222 Project Engineer, Mr. Kastor and Chesta Lorenzo of the Dynamics Office, Torino, Italy, gave freely of their time.

Advanced technology at Fokker-VFW BV, Schiphol-Oost, as related to the Fokker-VFW F-27 MK100-600 and F-28 1000-6000 series and other Netherlands developments was discussed with Ir. Bijlmer, Head, Research and Manufacturing; Mr. Earhardt, Mr. Coster, Assistant Director of Research, Dr. Quack, and Ir. P.F.A. Bijlmer, Chief Metals Research.

At Dornier GMBH, Research and Development Center, Immenstaad, Bordensee, Dipl. Ing. Friedhelm Zimmer and Weppler Roland courteously discussed the DO231M military transport, DO231C civil V/STOL Jet Transport development, and other stimulating West German air transport concepts. Dipl. Wirtsch, Ing. Gerald Wassum, International Relations, Aviation Development Programs, also discussed program developments.

In Oslo, consultation was accomplished through the courtesy of Lt. Col. Arne Borg, Chief Surgeon; Col. G. Odden, Chief of Operations and formerly Chief, Air Transport Squadron; Lt. Col. A. Granviken and Capt. Roald Alstad, Headquarters Flight Safety; and Lt. Col. Leif Lovestad, Liaison Officer, Royal Norwegian Air Force, Huseby; and Inspector Bjorn Ullebust, Chief of Aircraft Section, Directorate of Civil Aviation, Oslo, Norway.

Thanks also are due to the USAF AGARD Aerospace Medical Panel liaison officers Col. Donald I. Carter and Lt. Col. George S. Kush, whose thoughtful patience and encouragement are vastly appreciated.

Particular recognition is deserved by Karen Augustyn for her exhaustive editorial efforts over the final two months required to prepare, manage, and personally type the final manuscript.

David Zapp, University of Michigan major in Aerospace Engineering, provided some three months' effort in sifting through individual accident reports and many stacks of data. Assistance with illustrations was provided primarily by Elizabeth A. and Paul S. Nofs, and also by Steven Fisher and Carl Anderson, while secretarial support was provided by Carol Ann Birch. Acknowledgment is also made to my colleague, Dr. Hurley Robbins, Head, Biomathematics Dept., HSRI, The University of Michigan, for his systems contribution to the 1971 Air Force study which was used as a model for the present work. I am also grateful to Kathleen Weber and her staff at the Highway Safety Research Institute Information Center, The University of Michigan, who provided assistance with many hard to locate reference materials.

Many individuals provided technical information relative to specific inventions, devices, concepts and developments too numerous to list herein. However mention should be made of the assistance of Charles C. Kubokawa, Ames Research Center, NASA, Moffett Field, California, who is responsible for development of the NASA-Ames Air Transport Seat, and Fred L. Diamond, F.L. Diamond Co., Granada Hills, California, who generously shipped his DC-10 seat back deployment air bag restraint system for evaluation.

Generous assistance with technical review of various portions of the draft manuscript was provided by M. LeMedecin Général Gubernale, Executive Officer, Aerospace Medical Panel, AGARD, Paris, France; Médecin en Chef Classe J. Colin, Directeur Provisioirement de l'Ecole d'Application du Service de Santé pour l'Armée de l'Air et Centre de Recherches de Médecine Aeronautique, Paris, France (A.S.P.M.P. Co-ordinator for France); Air Commodore D.W. Atkinson, Director of Health and Research, Ministry of Defense, Royal Air Force, London; Squadron Leader David Reader, Royal Air Force Institute of Aviation Medicine, Farnborough; Major General (Generalstabsarzt) Heinz S. Fuchs, Amtschef Sanitatsmat der Bundeswehr, West Germany; Dr. Potten, Oberstazt, Abteilungsleit IV, Ergonomie, Flugmedizinisches Institut der Luftwaffe, Furstenfeldbruck, West Germany; Brig. General Gaetano Rotundo, M.D., Italian Air Force, Roma, AGARD ASMP Coordinator for Italy; and from the United States E.B. McFadden, Civil Aeromedical Institute, Federal Aviation Administration, Oklahoma City; Edward Santee, Boeing Commercial Airplane Company, Seattle; Vincent Curran, Eastern Airlines, Miami; John H. Enders, Chief, Aviation Safety Technology Branch, Office of Advanced Research and Technology, NASA Headquarters, Washington, D.C.; and C.O. Miller, President, System Safety, Inc., McLean, Virginia; and former Director, Bureau of Aviation Safety, National Transportation Safety Board.

The author is grateful to each of these individuals for the valuable critiques, comments, and information which have contributed greatly to the final product, however the author must take the sole responsibility for any errors in material contained herein not otherwise referenced. With any work of this scope, despite the attempt to document as accurately as possible, errors may still occur, and it is hoped that any corrections found by the reader may be brought to the author's attention.

This study is dedicated to Major General Thomas H. Crouch, MC USAF Ret., San Antonio, Texas, whose clinical skills have put back together many an air transport crewman, and at least one fighter pilot.

APPENDIX A

CIVIL AIR CARRIER ACCIDENTS*
UNITED STATES
(1964-1974)

1974	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 11	Grumman G-21	Kodiak	Missing	Fatal	5	0	0	0	1	0	4	Missing. Presumed dead.
12 01	Boeing 727	Northwest	Nr. Stony Pt., N.Y.	Fatal	3	0	0	0	3	0	0	Cause of crash undetermined. Pilot sent Mayday stating aircraft in stall.
12 01	Boeing 727	TWA	Nr. Washington, D.C.	Fatal	92	0	0	0	3	4	85	Aircraft descended below MOCA, crashed into high ground. Not survivable.
11 25	Boeing 727	Delta	Flushing, N.Y.	None	53	0	0	0	0	0	0	Collided with parked aircraft during taxi.
11 21	Douglas DC-9	Eastern	Jamaica, N.Y.	None	28	0	0	0	0	0	0	Collided with aircraft on ground.
11 21	Boeing 747	Northwest	Jamaica, N.Y.	None	22	0	0	0	0	0	0	Collided with DC-9 during taxi.
11 21	British AC 1-11	Allegheny	Albany, N.Y.	Serious	50	0	0	1	0	0	0	Elderly passenger slipped and fell while deplaning.
11 06	Douglas DC-8	Delta	Detroit, Mich.	Serious	126	0	0	1	0	0	0	Elderly passenger fractured ankle in turbulence. Seat belt sign off.
10 30	Lockheed 382	Alaska Int.	Nr. Bettles, Alaska	Fatal	4	0	0	0	4	0	0	Aircraft crashed due to wing separation inflight. Not survivable.
09 21	Boeing 747	Northwest	No. Pacific	Serious	300	0	0	1	0	0	0	Injury due to turbulence.
09 20	British AC 1-11	Allegheny	Pittsburgh, Pa.	Serious	50	0	0	1	0	0	0	Child thrown from seat in turbulence.
09 12	DeHavilland DHC-6	Wien Alaska	Kipnak, Alaska	None	11	0	0	0	0	0	0	Ground loop. Gear collapsed.
09 11	Douglas DC-9	Eastern	Charlotte, N.C.	Fatal	82	1	0	9	1	1	69	Aircraft crashed during instrument approach Crash partially survivable. Fuselage fractured on impact with tail section, including last 5 rows of seats, only part to retain any structural integrity. Fire erupted in cabin during crash sequence. Crash forces within human tolerability but most pass. found outside the 2 main cabin wreckage areas, indicating restraint failures. Restraints in last 5 rows remained intact, but most occupants who survived crash there, died due to post crash fire. Aux. exit through tail useable but attendant probably unable to open it because of her injuries. All survivors in rear of aircraft, either thrown out of wreckage or crawled through holes in fuselage. 3 survivors in forward section including copilot and stewardess crawled out cockpit window.

*Includes Pertinent Incidents.

1974	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
													31 passengers and 1 crewmember died from impact. 25 passengers died from burns and smoke inhalation. 1 passenger died from smoke inhalation. Remaining 5 in aft area died from combination of factors. Also, survivors wearing man made double knit clothing received more severe burns.
09 08	Boeing	707	TWA	In Ionian Sea	Fatal	88	0	0	0	3	6	77	Aircraft exploded in flight due to bomb in cargo area. Crash not survivable.
09 01	Douglas	DC-9	Eastern	Meridian, Miss.	Serious	64	0	1	0	0	0	0	Attendant injured in turbulence.
08 02	Lear	24	Jetway	Nr. Shoemakersville, Pa.	None	2	0	0	0	0	0	0	Aircraft made forced landing off airport due to fuel exhaustion.
07 27	Douglas	DC-8	Delta	Ft. Myers, Fla.	Serious	175	0	1	0	0	0	0	Attendant injured in turbulence. Seat belt sign on. 1 attendant thrown from seat when belt opened.
07 24	British	AC 1-11	Allegheny	Cleveland, Ohio	Serious	71	0	0	1	0	0	0	Passenger twisted ankle while deplaning. Fell down forward stair.
07 10	Boeing	727	American	Chicago, Ill.	Serious	53	0	0	1	0	0	0	False inflight fire warning. Passenger injured in evacuation.
07 08	Douglas	DC-10	National	Tampa, Fla.	None	172	0	0	0	0	0	0	Engine cowl separated in flight.
07 03	Lockheed	L1011	Delta	Nr. Atlanta, Ga.	Serious	151	0	0	2	0	0	0	Attendants injured in turbulence. TSTM in area. Belt sign on.
06 13	Douglas	DC-3	North Cay Airways	San Juan, P.R.	None	28	0	0	0	0	0	0	Engine fire during climbout. Landed without incident.
05 23	Lockheed	382	Saturn	Springfield, Ill.	Fatal	4	0	0	0	3	0	1	Wing separated inflight. Not survivable.
05 13	Boeing	707	Air France	O'Neill, Neb.	Serious	111	0	2	13	0	0	0	Aircraft operating in area of severe turbulence with no warning to passengers given. TSTM forecast and ground radar receiving echoes. Pass. observed intense lightning up to 30 min. before accident. Seat belt sign not on. Elderly lady suffered fractured ankle, and elderly man dislocated knee. Other injuries included severe cuts and skin abrasions. All injuries sustained by persons not secured by seat belts. Flight continued to Paris nonetheless.

1974	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
04 22	Boeing	707	Pan Am	Bali	Fatal	107	0	0	0	4	7	96	Aircraft struck mountain ridge. Not survivable.
04 18	Cessna	185	Howard Mays	Pt. Wakefield, Alaska	None	4	0	0	0	0	0	0	Aircraft nosed over during water landing.
04 02	Convair	240	Texas Int.	Arlington, Texas	Serious	14	0	1	0	0	0	0	Attendant injured in turbulence.
04 01	Boeing	707	TWA	Rosewood, Ohio	Serious	61	0	0	1	0	0	0	Passenger injured in unexpected severe turbulence.
04 01	Boeing	727	TWA	Terre Haute, Ind.	Serious	51	0	0	1	0	0	0	Elderly passenger thrown from seat in turbulence.
03 27	Douglas	DC-8	World	Anchorage, Alaska	Serious	233	0	0	1	0	0	0	Passenger injured during evacuation. Minor fire.
03 21	Lockheed	L1011	Eastern	Ft. Lauderdale, Fla.	Serious	186	0	0	1	0	0	0	Passenger injured in turbulence. Out of seat while belt sign on.
03 16	Cessna	185	Kodiak	New Stuhyahok, Alas.	None	2	0	0	0	0	0	0	Collided with snowbank on landing.
03 13	Convair	340	Sierra Pacific	Nr. Bishop, Cal.	Fatal	36	0	0	0	2	2	32	Aircraft crashed into ridge during climbout Not survivable.
02 21	Douglas	DC-9	Delta	Pontiac, Ill.	Serious	42	0	1	0	0	0	0	Attendant injured in CAT.
02 16	Boeing	707	TWA	Herndon, Va.	Serious	52	0	1	0	0	0	0	Attendant injured when galley coffee maker exploded during flight.
02 15	Douglas	DC-9	Delta	Alexandria, La.	Serious	69	0	1	0	0	0	0	Attendant injured in turbulence.
02 02	Boeing	747	Pan Am	Honolulu	Fatal	299	0	0	0	0	0	1	16 month old child asphyxiated by seat belt while unattended.
01 30	Boeing	707	Pan Am	Pago-Pago, American Samoa	Fatal	101	0	0	5	4	6	86	Accident was survivable. Only co-pilot sustained traumatic injuries after impact. Cabin structure remained intact and occupant restraint systems were adequate for crash forces. All other fatalities and injuries due to post crash fire. Primary emergency exits were not opened by crew. Passengers also crowded to the front and rear exits, ignoring window exits. All survivors were seated in the middle of aircraft, and had observed pre-flight briefing.
01 17	Boeing	707	TWA	Indianapolis, Ind.	None	3	0	0	0	0	0	0	Aircraft collided with runway lights. Gear collapsed.

1974	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
01 16	Boeing	707	TWA	Los Angeles	Serious	65	0	0	8	0	0	0	Excessively hard landing caused collapsing of nose gear. Aircraft destroyed by fire, but injuries were sustained while exiting aircraft, not by flames. Aircraft evacuated in 30-45 seconds.
01 13	Convair	580	Frontier	Cheyenne, Wyo.	Serious	47	0	1	0	0	0	0	Flight attendant injured in moderate turbulence.
01 06	Beechcraft	99	Air East, Inc.	Johnstown, Pa.	Fatal	17	1	0	4	1	0	11	Aircraft crashed while descending below published MDA. Crash basically not survivable due to high vertical impact loads. Occupiable space reduced substantially. Seat belts remained buckled but their floor anchorages, and seat tracks failed. No post crash fire. All injuries and fatalities due to impact.
01 04	Boeing	727	United	Tampa, Fla.	Serious	118	0	0	1	0	0	0	Engine failure on takeoff. Passenger injured while evacuating aircraft.
01 01	Boeing	707		San Antonio, Texas	None	129	0	0	0	0	0	0	Collision with aircraft while taxiing.

1973	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 22	Boeing 727	American	Detroit	Serious	94	0	0	1	0	0	0	Passenger injured during evacuation due to bomb threat.
12 21	Douglas DC-9	Delta	W. Lebanon, N.H.	Serious	94	0	1	0	0	0	0	Attendant injured in unforecasted CAT.
12 17	Douglas DC-9	Eastern	Greensboro, N.C.	Minor	89	0	0	0	0	0	0	Aborted takeoff on snow covered runway. Skidded off. Post crash fire.
12 17	Douglas DC-10	Iberian	Boston	Serious	167	0	1	15	0	0	0	Aircraft struck approach light piers during ILS approach. Then struck embankment and skidded to stop. After first impact captain's seat became loose and slid to its aft limits of travel. Post crash fire did occur but was extinguished before spreading. Injuries resulted only from evacuation. Cabin attendants could not open 3 of the exit doors. Aft cabin floor buckled causing failures of some restraint components, but no seats became completely detached. 5 persons trapped in aft cabin because aisles blocked. 4 escaped through fracture in top of fuselage. 3 of 4 were hospitalized when they slid off fuselage. 1 fractured ankle, 1 fractured pelvis, 1 fractured ankle and compression fracture of vertebra.
12 15	Lockheed L-1049	Aircraft Pool Leasing Co.	Miami, Fla.	Fatal	3	0	0	0	3	0	0	Aircraft crashed into residential area after departure killing 6 and injuring 2 people on the ground. Crash was not survivable due to impact. Post crash fire did occur.
11 27	Douglas DC-9	Eastern	No. Canton, Ohio	Serious	26	2	3	21	0	0	0	Aircraft overran runway on landing, plunging down 38 ft. embankment. No post crash fire. High vertical impact forces accounted for all injuries. Cabin and cockpit remained intact, but some head injuries were caused by the collapse of overhead racks onto seat backs during final impact; this also interfered with use of overwing exits. Evacuation was effective and orderly.

1973	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
11 27	Douglas DC-9	Delta	Chattanooga, Tenn.	Serious	79	2	2	38	0	0	0	Aircraft crashed during ILS approach. Crash was survivable with fuselage retaining structural integrity. Scattered fires occurred around fuselage, but died out or were extinguished. Flash fire occurred in rear of cabin but caused no serious injury. Emergency lighting was either inoperative or obscured by heavy smoke from fire in baggage compartment, making visibility very poor and hampering evacuation. Debris in aisle from galley also interfered with movement. Evacuation completed in 2 to 3 minutes. All injuries result of impact.
11 03	Boeing 707	Pan Am	Boston	Fatal	3	0	0	0	3	0	0	Aircraft crashed while on final approach. Crew reported excessive smoke in cockpit, which reached such severity that aircraft could not be controlled. Smoke caused by improper packaging of hazardous cargo. In this case nitric acid packed in sawdust. Crash was not survivable.
11 03	Douglas DC-10	National	Nr. Albuquerque	Fatal	128	0	4	20	0	0	1	No. 3 engine disintegrated in flight. Resulting damage caused inflight decompression with one passenger killed when he was pulled out of a blown out window. Passenger's safety belt was loosely connected. Smoke filled aft part of cabin following decompression. Deployment of passenger oxygen masks was unsuccessful in some parts of the cabin, and took as long as 3 minutes in other parts. Some passengers ignorant of use of mask. Injuries caused by decompression and smoke inhalation.
10 28	Boeing 737	Piedmont	Greensboro, N.C.	Minor	96	0	1	4	0	0	0	Aircraft overran runway on landing. Cabin remained intact. Cabin evacuated in orderly manner. Small post crash fire outside of fuselage caused no injury.

1973	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
10 08	Douglas DC-8	Flying Tiger	Tokyo, Japan	Fatal	3	0	0	0	0	0	0	Ground crewman run over during exit from gate.
09 27	Convair 600	Texas Inter.	Mena, Arkansas	Fatal	11	0	0	0	2	1	8	Aircraft operating visually in instrument conditions in mountainous terrain. Crashed into side of ridge, was not survivable.
09 08	Douglas DC-8	World Airways	King Cove, Alaska	Fatal	6	0	0	0	3	0	3	Aircraft deviated from published instrument procedures and crashed into mountainous terrain. Crash was not survivable.
09 04	Boeing 747	American	N. Atlantic Ocean	Serious	346	0	0	1	0	0	0	Passenger injured in CAT. Was not in seat at time.
08 28	Boeing 707	TWA	Los Angeles, Cal.	Fatal	152	0	2	2	0	0	1	While descending for LA, aircraft experienced violent pitch oscillations for a period of about 2 min. The passenger who died and those who were injured seriously were all standing in the aft part of cabin near galley and lavatory. The oscillations repeatedly threw them against floor and ceiling. Other passengers had minor injuries when thrown against arm rests and aircraft interior. 2 passengers had to change seats because of seat belt failure.
08 27	Boeing 707	TWA	No. Atlantic	Serious	84	0	0	1	0	0	0	Passenger injured in turbulence while standing in aisle.
08 25	Lockheed L-1011	Eastern	Nr. Grand Truk Is., Bahamas	Serious	179	0	0	1	0	0	0	Passenger injured in CAT.
08 23	Grumman G-21A	Kodiak	Togiak, Alaska	Minor	1	0	0	0	0	0	0	Ground-water loop.
08 22	Boeing 737	Frontier	Nr. Rapid City, S.D.	Serious	46	0	1	0	0	0	0	Aircraft oscillations caused injury of crewmember.
08 15	British AC 1-11	Allegheny	Nr. Baltimore, Md.	Serious	43	0	0	1	0	0	0	Passenger injured in turbulence. Seat belt sign on but passenger belt not fastened.
08 10	Douglas DC-10	National	Nr. New Orleans	Serious	213	0	1	0	0	0	0	Attendant injured while removing food service cart from lift.
08 08	Boeing 727	Braniff	Washington, D.C.	None	81	0	0	0	0	0	0	Tire failure on takeoff. Fire in landing gear area.
07 31	Douglas DC-9	Delta	Boston, Mass.	Fatal	89	0	0	1	3	3	82	Aircraft crashed into seawall at threshold of runway while on ILS approach. Crash not survivable. Controllers did not know of crash and had cleared 2 other aircraft to land after the accident. Both went around

1973	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
												because of weather. The lone survivor died 5 months later.
07 28	Grumman G-21A	Kodiak	Nr. Kodiak, Alaska	None	5	0	0	0	0	0	0	Encountered local cyclonic conditions and water spout during landing.
07 24	Boeing 737	Frontier	Nr. St. Louis	Serious	25	0	1	0	0	0	0	Attendant injured in turbulence near TSTM activity.
07 23	Fairchild 227B	Ozark	St. Louis	Fatal	44	2	0	4	0	1	37	Aircraft crashed while shooting ILS in TSTM activity. Crash was basically not survivable due to severe damage to cabin section on impact. All passenger seats but one were torn loose from floor. 3 seat belts failed. Both pilots did survive, since the cockpit remained relatively intact, but their injuries probably could have been greatly reduced had they had shoulder restraints. Cabin attendant was killed by cargo after the cargo restraint net failed.
07 22	Boeing 707	Pan Am	Papeete, Tahiti	Fatal	79	0	0	1	4	6	68	Aircraft crashed on takeoff. Investigation under jurisdiction of French government.
06 29	Boeing 737	Western	Nr. W. Yellowstone, Montana	Serious	39	0	1	0	0	0	0	Tires failed on takeoff. Friction fire started in landing gear area.
06 26	Cessna 402A	Kodiak	Dillingham, Alaska	None	2	0	0	0	0	0	0	Inadvertently retracted gear on landing.
06 23	Douglas DC-8	Icelandic	Jamaica, N.Y.	Serious	128	1	1	6	0	0	0	Full spoilers deployed inadvertently just before landing. Severe vertical loads on crash landing caused all injuries. Post crash fire did occur but was extinguished quickly. Evacuation was orderly. Injuries included neck/back strains, fractures to vertebrae.
06 21	Douglas DC-7	Skyways Int.	Dade County, Fla.	Fatal	3	0	0	0	3	0	0	Aircraft crashed while climbing out on takeoff in area of severe TSTM's. Inflight fire did occur. Aircraft crashed out of control. Accident not survivable.
06 20	Douglas DC-8	ONA	Bangor, Maine	Serious	261	0	0	3	0	0	0	Aircraft aborted takeoff after tire failure Fire in landing gear area. Evacuation of aircraft did not begin until 3 min. after aircraft came to a stop. Confusion as to location of fire. Left engines left idling for more than 3 min. after aircraft stopped and for nearly 2 min. after door light came

1973	Type Model Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
											on. Not all attendants at stations and they did not make use of megaphones so no clear instructions were given to passengers All injuries sustained during evacuation.
06 17	Convair 580 Allegheny	Pittsburgh, Pa.	Minor	53	0	0	0	0	0	0	Nose gear collapsed on takeoff.
06 04	Grumman G-44A Kodiak	Dillingham, Alaska	Serious	1	1	0	0	0	0	0	Lost control of aircraft on landing due to wake turbulence.
04 26	Boeing 747 Northwest	Tallahassee, Fla.	Serious	101	0	0	1	0	0	0	Passenger injured due to CAT. No warning given by crew.
04 19	Beech E18 Air Iowa	Davenport, Iowa	Fatal	6	0	0	0	1	0	5	Crash due to inflight wing separation. Accident not survivable.
04 13	Saberliner NA-265-60 Continental	Montrose, Colorado	Fatal	2	0	0	0	2	0	0	Aircraft crashed on takeoff due to deployed thrust reverser. Accident was not survivable.
04 10	Boeing 727 Eastern	Toledo, Ohio	None	37	0	0	0	0	0	0	Aircraft struck trees while executing instrument approach. Aircraft went around and then landed without incident. No equipment standby requested and controllers were not informed of accident.
04 09	Boeing 707 Pan Am	Miami, Fla.	None	3	0	0	0	0	0	0	Nose gear collapsed during taxi.
04 01	Douglas DC-9 Delta	New York-Atlanta	Serious	55	0	1	0	0	0	0	Attendant injured in CAT. TSTM in area.
03 17	Lockheed L-3826 Saturn	Pensacola, Fla.	None	3	0	0	0	0	0	0	Nose gear collapsed on landing.
03 17	Boeing 727 United	Nr. Harrisburg, Pa.	Serious	76	0	2	0	0	0	0	Moderate to severe turbulence due to TSTM's in area.
03 05	Boeing 707 American	Denver, Colo.	None	3	0	0	0	0	0	0	Pilot lost control of aircraft on takeoff. Post crash fire did occur.
03 03	Boeing 727 TWA	Wichita, Kansas	None	67	0	0	0	0	0	0	Gear collapsed on rollout.
02 28	Douglas DC-8 Delta	Nr. Las Vegas	Serious	128	0	1	0	0	0	0	Injury due to turbulence.
01 20	Boeing 707 American	Elk Grove Village, Illinois	None	72	0	0	0	0	0	0	Engine failure.
01 12	Lockheed L-1011 Eastern	Miami	None	13	0	0	0	0	0	0	Hard landing.

1972	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 29	Lockheed	L-1011	Eastern	Miami, Fla.	Fatal	176	1	9	67	3	2	94	Aircraft crashed in low cruise configuration. NTSB did not consider this survivable accident. Most survivors located near cockpit area, mid cabin service area, overwing area, and empennage section, all located at far end of wreckage path. Most fatalities found in center of crash path. Cabin structure nearly disintegrated. Survival of many of occupants due to passenger seat design. Flash fire developed after impact causing some passengers to suffer various degrees of burns.
12 28	Lockheed	L-1011	Eastern	Atlantic City, N.J.	None	110	0	0	0	0	0	0	Engine failure during cruise.
12 20	Douglas	DC-9	North Central	Chicago, Ill.	Fatal	45	0	0	9	0	0	10	Collision between these two aircraft occurred as DC-9 was taking off and 880 was taxiing across active in fog. The Convair received substantial damage but only 2 passengers suffered minor injuries during evacuation. DC-9 was destroyed. All fatalities occurred due to post crash fire. 9 out of the 10 failed to escape from aircraft. Inadequate lighting in cabin hampered evacuation. Crew's evacuation procedures inadequate.
12 20	Convair	880	Delta	Chicago, Ill.	None	93	0	0	0	0	0	0	
12 15	Boeing	747	Northwest	Miami, Fla.	Minor	160	0	0	0	0	0	0	Aircraft overran runway on landing. Minor injuries suffered during evacuation.
12 12	Boeing	707	TWA	Jamaica, N.Y.	None	3	0	0	0	0	0	0	Aircraft crashed during ILS approach. Crew escaped. No post crash fire.
12 08	Boeing	737	United	Chicago, Ill.	Fatal	61	0	1	15	3	0	40	Aircraft crashed on approach. Aircraft destroyed by impact and post crash fire. Fatalities caused by impact, smoke inhalation, and burns. No cabin lighting after crash. Most survivors located in aft section of cabin.
12 04	Convair	580	Frontier	Nr. Alamosa, Colo.	Serious	17	0	1	0	0	0	0	Attendant injured due to severe turbulence.
11 08	Boeing	727	Eastern	Atlanta, Ga.	None	3	0	0	0	0	0	0	Gear collapsed while taxiing.

1972	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
11 01	Boeing 707 TWA	St. Louis	Serious	81	0	0	1	0	0	0	Engine fire on landing rollout. Passenger injured in evacuation.
11 01	Fairchild FH227B Piedmont	Winston-Salem, N.C.	Serious	16	0	1	0	0	0	0	Miscellaneous acc.
10 30	Boeing 727 Northwest	Washington, D.C.	None	27	0	0	0	0	0	0	Gear collapsed during taxi.
10 24	Boeing 707 Pan Am	Gulf of Mexico	Serious	156	0	0	1	0	0	0	Passenger injured in turbulence when ignored seat belt sign.
10 16	Cessna 310C Pan Alaska	Anchorage-Juneau	Fatal	4	0	0	0	1	0	3	Aircraft missing.
10 01	Boeing 727 United	San Francisco	Minor	97	0	0	0	0	0	0	Aircraft collided with runway or approach lights.
09 30	Boeing 727 Delta	Nr. Norfolk, Va.	Serious	51	0	1	2	0	0	0	Injuries due to turbulence when operating in TSTM area.
09 28	Douglas DC-9-32 Delta	Chicago	None	34	0	0	0	0	0	0	Hard landing.
09 26	Lockheed L188A Reeve Aleutian Air.	Amchitka, Alaska	None	25	0	0	0	0	0	0	Collided with runway approach lights.
09 13	Boeing 707 TWA	San Francisco	None	3	0	0	0	0	0	0	Aircraft overran runway on aborted takeoff.
09 01	Boeing 747 TWA	Jamaica, N.Y.	Serious	353	0	0	8	0	0	0	Landing gear fire during taxi. Evacuation alarm procedure improper.
08 14	Fairchild FH227B Ozark	Chicago, Ill.	None	29	0	0	0	0	0	0	TSTM caused structural damage while aircraft was still on ground.
08 13	Boeing 707 JAT	Jamaica, N.Y.	Serious	186	0	1	15	0	0	0	Aircraft overran runway on aborted takeoff. Post crash fire did occur but did not cause injury. All injuries due to evacuation. No formal evacuation procedures used. Debris from galley cluttered aisles.
07 22	Convair 880 Delta	Nr. Knoxville, Tenn.	Serious	71	0	0	1	0	0	0	Injury due to turbulence when build ups were penetrated. Seat belt sign activated late.
07 18	Boeing 707 TWA	Nr. Windsor Lock, Conn.	Serious	56	0	1	0	0	0	0	Attendant injured during turbulence. TSTM's in area.
06 29	Convair 580 North Central	Nr. Appleton, Wis.	Fatal	5	0	0	0	2	1	2	Midair collision between these 2 air-
06 29	DeHavilland DHC-6 Air Wisc.	Nr. Appleton, Wis.	Fatal	8	0	0	0	2	0	6	craft. Crash not survivable.
06 28	Boeing 727 TWA	Nr. Gary, Indiana	Serious	71	0	1	0	0	0	0	Aircraft encountered small CU. Seat belt sign on. Attendant injured.
06 24	DeHavilland DH114 Prinair	Ponce, Puerto Rico	Fatal	20	0	0	15	2	0	3	Aircraft crashed during attempted go around due to automobile on runway. Cockpit area was completely destroyed. Causes of fatalities not given.

1972	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
06 22	Beech	E185	Aero Taxi	Cleveland, Ohio	Fatal	1	0	0	0	1	0	0	Aircraft crashed due to inflight wing separation. Crash not survivable.
06 21	Nihon	YS-11A	Piedmont	Nr. Washington, D.C.	Serious	24	0	1	0	0	0	0	Attendant injured in turbulence. Hurricane in area.
06 14	Douglas	DC-9	Southern	Chicago	None	22	0	0	0	0	0	0	Hard landing.
06 12	Douglas	DC-10	American	Nr. Windsor, Ont.	Minor	67	0	2	9	0	0	0	Decompression in flight caused aft cabin floor to buckle. Control malfunction. One passenger injured when struck by floor hatch. Passengers near damaged area relocated. Evacuation very effective and orderly. Injuries sustained in evacuation due to fact that passengers could not stabilize themselves going down the double occupancy slide, and were not in "feet first" position when they reached the ground.
06 10	Boeing	727	American	Flushing, N.Y.	Serious	77	0	2	0	0	0	0	Explosion of portable oxygen bottle on ground when turned on for passenger's use.
05 30	Douglas	DC-9	Delta	Ft. Worth, Texas	Fatal	4	0	0	0	3	1	0	Aircraft crashed on landing due to wake turbulence from DC-10. Cockpit area not survivable, but cabin remained relatively intact and the one occupant may have survived had there been no post crash fire.
05 18	Douglas	DC-9	Eastern	Ft. Lauderdale	Serious	9	1	1	1	0	0	0	Excessively hard touchdown caused main gear to collapse and separation of tail section from fuselage. Fire broke out on impact which destroyed fuselage. All occupants exited through forward main door. 3 passengers used escape chute, 3 jumped before deployment. All injuries due to impact forces.
05 10	Douglas	DC-9	Eastern	Atlanta	None	4	0	0	0	0	0	0	Fire in aircraft while parked due to short in electrical system.
05 08	Convair	600	Texas Inter.	Alexandria, La.	None	15	0	0	0	0	0	0	Nose gear collapsed on landing rollout.
05 07	Douglas	DC-8	Braniff	Nr. Santiago, Chile	Serious	85	0	0	2	0	0	0	Injuries due to CAT.
05 06	Boeing	747	Northwest	No. Pacific Ocean	Serious	128	0	0	1	0	0	0	Passenger injured in CAT while in lavatory.
05 02	Douglas	DC-10	Continental	Tucson, Ariz.	None	9	0	0	0	0	0	0	Incident. Engine failure in flight.

1972	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
04 26	Boeing 720B Northwest	Nr. Front Royal, Va.	Minor	84	0	2	0	0	0	0	Near midair collision between 720 and a Lockheed Corp. Convair 240. 2 attendants injured in 720 due to violent manuevering to avoid collision.
04 21	Douglas DC-8 Eastern	San Juan, P.R.	Fatal	94	0	0	0	0	0	0	Aircraft struck man on runway during takeoff.
04 21	Boeing 747 Northwest	No. Pacific Ocean	Serious	160	0	5	9	0	0	0	Aircraft encountered CAT. Seat belt sign had been turned off but passengers advised to keep them fastened. 2 children seriously injured. Small boy suffered fractured left arm just above elbow, and small girl sustained dislocated right shoulder. Other injuries were minor bruises, abrasions, and lacerations. Deficiencies reported in first aid equipment.
04 11	Sikorsky S-616 New York Airways	Jamaica, N.Y.	None	20	0	0	0	0	0	0	Helicopter collided with parked aircraft.
03 28	Convair 880 Delta	Nr. Little Rock, Ark.	Serious	58	0	1	2	0	0	0	Injuries due to turbulence in area of TSTMs No warning given to passengers.
03 19	Lockheed 188 Universal	Hill AFB, Utah	None	3	0	0	0	0	0	0	Engine failure in flight.
03 19	Douglas DC-9 Delta	Atlanta	None	87	0	0	0	0	0	0	Engine failure on takeoff. Fire occurred in engine and cabin areas.
03 11	Convair 580 Allegheny	Windsor Locks, Conn.	None	20	0	0	0	0	0	0	Engine failure during reverse thrust on landing roll. Aircraft swerved off runway.
03 08	Boeing 747 Pan Am	London, England	None	213	0	0	0	0	0	0	Both aircraft collided on ground during
03 08	Boeing 707 Pan Am	London, England	None	35	0	0	0	0	0	0	taxi.
03 05	Fairchild FH-227 Mohawk	Islip, N.Y.	Fatal	29	0	0	0	0	0	0	Ground crewman ran into prop while aircraft parked.
03 03	Fairchild FH-227 Mohawk	Albany, N.Y.	Fatal	48	0	1	31	2	0	14	Aircraft crashed on approach. Crash partially survivable. Parts of fuselage collapsed but some occupiable space in fore and aft ends of cabin. Crash forces within survivable limits for humans, but exceeded seat design limits. Most seats failed and most passengers thrown to forward part of cabin. No post crash fire. Cabin emergency lighting did not function. Only 1 passenger was able to evacuate aircraft before rescue crews came. Both pilots might have sur-

1972	Type Model	Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
												vived had they had shoulder restraints.
02 26	Douglas DC-8-51	Delta	Nr. Alma, Ga.	Serious	94	0	0	2	0	0	0	Injuries due to turbulence. 1 passenger hit by flying object, other thrown from seat when inadvertently released belt.
02 22	Beech D-18	ALII Air Hawaii	Hawaiian Islands	Fatal	8	0	0	0	1	0	7	Aircraft crashed into ocean in TSTM area. Cause unknown. Accident not survivable.
02 20	Beech 65B-80	Sun Valley	Fairfield, Idaho	Fatal	5	0	0	0	1	0	4	Aircraft crashed from engine fire in-flight which resulted in structural failure. Accident not survivable.
02 19	Boeing 727	Eastern	Washington, D.C.	Serious	88	0	0	1	0	0	0	Evacuation due to false fire alarm while aircraft parked. Passenger exited through window off wing with small child.
02 16	Convair 600	Texas Inter.	Beaumont, Texas	None	3	0	0	0	0	0	0	Engine failure during go around.
02 10	Lockheed 382E	Southern Air Trans.	Montaluo, Ecuador	None	3	0	0	0	0	0	0	Hard landing. Gear collapsed.
01 04	Boeing 747	National	Nr. Lake Charles, La.	Serious	330	0	1	4	0	0	0	Flight encountered turbulence. Seat belt sign on and prior warning had been given by crew. Other passengers and crew suffered minor injuries. Injured passengers did not have belts on or they were fastened loosely Deficiencies reported in first aid equipment.

1971	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 29	Boeing 727	Frontier	Nr. Kansas City, Mo.	Serious	92	0	0	1	0	0	0	Passenger injured in turbulence. Prior warning given. Not in seat.
12 23	Douglas DC-8	Eastern	No. Atlantic Ocean	Serious	146	0	1	0	0	0	0	Attendant injured in turbulence. No warning given.
12 21	Boeing 727	Eastern	Atlanta	None	3	0	0	0	0	0	0	Landing gear struck approach lights on landing.
12 17	Beech A99A	Texas Inter.	Houston, Texas	None	14	0	0	0	0	0	0	Landing gear failed to extend. Gear up landing.
12 12	Boeing 707	TWA	Nr. Kingston, N.Y.	Serious	33	0	0	1	0	0	0	Passenger injured in turbulence.
12 04	Douglas DC-9	Eastern	Raleigh, N.C.	Fatal	27	0	0	0	0	0	0	Aircraft collided with Cessna 206 during approach. Both occupants of Cessna were killed. DC-9 landed without incident.
11 24	Beech 99A	Frontier	Nr. Greeley, Colo.	None	8	0	0	0	0	0	0	Prop failure in flight.
11 17	Boeing 727	United	Nr. Milwaukee, Wis.	None	36	0	0	0	0	0	0	Engine failure in flight.
11 13	Boeing 707	TWA	Nr. Honolulu, Hawaii	Serious	97	0	0	1	0	0	0	Encountered CAT.
10 24	Beech 99A	Monmouth	Allentown, Pa.	Fatal	8	0	0	4	2	0	2	Aircraft crashed into mountain during instrument approach. Crash partially survivable. Post crash fire occurred with explosions which destroyed cockpit and cabin area. Survivors still strapped in their seats after fuselage came to rest. Able to evacuate before fire spread.
10 21	Beech E185	Chicago and Southern	Peoria, Ill.	Fatal	16	0	0	0	2	0	14	Aircraft struck high tension lines during approach. Crash not considered survivable. Fatalities due to impact and intense post crash fire.
10 09	Douglas DC-9	Delta	Chicago, Ill.	Fatal	16	0	0	0	0	0	0	Driver of ground vehicle killed when he struck wing of parked aircraft.
09 23	Boeing 707	TWA	Barcelona, Spain	Serious	119	0	0	2	0	0	0	Aircraft encountered turbulence immediately after seat belt sign turned on.
09 04	Boeing 727	Alaska Airlines	Nr. Juneau, Alaska	Fatal	111	0	0	0	3	4	104	Aircraft crashed into mountainous terrain during approach. Crash not survivable.
08 20	Convair 580	Allegheny	Pittsburgh, Pa.	None	53	0	0	0	0	0	0	Gear collapsed on landing.
08 19	Piper PA-31	Downeast	Augusta, Maine	Fatal	8	0	0	5	1	0	2	Aircraft crashed while on instrument approach. No information given as to survivability aspects.
08 18	Douglas DC-9	Delta	Nr. Savannah, Ga.	None	61	0	0	0	0	0	0	Aircraft damaged due to bird strike.

1971	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
08 16	Pilatas	PC6-H2	Wien Air Alaska	Akiak, Alaska	None	2	0	0	0	0	0	0	Gear collapsed after striking object on landing.
08 14	Douglas	DC-8	United	Yokota AB, Japan	None	4	0	0	0	0	0	0	Cargo shifted to rear of aircraft on take-off. Aborted OK.
08 08	Vickers	745D	Aloha	Honolulu	None	22	0	0	0	0	0	0	Fire occurred in aircraft after touchdown. Aircraft stopped on runway and evacuated without incident.
08 05	Convair	880	Delta	Nr. Spartanburg, S.C.	Serious	79	0	1	0	0	0	0	Attendant injured in turbulence. TSTM in area.
08 04	Boeing	707	Continental	Compton, Calif.	Serious	96	0	0	0	0	0	0	Midair collision between Boeing and Cessna 150. Boeing landed without incident. Instructor in Cessna seriously injured. Student received minor injuries.
07 30	Boeing	747	Pan Am	San Francisco	Serious	218	0	0	29	0	0	0	Aircraft damaged on takeoff when it struck approach lights. Takeoff continued, then returned to land. Two passengers seriously injured on initial impact when fragments of approach light structure penetrated cabin area. Other injuries occurred during evacuation. Landing gear fire was observed after touchdown, but it extinguished itself. No order to evacuate was given over PA system. Evacuation began only after flight officers opened No. 1 exits. 4 exit slides failed to deploy correctly or at all forcing passengers to concentrate on rear exits. This caused tail heavy loading and resulted in the aircraft tilting back on the rear fuselage. This made evacuation through forward exits dangerous and injuries to 8 passengers resulted because of their use. 8 passengers hospitalized with serious back injuries after using No. 1 slide.
07 26	Douglas	DC-8	United	No. Pacific Ocean	Serious	163	0	1	0	0	0	0	Attendant injured in turbulence.
07 25	Boeing	707	Pan Am	Manila, Philippines	Fatal	4	0	0	0	4	0	0	Aircraft crashed on approach. Investigation under jurisdiction of Philippine government.
07 23	Boeing	747	United	Chicago, Ill.	Serious	199	0	0	1	0	0	0	Engine fire on ground. Passenger injured during evacuation.

1971	Type Model	Airline	Location	Injury Index	Total Occup	Injuries			Fatalities			Remarks
						Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	
07 19	Boeing 727	United	Denver, Colo.	Minor	101	0	0	0	0	0	0	Gear collapsed during ground loop.
06 29	Boeing 747	TWA	Nr. Paris, France	Serious	144	0	0	1	0	0	0	Passenger injured during evacuation due to bomb threat.
06 20	Boeing 747	Northwest	Tokyo, Japan	None	219	0	0	0	0	0	0	Ground loop swerve. Investigation under jurisdiction of government of Japan.
06 20	Boeing 707	Pan Am	No. Pacific Ocean	Serious	80	0	0	2	0	0	0	Passenger injured in turbulence. TSTM's in area. Seat belt sign off.
06 11	Boeing 707	TWA	Nr. Phillipsburg, Pa.	Minor	?	0	0	0	0	0	0	Aircraft had to perform violent maneuver to avoid midair collision with an American 707. 3 passengers and the flight engineer received minor injuries.
06 08	Boeing 727	Continental	Nr. Denver, Colo.	Serious	80	0	0	1	0	0	0	Passenger injured during turbulence when left seat.
06 07	Convair 580	Allegheny	New Haven, Conn.	Fatal	31	1	0	2	1	1	26	Aircraft crashed on instrument approach. Except for cockpit area, crash was survivable. All except captain died because of post crash fire. 2 surviving passengers escaped through overwing exit. 15 of 27 fatally injured passengers were near the rear service door. Opening of that door by untrained people requires the following of instructions printed near door handle. Likely that the passengers attempted to open door but were unsuccessful. Copilot survived by being thrown clear. Only one cabin attendant was aboard aircraft and she was unable to help evacuation because of injuries received in crash.
06 06	Douglas DC-9	Air West	Nr. Duarte, Calif.	Fatal	49	0	0	0	2	3	44	Aircraft had midair collision with Marine F-4. Accident not survivable.
05 23	Cessna 185E	Kodiak	Swikshak, Alaska	None	2	0	0	0	0	0	0	Nosed over when landing on sandy beach.
05 22	Douglas DC-9	Texas Inter.	Nr. McAllen, Texas	Minor	70	0	0	0	0	0	0	Cargo door opened in flight.
05 18	Douglas DC-8	Delta	Newark, N.J.	Serious	82	0	1	0	0	0	0	Attendant not seated on takeoff. Fell and broke arm.
05 15	Douglas DC-8	United	San Francisco	Serious	48	0	0	5	0	0	0	Passengers injured during evacuation due to bomb threat.
05 14	Boeing 727	Eastern	Nr. York, Ky.	Serious	104	0	0	1	0	0	0	Passenger injured in CAT. Seat belt not fastened. Prior warning was given.

1971	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
05 13	Boeing 747 Northwest	Honolulu	None	42	0	0	0	0	0	0	Engine failure in flight. Landed without incident.
05 07	Boeing 737 Piedmont	Charlotte, N.C.	Serious	69	0	0	1	0	0	0	Passenger injured while evacuating aircraft.
05 06	DeHavilland DH-104 Apache Airlines	Coolidge, Ariz.	Fatal	12	0	0	0	2	0	10	Crash due to wing separation inflight. Severe turbulence reported in area.
04 16	Cessna 207 Western Alaska Airlines	Egegik, Alaska	Serious	1	1	0	0	0	0	0	Crash into frozen river.
04 01	Boeing 727 TWA	Chicago, Ill.	Serious	60	0	0	4	0	0	0	APU torched after engine start. Attendants overeacted and caused unwanted evacuation. All attendants unaware of proper procedures. Passengers injured in evacuation.
03 31	Boeing 720 Western	Ontario, Cal.	Fatal	5	0	0	0	5	0	0	Aircraft crashed due to structural failure. Accident not survivable.
03 29	Boeing 727 American	Nr. Cincinnati, Ohio	Serious	37	0	1	0	0	0	0	Attendant injured in CAT.
03 18	Lockheed 382B Saturn	Wichita, Kansas	None	4	0	0	0	0	0	0	Aircraft ground looped on landing. Gusty. Fire after impact.
02 26	Boeing 727 American	St. Louis, Mo.	None	90	0	0	0	0	0	0	Gear collapsed on landing roll.
02 17	Douglas DC-9 Southern	Gulfport, Miss.	None	11	0	0	0	0	0	0	Aircraft struck high tension lines during approach. Landed without incident.
02 10	Curtiss Wrt. C-46 Reeve Aleutian	Nondalton, Alaska	Serious	2	2	0	0	0	0	0	Aircraft broke through ice during landing on lake.
02 07	Boeing 747 Pan Am	Nr. Wilmington, N.C.	Serious	302	0	2	2	0	0	0	Injuries due to turbulence. Severe turbulence forecast. Pilot did not avoid area.
02 07	Boeing 727 National	Nr. St. Petersburg, Fla.	Serious	82	0	1	0	0	0	0	Attendant injured in turbulence.
01 11	Douglas DC-9 Delta	Jackson, Miss.	None	27	0	0	0	0	0	0	Aircraft collided with runway lights during rollout in poor visibility.
01 09	Boeing 707 American	Edison, N.J.	Fatal	21	0	0	0	0	0	0	Aircraft collided in midair with Cessna 150. Both occupants of Cessna were killed. Boeing landed without incident.
01 03	Douglas DC-8 United	100 mi. east of Kansas City, Mo.	Serious	119	0	0	1	0	0	0	Passenger injured in CAT. Seat belt sign off.

1970	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 28	Boeing 727	Trans Caribbean	St. Thomas, V.I.	Fatal	55	3	4	43	0	0	2	Crew lost control of aircraft on landing. Accident was survivable. Fuselage broke into 3 sections, but cabin structure remained intact. 2 passengers received fatal injuries from post crash fire. Impact of aircraft against side of hill caused lateral loads on seats thus at least 8 known seat failures occurred, most of which were lateral. Design criteria of seats for lateral strength is only 1 1/2g. Evacuation very effective. Many passengers utilized breaks in fuselage to escape.
12 27	Boeing 747	Delta	Nr. Knoxville, Tenn.	Serious	76	0	1	0	0	0	0	Attendant injured in fall down spiral staircase.
12 24	Boeing 707	Pan Am	Nr. Northway, Alas.	Serious	75	0	0	1	0	0	0	Baby injured when thrown from mother's arm in unforecast CAT.
12 23	Convair 580	Frontier	Kansas City, Mo.	Minor	33	0	0	0	0	0	0	Gear collapsed during taxi.
12 17	Beech B-55	Mohawk	Burlington, Vt.	None	2	0	0	0	0	0	0	Aircraft collided with snowbank on landing.
12 16	Boeing 727	Continental	Burbank, Calif.	None	91	0	0	0	0	0	0	Gear collapsed on landing roll.
12 10	Convair 640	Caribbean-Atlantic	St. Thomas, V.I.	None	20	0	0	0	0	0	0	Gear collapsed after hard landing.
12 10	Martin 404	Southern	Atlanta, Ga.	Fatal	10	0	0	0	0	0	0	Ground crewman struck by prop while aircraft parked.
11 30	Boeing 707	TWA	Tel Aviv, Israel	Fatal	3	0	0	0	0	0	0	Aircraft collided with C-97 being towed on runway. 3 people fatally injured in other aircraft. Investigation under jurisdiction of government of Israel. Fire after impact.
11 28	Boeing 720	United	Pt. Reyes, Cal.	Serious	56	0	1	0	0	0	0	Attendant injured in turbulence. Seat belt sign on too late.
11 27	Douglas DC-8	Capitol Int.	Anchorage, Alaska	Fatal	229	3	3	43	0	1	46	Aircraft crashed when it overran runway on takeoff. Fuselage fractured in aft section. Fire broke out at first of 3 subsequent impacts. Most of cabin area was destroyed by fire. All fatalities result of fire. Only 1 passenger received injuries during impact that would restrict his escape. After first impact cabin lights failed. During impact sequence large amounts of interior fixtures, galley equipment, life

1970	Type Model	Airline	Location	Injury Index	Total Occup	Injuries			Fatalities			Remarks
						Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	
												rafts, overhead racks were thrown into the aisles and obstructed exits. Most fatalities occurred in area aft of wing and forward of fuselage break. Some attendants' fold out jump seats failed during impact hampering their ability to direct evacuation.
11 26	Grumman G-21	Alaska	Wrangell, Alaska	Minor	3	0	0	0	0	0	0	Aircraft ground looped on landing.
11 20	Boeing 727	Continental	Nr. Denver, Colo.	Serious	58	0	1	0	0	0	0	Attendant injured in CAT.
11 14	Douglas DC-9	Southern	Huntington, W. Va.	Fatal	75	0	0	0	2	2	71	Aircraft crashed on instrument approach. Accident was not survivable.
11 09	DeHavilland DHC-6	Mississippi Valley	LaCrosse, Wis.	Serious	6	2	0	3	0	0	0	Aircraft crashed on instrument approach. No post crash fire.
11 07	Boeing 707	Pan Am	No. Pacific Ocean	Serious	109	0	1	0	0	0	0	Attendant injured in turbulence.
11 04	Boeing 727	National	Savannah, Ga.	None	31	0	0	0	0	0	0	Gear collapsed on taxi.
11 04	Boeing 747	Pan Am	Nr, Nantucket, Mass.	Serious	163	0	1	6	0	0	0	Aircraft encountered moderate-severe turbulence. Seat belt sign on and had been for nearly 30 min. Crew gave no explanation to passengers. Most injuries sustained by passengers not secured by seat belts. 2 passengers received spinal compression fractures; others hospitalized in emergency room and released.
10 10	Lockheed 382B	Saturn	Wrightstown, N.J.	Fatal	3	0	0	0	3	0	0	Aircraft crashed on approach in poor weather. Crew became disoriented by light glare, fog during transition from instrument to visual flight.
10 02	Martin 404		Nr. Silver Plume, Colo.	Fatal	40	1	0	9	1	1	28	Aircraft crashed into mountainous terrain at low airspeed. Cabin structure remained relatively intact after crash but post crash fire destroyed it. Passengers' seats were pushed together in forward section. All but one of surviving passengers did not have seat belts on. Many persons survived impact but were unable to evacuate aircraft before fire. Survivors escaped through 2 holes in fuselage.

1970	Type Model	Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
10 02	Cessna 207	Kodiak	Sitkinak, Alaska	Serious	1	1	0	0	0	0	0	Aircraft stalled on initial climb after takeoff.
09 29	Boeing 720	Braniff	Dallas, Texas	None	54	0	0	0	0	0	0	Gear collapsed on landing roll.
09 21	Douglas DC-8	United	Nr. Denver, Colo.	Serious	119	0	1	1	0	0	0	Injuries due to turbulence. Seat belt sign on. Belts not fastened.
09 18	Boeing 707	Braniff	No. Pacific	Serious	173	0	1	0	0	0	0	Attendant injured in turbulence. Seat belt sign turned on just before encounter.
09 16	Convair 600	Texas Int.	Nr. Lake Charles, La.	Serious	16	0	1	0	0	0	0	Attendant injured in turbulence.
09 15	Douglas DC-8	Alitalia	Jamaica, N.Y.	Serious	156	0	5	64	0	0	0	After hard landing aircraft veered off runway. Fuselage broke in two aft of wing. Evacuation took approximately 3 min. No post crash fire. 51 passengers suffered contusions, 7 lower back sprain, 5 lacerations.
09 15	Fairchild FH-227	Mohawk	Philadelphia, Pa.	None	12	0	0	0	0	0	0	Collided with object while taxiing.
09 08	Douglas DC-9	Delta	Louisville, Ky.	Minor	94	0	0	0	0	0	0	Aircraft landed short of runway. Aft fuselage buckled. Some minor injuries sustained because of hard landing. Evacuation without incident.
09 08	Douglas DC-8	Trans Int. Airlines	Jamaica, N.Y.	Fatal	11	0	0	0	3	8	0	Aircraft crashed on takeoff when stone jammed elevator in up position. Accident not survivable.
08 24	Lockheed 188	Universal	Hill AFB, Utah	Minor	3	0	0	0	0	0	0	Aircraft crashed on takeoff. Unable to maintain control. Fire after impact.
08 15	Douglas DC-8	National	Nr. Trenton, N.J.	Serious	106	0	2	0	0	0	0	Aircraft turned into TSTM by controller. Pilot had requested deviation. Injuries due to turbulence.
08 13	Boeing 707	Pan Am	Nr. Durazno, Uruguay	Serious	50	0	1	0	0	0	0	Attendant injured in turbulence.
08 08	Convair 990	Modern Air Trans.	Acapulco, Mexico	Serious	8	3	5	0	0	0	0	Aircraft undershot runway. Fire after impact. Investigation under jurisdiction of Mexican government.
07 27	Douglas DC-8	Flying Tiger	Naha AB, Okinawa	Fatal	4	0	0	0	4	0	0	Aircraft crashed just offshore on approach end of runway. Cockpit section was separated from fuselage and came to rest inverted almost entirely submerged. Crash was survivable. When rescue parties reached cockpit section 2 crewmembers still alive and could communicate with them through hole in bottom of fuselage. But tide came in before

1970	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
												crew could be released from wreckage and they drowned. Captain received fatal injuries during impact. Was not wearing shoulder restraint. Other crew member died from asphyxiation.
07 19	Boeing 737	United	Philadelphia, Pa.	Serious	61	0	0	1	0	0	0	Aircraft overran runway on aborted takeoff. Fuselage remained intact with no seat failures. Evacuation orderly. 1 passenger seriously injured when she fractured her ankle going down slide.
07 02	Short Bros. SC-7	Jetco	Washington, D.C.	Fatal	2	0	0	0	2	0	0	Aircraft crashed when shifting cargo caused loss of control. Crash not survivable.
06 22	Grumman G-21	Reeve Aleutian	False Pass, Alaska	Minor	4	0	0	0	0	0	0	Struck submerged object on water landing.
06 15	Grumman G-21A	Western Alaska	New Stuyahok, Alaska	Minor	4	0	0	0	0	0	0	Failed to retract landing gear in water landing.
06 09	Douglas DC-8F	Trans Carribean	Bangor, Maine	Serious	228	0	0	2	0	0	0	Tires blew out on takeoff. Fire in landing gear area.
06 03	Boeing 727	Eastern	Newark, N.J.	None	105	0	0	0	0	0	0	APU caught fire on ramp while aircraft parked.
05 29	Douglas DC-8	National	Grand Isle, La.	Serious	56	0	1	0	0	0	0	Aircraft deviating between 2 TSTM's. Warning to attendant was late.
05 27	Douglas DC-8	United	Nr. Goodland, Kans.	Serious	60	0	2	1	0	0	0	Injuries due to turbulence. In TSTM area.
05 18	Boeing 727	United	Chicago, Ill.	Serious	72	0	0	1	0	0	0	Passenger injured in evacuation. Fire occurred on ground.
05 18	Lockheed 382E	Delta	San Francisco, Cal.	None	3	0	0	0	0	0	0	Brake failed after aborted takeoff. Fire in gear area.
05 09	Lear Jet L23A	Executive Jet Av.	Pellston, Mich.	Fatal	6	0	0	0	2	0	4	Aircraft crashed during instrument approach Crash not survivable.
05 02	Douglas DC-9	ONA	Nr. St. Croix, V.I.	Fatal	63	0	2	35	0	1	22	Aircraft ditched because of fuel exhaustion After ditching aircraft remained afloat for approximately 10 min. Passengers warned 10 min. prior to ditching, thus many were not prepared. Several passengers and attendants were still standing and others did not have their belts fastened when aircraft ditched. Galley equipment thrown into aisle and obstructed access to life raft. Raft was inadvertently inflated inside cabin, cutting off flight crew's access to cabin. Most

1970	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
												passengers exited through aft right over-wing exit. Cause of fatalities not given. 8 femalc and 3 male passengers received spinal injuries. 4 passengers suffered rib fractures. Other injuries included fractured right shoulder, left clavicle, chip knee fracture, fracture of the sternum. Also female passenger suffered severe pulmonary edema. 1 fatally injured passenger recovered died of drowning.
04 20	Douglas DC-8	Airlift Int.	No. Pacific	Serious	210	0	2	1	0	0	0	Flight encountered turbulence while steering around build ups.
04 14	Douglas C-54	Compania Ecuatoriana	Miami, Fla.	Fatal	2	0	0	0	2	0	0	Aircraft crashed on departure. Crash not survivable.
04 06	Nihon YS-11A	Piedmont	Nr. Charleston, W. Va,	None	25	0	0	0	0	0	0	Aircraft damaged in flight when struck by lightning. Landed without incident.
03 28	Boeing 720B	Western	Nr. Annette Is., Alaska	None	27	0	0	0	0	0	0	Inflight engine failure. Landed without incident.
03 22	Beech C-45H	Commuter Airlines	Binghamton, N.Y.	Fatal	11	1	0	7	1	0	2	Aircraft overran runway on aborted takeoff. Crash was survivable with fuselage remaining basically intact. Post crash fire occurred and all fatalities were due to it.
03 20	Douglas DC-6	Southern Air Trans.	Oshima Isle, Japan	Serious	12	0	1	0	0	0	0	Attendant injured when aircraft penetrated cloud tops.
03 18	Douglas DC-8	Braniff	Nr. Guayaquil, Ecuador	Serious	73	0	0	1	0	0	0	Passenger injured in CAT.
03 04	Sikorsky S-61L	New York Air.	Flushing, N.Y.	None	9	0	0	0	0	0	0	Fire started in aircraft while parked.
03 02	Boeing 720	United	Chicago, Ill.	Serious	95	0	0	1	0	0	0	Engine fire started on ground.
02 26	British AC 1-11	American	Cleveland, Ohio	Serious	37	0	0	1	0	0	0	Passenger injured while deplaning.
02 25	Boeing 727	American	Nr. Phillipsburg, Pa.	Serious	67	0	0	1	0	0	0	Passenger injured in CAT. Seat belt sign on.
02 23	Nihon YS-11A	Piedmont	Nr. Warrentown, Va.	Serious	20	0	1	0	0	0	0	Attendant injured when aircraft made evasive maneuver to avoid collision with C-150.
02 11	Boeing 707	Pan Am	Stockton, Cal.	Serious	7	1	0	0	0	0	0	Aircraft overran runway on simulated 3 engine landing. Wet runway.

1970	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
02 10	DeHavilland DHC-6 Pilgrim Aviation	Nr. Waterford, Conn.	Fatal	5	0	0	0	2	0	3	Aircraft ditched in Long Island Sound due to fuel exhaustion. 2 passengers later found; rest missing, presumed dead. Aircraft later raised from 60 feet of water. Fuselage intact. No one found in cabin. All life preservers and other flotation equipment in aircraft.
01 28	DeHavilland DH-104 Tag	In Lake Erie	Fatal	9	0	0	0	2	0	7	Aircraft crashed into Lake Erie after inflight wing separation. Accident not survivable.
01 17	Convair 240 Aspen Airways	Aspen, Colo.	None	27	0	0	0	0	0	0	Pilot failed to lower gear on landing.
01 16	Short Bros. SC-7 Wien Consolidated	Cape Newman, Alaska	None	12	0	0	0	0	0	0	Engine failure on takeoff run.
01 11	Douglas DC-9 Texas Int.	Harlingen, Texas	None	41	0	0	0	0	0	0	Aircraft struck trees on instrument approach. Performed missed approach, and later landed without incident.

1969	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 21	Boeing 720	Continental	Nr. Denver, Colo.	Serious	94	0	0	1	0	0	0	Passenger injured in CAT. Seat belt sign on. Warning given by crew.
12 18	Nihon YS-11A	Piedmont	Baltimore, Md.	Serious	22	0	0	0	0	0	0	Pedestrian on ramp seriously injured when walked into prop.
12 13	Boeing 727	Eastern	Nr. Pittsburgh, Pa.	Serious	96	0	0	1	0	0	0	Miscellaneous.
12 01	Boeing 707	Pan Am	Sydney, Australia	None	136	0	0	0	0	0	0	Gear collapsed on takeoff from bird strike.
11 28	Douglas DC-8	Eastern	Newark, N.J.	None	123	0	0	0	0	0	0	Engine failure on takeoff. Aborted safely.
11 19	Fairchild FH-227	Mohawk	Nr. Glens Falls, N.Y.	Fatal	14	0	0	0	2	1	11	Aircraft flew into side of mountain while on instrument approach. Crash not survivable.
10 16	Douglas DC-8	Seabord	Stockton, Cal.	None	5	0	0	0	0	0	0	Aircraft overran runway on aborted takeoff. Impact and post crash fire destroyed aircraft. Crew escaped uninjured.
10 12	Boeing 707	TWA	No. Pacific	Serious	155	0	0	1	0	0	0	Aircraft flying near typhoon area. Injury due to turbulence.
10 11	Boeing 707	TWA	No. Pacific	Serious	70	0	2	0	0	0	0	Attendants injured in turbulence. Did not see seat belt sign on due to cargo stowed in rear seats.
09 26	Boeing 727	Eastern	New Orleans, La.	Fatal	3	0	0	0	0	0	0	Aircraft struck child on runway during takeoff.
09 17	Douglas DC-8	Delta	Dallas, Texas	None	84	0	0	0	0	0	0	Gear collapsed on takeoff run.
09 15	Boeing 727	TWA	Philadelphia, Pa.	Serious	76	0	0	2	0	0	0	Alarm inadvertently activated during taxi. Passengers injured during evacuation.
09 09	Douglas DC-9	Allegheny	Nr. Fairland, Ind.	Fatal	82	0	0	0	2	2	78	Aircraft collided in midair with PA-28. Accident not survivable. Pilot of other aircraft received fatal injuries.
09 04	Convair 880	Delta	Nr. Jackson, Miss.	Serious	54	0	1	0	0	0	0	Attendant injured in turbulence. TSTM's forecast on route.
08 29	Boeing 707	TWA	Damascus, Syria	Serious	125	0	0	1	0	0	0	Aircraft hijacked. Passenger injured during evacuation. Investigation under jurisdiction of Syrian government.
08 29	Douglas DC-9	Continental	Denver, Colo.	None	3	0	0	0	0	0	0	Aircraft damaged on hard landing during training flight.
08 26	Boeing 707	Continental	No. Pacific	Serious	173	0	1	0	0	0	0	Attendant injured in turbulence. TSTM's in area.
08 18	Douglas DC-9	Southern	Eglin AFB, Fla.	None	23	0	0	0	0	0	0	Aircraft struck parked fuel truck during taxi.
08 12	Pilatas PC-6H2	Wien Consol.	Chevak, Alaska	None	9	0	0	0	0	0	0	Gear collapsed on landing when aircraft hit rut.

1969	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
08 12	Douglas DC-9 Carribean Atlantic	St. Thomas, V.I.	None	119	0	0	0	0	0	0	Aircraft overran runway on landing. Skidded across road and seriously injured 3 occupants of ground vehicles that the aircraft struck. Evacuation orderly with no post crash fire.
08 03	Boeing 707 American	Ft. Worth, Texas	Fatal	5	0	0	0	0	0	0	Aircraft collided in flight with Cessna 172. Pilot of Cessna fatally injured. Boeing landed without incident.
08 02	Douglas DC-8 Eastern	No. Atlantic	Serious	110	0	0	1	0	0	0	Passenger not in seat when seat belt sign on. Injured in turbulence.
08 02	Boeing 707 Pan Am	No. Pacific	Serious	98	0	1	2	0	0	0	Injuries due to CAT.
08 02	Douglas DC-8 Delta	Atlanta, Ga.	Serious	176	0	1	0	0	0	0	Attendant inadvertently released seat belt in TSTM area.
08 01	Convair 600 Texas Int.	Houston, Texas	None	23	0	0	0	0	0	0	Nose gear collapsed on landing.
08 01	Boeing 707 Pan Am	Brussels, Belgium	None	3	0	0	0	0	0	0	Aircraft ran off runway on landing roll. Under jurisdiction of government of Belgium.
07 29	Convair 990 American	Ft. Worth, Texas	None	3	0	0	0	0	0	0	Gear collapsed on hard landing during training flight.
07 29	Boeing 727 Airlift Int.	Jamaica, N.Y.	None	4	0	0	0	0	0	0	Pilot attempted TIO from too short a runway Gear collapsed on overrun.
07 26	Boeing 720 United	Nr. Janesville, Wis.	Serious	126	0	0	1	0	0	0	Seat belt sign on. Pilot did not warn passengers. Pilot did not receive severe weather forecast.
07 26	Boeing 707 TWA	Pomona, N.J.	Fatal	5	0	0	0	5	0	0	Aircraft crashed on simulated 3 engine go-around. Lost directional control due to complete hydraulic failure. Crash not survivable. Aircraft destroyed by impact and fire.
07 23	Douglas DC-8 Seabord	No. Pacific	Serious	227	0	2	0	0	0	0	Seat belt sign turned on too late after entering area of build ups.
07 22	Douglas DC-8 Delta	Evergreen, Ala.	Serious	82	0	1	0	0	0	0	Seat belt sign turned on too late. Attendant injured while serving passengers.
07 20	Douglas DC-8 Capitol Int.	New Castle, Del.	None	11	0	0	0	0	0	0	Struck ILS antennae during go-around. Landed without incident.
07 15	DeHavilland DHC-6 New York Airways	Jamaica, N.Y.	Fatal	14	0	1	5	2	1	0	Aircraft encountered wake turbulence on takeoff. Intersection departure, warned by tower.
07 13	Sikorsky S-61L Los Angeles Airways	Chino, Cal.	None	21	0	0	0	0	0	0	Aircraft experienced inflight structural failure.

1969	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
07 06	Beech 99	Air South	Nr. Monroe, Ga.	Fatal	14	0	0	0	2	0	12	Change in longitudinal trim caused vertical dive. Recovery not possible. Crash not survivable.
06 27	Vickers 745D	Aloha	Honolulu	None	14	0	0	0	0	0	0	Collided with parked aircraft during taxi.
06 25	Boeing 727	TWA	Chicago	Serious	67	0	0	1	0	0	0	Gear collapsed when aircraft traveling at excessive speed during taxi.
06 24	Convair 880	JAL	Moses Lake, Wash.	Fatal	5	2	0	0	2	1	0	Aircraft crashed during simulated 3 engine climbout for training flight. Aircraft destroyed by impact and post crash fire. Accident survivable except for fire. All exits jammed by impact. Survivors escaped through break in aft fuselage. Area engulfed by flames. 2 fatally injured crewmen found outside aircraft, another in cockpit. Survivors sustained severe burn injuries.
06 10	Convair 440	Delta	Macon, Ga.	None	47	0	0	0	0	0	0	Gear collapsed on hard landing.
05 14	Boeing 727	National	Washington Natl., D.C.	None	40	0	0	0	0	0	0	Two aircraft collided during taxi.
05 14	Boeing 727	National	Washington Natl., D.C.	None	76	0	0	0	0	0	0	
05 08	Douglas DC-8	Delta	Chicago	None	72	0	0	0	0	0	0	Two aircraft collided during taxi.
05 08	Fairchild FH-227	Ozark	Chicago	None	2	0	0	0	0	0	0	
05 03	Douglas DC-9	ONA	Sacramento, Cal.	None	2	0	0	0	0	0	0	Aircraft substantially damaged in hard landing.
05 02	Grumman G-44	Kodiak	Kodiak, Alaska	Serious	1	1	0	0	0	0	0	Stalled during approach with both engines out.
04 27	Douglas DC-8	Eastern	Over Cuba	Serious	191	0	0	6	0	0	0	Aircraft encountered turbulence due to buildups. Gave ample warning to cabin, but failed to slow aircraft to turbulence penetration t/s.
04 27	Douglas DC-8	Eastern	No. Atlantic	Serious	115	0	0	8	0	0	0	Aircraft encountered turbulence from buildups. Pilot warned attendants, but they did not check passengers' seat belts.
04 24	Douglas DC-9	Air West	Nr. Las Vegas, Nev.	Serious	34	0	0	1	0	0	0	Aircraft encountered CAT. Seat belt sign on. Passenger fractured knee while in lavatory.

1969	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
04 08	Boeing 707 TWA	Nr. St. Louis, Mo.	Serious	59	0	1	0	0	0	0	Attendant injured in turbulence from buildups.
03 20	Boeing 707 Pan Am	Nr. Honolulu	Serious	79	0	0	1	0	0	0	Passenger in aisle when CAT encountered. Seat belt sign on. Thrown to floor.
03 16	Douglas DC-8 Delta	Nr. Pulaski, Va.	Serious	65	0	0	1	0	0	0	Stewardess thrown to ceiling while standing in aisle. CAT. Seat belt sign on.
03 13	DeHavilland DHC-6 Wien Consolidated	Minchumina, Alaska	Fatal	5	0	0	0	0	0	1	Pilot experienced white out during approach. Passenger fatally injured when seat belt came undone during impact.
03 05	DeHavilland 114-2 Puerto Rico Int.	San Juan, Puerto Rico	Fatal	19	0	0	0	2	0	17	Aircraft vectored into mountain tops by student controller. Crash not survivable.
02 21	Boeing 720 Pan Am	Nr. Houston, Texas	Serious	31	0	1	0	0	0	0	Attendant injured in turbulence from buildups. Seat belt announcement had been made.
02 18	Douglas DC-3 Hawthorn Nevada	Nr. Lone Pine, Cal.	Fatal	35	0	0	0	2	1	32	Aircraft flew into shear cliff in IFR conditions on UFR Flight Plan. Crash not survivable.
02 09	Boeing 727 United	Seattle, Wash.	Serious	82	0	0	1	0	0	0	Passenger fell and broke ankle returning to seat in CAT. Seat belt sign on.
02 09	Boeing 727 Pan Am	Berlin, W. Ger.	Serious	116	0	0	2	0	0	0	Engine failure on takeoff.
02 07	Boeing 707 Pan Am	So. Pacific	Serious	83	0	0	1	0	0	0	Aircraft penetrated CB tops. Seat belt sign on.
02 06	Douglas DC-9 Texas Int.	Harlingen, Texas	Serious	59	0	0	0	0	0	0	Aircraft overtook and collided with PA28 on final approach. Pilot of PA28 seriously injured. DC-9 landed without incident.
02 02	Boeing 707 TWA	Dulles Airport, Va.	None	81	0	0	0	0	0	0	Ground vehicle collided with aircraft while pulling up to loading gate.
02 02	Fairchild FH-227 Ozark	St. Louis, Mo.	Fatal	29	0	0	0	0	0	0	Ground crewman walked into prop while aircraft parked.
01 31	Douglas DC-8 Delta	Jacksonville, Fla.	None	178	0	0	0	0	0	0	Gear collapsed during taxi.
01 18	Boeing 727 United	Nr. Los Angeles	Fatal	38	0	0	0	3	3	32	Complete electrical failure on takeoff. Engine fire warning light came on. Crew became disoriented. Aircraft crashed offshore. Impact forces severe. One body recovered, parts of others. Crash not survivable.

1969	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
01 16	Boeing 727	United	Nr. San Diego, Cal.	Serious	57	0	1	0	0	0	0	Attendant injured during evasive maneuver to avoid military jet aircraft.
01 14	Boeing 727	National	Miami, Fla.	None	29	0	0	0	0	0	0	Ground vehicle collided with aircraft while parked at gate.
01 13	Douglas DC-8	SAS	Nr. Los Angeles	Fatal	45	3	3	11	0	3	12	Aircraft inadvertently ditched offshore during instrument approach. 11 persons missing presumed dead. Fuselage broke into 3 sections on impact. First failure occurred at aft pressure bulkhead. Second at trailing edge of wing. Forward section remained afloat for 20 hours, other 2 sank rapidly. Fuselage section aft of wing did not retain any structural integrity, trapping many passengers which, combined with the rapidly sinking structure, was factor in most of the fatalities. Long trailing ends of seat belts also hampered passengers' ability to evacuate. 18 passenger survivors from forward section, 6 survivors from aft section. All of the 4 fatally injured persons recovered died from drowning. 2 life rafts were punctured by metal fragments and rapidly deflated.
01 11	Fairchild FH-227	Piedmont	Lynchburg, Va.	Serious	23	0	0	0	0	0	0	Ground crewman walked into prop.
01 06	Convair 440	Allegheny	Nr. Bradford, Pa.	Fatal	28	0	1	16	2	0	9	Aircraft crashed into trees while on instrument approach. Descent below MDA. Crash was partially survivable. Cockpit and forward sections of cabin destroyed. Aircraft's final impact and final position were inverted, thus cockpit received most of impact forces. Cabin section in front of row 7 demolished. Aft of row 7 was relatively intact but the ceiling of cabin was crushed upward to seat backs. 12 survivors seated behind row 7. 5 were seated in front of 7 on right side of cabin. The 5 survivors ahead of row 7 were thrown outside the fuselage very close to the time the fuselage came to a rest, the others remained inside. Escape was made through the window exits and holes in the fuselage.

1968	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 27	Douglas	DC-9	Ozark	Sioux City, Iowa	Serious	68	2	1	10	0	0	0	Aircraft crashed on takeoff because of ice on wings. Accident was survivable with fuselage remaining intact. The fact that there was no post crash fire contributed greatly to the survivability. Captain and copilot were not wearing shoulder restraints. Both received back injuries, and captain received head injuries in addition. Stewardess's seat in forward section failed during impact resulting in her receiving head injuries. Emergency lighting was functional, but passengers stated that cabin lighting was very low. Also emergency fire equipment was not readily available on field.
12 27	Convair	580	North Central	Chicago, Ill.	Fatal	45	0	1	17	3	0	24	Aircraft crashed into hangar at threshold of runway while executing missed approach. Main cabin area came to rest inside hangar in inverted position. Cockpit and forward fuselage area, outside hangar, destroyed by impact and post crash fire. Main cabin area extensively damaged by impact, but remained free of fire damage. Crash was partially survivable. Cockpit and forward fuselage seat rows 1-5 were not survivable. Area of rows 6-7 questionable survivability. Area of rows 8-12 considered survivable. Out of 24 double passenger seats, only 5 found intact. All seats forward of row 8 were separated or partially separated from cabin floor. Direct correlation between severity of injury of occupants, and restraint system failures.
12 26	Boeing	707	Pan Am	Anchorage, Alaska	Fatal	3	0	0	0	3	0	0	Aircraft crashed on takeoff when pilot neglected to add flaps. Aircraft almost completely destroyed by impact and resulting fire. Crash not survivable.

1968	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 24	Convair 580	Allegheny	Bradford, Pa.	Fatal	47	0	1	26	3	0	17	Aircraft descended below MDA. Struck trees and finally came to rest inverted. Most impact forces taken by cockpit and forward fuselage. 26 of 27 survivors seated in rearmost 9 rows. 1 survivor in front row. Most survivors were still in seats after impact. Primary means of escape was through rear left cabin door, which was torn off on impact and through hole in fuselage near wing. Minor fire during impact with trees, but none continued to burn after crash. Some passengers trapped in wreckage and had to be dug out. Flight crew both killed due to traumatic head injuries.
12 12	Boeing 707	Pan Am	Caracas, Venezuela	Fatal	51	0	0	0	3	6	42	Undershot runway on final. Investigation under jurisdiction of government of Venezuela.
12 02	Fairchild F-27B	Wien Consolidated	Pedro Bay, Alaska	Fatal	39	0	0	0	2	1	36	Aircraft experienced inflight structural failure due to extreme turbulence. Accident was not survivable.
11 23	Boeing 707	Pan Am	Nr. Cachimbo, Brazil	Serious	?	0	1	0	0	0	0	Injury due to turbulence. No. of passengers aboard unreported. Investigation under jurisdiction of Brazilian government.
11 22	Douglas DC-8	JAL	San Francisco	None	107	0	0	0	0	0	0	Aircraft inadvertently ditched in Bay during ILS approach. Aircraft came to rest on bottom, cabin did not flood. Some difficulty with getting life jackets occurred because of carry on luggage jammed under seats. Considerable indecision by crew as whether to evacuate aircraft. Captain ordered evacuation after noticing fuel on surface of water. No injuries occurred during ditching or evacuation.
11 19	Boeing 707	American	Martinsburg, W. Va.	None	38	0	0	0	0	0	0	Engine failure inflight. Landed without incident.
11 19	Lockheed 188	Northwest	Minneapolis, Minn.	Fatal	63	0	0	0	0	0	0	Ground crewman walked into prop, fatally injured.
10 28	Boeing 707	Pan Am	No. Pacific	Serious	64	0	2	0	0	0	0	Aircraft encountered CAT. Seat belt sign off, but passengers warned to keep belts loosely fastened.

1968	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
10 25	Fairchild	FH-227	Northeast	Nr. Hanover, N.H.	Fatal	42	0	1	9	2	0	30	Aircraft crashed into mountain top during instrument approach. Aircraft destroyed by impact and post crash fire. Location of crash made it very difficult for rescue parties to get to scene. All survivors were seated in aft end of cabin. Injuries to survivors included contusions, abrasions, lacerations, fractured ribs, and limbs, 2 vertebral fractures, 1 fractured hip. 7 fatally injured passengers found away from wreckage, all suffered severe traumatic injuries. Rest were found in fire area of wreckage, cause of death not given. Much evidence of trauma due to decelerative forces. Most deaths due to impact.
10 05	Boeing	707	Northwest	Nr. Jamaica, N.Y.	Serious	95	0	0	1	0	0	0	Seat belt sign on. Passenger left seat and tripped over briefcase left in aisle.
10 03	Boeing	727	United	Nr. Fillmore, Cal.	Serious	45	0	1	0	0	0	0	Attendant injured in turbulence. Seat belt sign on.
09 28	Douglas	DC-7	Airlift Int.	Miami, Fla.	None	4	0	0	0	0	0	0	Gear collapsed when aircraft overran runway.
09 27	Douglas	DC-7	Universal	Cherry Point, N.C.	Serious	3	1	0	0	0	0	0	Aircraft crashed on instrument approach. Fire after impact.
09 23	Boeing	727	American	Springfield, Ill.	Serious	87	0	0	5	0	0	0	Passenger injured in evacuation due to bomb threat. Jumped or slid from leading edge of wing.
09 14	Boeing	707	Pan Am	No. Atlantic	Serious	147	0	0	1	0	0	0	Passengers injured in evacuation due to bomb cient time to return to seats after sign turned on.
09 06	Lockheed	L-188	American	Cleveland, Ohio	None	39	0	0	0	0	0	0	Aircraft collided with Boeing during taxi.
09 06	Boeing	720	United	Cleveland, Ohio	None	55	0	0	0	0	0	0	
08 14	Douglas	DC-8	Pan Am	Nr. Presque Isle, Maine	Serious	146	0	0	1	0	0	0	Passenger in aisle. Fractured foot. CAT.
08 14	Sikorsky	S-61L	Los Angeles	Compton, Cal.	Fatal	21	0	0	0	2	1	18	Main rotor separated inflight. Crash not survivable.
08 12	Grumman	G-21	Alaska Airlines	Juneau, Alaska	None	1	0	0	0	0	0	0	Failed to retract gear for water landing.
08 10	Boeing	737	United	Nr. Herndon, Va.	Serious	48	0	0	1	0	0	0	Passenger fell while returning to seat.

1968	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
08 10	Fairchild	FH-227	Piedmont	Charleston, W. Va.	Fatal	37	0	0	2	2	1	32	Aircraft crashed into embankment at threshold of runway. Crash not survivable, aircraft destroyed by impact and post crash fire. All fatalities due to severe trauma. 5 survivors removed from wreckage, 3 later died. All survivors thrown clear of cabin area during impact sequence.
08 07	Boeing	727	United	Boston, Mass.	Minor	83	0	0	0	0	0	0	Pilot undershot runway on landing. Gear collapsed. Substantial damage.
08 06	Douglas	DC-8	United	New Richmond, Wis.	Serious	116	0	0	2	0	0	0	Penetrated buildups, not on radar nor forecast.
08 05	Sud Aviation	210	United	Elwood, Pa.	Serious	52	0	1	0	0	0	0	Attendant injured in CAT. Seat belt sign off.
08 05	Boeing	707	Flying Tiger	Travis AFB, Cal.	None	3	0	0	0	0	0	0	Engine fire occurred on landing roll.
08 04	Convair	580	North Central	Nr. Milwaukee, Wis.	Fatal	12	1	0	0	0	0	0	Aircraft collided in midair with Cessna 150. Cessna struck in forward baggage area. Copilot seriously injured, suffered crushed bones in lower right leg. 3 occupants of Cessna were fatally injured. Convair landed without incident.
07 25	Convair	580	Allegheny	Morgantown, W.Va.	Minor	46	0	0	0	0	0	0	Gear collapsed on landing roll.
07 23	Boeing	707	Northwest	Lafayette, Ind.	Serious	64	0	1	0	0	0	0	Attendant injured in turbulence. Seat belt sign on.
07 20	Lockheed	188C	Northwest	Nr. Billings, Mont.	Serious	21	0	2	1	0	0	0	Turbulence due to mountain wave. Seat belt sign on.
07 11	Boeing	727	TWA	Nr. Phillipsburg, Pa.	Serious	41	0	2	0	0	0	0	Aircraft penetrated cumulus line. Passengers and crew warned.
07 05	Boeing	727	Air West	Nr. Hector, Cal.	Serious	12	0	1	0	0	0	0	Penetrated buildups.
07 02	Douglas	DC-7	Universal	Philadelphia	None	3	0	0	0	0	0	0	Gear collapsed on rollout.
06 30	Convair	340	Delta	Memphis, Tenn.	None	26	0	0	0	0	0	0	Gear up landing.
06 28	Douglas	DC-3	Purdue	Nr. Vichy, Mo.	Fatal	27	0	0	0	0	0	1	Passenger inadvertently opened air stair door inflight. Safety chain failed and passenger fell out.
06 26	Boeing	727	American	Columbus, Ohio	Serious	32	0	0	2	0	0	0	False fire alarm caused evacuation. Passengers injured when they jumped from wing.
06 24	Convair	580	North Central	Nr. Sioux Falls, S.D.	None	21	0	0	0	0	0	0	Left prop separated when aircraft collided with TV tower guy wire. Landed without incident.

1968	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
06 24	Canadair CL-44 Airlift Int.	Saigon, Vietnam	None	7	0	0	0	0	0	0	Aircraft made hard landing.
06 13	Boeing 707 Pan Am	Calcutta, India	Fatal	62	0	0	0	1	0	5	Aircraft undershot runway. Collided with buildings. Fire after impact. Under jurisdiction of Indian government.
06 12	Douglas DC-8 Eastern	Nr. Norfolk, Va.	Serious	105	0	0	1	0	0	0	TSTM in area. Pilot did not give verbal warning to passengers and crew. Seat belt sign on.
06 12	Boeing 727 United	Nr. Denver, Colo.	None	62	0	0	0	0	0	0	Aircraft collided in midair with small general aviation aircraft. Both aircraft landed without further incident. No one injured in either aircraft.
06 08	Boeing 727 United	Salt Lake City	Serious	92	0	0	1	0	0	0	Gear collapsed on landing roll.
06 08	Armstrong AW-650 Universal	Little Rock, Ark.	Minor	3	0	0	0	0	0	0	Gear up landing.
06 03	Boeing 727 TWA	Flushing, N.Y.	Serious	102	0	1	0	0	0	0	Undershot landing. Struck approach lights. Emergency landing at JFK.
05 22	Sikorsky S-61L Los Angeles Airways	Paramount, Cal.	Fatal	23	0	0	0	2	1	20	Aircraft crashed due to main rotor blade separation. Crash not survivable.
05 17	Pilatas PC6-H2 Wien Consolidated	Venetic, Alaska	None	1	0	0	0	0	0	0	Ground looped on landing.
05 13	Boeing 720B American	Nr. Mason City, Iowa	Serious	85	0	0	1	0	0	0	Passenger injured in CAT. Seat belt sign off but crew warned passengers to keep belts fastened.
05 03	Lockheed L-188 Braniff	Nr. Dawson, Texas	Fatal	85	0	0	0	3	2	80	Aircraft experienced inflight wing separation in area of severe TSTM's. Crash not survivable.
04 28	Douglas DC-8 Capitol	Atlantic City, N.J.	Serious	4	2	0	0	0	0	0	Student lost control on simulated 2 engine landing. Landed off runway and struck ditch. Aircraft destroyed.
04 23	Douglas DC-8 Braniff	Quito, Ecuador	Minor	164	0	0	0	0	0	0	Aircraft overshot runway. Under jurisdiction of government of Ecuador.
04 02	Boeing 727 United	Yakima, Wash.	Serious	64	0	0	1	0	0	0	Passenger injured in CAT.
03 27	Douglas DC-9 Ozark	St. Louis, Mo.	Fatal	49	0	0	0	0	0	0	Aircraft collided in midair with Cessna 150. Cessna destroyed and its 2 occupants fatally injured. DC-9 landed without incident.
03 23	Douglas DC-8 Eastern	Jamaica, N.Y.	None	69	0	0	0	0	0	0	Landing gear collapsed on touchdown.

1968	Type Model Airline	Location	Injury Index	Total Occup	Injuries			Fatalities			Remarks
					Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	
03 21	Boeing 727 United	Chicago, Ill.	Serious	3	1	0	0	0	0	0	Aircraft crashed and was destroyed on takeoff. Captain sustained serious injuries. Post crash fire did occur.
03 20	Convair 440 Delta	Evansville, Ind.	Minor	42	0	0	0	0	0	0	Aircraft crashed during attempted single engine go-around.
03 03	Lockheed L-188 Northwest	Wash. Natl. Arpt., D.C.	Serious	83	0	0	0	0	0	0	Ground crewman seriously injured when he ran into prop while aircraft parked.
03 02	Boeing 727 Eastern	Nr. Appleton, Ohio	Serious	89	0	2	0	0	0	0	Attendants injured when aircraft underwent evasive maneuver to avoid collision.
03 02	Lockheed 188 American Flyers Airline	Seattle, Wash.	Serious	87	0	0	1	0	0	0	Boarding passenger ran under left wing into turning prop.
02 29	British AC 1-11 American	Boston, Mass.	Minor	43	0	0	0	0	0	0	Gear collapsed on landing roll.
02 15	Douglas DC-6 Delta	Chattanooga, Tenn.	None	3	0	0	0	0	0	0	Pilot riding in jump seat inadvertently raised gear on takeoff roll.
01 28	Douglas DC-8 Pan Am	No. Atlantic	Serious	64	0	0	1	0	0	0	Passenger injured in CAT. Had seat belt on loosely. Seat belt sign on, and announcement made.
01 28	Convair 640 Hawaiian	Nr. Hilo, Hawaii	Serious	45	0	0	1	0	0	0	Passenger thrown from seat when inadvertently released belt in TSTM area. Sign on.
01 28	Convair 440 North Central	Nr. Benton Harbor, Michigan	Minor	38	0	0	0	0	0	0	Pilots misread altimeter, struck Lake Mich. Lost nose gear. Landed successfully at O'Hare.
01 27	Boeing 707 World Airways	Oakland, Cal.	None	10	0	0	0	0	0	0	Aircraft ground looped.
01 25	Boeing 707 Pan Am	Nr. Kandahar, Afghan.	Serious	78	0	1	5	0	0	0	Injuries due to turbulence.
01 25	Douglas DC-8 Eastern	No. Atlantic Ocean	Serious	191	0	1	1	0	0	0	Injuries due to turbulence. TSTM's in area not on radar.
01 13	Boeing 707 Pan Am	No. Pacific Ocean	Serious	67	0	0	2	0	0	0	Passengers injured in turbulence. Advised to keep seat belts fastened, but didn't.
01 11	Douglas DC-6 Southern Air Trans.	Indian Ocean	Serious	7	0	1	0	0	0	0	Off duty crewmember thrown from bunk in CAT.
01 01	Douglas DC-8F Capitol	McGuire AFB, N.J.	None	192	0	0	0	0	0	0	Aircraft ground looped during taxiing. Snow covered glaze ice on runway.
01 01	Martin 404 Southern	Oxford, Miss.	None	3	0	0	0	0	0	0	Undershot runway. Gear collapsed. Fire after impact.

1967	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 21	Douglas DC-3 Frontier	Denver, Colo.	Fatal	2	0	0	0	2	0	0	Aircraft crashed on takeoff due to failure to remove elevator control lock. Crash not survivable.
12 11	Vickers 745D United	Canton, Ohio	Serious	18	0	0	1	0	0	0	Gear collapsed when aircraft overshot runway.
12 08	Boeing 720 Western	Nr. Denver, Colo.	Serious	73	0	0	1	0	0	0	Malfunction in pitch control. Passenger thrown to floor of lavatory.
12 03	Aero Commander 500-B Eastern	Homestead, Fla.	None	3	0	0	0	0	0	0	Gear up landing on training flight.
11 28	Curtiss C-46A Airlift Int.	Key West, Fla.	None	2	0	0	0	0	0	0	Ground loop on landing.
11 28	Viscount 745D United	Raleigh-Durham, N.C.	Serious	43	0	0	1	0	0	0	Gear collapsed on landing roll.
11 20	Grumman G-44 Kodiak	Kodiak, Alaska	None	2	0	0	0	0	0	0	Hard water landing in bad weather. Pilot not instrument rated.
11 20	Convair 880 TWA	Constance, Ky.	Fatal	82	0	2	10	3	2	65	Aircraft crashed during ILS approach. Little information given on survivability aspects. Post crash fire did occur. 22 survivors removed from wreckage but 10 later died. One passenger in window seat escaped through break in fuselage. Only one able to give account of escape. On initial impact he placed head between his knees and escaped serious injury. Most fatalities due to impact. Although some fire exposure contributed to fatalities.
11 14	Lockheed B82B Alaska' Airlines	Anchorage, Alaska	None	9	0	0	0	0	0	0	Gear up landing.
11 06	Boeing 707 TWA	Erlanger, Ky.	Fatal	35	0	2	8	0	0	1	Aircraft overran runway on aborted takeoff. Substantial damage occurred from ground slide and fire. Fuselage fractured just ahead of wing root, otherwise cabin and cockpit remained structurally intact. Post crash fire occurred in area of right wing. Attendants opened forward galley and aft main, but were unable to inflate slides before being pushed out of aircraft by passengers. Emergency lighting satisfactory. 84 chain locks of the drop down tables failed to restrain them in stowed position.

1967	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
													One injured passenger died 4 days later, cause of death not given. 2 survivors sustained spinal fractures; 1 of these passengers died in corrective surgery.
11 02	Convair	880	Northeast	Nr. Jacksonville, Fla.	Serious	25	0	0	1	0	0	0	Aircraft penetrated top of buildup. Seat belt sign off. Radar not used.
11 01	Convair	340T	Frontier	Great Falls, Mont.	Minor	4	0	0	0	0	0	0	Aircraft struck object during instrument approach. Went around and landed at alternate. Nose gear collapsed on landing.
10 27	Aero Commander	500-B	Eastern	Miami, Fla.	None	3	0	0	0	0	0	0	Gear retracted on taxi during training flight.
10 18	Viscount	745D	United	Allentown, Pa.	None	50	0	0	0	0	0	0	Gear collapsed on landing roll.
10 13	Curtiss	C-46A	WienAlaska	Fairbanks, Alaska	None	2	0	0	0	0	0	0	Gear collapsed on landing roll.
10 05	Douglas	DC-6A	Universal	Kansas City, Mo.	None	3	0	0	0	0	0	0	Aircraft undershot runway. Collided with dirt bank.
10 01	Douglas	DC-8	Eastern	Nr. Jacksonville, Fla.	Serious	113	0	0	1	0	0	0	Passenger injured in CAT. Crew gave warning. Seat belt sign on. Passenger failed to remain in seat.
09 29	Boeing	707	Pan Am	Nr. Ubon, Thailand	Serious	92	0	1	0	0	0	0	Stewardess fractured pelvis during fall in turbulence.
09 16	Douglas	DC-8	Delta	Nr. Banning, Cal.	Serious	134	0	0	1	0	0	0	Aircraft performed evasive maneuver to avoid colliding with Navy T-33. Passenger injured back.
09 09	Boeing	707	Pan Am	Frankfurt, Germany	Serious	174	0	0	2	0	0	0	Engine failure on takeoff. Jurisdiction of German government.
09 08	Douglas	DC-6	United	Vandalia, Ohio	Fatal	33	0	0	0	0	0	0	Aircraft struck person on runway during landing roll. Fatally injured.
09 08	Convair	580	Frontier	Denver, Colo.	None	14	0	0	0	0	0	0	Aircraft made emergency wheels up landing. Substantial damage.
09 03	Lockheed	188	National	New Orleans, La.	None	5	0	0	0	0	0	0	Prop failure during takeoff run.
08 30	Douglas	DC-8	Eastern	Cocoa, Fla.	Serious	111	0	1	1	0	0	0	Pilot failed to divert around buildups on advice from ATC. Seat belt sign off. Injuries due to turbulence.
08 30	Grumman	G-21A	Alaska Coastal	Prince Rupert, Can.	None	9	0	0	0	0	0	0	Struck submerged log on water landing.
08 25	Douglas	DC-8	Eastern	No. Atlantic	Serious	108	0	2	1	0	0	0	Injuries due to CAT. Seat belt sign off.
08 18	Boeing	707	Continental	Nr. Manila, Philippine Islands	Serious	132	0	1	0	0	0	0	Pilot warned crew and passengers of turbulence. Stewardess thrown from seat.

1967	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
07 31	Vickers 745D Aloha	Honolulu, Hawaii	None	33	0	0	0	0	0	0	Fire inflight. Caused by electrical systems.
07 23	Convair 340	Des Moines, Iowa	None	9	0	0	0	0	0	0	Engine failure inflight. Forced landing made.
07 19	Boeing 727 Piedmont	Hendersonville, N.C.	Fatal	79	0	0	0	3	2	74	Aircraft collided in midair with Cessna 310. Crash not survivable. All occupants of Boeing received fatal injuries, as well as the 3 occupants of the Cessna. Both aircraft destroyed.
06 26	Viscount 745D United	Grand Rapids, Mich.	Serious	33	0	0	1	0	0	0	Nose gear collapsed on takeoff roll.
06 26	Pilatas PC-6A Northern Consolidated	Kalskag, Alaska	None	2	0	0	0	0	0	0	Aircraft ground looped on landing. Fire after collision with ditches.
06 24	Convair 880 Delta	Newark, N.J.	None	59	0	0	0	0	0	0	Engine failure inflight. Landed without incident.
06 23	British AC 1-11 Mohawk	Nr. Blossburg, Pa.	Fatal	34	0	0	0	2	2	30	Inflight fire severed all pitch control to empennage. Pilots unable to maintain altitude. Crash not survivable.
06 22	Lockheed 1049H Airlift Int.	Nr. Saigon, So. Vietnam	Fatal	7	0	0	0	3	0	4	Collided in flight with other aircraft.
06 20	Douglas DC-6 United	70E Hayes Cr., Neb.	Serious	52	0	1	0	0	0	0	Attendant injured in turbulence. Seat belt sign on. Belt not fastened.
06 09	Douglas DC-8 United	Nr. Detroit, Mich.	Serious	65	0	1	0	0	0	0	Attendants injured in turbulence.
06 09	Boeing 727 Eastern	Nr. Massena, N.Y.	Serious	79	0	0	1	0	0	0	Aircraft penetrated buildups. Passengers warned. Belt not fastened.
05 19	Martin 404 Piedmont	Wilmington, N.C.	Serious	3	0	1	0	0	0	0	Stewardess wearing high heeled shoes. Stumbled and broke ankle.
05 15	Boeing 727 Eastern	Nr. Philadelphia, Pa.	Serious	99	0	0	1	0	0	0	Passenger out of seat when turbulence encountered. Seat belt sign on well in advance.
05 01	Douglas DC-8 United	Nr. Cleveland, Ohio	Serious	57	0	1	0	0	0	0	Stewardess fell, broke ankle wearing high heeled shoes in very light turbulence.
04 29	Boeing 727 United	Salt Lake City	None	56	0	0	0	0	0	0	Gear collapsed in ground loop swerve on landing.
04 25	Convair 640 Carribean Atlantic	San Juan, P.R.	Minor	57	0	0	0	0	0	0	Fire in hydraulics system caused off airport emergency landing on land. Ground loop due to brake fialure. Fire uncontrolled. Damage substantial.
04 25	Boeing 707 TWA	San Francisco	None	3	0	0	0	0	0	0	Gear collapsed on landing roll. Previous hard landing prior to crew change. No report made.

1967	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
04 17	Lockheed 1049H Alaska	Kotzebue, Alaska	None	32	0	0	0	0	0	0	Gear up landing during whiteout conditions.
04 15	Convair 440 Delta	Milwaukee, Wis.	None	2	0	0	0	0	0	0	Pilot inadvertently retracted gear during landing roll. Training flight.
04 08	Nord Avion 262-A Lake Central	Chicago, Ill.	None	9	0	0	0	0	0	0	Fire in engine during climbout. Landed without incident.
04 07	Boeing 727 United	Tampa, Fla.	Serious	103	1	0	0	0	0	0	Intentional gear up landing. Engineer injured during evacuation. Landed on foam runway.
04 04	Douglas DC-8 United	Nr. Springfield, Ill.	Serious	67	0	0	1	0	0	0	Passenger, age 92, fell, broke leg while returning to seat in turbulence. Seat belt sign turned on while in lavatory.
04 03	Beech C-45H Lexington Air Taxi	Lexington, Ky.	Fatal	9	0	0	0	1	0	8	Aircraft chartered by Piedmont Airlines to allow passengers to make connections after own aircraft delayed. Beech crashed on climbout due to excessive aft cargo loading combined with engine fire. Went into spin 300 ft. Crash not survivable.
03 30	Douglas DC-8 Delta	Kenner, La.	Fatal	6	0	0	0	6	0	0	Aircraft on training flight crashed during simulated 2 engine out landing. Aircraft crashed into residential area and motel fatally injuring 18 people on the ground. Crash not survivable.
03 29	Boeing 720 United	Nr. Sheridan, Wyo.	Serious	49	0	0	1	0	0	0	Passenger injured in CAT. Seat belt not fastened. Later died due to heart condition
03 23	Douglas DC-7 Universal	Travis AFB, Cal.	None	3	0	0	0	0	0	0	Aircraft collided with object during taxi.
03 14	Lockheed 1049G Eastern	Newark, N.J.	None	82	0	0	0	0	0	0	Lockheed collided with Vertol during taxi.
03 14	Vertol 10711 New York	Newark, N.J.	None	17	0	0	0	0	0	0	Substantial damage to both aircraft.
03 11	Boeing 707 American	Nr. Newark, N.J.	Serious	19	0	1	0	0	0	0	Attendant injured when aircraft performed evasive maneuver to avoid colliding with light twin.
03 10	Fairchild F-27 West Coast	Nr. Klamath Falls, Oregon	Fatal	4	0	0	0	2	1	1	Aircraft crashed into mountain during climbout. Lost control due to structural icing. Crash not survivable.
03 09	Douglas DC-9 TWA	Nr. Urbana, Ohio	Fatal	25	0	0	0	2	2	21	DC-9 collided in midair with general aviation aircraft. Pilot of other aircraft fatally injured. Crash not survivable.
03 07	Lockheed 382B Delta	Memphis, Tenn.	Serious	3	0	0	0	0	0	0	TV cameraman seriously injured when struck by wingtip of Lockheed while standing on top of 11 ft. loading stand.

1967	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
03 06	Boeing 727 United	Polo, Ill.	Serious	74	0	1	0	0	0	0	Attendant injured in CAT. Seat belt sign on.
03 05	Convair 340 Lake Central	Nr. Marseilles, Ohio	Fatal	38	0	0	0	2	1	35	Aircraft crashed due to separation of prop blades and their penetration of fuselage causing structural failure. Crash not survivable.
02 27	Lockheed 1049 Eastern	Newark, N.J.	None	2	0	0	0	0	0	0	Lockheed collided with Vertol taxiing.
02 27	Vertol 107-11 New York	Newark, N.J.	None	5	0	0	0	0	0	0	
02 24	Douglas DC-6 Northeast	Nr. Holmdel, N.J.	Minor	14	0	0	0	0	0	0	Aircraft experienced explosive decompression at 15,000 ft. Damage substantial.
02 22	Douglas DC-6 Northeast	Martha's Vineyard, Mass.	None	24	0	0	0	0	0	0	Gear collapsed on landing roll.
02 17	Martin 404 Southern	Atlanta, Ga.	None	29	0	0	0	0	0	0	Nose gear failed to extend. Landing made on mains.
02 14	Fairchild FH-227 Northeast	Boston, Mass.	None	3	0	0	0	0	0	0	Pilot inadvertently retracted gear during landing roll. Training flight.
02 10	Lockheed 1049H Flying Tiger	Nr. DaNang, So. Vietnam	None	4	0	0	0	0	0	0	Aircraft made emergency landing off airport on land. No. 2 engine and prop separated.
01 31	Douglas DC-6 Saturn	San Antonio, Texas	Fatal	3	0	0	0	3	0	0	Aircraft flew through trees and then hit a cliff approx. 1100 ft. below glide slope. Not survivable.
01 23	Convair 640 Carribean Atlantic	San Juan, P.R.	Minor	28	0	0	0	0	0	0	Aircraft undershot runway. Landed 250 ft. short.
01 20	Fairchild FH-227 Northeast	East Boston, Mass.	None	18	0	0	0	0	0	0	Nose gear collapsed on touchdown.
01 19	Vickers 745D United	Norfolk, Va.	Serious	50	0	0	0	0	0	0	Driver of ground vehicle seriously injured when drove in path of landing Viscount.

1966	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 30	Douglas DC-7 Airlift Int.	Saigon, Vietnam	Minor	4	0	0	0	0	0	0	Gear retracted on takeoff run.
12 24	Canadair CL-44 Flying Tiger	Nr. Tourane, Vietnam	Fatal	4	0	0	0	4	0	0	Aircraft crashed during approach.
12 04	Viscount V-700 United	Chicago, Ill.	None	50	0	0	0	0	0	0	Aircraft hydroplaned during landing roll. Collided with ditch. Substantial damage.
11 29	Convair 340 Allegheny	New Cumberland, Pa.	None	16	0	0	0	0	0	0	Aircraft overran runway on aborted takeoff after complete electrical failure.
11 26	Boeing 707 American	Oakland, Cal.	None	134	0	0	0	0	0	0	Gear collapsed on hard landing.
11 20	Martin 404 Piedmont	Nr. New Bern, N.C.	Fatal	3	0	0	0	2	1	0	Aircraft descended below obstructing terrain and crashed in dark wooded area.
11 15	Curtiss C-46 Zantop	Los Alamitos, Cal.	None	2	0	0	0	0	0	0	Gear collapsed during landing roll.
11 15	Boeing 727 Pan Am	Nr. Berlin, Germany	Fatal	3	0	0	0	3	0	0	Aircraft crashed into East Zone during approach to Berlin. On the scene investigation not allowed by Soviets. Only 50% of wreckage returned. Aircraft destroyed by impact and post crash fire. Crash appeared to be nonsurvivable.
11 14	Fairchild F-27 Ozark	Chicago, Ill.	Minor	43	0	0	0	0	0	0	Gear collapsed during taxi.
11 12	Boeing 720 United	Nr. Billings, Mont.	Serious	81	0	0	1	0	0	0	Passenger injured in CAT. Fell while returning to seat. Cockpit warning given.
11 02	Boeing 727 American	Flushing, N.Y.	None	72	0	0	0	0	0	0	Aircraft struck approach light pier short of runway. Gear collapsed on touchdown.
10 28	Pilatas PC6BH2 Wien Alaska	Kotzebue, Alaska	None	4	0	0	0	0	0	0	Collided with parked aircraft during taxi.
10 22	Douglas DC-8 Delta	New Orleans, La.	Minor	111	0	0	0	0	0	0	Aircraft undershot runway and landed in sod. Sank into soft turf and struck runway lip. Substantial damage.
10 18	Boeing 707 TWA	Los Angeles, Cal.	Minor	59	0	0	0	0	0	0	Gear collapsed due to hard landing.
10 13	Viscount 745 United	Muskegon, Mich.	None	13	0	0	0	0	0	0	Aircraft overshot runway on landing. Gear collapsed.
10 11	Sikorsky S-61 San Francisco Oakland Helicopter	Mountain View, Cal.	None	5	0	0	0	0	0	0	Helicopter made emergency off airport landing due to complete engine failure.
10 03	Douglas C-54B Southern Air Trans.	Miami, Fla.	None	2	0	0	0	0	0	0	Inadvertently raised gear on landing roll.
10 01	Douglas DC-9 West Coast	Nr. Wemme, Ore.	Fatal	18	0	0	0	3	2	13	Aircraft crashed into mountainous terrain, cause unknown. Aircraft destroyed by impact. Crash not survivable.
09 30	Lockheed 188 American	Indianapolis, Ind.	Serious	75	0	1	0	0	0	0	Stewardess broke ankle while serving meal in turbulence.

1966	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
09 30	Boeing 720B Pan Am	Nr. Kingston, Jamaica	Serious	111	0	0	1	0	0	0	Passenger injured in turb. Under jurisdiction of Jamaican gov't.
09 28	Convair 440 Eastern	Richmond, Va.	None	33	0	0	0	0	0	0	Aircraft struck trees at end of run-way during climbout. Continued to des-tination.
09 25	Boeing 727 Pacific	San Francisco,Cal.	Minor	70	0	0	0	0	0	0	Aircraft collided with building during taxi.
09 23	Douglas DC-3 Frontier	Nr. Rapid City, S.D.	Serious	10	0	1	0	0	0	0	Attendant injured in turb. TSTM in area.
09 22	Douglas DC-8 Delta	Nr. Macon, Ga.	Serious	38	0	0	1	0	0	0	Passenger injured in CAT. Pilot briefed, inadequate warning to passengers.
09 15	Lockheed 188 American	Montezuma, N.Y.	None	11	0	0	0	0	0	0	Aircraft received substantial damage from bird strikes.
09 12	Douglas DC-7 Airlift Int.	Tokyo, Japan	Serious	4	1	0	0	0	0	0	Aircraft unable to take off due to im-proper cargo loading. Overran runway. Destroyed.
09 09	Boeing 707 Pan Am	Nr. Honolulu, Hawaii	Serious	149	0	0	1	0	0	0	Passenger injured in turb. TSTM in area.
08 22	SudAvia 210 United	Newark, N.J.	None	13	0	0	0	0	0	0	Gear collapsed during taxi.
08 22	Lockheed 188 Western	Nr. San Diego,Cal.	Serious	69	0	0	1	0	0	0	Passenger injured in lavatory due to turb. Seat belt sign on. TSTM in area.
08 21	Grumman G21 Alaska Coastal	Juneau, Alaska	Fatal	9	0	0	0	1	0	8	Aircraft crushed in inaccessible terrain. Not survivable.
08 11	Nord 262 Lake Central	Martinsburg, W.Va.	Minor	17	0	0	0	0	0	0	Turbine failed in flight. Fragments penetrated main cabin.
08 09	Boeing 707 American	Nr. Harrisburg, Pa.	Serious	140	0	0	7	0	0	0	Passenger standing in aisle after belt sign turned on and warning given by crew.
08 06	British AC 1-11 Braniff	Nr. Falls City, Neb.	Fatal	42	0	0	0	2	2	38	Aircraft broke up in flight after pene-trating squall line. Not survivable.
08 04	Boeing 720 Western	Nr. Los Mochis, Mex.	Serious	98	0	0	1	0	0	0	Under jurisdiction of Mexican gov't.
08 04	Nord Avion 262 Lake Central	Morgantown, W.Va.	Serious	19	0	0	2	0	0	0	Turbine failed in flight. Cabin punctured
07 28	Curtiss C-46 Zantop	Port Elizabeth, N.J.	Serious	2	1	0	0	0	0	0	Engine failure in flight. Intentional gear up landing.
07 27	Douglas DC-3 Frontier	Gallup, N. Mex.	Serious	16	0	0	3	0	0	0	Aircraft ground looped on takeoff. Fire after impact. Damage substantial.
07 21	Lockheed L-188 Braniff	Fort Worth, Tex.	None	38	0	0	0	0	0	0	Aircraft made gear up landing.
07 11	Convair 600 Trans Texas	Harlingen, Tex.	None	21	0	0	0	0	0	0	Gear collapsed on touchdown.
07 09	Martin 404 Piedmont	Roanoke, Va.	Serious	42	0	0	1	0	0	0	Gear collapsed while aircraft parked on ramp.

1966	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
06 29	Boeing 720	American	Mojave, Cal.	Minor	6	0	0	0	0	0	0	Aircraft undershot landing during simulated 4-engine flameout approach. Substantial damage.
06 27	Convair 600	Central	Nr. Hot Springs, Ark.	Serious	17	0	1	0	0	0	0	Attendant injured during evasive manuever to avoid collision with light aircraft.
06 26	Douglas DC-3	Frontier	Hastings, Neb.	None	4	0	0	0	0	0	0	Aircraft ground looped during landing. Substantial damage.
06 18	Boeing 727	Eastern	Melbourne, Fla.	Serious	88	0	1	0	0	0	0	Aircraft penetrated build-ups. Seat belt sign on.
06 17	Convair 440	North Central	Chicago, Ill.	None	2	0	0	0	0	0	0	Engine failure during training flight.
06 16	Curtiss C-46	Zantop	Columbia City, Ind.	Fatal	2	0	0	0	2	0	0	Collided with light aircraft in flight. Aircraft destroyed. Pilot of other plane fatally injured.
06 06	Sikorsky S-61	San Fran.-Oakland Hel.	San Francisco, Cal.	Minor	8	0	0	0	0	0	0	Collided with gate during taxi. Substantial damage.
05 30	Pilatas PC6	Wien Alaska	Nr. Rampart, Alas.	None	6	0	0	0	0	0	0	Forced landing after engine failure. Substantial damage.
05 18	Douglas DC-7	United	Denver, Colo.	None	4	0	0	0	0	0	0	Gear collapsed on landing roll.
05 15	Douglas DC-8	United	Nr. Oncil, Neb.	Serious	40	0	0	2	0	0	0	Flight in area of squall line. Crew gave no warning to passengers.
05 12	Convair 240	Trans Texas	Ft. Worth, Tex.	None	8	0	0	0	0	0	0	Prop. failed on take-off run.
05 08	Boeing 727	Eastern	Ft. Worth, Tex.	None	4	0	0	0	0	0	0	Intentional gear up landing.
04 29	Sikorsky S-616	Los Angeles Airways	Los Angeles, Cal.	None	2	0	0	0	0	0	0	Simulated engine out landing during training flight. Substantial damage.
04 27	Curtiss C-46	Zantop	St. Louis, Mo.	None	2	0	0	0	0	0	0	Aircraft overshot runway; collided with approach lights. Substantial damage.
04 22	Lockheed 188	American Flyers	Ardmore, Okla.	Fatal	98	0	0	15	3	2	78	Heart condition of captain suspected to have caused aircraft to crash into hilltop during instrument approach. Aircraft was destroyed by impact. Most passenger seats separated from aircraft and scattered on the ground during last 150 feet of travel. 18 survivors were found in wreckage. 10 found in last 150 feet of wreckage area. 2 hiked out area. 6 found in ground further down hill. 3 later succumbed to injuries. All fatalities resulted from injuries received during impact. Scattered fires occurred along entire impact area.

1966	Type · Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
04 09	Boeing 720	United	Oakland, Cal.	None	8	0	0	0	0	0	0	Gear collapsed on take-off run. Ground loop.
04 01	Convair 340	Allegheny	Bradford, Pa.	None	47	0	0	0	0	0	0	Gear collapsed on hard landing.
03 24	Canadair A-44	Flying Tiger	Alameda, Cal.	None	3	0	0	0	0	0	0	Aircraft received substantial damage during hard touchdown.
03 24	Viscount 812	Continental	Colo. Springs, Colo.	None	13	0	0	0	0	0	0	Gear collapsed during hard landing.
03 21	Canadair A-44	Flying Tiger	Norfolk, Va.	Minor	6	0	0	0	0	0	0	Hard landing. Nose over. Fire after impact.
03 15	Sikorsky S-61	L.A. Airways	Los Angeles, Cal.	Serious	3	0	0	0	0	0	0	Gear collapsed during engine run up. Ground crew man seriously injured by flying debris.
03 05	Boeing 727	Eastern	Miami, Fla.	Minor	103	0	0	0	0	0	0	Intentional gear up landing.
03 04	Douglas DC-9	Delta	Chicago, Ill.	Serious	67	0	0	1	0	0	0	Passenger injured while deplaning. Fell down stairs.
03 03	Douglas DC-6	Delta	Birmingham, Ala.	None	47	0	0	0	0	0	0	Aircraft ground looped. Gear collapsed.
03 01	Vertol 107-11	New York Airways	Jamaica, N.Y.	None	9	0	0	0	0	0	0	Aft rotors struck fuselage during start.
02 27	Douglas DC-8	Delta	New Orleans, La.	None	97	0	0	0	0	0	0	Aircraft overshot runway on landing roll. Substantial damage.
02 17	Curtiss C-46	Reeve Aleutian	Homer, Alaska	None	2	0	0	0	0	0	0	Ground looped during taxi.
02 13	Boeing 720		Dallas, Tex.	None	127	0	0	0	0	0	0	Engine exploded during reverse thrust cycle on landing.
02 13	Cessna 185	Wien Alaska	Bornite, Alaska	None	3	0	0	0	0	0	0	Engine failure in flight.
02 10	Fairchild F-27	Allegheny	Gr. Pittsburgh Airport, Pa.	None	15	0	0	0	0	0	0	Gear collapsed on landing roll.
02 08	Cessna 180	Western Alaska	Dillingham, Alaska	None	2	0	0	0	0	0	0	Aircraft collided with snowblower on take-off.
01 30	Boeing 707	American	Nr. Los Angeles, Calif.	Serious	75	0	0	1	0	0	0	Passenger injured in CAT.
01 23	Boeing 707	Eastern	Jamaica, N.Y.	None	136	0	0	0	0	0	0	Gear collapsed during landing.
01 12	Boeing 720	Continental	Nr. Denver, Colo.	Serious	6	0	1	0	0	0	0	Trainee fell in cabin during stabilator trim maneuver.

1965	Type Model	Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
12 25	Douglas DC-8	JAL	San Francisco, Cal.	None	41	0	0	0	0	0	0	No. 1 engine failed in flight. Aircraft landed without incident. Evacuation orderly with no injuries.
12 22	Douglas DC-8	United	Nr. San Diego, Cal.	Serious	10	0	1	0	0	0	0	Attendant injured in turbulence.
12 20	Grumman G-73	Northern Consolidated	Bethel, Alaska	None	8	0	0	0	0	0	0	Aircraft received substantial damage from premature lift off.
12 16	Curtiss C-46	Zantop	Detroit, Mich.	Serious	2	0	0	0	0	0	0	Ground crewman seriously injured when he walked into rotating propellor.
12 15	Lockheed L-1049	Flying Tiger	Alamosa, Colo.	Fatal	3	0	0	0	3	0	0	Pilot became disoriented and crashed into mountainous terrain.
12 08	Fairchild F-27	Bonanza	Yuma, Ariz.	None	17	0	0	0	0	0	0	Pilot inadvertently retracted gear on landing roll.
12 07	Boeing 727	National	Tampa, Fla.	None	60	0	0	0	0	0	0	Engine failure on take-off.
12 04	Boeing 707	TWA	Carmel, N.Y.	Fatal	58	0	0	0	0	0	0	(See below)
12 04	Lockheed L1049	Eastern	Carmel, N.Y.	Fatal	54	2	2	45	1	0	3	Lockheed and Boeing had midair collision. Boeing landed without incident or injury. Lockheed made forced landing off airport. Fuselage of Lockheed separated into 3 main sections. All but 2 of the passengers remained in fuselage in vicinity of their seats, throughout crash sequence. Several passengers found themselves out of their seats after impact and others had difficulty releasing belts. Captain and one passenger died due to "inhalation of products of combustion." Two others succumbed later to injuries received in crash. Passengers evacuated through breaks in fuselage, forward cockpit crew door, left main cabin door, and opening in aft end of cabin near pressure dome area.
12 01	Douglas DC-3	West Coast	Hoquiam, Wash.	Minor	13	0	0	0	0	0	0	Aircraft overshot runway and collided with dirt bank on landing. Substantial damage.
11 24	Fairchild F-27	Pacific	Nr. Woodside, Cal.	None	33	0	0	0	0	0	0	In flight lightning strike caused substantial damage.
11 15	DeHavilland DHC-2	Wien Alaska	Artic Village, Alaska	None	1	0	0	0	0	0	0	Aircraft damaged substantially in hard landing.

1965	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
11 11	Boeing 727	United	Salt Lake City, Utah	Fatal	91	3	3	29	0	0	43	Aircraft undershot runway on landing. Post-crash fire resulted and destroyed aircraft. Fire mostly contained within fuselage, feeding on cabin interior. All fatalities due to smoke, intense heat, and fire. No traumatic injuries to prevent escape. All exits were utilized. Stewardesses could not reach their assigned stations after impact. Stewardesses not seated near exits during landing.
11 08	Boeing 727	American	Nr. Constance, Ky.	Fatal	62	0	1	3	3	2	53	Aircraft crashed while turning final on visual approach. Aircraft destroyed by impact and post-crash fire. Cabin area completely consumed. 3 of 4 survivors were thrown clear during impact sequence. 4th was seated in foremost row of seats and crawled out through hole in forward fuselage. Fatalities caused by severe trauma, fire, or both. Crash basically not survivable.
11 08	Convair 240	Trans Texas	College Sta., Tex.	None	10	0	0	0	0	0	0	Aircraft ground looped on landing roll, due to uncontrolled propellor reversal.
10 17	Douglas DC-6	United	Huntsville, Ala.	Minor	16	0	0	0	0	0	0	Gear retracted on take-off run. Cause unknown.
10 17	Boeing 707	Contintental	Glenwood Spgs., Colo.	Serious	115	0	1	1	0	0	0	Injuries due to CAT.
10 16	Douglas DC-7	Eastern	Charlotte, N.C.	None	62	0	0	0	0	0	0	Aircraft undershot runway. Gear collapsed. Fire in wing area after impact.
10 15	Douglas DC-8	United	San Diego, Cal.	None	118	0	0	0	0	0	0	Collided with parked aircraft during taxi. Minor damage.
10 14	Argosy AW-650	Zantop	2-S, Piqua, Ohio	None	3	0	0	0	0	0	0	Total in flight engine failure forced landing off airport. Collided with support pylon of highway overpass. Collided with car. No injuries.
10 09	Douglas DC-8	United	Nr. Los Angeles, Cal.	Serious	45	0	0	1	0	0	0	Passenger injured in evasive maneuver to avoid collision with PA-23.

1965	Type Model Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
10 01	Pilatas PC6 Wien Alaska	Selawik, Alaska	None	6	0	0	0	0	0	0	Ground looped on landing. Gear collapsed.
09 22	Douglas DC-6 United	Nr. Des Moines, Iowa	Serious	74	1	0	0	0	0	0	Bird strike.
09 20	Lockheed 1049 American Flyers	Ardmore, Okla.	None	3	0	0	0	0	0	0	Overshot runway on landing. Collided with ditches. Substantial damage.
09 19	Martin 404 Pacific	San Jose, Cal.	Serious	7	0	0	0	0	0	0	Ground crewman's arm struck by prop.
09 17	Boeing 707 Pan Am	Montserrat, BWI	Fatal	30	0	0	0	3	6	21	Aircraft descended below safe altitude. TSTM's in area. Under jurisdiction of British government.
09 14	Douglas DC-3 North Central	Stevens Pt., Wis.	None	8	0	0	0	0	0	0	Aircraft struck trees on instrument approach.
09 14	Douglas DC-3 Cordova	McCarthy, Alaska	None	4	0	0	0	0	0	0	Aircraft ground looped on landing roll. Struck gravel bank along side runway.
09 13	Convair 880 TWA	Kansas City, Mo.	None	4	0	0	0	0	0	0	Aircraft stalled on takeoff. Training flight. Aircraft destroyed. Fire after impact.
09 13	Curtiss C-46 Zantop	Dover, Dela.	None	3	0	0	0	0	0	0	Aircraft made forced landing off airport. False fire warning.
09 11	Boeing 720 Braniff	Mexico City, Mex.	None	127	0	0	0	0	0	0	Gear collapsed on landing roll.
09 04	Aero Commander 680 Cordova	Lk. Tustumena, Alas.	Fatal	5	0	0	0	1	0	3	Aircraft crashed in lake. Continued VFR into adverse weather.
09 01	British AC 1-11 Mohawk	Utica, N.Y.	Minor	32	0	0	0	0	0	0	Gear collapsed on landing roll.
08 31	Curtiss C-46 Zantop	Atlanta, Ga.	None	2	0	0	0	0	0	0	Gear collapsed on landing roll.
08 23	Cessna 185 Wien Alaska	Bettles, Alaska	None	4	0	0	0	0	0	0	Aircraft collided with oil drums during taxi.
08 17	Boeing 720 Continental	Nr. Leavenworth, Kansas	Serious	170	0	1	0	0	0	0	Attendant injured during evasive maneuver to avoid colliding with another aircraft.
08 16	Boeing 727 United	In Lake Michigan	Fatal	30	0	0	0	3	3	24	Aircraft descended below assigned altitude and struck lake. Destroyed by impact. Crash not survivable. Cause of descent unknown.
08 15	Douglas DC-6 United	Boston, Mass.	None	3	0	0	0	0	0	0	Gear collapsed on landing roll.
08 12	Lockheed L-188 Western	Battle Mtn., Nev.	Serious	94	0	1	0	0	0	0	Attendant injured in turbulence.
08 12	Curtiss C-46 Zantop	Nr. Salem, Ore.	None	2	0	0	0	0	0	0	Cargo tiedown lines separated in turbulence. Damage substantial.
08 02	Douglas DC-3 Northeast	Nr. Newport, Vt.	Serious	8	0	1	0	0	0	0	Attendant out of seat when turbulence encountered.
07 23	Convair 440 Allegheny	Montorsville, Pa.	Serious	40	2	2	19	0	0	0	Aircraft crashed on climbout after engine failure. Fire after impact.

1965	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
07 17	Douglas	DC-6	Zantop	Nr. San Jose, Cal.	None	4	0	0	0	0	0	0	Engine cowl separated inflight. Damaged vertical stabilizer.
07 06	Boeing	707	TWA	Nr. Omaha, Neb.	Serious	52	0	1	0	0	0	0	Attendant injured when seat belt attach fitting failed.
07 05	Boeing	707	American	Nr. Texarkana, Ark.	None	100	0	0	0	0	0	0	Hail damage to aircraft. TSTM with large anvil.
07 01	Boeing	707	Continental	Kansas City, Mo.	Minor	66	1	1	3	0	0	0	Aircraft overran runway due to hydroplaning. Collided with blast wall. Fuselage broken into 3 sections. All injuries minor. Second officer received back injuries from compressive forces of final impact. Attendant left seat before impact received cuts and bruises. Emergency cabin lighting functioned properly. Cockpit door to cabin jammed shut during impact. Forward passenger entry door also obstructed and could not be opened. Minor fire damage found near baggage area.
06 28	Boeing	707	Pan Am	San Francisco, Cal.	None	153	0	0	0	0	0	0	No. 4 engine exploded in flight. Fragments penetrated wing causing explosion in outboard reserve fuel tank. Aircraft landed without further incident. Evacuation orderly.
06 09	Douglas	DC-8	National	San Francisco, Cal.	None	77	0	0	0	0	0	0	Engine fire started during climbout. Landed without incident.
05 29	Douglas	DC-3	Reeve Aleutian	Nikolski, Alaska	None	5	0	0	0	0	0	0	Gust of wind caused premature liftoff and stall. Substantial damage.
05 18	Douglas	DC-6A	Aaxico Airlines	Knob Noster, Mo.	None	3	0	0	0	0	0	0	Aircraft crashed during ILS approach. Aircraft destroyed by impact and ground fire. All crewmembers exited through crew entrance door.
05 11	Boeing	707	American	El Paso, Texas	None	131	0	0	0	0	0	0	No. 7 wheel separated from aircraft after takeoff. Landed without incident.
05 09	Boeing	707	American	Nr. Mineral Wells, Texas	None	96	0	0	0	0	0	0	Gear collapsed on hard landing.
05 05	Sikorsky	S-6LA	S.F. and Oakland	San Francisco, Cal.	None	2	0	0	0	0	0	0	Collided with automobile during taxi.
05 04	Convair	880	TWA	Nr. Chicago, Ill.	Serious	63	0	0	1	0	0	0	Passenger injured in turbulence. No announcement made of activation of seat belt sign.

1965	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
05 03	Boeing 720 Continental	Los Angeles, Cal.	None	22	0	0	0	0	0	0	2 engines failed during initial climbout. Landed without incident.
04 27	Convair 340 Carribean Atlantic	Ponce, P.R.	None	46	0	0	0	0	0	0	Aircraft undershot runway. Hard landing.
04 23	Boeing 707 Pan Am	Merida, Mex.	None	100	0	0	0	0	0	0	Hard landing. Under jurisdiction of Mexican government.
04 23	Douglas DC-6 AAXICO	W. Slope, Mt. Rainier, Wash.	Fatal	5	0	0	0	5	0	0	Aircraft crashed into west slope of Mt. Rainier when continued VFR in IFR conditions. Crash not survivable.
04 19	Lockheed L-188 Eastern	Nr. Tallahassee, Fla.	Serious	58	0	1	0	0	0	0	Attendant injured while returning to seat.
04 19	Cessna 180 Cordova	English Bay, Alaska	Serious	3	1	0	2	0	0	0	Aircraft stalled on final.
04 16	Sikorsky S-62A S.F. and Oakland	San Francisco, Cal.	Minor	2	0	0	0	0	0	0	Bird strike caused inflight engine failure. Autorotative forced landing. Aircraft destroyed.
04 16	Fairchild F-27 Bonanza	Las Vegas, Nev.	Serious	2	2	0	0	0	0	0	Aircraft crashed on takeoff. Flaps not symmetric. Aircraft destroyed.
04 15	Sikorsky S-62A S.F. and Oakland	2 S.E. Morga, Cal.	Minor	2	0	0	0	0	0	0	Inflight engine failure. Autorotative forced landing on water. Aircraft destroyed.
04 01	Fairchild F-27A Bonanza	Nr. Julian, Cal.	Serious	43	0	0	1	0	0	0	Passenger injured in turbulence while standing in galley. Seat belt sign on.
03 28	Fairchild F-27A Bonanza	Prescott, Ariz.	Serious	41	0	0	1	0	0	0	Passenger injured in turbulence. Seat belt sign on. Passenger left seat.
03 26	Boeing 707 Pan Am	Saigon, S. Vietnam	None	170	0	0	0	0	0	0	Dragged pod on landing.
03 25	Convair 440 Mohawk	Albany, N.Y.	None	43	0	0	0	0	0	0	Fire in baggage compartment while taxiing from landing.
03 19	Boeing 720 Braniff	Houston, Texas	None	61	0	0	0	0	0	0	Hard landing. Substantial damage.
03 17	Boeing 727 TWA	Kansas City, Mo.	None	97	0	0	0	0	0	0	Hard landing. Substantial damage.
03 14	Sud Avion Caravelle United	Ypsilanti, Mich.	Serious	54	0	0	1	0	0	0	Engine fire on ground. Passenger injured during evacuation.
03 05	Douglas DC-8 Eastern	Jamaica, N.Y.	None	84	0	0	0	0	0	0	Dragged engine pod in crosswind landing. Engine separated from wing.
03 04	Douglas DC-6 United	Ft. Wayne, Ind.	Minor	58	0	0	0	0	0	0	Aircraft collided with snowbank on landing. Gear collapsed.
03 02	Convair 880 Northeast	Nr. Wilmington, N.C.	Serious	97	0	0	2	0	0	0	Injuries due to turbulence. Seat belts not fastened.
02 22	Convair 240 Mohawk	Nr. Jamaica, N.Y.	Serious	47	0	1	0	0	0	0	Attendant injured in application of negative G's to lock landing gear down.

1965	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
02 17	Boeing	707	TWA	Los Angeles, Cal.	None	14	0	0	0	0	0	0	Collided with parked C-172.
02 08	Curtiss	C-46A	Zantop	Atlanta, Ga.	None	4	0	0	0	0	0	0	Gear collapsed on landing roll.
02 08	Douglas	DC-7B	Eastern	Nr. Jones Beach, N.Y.	Fatal	84	0	0	0	3	2	79	Pilot became spatially disoriented after evasive maneuver to avoid colliding with another aircraft. Crashed offshore.
01 31	Boeing	707	Pan Am	Nr. Bermuda Is.	Serious	75	0	0	2	0	0	0	Passengers injured in turbulence. Seat belts not fastened. Airspeed at time 0.8 Mach.
01 24	Caravelle	VIR	United	Nr. Allentown, Pa.	Serious	31	0	1	0	0	0	0	Attendant in galley thrown to floor. Seat belt sign on.
01 23	Boeing	720	Northwest	Nr. Chicago, Ill.	Serious	50	0	0	2	0	0	0	Seat belt sign malfunction. Injuries due to turbulence.
01 21	Martin	404	Piedmont	Weyers Cave, Va.	None	28	0	0	0	0	0	0	Aircraft undershot runway on landing. Collided with snowbank. Fire after impact.
01 21	Convair	340	Allegheny	Lancaster, Pa.	Serious	25	0	1	1	0	0	0	Engine failure in flight. Overshot runway on landing. Substantial damage.
01 18	Convair	440	Mohawk	Windsor Lock, Conn.	Serious	13	0	0	1	0	0	0	
01 08	Convair	240	Central	Tulsa, Okla.	None	12	0	0	0	0	0	0	Intentional gear up landing.
01 08	Douglas	DC-8	Eastern	San Juan, P.R.	None	90	0	0	0	0	0	0	Gear collapsed during taxi.

1964	Type Model Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
12 30	Curtiss C-46A Zantop	Detroit, Mich.	Fatal	4	0	0	0	2	0	2	Cause of crash undetermined.
12 30	Convair 340 United	Saugus, Cal.	Minor	47	0	0	0	0	0	0	Fuel starvation during cruise. Forced landing off airport. Substantial damage.
12 24	Lockheed 1049 Flying Tiger	San Francisco, Cal.	Fatal	3	0	0	0	3	0	0	Aircraft crashed into ridge follwing departure. Crash not survivable.
12 22	Cessna 185 Cordova	Seldovia, Alaska	None	2	0	0	0	0	0	0	Ground looped on landing roll.
11 28	Pilatas PC-6A Wien Alaska	Nr. Hughes, Alaska	None	5	0	0	0	0	0	0	Gear collapsed on landing.
11 25	Curtiss C-46 Zantop	Covington, Ky.	None	2	0	0	0	0	0	0	Gear collapsed on landing.
11 24	Curtiss C-46 Delta	Baton Rouge, La.	None	2	0	0	0	0	0	0	Overshot landing, collided with ditches. Substantial damage.
11 23	Boeing 707 TWA	Rome, Italy	Fatal	73	0	2	9	3	2	43	Aircraft collided with steam roller on takeoff. Under jurisdiction of Italian government.
11 20	Curtiss C-46A Zantop	Inkster, Mich.	None	2	0	0	0	0	0	0	Inadequate snow removal from wings. Stalled on climbout. Aircraft destroyed.
11 19	Douglas DC-4 Slick	Norfolk, Va.	None	2	0	0	0	0	0	0	Gear collapsed during taxi.
11 19	Argosy AW-650 Zantop	Gwin, Mich.	None	3	0	0	0	0	0	0	Fire in flight. Landed without incident.
11 15	Fairchild F-27A Bonanza	Las Vegas, Nev.	Fatal	29	0	0	0	2	1	26	Aircraft crashed into mountainous terrain during instrument approach., Aircraft destroyed by impact. Crash not survivable.
11 15	Lockheed 749A TWA	Wichita, Kans.	Serious	20	0	0	2	0	0	0	Passenger seat belt failed in severe turbulence.
11 12	Grumman G-44 Kodiak	Cape Atitak, Alas.	None	5	0	0	0	0	0	0	Wing float struck submerged object during water takeoff.
11 12	Boeing 707 American	Nashville, Tenn.	None	66	0	0	0	0	0	0	Gear collapsed during taxi.
11 12	Canadair CL-44 Flying Tiger	Detroit, Mich.	None	3	0	0	0	0	0	0	Gear collapsed on landing roll.
11 09	Convair 880 TWA	Chicago, Ill.	Serious	50	0	2	0	0	0	0	Attendants injured in evasive maneuver to avoid midair collision.
11 05	Boeing 720 United	San Francisco, Cal.	Minor	94	0	0	0	0	0	0	Gear collapsed on landing.
10 31	Sikorsky S58C Chicago Helicopter	Joliet, Ill.	Serious	2	0	0	0	0	0	0	Ground crewman seriously injured by sling load.
10 30	Curtiss C-46F Zantop	Pittsburgh, Pa.	None	2	0	0	0	0	0	0	Engine failure in flight. Gear collapsed on landing.
10 25	Convair 340 Frontier	Rock Springs, Ark.	Minor	27	0	0	0	0	0	0	Gear collapsed during hard landing.
10 10	Curtiss C-46 Capitol	Charleston, S.C.	None	2	0	0	0	0	0	0	Engine failure on takeoff.

1964	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
10 02	Convair 285ACF	Alaska Coastal	Chichagof Is., Alaska	Fatal	3	1	0	0	1	0	0	Aircraft destroyed during hard landing.
09 23	Douglas DC-8	Eastern	San Juan, P.R.	Fatal	99	0	0	0	0	0	0	Ground crewman run over as aircraft pushed from gate.
09 22	Douglas DC-3	Atlantic	San Juan, P.R.	None	2	0	0	0	0	0	0	Aircraft stalled out after initial climb. Fire after impact. Substantial damage.
09 22	Viscount 700	United	Nr. Springfield, Va.	Serious	42	0	2	0	0	0	0	Attendants injured in evasive maneuver to avoid midair collision with AF plane.
09 22	Boeing 720	Western	Sacramento, Cal.	Minor	56	0	0	0	0	0	0	Aircraft undershot runway. Gear collapsed.
09 14	Convair 440	Frontier	Farmington, N. Mex.	None	23	0	0	0	0	0	0	Gear collapsed during hard landing.
09 07	Boeing 720	Northwest	Nr. Minneapolis, Minn.	Serious	92	0	1	1	0	0	0	Injuries due to turbulence.
09 06	Vertol 107	N.Y. Airways	New York, N.Y.	None	2	0	0	0	0	0	0	Collided with parked aircraft during taxi.
08 26	Boeing 707	TWA	Kansas City, Mo.	None	138	0	0	0	0	0	0	Aircraft undershot runway. Both main gear sheared off. Fire after impact.
08 26	Argosy AW650	Zantop	Oscoda, Mich.	None	3	0	0	0	0	0	0	Aircraft porpoised excessively after take-off. Takeoff aborted. Gear up landing.
07 24	Douglas DC-8	Eastern	Nr. Gainesville, Fla.	Serious	137	0	0	1	0	0	0	Passenger injured in turbulence. Did not comply with seat belt sign.
07 20	Douglas DC-7	Eastern	Charlotte, N.C.	None	57	0	0	0	0	0	0	Gear collapsed from ground loop during landing roll.
07 20	Douglas DC-3	Central	Pueblo, Colo.	Serious	14	0	1	0	0	0	0	Attendant injured in CAT.
07 17	Grumman G-44	Cordova	Cordova, Alaska	None	8	0	0	0	0	0	0	Gear up landing on land. Passengers included two infants.
07 17	Douglas DC-7	Eastern	Richmond, Va.	Minor	76	0	0	0	0	0	0	Undershot runway. Gear collapsed.
07 15	Lockheed 1049	Eastern	New York, N.Y.	Serious	20	0	1	0	0	0	0	Injury due to turbulence.
07 12	Pilatas PC-6	Wien Alaska	Ruby Creek, Alaska	None	2	0	0	0	0	0	0	Gear collapsed during ground loop.
07 12	Cessna 185	Wien Alaska	Nr. Kotzebue, Alas.	None	4	0	0	0	0	0	0	Stalled on initial climbout. Collided with parked PA20.
07 09	Viscount 745D	United	Nr. Parrotsville, Tenn.	Fatal	39	0	0	0	2	2	35	Inflight fire rendered aircraft uncontrollable. Crash was not survivable. 1 passenger died from free fall. Found 1.6 miles from wreckage site. Aircraft destroyed by fire and impact.
07 08	Sud Avion Caravelle	United	Nr. Knoxville, Tenn.	Fatal	54	0	0	0	0	0	1	Seat belt failed to hold passenger in turbulence. Cause of death not given.

1964	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
07 01	Boeing 720 American	Jamaica, N.Y.	None	12	0	0	0	0	0	0	Gear collapsed during ground loop. Fire after impact.
07 01	Convair 880 TWA	Nr. Allentown, Pa.	Serious	45	0	1	0	0	0	0	Attendant injured in CAT.
06 30	Douglas DC-8 National	Jamaica, N.Y.	None	71	0	0	0	0	0	0	Collided with parked L-1049 during taxi.
06 23	Cessna 180 Western Alaska	Togiak, Alaska	Serious	3	1	0	0	0	0	0	Aircraft nosed over on landing.
06 05	Douglas DC-6 Northeast	Flushing, N.Y.	None	43	0	0	0	0	0	0	Undershot runway. Gear collapsed.
05 29	Boeing 707 TWA	Paris, France	None	103	0	0	0	0	0	0	Gear collapsed during ground loop on takeoff.
05 12	Viscount 745D United	Chantvilly, Va.	Minor	3	0	0	0	0	0	0	Inadvertent gear up landing.
05 08	Sikorsky S-61L L.A. Airways	Anaheim, Cal.	None	17	0	0	0	0	0	0	Collided with fence on landing. Substantial damage.
05 07	Fairchild F-27 Pacific	Nr. San Ramon, Cal.	Fatal	44	0	0	0	2	1	41	Suicidal passenger shot pilot and copilot. Aircraft crashed uncontrolled.
05 04	Douglas DC-GB United	Rochester, N.Y.	None	29	0	0	0	0	0	0	Gear collapsed on takeoff run.
04 24	Lockheed 188 Northwest	Cleveland, Ohio	Minor	84	0	0	0	0	0	0	Intentional gear up landing.
04 17	Cessna 185 Wien Alaska	Nr. Elim, Alaska	Fatal	2	0	0	0	1	0	1	Continued VFR in adverse weather. White out conditions.
04 11	Douglas DC-6 Pan Am	Nr. San Jose, Costa Rica	Serious	25	0	1	0	0	0	0	Injury due to turbulence.
04 10	Douglas DC-3 Northeast	Montpelier, Vt.	None	20	0	0	0	0	0	0	Collided with parked PA-22 during ground loop.
04 07	Boeing 707 Pan Am	Jamaica, N.Y.	Serious	145	0	1	15	0	0	0	Aircraft overshot runway. Came to rest in water.
04 06	Cessna 185 Wien Alaska	Nr. Bull River, Alaska	None	3	0	0	0	0	0	0	Aircraft stalled out on initial climbout.
03 26	Convair 880 Delta	Nr. Tampa, Fla.	Serious	93	0	0	1	0	0	0	Injury due to turbulence.
03 22	DeHavilland DHC-2 Wien Alaska	Nr. Umiat, Alaska	None	2	0	0	0	0	0	0	Collided with snowbank. Gear collapsed.
03 17	Boeing 720 Northwest	Nr. Billings, Mont.	Serious	40	0	1	0	0	0	0	Attendant injured in CAT.
03 12	Douglas DC-3 Frontier	Miles City, Mont.	Fatal	5	0	0	0	2	1	2	Aircraft descended below MDA. Crashed on final approach. Fire after impact.
03 10	Douglas DC-4 Slick	Boston, Mass.	Fatal	3	0	0	0	3	0	0	Aircraft crashed due to airframe icing. On initial approach.
03 09	Lockheed 749 TWA	Boston, Mass.	None	14	0	0	0	0	0	0	Gear collapsed on touchdown.
03 04	Douglas DC-3 Southern	Tupelo, Miss.	None	5	0	0	0	0	0	0	Aircraft nosed over during taxi.
02 29	Martin 404 Mohawk	Binghamton, N.Y.	None	44	0	0	0	0	0	0	Inadvertently retracted gear on landing rollout.

1964	Type Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
02 25	Douglas DC-8	Eastern	New Orleans, La.	Fatal	58	0	0	0	3	4	51	Aircraft crashed into lake during climb-out. Crash not survivable.
02 24	Boeing 720	Northwest	Miami, Fla.	None	40	0	0	0	0	0	0	Engine failed during climbout. Landed without incident.
02 21	Curtiss C-46A	Zantop	Denver, Colo.	None	3	0	0	0	0	0	0	Pilot retracted gear on landing roll.
02 13	Convair 440	Hawaiian	Hilo, Hawaii	Serious	40	0	0	0	0	0	0	Aircraft overshot runway on landing roll. Collided with ditch. Substantial damage.
02 12	Fairchild F-27	Bonanza	Las Vegas, Nev.	None	34	0	0	0	0	0	0	Aircraft overshot runway on landing. Collided with snowbank.
02 12	Douglas DC-3	Southern	Huntsville, Ala.	Serious	29	0	0	1	0	0	0	Passenger's belt released in turbulence.
01 21	Grumman G-44	Kodiak	Karlak, Alaska	None	4	0	0	0	0	0	0	Aircraft undershot runway. Gear collapsed.
01 20	Grumman G-21A	Alaska Coastal	Petersburg, Alaska	None	2	0	0	0	0	0	0	Aircraft collided with wires during low pass. Substantial damage.
01 13	Viscount 745D	United	Nr. Asheville, N.C.	Serious	23	0	1	0	0	0	0	Attendant injured in CAT.
01 11	Fairchild F-27	Ozark	St. Louis, Mo.	None	2	0	0	0	0	0	0	Inadvertent gear up landing.
01 05	Douglas DC-3	Pan Am	Miami, Fla.	None	2	0	0	0	0	0	0	Fire developed during engine start.
01 01	Convair 880	TWA	Boston, Mass.	Minor	64	0	0	0	0	0	0	Aircraft overshot runway. Gear collapsed.
01 01	Curtiss C-46A	AAXICO	Hill AFB, Utah	None	3	0	0	0	0	0	0	Gear collapsed on landing roll.

APPENDIX B

CIVIL AIR CARRIER ACCIDENTS*

NATO COUNTRIES (EXCLUDING U.S.) (1964-1974)

1974	Type Model Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
12 24	Herald British Island Airways	Jersey Airport	None	53	0	0	0	0	0	0	Aircraft crashed during single engine approach.
12 04	British AC 1-11 British Airways	Hurn Airport	None	4	0	0	0	0	0	0	Intentional gear up landing.
12 04	SVG-10 British Airways	Japan	None	17	0	0	0	0	0	0	Incident. All engines ran down due to fuel exhaustion in one tank. Restart made. Landed without incident.
11 20	Boeing 747 Lufthansa	Nairobi Airport	Fatal	157		4	16		4	55	Pilot failed to extend leading edge slats on takeoff. Crashed shortly after becoming airborne.
10 29	Lockheed L-188 Panartic Oils	Nr. Rae Point NWT, Can.	Fatal	34	0	0	2	3	1	28	Crashed in ice and water short of runway during approach.
10 04	Douglas DC-GB Delta Air	Southend, Essex	None	105	0	0	0	0	0	0	Engineer inadvertently retracted gear on takeoff.
09 03	Boeing 747 British Airways	Nairobi	None								Incident. Aircraft descended below Glides Slope during automatic pilot controlled ILS. Landed without incident.
09 02	Boeing 707 Laker Airways	Gatwick Airport	None	158	0	0	0	0	0	0	Hard landing.
06 21	Boeing 727 Dan Air	Nr. Luton, England	None	134	0	0	0	0	0	0	Aircraft overran runway on takeoff. Struck LOC antennae, landed without incident.
06 12	TU-134A Aviogenex (YU)[1]	Brussels, Belgium	None	85	0	0	0	0	0	0	Gear up landing.
06 06	Boeing 707 British Airtoure	Heraklion, Crete	None	142	0	0	0	0	0	0	Hard landing.
05 23	Boeing 747 Singapore	Rome, Italy	None	354	0	0	0	0	0	0	Incident. Engine failure in flight.
05 20	Heron Peters Aviation (G)	Sumburgh, Shetlands	None	15	0	0	0	0	0	0	Aircraft slid off runway. Gear collapsed.
05 09	Hawker Siddeley 125 McAlpine(G)	Luton, England	None	2	0	0	0	0	0	0	Dragged wingtip on landing.
04 18	British AC 1-11 Court Line	Luton, England	Fatal	91	0	0	0	0	0	0	Aircraft collided with taxiing Aztec during takeoff. One of 2 occupants in Aztec fatally injured. Substantial damage to 1-11.
04 15	PBY5A Austin Airways (CF)	Hamilton, Can.	None	4	0	0	0	0	0	0	Aircraft struck debris during water landing.
04 01	Douglas DC-10 Lufthansa	Sydney, Australia	None	36	0	0	0	0	0	0	Incident. Aircraft overran runway during landing. Came to rest in sand. No damage.
03 22	Super Guppy UTA (F)	Lemwerder, Germany	None	3	0	0	0	0	0	0	Nose gear collapsed during takeoff run.

*Includes Pertinent Incidents.

[1] Letters in parentheses designate country of registry according to World Airline Accident Summary, Civil Aviation Authority, U.K.

Note: In none of above cases are data avilable at this time concerning occupant injuries or emergency egress.

1974	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
03 15	Caravelle Sterling (OY)	Tehran, Iran	Fatal	96	0	0	0	0	0	15	Gear collapsed during taxi. Ruptured fuel tank. Fire resulted.
03 12	Viscount British Midland	St. Mawgan, Newquay	None	25	0	0	0	0	0	0	Hard landing. Gear collapsed.
03 05	Douglas DC-10 THY (TC)	Paris, France	Fatal	345	0	0	0	3	7	334	Aircraft crashed during climbout due to explosive decompression.
02 28	Douglas DC-7 Aer Turas	Luton, England	Serious	11	0	1	1	0	0	0	Aircraft overran runway during landing. Injuries resulted because occupants were not secured in seats.
02 08	Douglas DC-8 UTA (F)	Los Angeles, Cal.	Serious	162	0	0	1	0	0	0	Fire occurred in landing gear area. Takeoff aborted. Pass. broke ankle during evacuation.
01 29	Boeing 707 Laker (G)	Nr. Darwin, Aus.	None	160	0	0	0	0	0	0	Part of trailing edge of flap separated during approach. Landed without incident.
01 26	Fokker F28 THY (TC)	Cumaouasi, Turkey	Fatal	72		1	6	2	1	62	Aircraft crashed on takeoff.
01 25	Douglas DC-3 St. Felicien Air Services (CF)	Akpatok Is., Can.	None	10	0	0	0	0	0	0	Ground looped on landing.
01 14	British AC 1-11 BAED	Templehof, Berlin	None	14	0	0	0	0	0	0	Gear collapsed on landing.
01 01	Fokker F28 Itavia (I)	Nr. Turin	Fatal	42	0	1	3	2	1	35	Aircraft crashed during approach. Post crash fire occurred.

1973	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 22	Caravelle Royal Air Maroc (QO)	Nr. Tetuan, Tangier	Fatal	105				3	4	98	Crashed into mountainous terrain during approach.
12 20	Boeing 707 DLH (D)	Delhi, India	None	109	0	0	0	0	0	0	Aircraft struck building during approach. Crash landed on runway. Fire after impact. Aircraft destroyed.
12 14	Skyvan Loganair (G)	Gatwick, G.B.	None	2	0	0	0	0	0	0	Aircraft ground looped during landing.
11 12	Nord 262 Rosseau Aviation (F)	Craon, France	None	5	0	0	0	0	0	0	Aircraft made off airport forced landing due to fuel exhaustion.
09 04	Herald British Is. Airways (G)	Gatwick, G.B.	None	45	0	0	0	0	0	0	Nose gear collapsed after parking at gate.
07 17	Convair 640 SATA (HB)	Troms/Langues, Nor.	None	60	0	0	0	0	0	0	Gear partially collapsed during hard landing.
07 11	Boeing 707 Varig (PP)	Nr. Paris, France	Fatal	134	4	6	1	0	0	116	Aircraft descending for Orly, cabin began to fill with heavy smoke coming from rear lavatory. Attempts to distinguish source of smoke unsuccessful. Cabin depressurized and rear discharge valve opened but smoke continued to spread through entire aircraft. Flight crew unable to see instruments so forced landing was made in level area 4 miles from airport. Crash landing was survivable, 7 occupants escaped through cockpit windows, 2 attendants through left forward door and 1 through right galley forward door. 3 passengers rescued but only 1 survived. All deaths due to CO_2 or toxic gas inhalation. No survivors aft of galley. Only flight crew used oxygen masks through period. Fire fed on cabin interior. Aircraft destroyed by postcrash fire.
06 16	Boeing 707 Air France (F)	Buenos Aires	None	86	0	0	0	0	0	0	No. 4 engine and part of right wing separated from aircraft during hard landing. Fire broke out in wing area. Occupants quickly evacuated using slides. Minor bruises sustained by 2 passengers.
06 08	Viscount British Midland (G)	East Midlands Arpt.	None	62	0	0	0	0	0	0	Gear collapsed on landing.
05 29	Douglas DC-3 Air Gaspe (CF)	Nr. Rimouski, Can.	Fatal	4	0	0	0	2	1	1	Aircraft struck tree during instrument approach. Fire occurred on impact.
05 27	Caravelle Sterling	Gothenburg, Sweden	None	135	0	0	0	0	0	0	Hard landing. Substantial damage.

1973	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
05 19	Comet 4B Dan Air	Manston, England	None	120	0	0	0	0	0	0	Nose gear failed to extend. Emergency landing made on foam runway.
04 22	Boeing 707 BWIA (9Y)	Toronto, Canada	None	58	0	0	0	0	0	0	Nose gear would not extend. Landing made at Toronto.
04 11	Douglas DC-3 Kenting (CF)	Forbisher Bay, Can.	None	3	0	0	0	0	0	0	Aircraft ground looped on takeoff.
04 10	Vanguard Invicta International (G)	Nr. Basle, Switz.	Fatal	145		1	35		4	104	Aircraft crashed into mountainous terrain while executing missed approach.
04 07	Boeing 707 Air France	Los Angeles, Cal.	None	76	0	0	0	0	0	0	Aircraft collided with taxiing Aztec during takeoff run. No injuries to occupants of either aircraft. Boeing landed without incident.
04 07	Douglas Dc-7 Spantax (EC)	Lisbon, Portugal	None	84	0	0	0	0	0	0	Nose gear collapsed on landing.
04 03	Trident 1 BEA (G)	Paris	Minor	118	0	0	0	0	0	0	Nose failed to extend. Emergency landing made. 1 passenger received minor injuries when her head struck seat in front of her during roll out. Pass. evacuated using mid section slides.
03 05	Douglas DC-9 Iberia (EC)	Nantes, France	Fatal	68	0	0	0	2	4	62	Two aircraft collided in midair. DC-9
03 05	Convair 990 Spantax (EC)		None	108	0	0	0	0	0	0	crashed fatally injuring all occupants. Convair with large section of port wing missing made safe emergency landing.
02 21	British AC 1-11 BEA (G)	Durham, G.B.	None	3	0	0	0	0	0	0	Pilot inadvertently made gear up landing during training flight.
02 19	Trident 2E BEA (G)	Nr. Brighton, Sussex	None	58	0	0	0	0	0	0	Section of flaps separated from aircraft during climbout. Landed without incident.
01 30	Douglas DC-9 SAS (LN)	Oslo, Norway	None	33	0	0	0	0	0	0	Pilot aborted takeoff. Aircraft overran runway, sank in sea offshore of threshold.
01 25	Curtiss C-46 Reindeer Air Services (CF)	Sachs Harbor, Can.	None	2	0	0	0	0	0	0	Aircraft ground looped due to patch of deep snow during landing roll.
01 24	Vanguard BEA (G)	Tees-Side Arpt., G.B.	None	3	0	0	0	0	0	0	Aircraft dragged wingtip during simulated 3 engine takeoff. Landed without incident.
01 24	Douglas DC-3 Harrison Airway (CF)	Burns Lake, Can.	None	6	0	0	0	0	0	0	Aircraft overran runway on landing.
01 19	Viscount British Midland (G)	Birmingham, G.B.	None	3	0	0	0	0	0	0	Gear failed to extend.
01 19	Viscount BEA (G)	BenMore, Perthshire	Fatal	4	0	0	0	2	0	2	Aircraft crashed into mountainous terrain during test flight.
01 02	Boeing 707 Pacific Western (CF)	Edmunton, Canada	Fatal	5	0	0	0	5	0	0	Aircraft crashed during instrument approach

1972	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 23	Fokker F-28 Braathens SAFE (LN)	Nr. Oslo, Norway	Fatal	45	0	0	5	2	1	37	Crashed during approach.
12 06	Douglas DC-3 Superior Airways (CF)	Canada	None	3	0	0	0	0	0	0	Aircraft entered high speed stall.
12 01	Douglas DC-5 Reindeer Air Service (CF)	Nr. Normal Wells, Alberta	Fatal	2	0	0	0	2	0	0	Aircraft crashed enroute. Wreckage found on 6,000 ft. mountain.
10 30	Fokker F-27 Aero Transporti Italiane (I)	Nr. Poggiorsini, Italy	Fatal	27	0	0	0	2	1	24	Crashed into high ground enroute.
10 27	Viscount Air Inter (F)	Nr. Clermont-Ferrant, France	Fatal	68	0	0	8	3	2	55	Aircraft crashed during approach.
10 26	Nord 262 Cimber Air (D)	Dusseldorf, Ger.	None	9	0	0	0	0	0	0	Intentional gear up landing.
10 23	Caravelle Sterling Airways (OY)	Gothenburg, Sweden	None	89	0	0	0	0	0	0	Nose gear collapsed on landing.
10 21	YS-11A Olympic (SX)	Nr. Athens, Greece	Fatal	53	3		13	1		36	Aircraft crashed into sea during approach.
10 15	Fokker F-27 Aero Trans. Ital. (I)	Rome, Italy	None	19	0	0	0	0	0	0	Engine separated during takeoff. Safe landing made.
10 10	Fokker F-27 Braathens SAFE (LN)	Alesund, Norway	None	9	0	0	0	0	0	0	Nose gear not extended on landing.
10 10	Douglas DC-3 Nordair (CF)	Nicholson Pt., Can.	None	6	0	0	0	0	0	0	Ground looped due to brake failure.
10 01	Herald British Is. Airways (G)	Blackpool, G.B.	None	54	0	0	0	0	0	0	Right main gear failed to extend on landing.
09 25	Consolidated PBY-5A Austin (CF)	Poste de la Baleire Can.	None	16	0	0	0	0	0	0	Prop oversped could not be feathered. Initiated go around during approach due to unsafe gear warning light. Unable to maintain altitude on one engine.
09 21	Boeing 727 Air France (F)	Gatwick, G.B.	None	158	0	0	0	0	0	0	Dragged leading edge slat on landing.
09 20	Viscount British Midland (G)	Jersey, Channel Is.	None	44	0	0	0	0	0	0	All 4 engines overheated during landing.
08 20	Comet 4 Dan Air (G)	Salzburg, Austria	None	25	0	0	0	0	0	0	Nose gear collapsed on landing.
08 19	Boeing 707 THY (TC)	Sofia, Bulgaria	None	?	0	0	0	0	0	0	Aircraft lost 2 engines. Made emergency landing. Dragged wingtip on landing.
07 29	Viscount Northeast Airlines (G)	Belfast Airport	None	77	0	0	0	0	0	0	Gear collapsed on landing.
07 19	British AC 1-11 British Caledonian (G)	Corfu, Greece	Fatal	84	0	0	0	0	0	1	Aircraft overran runway on aborted takeoff. Came to rest in shallow water. None injured, but elderly lady collapsed and died after being helped off aircraft.
06 29	Hansa HFB-320 Inter-City Flng. (D)	Blackpool, G.B.	Fatal	8	0	0	1	2	0	5	Gust Lock not removed from horiz. stabilizer. Aborted too late. Collided with structures outside airport boundary. Post crash fire resulted.
06 27	Boeing 707 Wardair (CF)	Toronto, Can.	None	200	0	0	0	0	0	0	Tire blew out on takeoff roll. Substantial damage to landing gear area.

1972	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
06 18	Trident 1 BEA (G)	Staines, Middlesex	Fatal	118	0	0	0	3	6	109	Aircraft crashed during climbout. Leading edge slats retracted at too low airspeed. Aircraft stalled.
05 21	Fokker F-27 DTA (CR)	Nr. Lobito, Angola	Fatal	25		1	2		5	17	Aircraft crashed into sea during approach.
05 05	Douglas DC-8 Alitalia (I)	Mt. Lunga, Sicily	Fatal	115	0	0	0	3	4	108	Crashed into mountains during approach.
04 23	Boeing 727 Lufthansa (D)	Frankfurt, Ger.	None	92	0	0	0	0	0	0	Rt. main gear failed to extend. Emergency landing made on foam runway.
04 23	Boeing 707 Wardair (CF)	Christchurch, Barbados	None	?	0	0	0	0	0	0	Aircraft collided with taxiing Convair 440 during takeoff. Minor damage to 707. Substantial damage to 440. No injuries.
04 16	Fairchild F27 Quebecair (CF)	Quebec	None	29	0	0	0	0	0	0	Gear collapsed during taxi.
04 16	Fokker F-27 ATI (I)	Nr. Frosinone, It.	Fatal	18	0	0	0	2	1	15	Crashed enroute in high ground.
04 07	Douglas DC-8 SAS (LN)	Stavanger, Norway	None	4	0	0	0	0	0	0	Cargo shifted on takeoff causing substantial damage. Takeoff aborted.
04 06	Douglas DC-6 NV Delta Air Trans. (OE)	Ostend, Belgium	None	35	0	0	0	0	0	0	Engineer inadvertently retracted gear during takeoff.
04 06	Boeing 737 Nordair (CF)	Charlottetown	None	3	0	0	0	0	0	0	Overran runway during landing.
03 30	Douglas DC-3 Austin Airways (CF)	Ft. Albany, Ont.	None	3	0	0	0	0	0	0	Aircraft undershot runway. Substantial damage.
03 21	Super Guppy Aeromaritime (F)	Hamburg, Ger.	None	3	0	0	0	0	0	0	Nose gear collapsed during hard landing.
03 14	Caravelle Sterling Airways (OY)	Nr. Fajairah	Fatal	112	0	0	0	2	4	106	Crashed into mountains during descent for approach.
03 12	Boeing 707 T.A.P. (CS)	Lisbon	None	?	0	0	0	0	0	0	Incident. Nose began to retract during touch and go. Did not affect takeoff.
02 18	Boeing 747 BOAC (G)	Zurich, Switz.	Serious	271	0		3	0	0	0	On landing roll fire started in No. 2 engine. Evacuation ordered. Took 60 sec. 1 broken ankle, 1 broken leg, 1 broken wrist, were sustained by 3 occupants respectively during evac.
01 28	Vickers VC-10 British Caledonian (G)	Gatwick, G.B.	None	4	0	0	0	0	0	0	Aircraft overran runway. Substantial damage.
01 28	Viscount Lufthansa (D)	Hurn Airport	None	2	0	0	0	0	0	0	Aircraft undershot runway. Main gear collapsed during hard touchdown. Fire in No. 3 engine broke out but quickly extinguished.
01 24	Boeing 707 THY (TC)	Ankara, Turkey	None	?	0	0	0	0	0	0	Nose gear collapsed on hard landing.

1972	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
01 22	Boeing 720B PIA (AP)	Ankara, Turkey	None	44	0	0	0	0	0	0	Aircraft right of runway during final. Pilot attempted to correct. Left gear collapsed on touchdown.
01 21	Douglas DC-9 THY (TC)	Nr. Adana, Turkey	Fatal	5		3	0	1	0	0	Cabin depressurized. Aircraft crashed while making emergency landing.
01 11	Canadair CL-44 Trans Meridian (G)	Nr. Jeddah, Saudi Arabia	None	5	0	0	0	0	0	0	Engine failure inflight.
01 05	Douglas DC-3 MacKenzie Air (CF)	Nr. Norman Wells, NWT	None	14	0	0	0	0	0	0	Aircraft made forced landing off airport due to complete engine failure.

1971	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 28	Viscount Air Inter (F)	Aulnat Arpt., Fr.	None	2	0	0	0	0	0	0	Swerved off runway during simulated 3 engine takeoff.
12 26	Douglas DC-9 Swissair (HB)	Vienna, Austria	Fatal	74	0	0	0	0	0	0	Collided with taxiing Beech 55 during takeoff. Pilot of Beech fatally injured. No injuries to occupants of DC-9, but substantial damage.
12 17	Convair 440 Pan Adria (YU)	Ronchi del Legionari, Italy	Serious	22	2	2	18	0	0	0	Aircraft crashed during approach. Post crash fire occurred but quickly extinguished
12 12	Boeing 737 Britannia (G)	Birmingham Arpt., G.B.	Fatal	114	0	0	0	0	0	0	Aircraft struck man on runway during landing. Fatally injured.
12 05	Nord 262 Rousseau (F)	Lannion, France	Fatal	3	1	0	0	2	0	0	Aircraft crashed into trees after overshooting runway during ILS approach.
11 08	Convair 640 PWA (CF)	Vancouver	None	2	0	0	0	0	0	0	Nose gear failed to extend.
10 18	Douglas DC-3 DETA (CR)	Nova Lisboa	None	19	0	0	0	0	0	0	Landing gear failed, ran off runway.
10 02	Vanguard BEA (G)	Aarsele, Belgium	Fatal	63	0	0	0	3	5	55	Rear pressure bulkhead ruptured causing separation of tailplane inflight.
09 17	Douglas DC-4 Air Caicos (CF)	Sarasota, Fla.	None	2	0	0	0	0	0	0	Left main gear failed to extend during landing.
09 06	British AC 1-11 Pan Int. (D)	Nr. Hasloh, Ger.	Fatal	121		5	94		1	21	Aircraft unable to maintain altitude due to power loss. Crashed into highway bridge while attempting forced landing.
08 31	Fairchild F-27 Quebecair (CF)	Harve, St. Pierre, Can.	None	37	0	0	0	0	0	0	Landing gear damaged due to undershoot. Went around and made emergency landing on foamed runway.
08 30	Convair 440 Aeroservicios Puntarenas (TI)	Ft. Lauderdale, Fla.	None	5	0	0	0	0	0	0	Gear collapsed when aircraft ran off of runway during takeoff by student.
08 28	IL-18 MALEU (HA)	Nr. Copenhagen	Fatal	34	0	0	2	3	6	23	Crashed offshore of threshold during ILS.
08 17	Fokker F-27 CE Postale (F)	S.W. of Paitiers, Fr.	Serious	3	1	0	0	0	0	0	Forced landing off airport made when crewman inadvertently shut engines down.
07 24	Douglas DC-3 Air France (GV)	Nr. Bamako	Fatal	6	2	0	4	0	0	0	Aircraft crashed into hill during climbout.
07 17	Douglas DC-9 Martins Lachverviersmaatschappif (PH)	Nr. Venice	None	?	0	0	0	0	0	0	Aircraft damaged by hail.
06 18	Vickers VC-10 British Caledonian (G)	Over Andes	None	34	0	0	0	0	0	0	Aircraft sustained substantial damage due to severe CAT.
06 03	Douglas DC-3 Moormanair (PH)	Southend Arpt., G.B.	None	36	0	0	0	0	0	0	Aircraft overran runway during single engine emergency landing.

1971	Type Model Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
03 18	Carvair BAF (G)	Le Touquet	None	18	0	0	0	0	0	0	Nose gear collapsed on landing.
03 08	Boeing 707 BOAC (G)	Prestwick Arpt., Ayrshire	None	4	0	0	0	0	0	0	Rudder malfunctioned during training flight.
02 05	Boeing 747 Air France (F)	Montreal	None	140	0	0	0	0	0	0	Nose gear failed to extend on landing.
01 29	Douglas DC-8 CPA (CF)	Sydney, Australia	None	148	0	0	0	0	0	0	Aircraft was struck by 727 taking off during taxi from landing. No injuries in either aircraft. 727 landed without incident. Substantial damage to both.
01 19	Trident 3B BEA (G)	Thurleigh	None	5	0	0	0	0	0	0	Aircraft struck Comet waiting on runway while executing missed approach during training flight.
01 13	Douglas DC-9 KLM (PH)	Nr. Amsterdam	None	?	0	0	0	0	0	0	Engine failure during climbout. Landed without incident.

1970	Type Model Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
12 31	Nord 262 Societe de Travail Aerien (F)	Unknown	Fatal	31	0	0	0	2	1	28	Aircraft departed Algiers. Lost without a trace.
12 30	Caravelle Alitalia (I)	Turin	Fatal	38	0	0	0	0	0	0	Collided with ground vehicle during take-off. Driver of vehicle fatally injured.
12 28	Douglas DC-3 Millard-Air (CF)	Toronto, Ont.	None	24	0	0	0	0	0	0	Gear would not extend on landing.
12 28	Nord 262 Pacific Western (CF)	Richmond, B.C.	None	4	0	0	0	0	0	0	Aircraft made forced landing off airport due to complete engine failure.
12 22	Boeing 720 Trans-Polar (LN)	Keflavik	None	144	0	0	0	0	0	0	Engine fire inflight. Extinguishers ineffective. Fire died out in approach to emergency landing.
12 19	Douglas DC-GB Sobeliar (OO)	Malaga	None	7	0	0	0	0	0	0	Left main gear failed to extend.
12 02	Canadair CL-44 Loftleider (TF)	Nr. Dacca	Fatal	4	0	0	0	0	0	0	Aircraft crashed into farmhouse during approach. 4 people on ground fatally injured.
11 05	Douglas DC-GB Olympic (SX)	Corfu Is.	None	?	0	0	0	0	0	0	Nose gear collapsed on landing roll.
10 30	Boeing 707 Air France (F)	Nouassuer Arpt.	None	?	0	0	0	0	0	0	Incident. No. 3 engine exploded on initial takeoff roll.
10 07	DeHavilland Comet 4 Dan Air (G)	Newcastle	None	9	0	0	0	0	0	0	Gear up landing inadvertently made during training flight.
10 01	Trident 1 BEA (G)	Rome, Italy	None	71	0	0	0	0	0	0	Engine failed during takeoff run; successfully aborted.
09 26	Fokker F-27 SAS (TF)	Nr. Vagar	Fatal	34			23	1		7	Aircraft crashed into island during instrument approach.
09 15	Douglas DC-8 Alitalia (I)	Jamaica, N.Y.	Serious	150	0	5	64	0	0	0	Aircraft veered off runway after hard landing. Fuselage failed aft of wing. Evac. took 3 min. 11 of injured occupants were hospitalized.
08 17	Boeing 747 Air France (F)	St. Jean, Quebec	None	193	0	0	0	0	0	0	Inflight engine failure.
07 20	Boeing 737 Condor Flugdienst (D)	Nr. Tarragona, Spain	Fatal	100	0	0	0	0	0	0	Aircraft collided in midair with Piper. 3 occupants of Piper fatally injured. 737 landed without incident. Minor damage to port wing.
07 19	British AC 1-11 Bavaria Flug (D)	Gerona Arpt.	None	85	0	0	0	0	0	0	Aircraft overran runway on aborted takeoff and collided with embankment 6 m high. Aircraft destroyed.
07 05	Douglas DC-8 Air Canada (CF)	Toronto, Ont.	Fatal	109	0	0	0	3	6	100	Aircraft crashed during go around after extremely hard landing causing structural failure. Wing section separated from aircraft at 3,000 ft.

1970	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
07 03	Comet 4C Dan Air (G)	Sierra del Montseny, Spain	Fatal	112	0	0	0	3	4	105	Aircraft crashed during descent to landing.
06 26	Douglas DC-8 Alitalia (I)	Nr. Damascus, Syria	None	104	0	0	0	0	0	0	Aircraft hit by missile over Syria. Substantial damage to left wing. Landed without incident.
06 22	Boeing 707 BOAC (G)	London Arpt.	None	63	0	0	0	0	0	0	Engine failure during climbout. Landed without incident.
06 19	Douglas DC-3 Austin Airways (CF)	Nr. Val'd Or	None	28	0	0	0	0	0	0	Aircraft over gross weight when engine failed on initial climbout. Unable to maintain altitude. Crashed into trees. Fuselage rotated 180° during impact affording passengers more protection by seat backs.
06 10	Airspeed AS57 Ambassador 2 Dan Air (G)	Nr. Lille, France	None	39	0	0	0	0	0	0	Tire burst on climbout. Landed without incident.
06 09	Boeing 707 Air France (F)	Nr. Nantucket	None	166	0	0	0	0	0	0	Engine failure inflight. Landed at JFK.
05 26	SVC-10 BOAC (G)	Calcutta	None	?	0	0	0	0	0	0	2 engines failed on climbout due to bird strike. Landed without incident.
05 21	Douglas DC-3 SAFE (G)	Jeddah Arpt.	None	3	0	0	0	0	0	0	Gear collapsed on landing.
04 30	Boeing 707 Qantas (UH)	Rome	None	55	0	0	0	0	0	0	Aircraft veered off runway and became bogged in soft sand on takeoff. 1 passenger sustained minor injuries in evacuation.
04 30	Canadair CL-44 Icelandic (TF)	New York	None	201	0	0	0	0	0	0	Gear collapsed on landing.
04 19	Douglas DC-8 SAS (SE)	Rome	Serious	65	0	2	10	0	0	0	No. 1 engine compressor disintegrated during takeoff starting fire in center fuel tank. Takeoff aborted. Aircraft destroyed.
04 07	Viscount THY (TC)	Istanbul	None	4	0	0	0	0	0	0	Aircraft overran runway on aborted takeoff during training flight.
03 28	Fokker F-27 DETA (CR)	Gago Arpt.	Fatal	3	0	0	0	3	0	0	Aircraft crashed on climbout with one engine feathered during training flight.
03 19	Viscount THY (TC)	Ankara, Turkey	None	?	0	0	0	0	0	0	Nose gear collapsed on landing.
03 14	Douglas DC-8 Air Canada (CF)	Zurich, Switz.	None	111	0	0	0	0	0	0	Nose gear collapsed on takeoff roll.
03 06	Jetstream Bavaria Flug (D)	Nr. Samedan	Fatal	11	0	0	0	2	0	9	Aircraft crashed while attempting forced landing in snow due to engine fire. Struck power lines.
03.01	Viscount Air Canada (CF)	Nr. Vancouver	Fatal	33	0	0	0	0	0	0	Aircraft collided with Ercoupe during descent to landing. Pilot of Ercoupe fatally injured. Viscount landed without incident. Minor damage.

					Injuries			Fatalities			
1970	Type Model Airline	Location	Injury Index	Total Occup	Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	Remarks
02 21	Caravelle Austrian (OE)	Nr. Frankfurt	None	39	0	0	0	0	0	0	Bomb exploded in forward baggage compartment. Safe emergency landing made.
02 17	Carvair British Air Ferries (G)	Rotterdam	None	6	0	0	0	0	0	0	Aircraft collided with approach lights during landing. Falling snow.
02 17	Fokker F-27 THY (TC)	Samsun	None	?	0	0	0	0	0	0	Aircraft overshot runway. Substantial damage.
02 09	Comet 4C UAA (SU)	Munich, Ger.	None	23	0	0	0	0	0	0	Overran runway on aborted takeoff. Aircraft destroyed.
02 04	Nord 262 Rosseau (F)	Nr. Paris	None	16	0	0	0	0	0	0	Aircraft made forced landing off airport due to total engine failure. Minor damage.
01 22	Vickers Viscount 814 British Midland (G)	London Arpt.	Serious	38	0	0	1	0	0	0	Aircraft made emergency landing due to engine fire. Passenger injured in evac.
01 19	Vickers Viscount Cambrian (G)	Bristol	None	63	0	0	0	0	0	0	Aircraft substantially damaged in hard landing.

1969	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 27	Fokker F-27 Maersk Air (OY)	Nr. Ronne Arpt.	None	4	0	0	0	0	0	0	Aircraft crashed into sea during simulated single engine climbout. Training flight.
12 26	Vickers Viscount BEA (G)	Templehof	None	66	0	0	0	0	0	0	Pilot became disoriented during touch-down, lost directional control. Gear collapsed.
12 22	Vickers Viscount Luxair (LX)	Luxembourg	None	?	0	0	0	0	0	0	Nose gear collapsed.
12 20	Fairchild F-27 Great Northern (CF)	Inuvik	None	?	0	0	0	0	0	0	Badly damaged on landing.
12 08	Douglas DC-GB Olympic (SX)	Nr. Athens	Fatal	90	0	0	0	3	2	85	Crashed into mountain during instrument approach.
12 03	Boeing 707 Air France (F)	Caracas, Venezuela	Fatal	62	0	0	0	4	17	41	During climbout aircraft nosed over and dove into sea.
11 29	Douglas DC-9 Alitalia (I)	Catania	None	?	0	0	0	0	0	0	Landing accident - damaged.
11 27	SVC-10 BOAC (G)	Nr. Reading, Berk-shire	None	69	0	0	0	0	0	0	2 engines failed during climbout. Landed without incident.
11 15	Douglas DC-8 KLM (PH)	Groningan Arpt.	None	4	0	0	0	0	0	0	Hard landing. Substantial damage. Training flight.
11 09	Douglas DC-3 (CF)	Timmins, Ont.	Fatal	4	0	?	?	2	?	?	Aircraft crashed while executing instrument approach. Weather below minimums.
10 19	Canadair CL-44 Loftleidir (TE)	No. Atlantic	None	200	0	0	0	0	0	0	Incident. No. 1 wing life raft inflated inflight. Struck horiz. stabilizer. Minor damage.
09 17	Convair 640 Pacific Western (CF)	N.W. of Campbell River	Fatal	15		2	9		2	2	Aircraft crashed into hill during instrument approach. After impact aircraft rotated and slid backwards. Cabin area remained intact. Survivors escaped through rear exits before fire destroyed cabin section.
09 09	Caravelle SE210 Air France (F)	Marseilles	None	93	0	0	0	0	0	0	Aircraft settled back on runway, gear up, following takeoff. Substantial damage.
09 03	Fokker F-27 Icelandair (TF)	Vestmanaeyjar	None	51	0	0	0	0	0	0	Nose high attitude on landing damaged tail section.
08 20	Vickers Viscount 701 Cambrian (G)	Glamorgan Arpt.	None	66	0	0	0	0	0	0	Overran runway on landing. Minor damage.
08 17	British AC 1-11 Laker (G)	Over Germany	None	89	0	0	0	0	0	0	Inflight fire caused dense smoke on flight deck. Successful emergency landing made.
08 11	Lockheed 382B (CF)	Eureka Airstrip	None	4	0	0	0	0	0	0	Overran runway on landing.

1969	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
08 09	Lockheed 1049 Air Cameroun (F)	80 km from Donala	Fatal	4	0	0	0	4	0	0	Aircraft crashed into mountainous terrain during instrument approach.
08 03	Lockheed 1049 Canairelief (CF)	Uli, Biafra	Fatal	4	0	0	0	4	0	0	Crashed on landing.
08 02	Caravelle 210 Alitalia (I)	Marseilles	None	44	0	0	0	0	0	0	Overran runway on landing.
07 26	Ambassador BKS (G)	Gatwick	None	8	0	0	0	0	0	0	Nose gear collapsed on landing.
07 23	Douglas DC-3 Air Djibouti (F)	Off Khor, Ambadu	None	4	0	0	0	0	0	0	Bird strike caused total engine failure. Aircraft ditched in sea.
07 16	Lockheed 382 PWA (CF)	Caycaya Arpt.	None	?	0	0	0	0	0	0	Aircraft wing struck ground on landing. Separated from fuselage. Aircraft destroyed.
06 13	Herald BUIA (G)	Blackpool	None	54	0	0	0	0	0	0	Nose gear failed to extend.
05 28	Douglas DC-4 C.E. Postal (F)	Paris	None	3	0	0	0	0	0	0	Aircraft overran runway when 2 engines failed during takeoff.
05 24	Fokker F-27 ATI (I)	Reggio Calabria, Italy	Fatal	36		2	13	0	0	1	Aircraft undershot runway during approach. Collided with river embankment.
04 30	Douglas DC-GB Alitalia (I)	Bari	None	?	0	0	0	0	0	0	Landing accident. Substantial damage.
04 20	Britannia Monarch (G)	Luton	None	7	0	0	0	0	0	0	Nose gear collapsed on landing.
04 12	British AC 1-11 Autair (G)	Luton	None	90	0	0	0	0	0	0	Nose wheel tires burst during hard landing.
04 07	Vickers Viscount Air Canada (CF)	Seven Is., Can.	Fatal	21	0	0	0	0	0	1	Aircraft made emergency landing due to fire in wheel well area. Loss of control of No. 1 engine and loss of brakes during evacuation caused aircraft to circle to right out of control.
03 28	Douglas DC-3 BIAS (OO)	Libyan Desert	None	?	0	0	0	0	0	0	Crashed on landing. Substantial damage.
03 20	Vickers Viscount British Midland (G)	Manchester Arpt.	Fatal	4	0	0	0	2	1	0	Aircraft crashed out of control during sim. engine out takeoff. Both pilots and stewardess fatally injured. 1 stewardess uninjured.
02 25	Fokker F-28 LTU (PH)	Lapenhagen Arpt.	None	11	0	0	0	0	0	0	Aircraft settled back on runway during takeoff. Dragged right wingtip.
02 20	Vickers Viscount British Midland (G)	E. Midland Arpt.	None	53	0	0	0	0	0	0	Pilot failed to flare aircraft during landing in adverse weather. Fuselage ruptured. Aircraft destroyed.
02 09	Boeing 727 Pan Am (N)	Berlin, W. Ger.	Serious	116	0	0	2	0	0	0	Takeoff aborted due to engine failure.
02 02	Vickers Viscount THY (TC)	Ankara	None	26	0	0	0	0	0	0	Struck tower on approach to landing. Destroyed by post impact fire.
01 14	British AC 1-11 British United (G)	Nr. Milan, Italy	Serious	33	0	6	0	0	0	0	Aircraft made forced landing off airport following takeoff. Cabin area remained intact.

						Injuries			Fatalities			
1969	Type	Model	Airline	Location	Injury Index	Total Occup	Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	Remarks
01 13	Douglas	DC-8	SAS (LN)	Nr. Los Angeles	Fatal	45	3	3	11	0	3	12	Aircraft inadvertently ditched offshore during instrument approach. Fuselage broke into 3 sections on impact. First failure occurred at aft pressure bulkhead. Second at trailing edge of wing. Forward section remained afloat for 20 hours. Other 2 sank rapidly. Fuselage section aft of wing did not retain any structural integrity, trapping many passengers, combined with rapidity of sinking, contributed to most fatalities. Long trailing ends of seat belt hampered pass. ability to evacuate quickly. 18 survivors from forward section, 6 survivors from aft. All of 4 bodies recovered, death from drowning. 2 life rafts punctured by sharp metal fragments, and rapidly deflated.
01 05	Boeing	727	Aria Afghan (YA)	Gatwick Arpt.	Fatal	65		3	12		5	45	Aircraft descended below G.S. during ILS. Crashed into house. 2 occupants of house fatally injured. Fire broke out on impact.

1968	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
10 27	Vickers Vanguard BEA (G)	Belfast, N.I.	None	86	0	0	0	0	0	0	Overran runway on landing due to hydro-planing. Substantial damage.
10 22	Herald Itavia (I)	Bologna, Italy	None	?	0	0	0	0	0	0	Gear collapsed.
10 22	Douglas DC-9 THY (TC)	Vienna, Austria	None	77	0	0	0	0	0	0	Attempted landing on road short of runway. Collided with structures during final. Regained altitude and landed safely on runway.
10 22	Boeing 727 Pan Am (N)	Stuttgart, Ger.	None	54	0	0	0	0	0	0	Right main gear failed to extend.
09 30	Ambassador Dan Air (G)	Manston Arpt.	None	2	0	0	0	0	0	0	Intentional gear up landing on foamed runway.
09 28	Carvair EPA (CF)	Twin Falls	None	38	0	0	0	0	0	0	Gear collapsed when aircraft struck em-bankment on final. Go around performed followed by successful emerg. landing.
09 11	Caravelle Air France (F)	Nr. Nice	Fatal	95	0	0	0	2	4	89	Crew reported fire on board enroute. Crashed out of control into sea.
09 04	Heron Nor Flyselskap (LN)	Nr. Bodo, Norway	None	?	0	0	0	0	0	0	Ditched into sea. All occupants evacuated safely.
08 17	Herald Itavia (I)	Ciampino Arpt.	None	?	0	0	0	0	0	0	Damaged landing gear.
08 09	Vickers Viscount BEIAL (G)	Nr. Munich	Fatal	48	0	0	0	2	2	44	Total electrical failure in instrument conditions. Aircraft crashed out of control.
08 02	Douglas DC-8 Alitalia (I)	Nr. Malpensa Arpt.	Fatal	95	3	7	72	0	0	13	Aircraft crashed during instrument approach.
07 13	Boeing 707 Sabena (OO)	Nr. Lagos, Nigeria	Fatal	7	0	0	0	5	0	2	Aircraft crashed during instrument approach. Completely destroyed by impact fire.
07 04	Vickers Viscount BUA (G)	Jersey Arpt., C.I.	None	5	0	0	0	0	0	0	Nose gear collapsed on landing.
07 03	Ambassador BKS Air Transp. (G)	London	Fatal	8	0	0	2	3	0	3	Aircraft went out of control during landing. Crashed into terminal. 27 people on ground received minor injuries, 2 serious. 2 passengers survived.
06 15	Fairchild F-27 (CF)	Resolute Bay, NWT	None	12	0	0	0	0	0	0	Aircraft low on fuel. Crashed during non-standard descent on instruments.
06 14	Trident 1 BEA (G)	Shannon Arpt.	None	4	0	0	0	0	0	0	Damaged on hard landing.
05 09	Hawker-Siddeley 748 Skyways Coach (G)	Manston Arpt.	None	30	0	0	0	0	0	0	Nose gear failed to extend. Landing made on foamed runway. 2 pass. slightly in-jured during evacuation.
05 04	Vickers Viscount Channel Air-ways (G)	Southend, Essex	Serious	83		2	6	0	0	0	Overshot runway, collided with dirt bank.

1968	Type Model Airline	Location	Injury Index	Total Occup	Injuries			Fatalities			Remarks
					Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	
04 08	Boeing 707 BOAC (G)	London	Fatal	127	0	0	38	0	1	4	Aircraft experienced engine fire during climbout. Returned and made safe landing, but fire persisted and fuel tanks in port wing exploded. 4 passengers and 1 stewardess overcome by heat before they could evacuate aircraft. Fuel shut off valve not activated during initial fire. Airport fire service efficiency poor due to faulty equipment and poor deployment.
03 16	Vickers Viscount Turk Hava Yollari (TC)	Nr. Yesilkoy Arpt.	Fatal	55	0	0	0	1	0	0	At 15,000 ft. forward passenger door failed. Third pilot sucked out during decompression. Emergency landing successful.
03 05	Boeing 707 Air France (F)	Guadalupe	Fatal	63	0	0	0	3	8	52	Aircraft crashed during visual approach at night.
03 02	Britannia 318 Cubana de Aviacion (CU)	Gander Arpt.	None	75	0	0	0	0	0	0	Aircraft struck trees during instrument approach. Landed safely.
02 21	Caravelle Air Inter (F)	Orly Arpt.	None	62	0	0	0	0	0	0	Overran runway on landing. Collided with ILS antenna.
02 17	Argosy BEA (G)	Btn. Troges and Montidier, France	None	2	0	0	0	0	0	0	Prop separated inflight causing substantial damage. Safe emergency landing.
02 07	Boeing 707 Canadian Pacific (N)	Vancouver, B.C.	Fatal	61	1	0	17	0	1	0	Overran runway on landing. Operated by U.S. supplemental carrier (Standard Airways). 1 cabin attendant and 1 airport employee fatally injured.
02 04	Comet 4B Olympic (G)	Akrotiri, Cyprus	None	60	0	0	0	0	0	0	Right main gear failed to lock and collapsed on landing.
01 27	Heron Air Comores (F)	Comoro Is.	Fatal	16	0	0	1	1	0	14	Aircraft made go around after striking runway lights. Crashed into sea during climbout.
01 25	Vickers VC-10 BOAC (G)	Rome, Italy	None	120	0	0	0	0	0	0	During taxi wheel from main gear separated causing small fire. Quickly went out.
01 20	Douglas DC-7B Transair AB (SE)	Munich	None	38	0	0	0	0	0	0	Nose gear collapsed on landing.
01 07	Douglas DC-7B Internorel AB (SE)	Salzburg, Austria	None	55	0	0	0	0	0	0	Aircraft collided with power line during ILS approach but landed safely.
01 01	Douglas DC-8 Swissair (HB)	Frankfurt	None	28	0	0	0	0	0	0	Aircraft veered off runway during takeoff roll. Substantial damage.

1967	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 25	Douglas DC-GB Sterling (OY)	Torslanda, Gothenburg, Sweden	None	55	0	0	0	0	0	0	Aircraft substantially damaged during hard landing.
12 17	Douglas DC-7 Trans Meridian (G)	Istanbul	None	5	0	0	0	0	0	0	Gear collapsed on landing roll.
12 04	Argosy BEA (G)	Stansted Arpt.	None	3	0	0	0	0	0	0	Aircraft went out of control during simulated 3 engine takeoff. Cartwheeled on right wing and caught fire. Crew escaped through hole in fuselage. Aircraft destroyed.
12 03	Trident BEA	Copenhagen	None	82	0	0	0	0	0	0	Aircraft undershot runway on landing. Substantial damage.
11 21	Boeing 707 BOAC	Honolulu	Serious	52	0	0	1	0	0	0	Engine fire on takeoff run. Takeoff aborted fire extinguished by airport emergency service.
11 21	Carvair CAT (F)	Over Sahara Desert	None	?	0	0	0	0	0	0	Engine failure inflight.
11 11	Boeing 707 Olympic (SX)	Athens	None	158	0	0	0	0	0	0	Engine failure during climbout.
11 04	Caravelle Iberian (EC)	Nr. Ferhnhurst, Sussex	Fatal	37	0	0	0	2	5	30	Crashed during descent for landing at London.
11 02	Douglas DC-8 Alitalia (I)	Chicago	None	?	0	0	0	0	0	0	Engine failure during climbout.
10 12	Comet 4B BEA (G)	100 m E. of Rhodesia	Fatal	66	0	0	0	3	4	59	Aircraft crashed due to bomb exploding in cabin.
09 21	Vickers Viscount Air Lingus (EI)	Bristol Arpt.	None	21	0	0	0	0	0	0	Wingtip struck runway on landing. Pilot attempted go around but aborted attempt and landed gear up.
09 14	Ambassador Autair Int. Airways (G)	Luton	None	69	0	0	0	0	0	0	Aircraft overran runway on landing. Gear collapsed.
09 09	Boeing 707 Pan Am (N)	Frankfurt	Serious	174	0	0	2	0	0	0	Engine failure during takeoff run. Fire resulted.
09 03	Dart Herald 101 Autair Int. (G)	Luton Arpt.	None	47	0	0	0	0	0	0	Aircraft settled back on runway, gear up, following takeoff. Passengers left through normal entrance doors.
08 15	Hawker-Siddeley 748 Channel Airways (G)	Portsmouth Arpt.	None	56	0	0	0	0	0	0	Overran runway. Sod strip landing.
08 15	Hawker-Siddeley 748 Channel Airways (G)	Portsmouth Arpt.	None	21	0	0	0	0	0	0	Also overran sod runway on landing.
08 15	Vickers Viscount Channel (G)	Basle-Bulhouse	None	83	0	0	0	0	0	0	Substantial damage due to hard landing.
08 09	Douglas DC-3 Cambrian (G)	Abbotsinch Arpt.	None	34	0	0	0	0	0	0	Prop separated during climbout. Safe 1 engine landing made.

1967	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
08 09	Vickers VC-10 BOAC (G)	Jamaica, N.Y.	None	165	0	0	0	0	0	0	Section of flap separated from aircraft on final.
07 23	Vickers Viscount Falcon (SE)	Over Germany	None	?	0	0	0	0	0	0	Prop separated inflight. Landed safely.
07 18	Vickers Viscount BEA (G)	Glasgow	None	2	0	0	0	0	0	0	Pilot aborted takeoff after flap failure. Overran end of runway. Training flight.
06 23	Fokker F-27 Braathens (LN)	Sola	None	?	0	0	0	0	0	0	Damaged. No injuries.
06 04	Canadair C4 British Midland (G)	Stockport, Cheshire	Fatal	84	2	0	10	0	3	69	Aircraft crashed during ILS approach. Left wing sheared off by building, leaving large hole in fuselage. Cockpit section separated from fuselage;10 min. after impact fire broke out in main wreckage. Rescuers able to evacuate 10 people from wreckage before flames pushed them back. Cockpit section still clear of fire and the 2 pilots were evacuated.
06 03	Douglas DC-4 Air Ferry (G)	Nr. Perpignan	Fatal	88	0	0	0	2	3	83	Aircraft descended below MOCA. Crashed into mountain. Carbon monoxide leaking into cabin from defective heater.
05 23	Douglas DC-8 Air Canada (CF)	Ottawa	Fatal	3	0	0	0	3	0	0	Aircraft on training flight. Rolled inverted on final and crashed.
05 15	Curtiss C-46A (CF)	Cape Dyer	Fatal	4	0	0	0	2	0	2	Aircraft crashed during approach in whiteout conditions.
05 07	Douglas DC-3 Morton Air Services (G)	Rotterdam	None	34	0	0	0	0	0	0	Pilot lost control of aircraft on takeoff when seat slid backwards.
05 03	Douglas DC-3 Flugsyn (TF)	Vestmannisles	Fatal	3	0	0	0	3	0	0	Aircraft crashed into island south of Iceland.
05 03	Vickers Viscount Channel (G)	Southend Arpt.	Fatal	3	0	0	0	0	0	0	Aircraft crashed during simulated 3 engine takeoff. 2 men on ground were fatally injured, and 1 man on ground seriously injured.
04 28	Consolidated PBY5A (CF)	Gander Inter. Arpt.	None	2	0	0	0	0	0	0	Aircraft veered off runway on takeoff, collided with snowbank.
04 21	Convair 440 SAS (LN)	Kirkenes	None	?	0	0	0	0	0	0	Gear collapsed on landing.
04 20	Britannia BEIAL (G)	Manston Arpt.	None	65	0	0	0	0	0	0	Landing gear would not lock down. Safe emergency landing made on foamed runway.
03 31	Boeing 707 BOAC (G)	London Arpt.	None	5	0	0	0	0	0	0	Nose gear failed to extend on landing.
03 08	Carvair Compagnie Air Trans. (F)	Nr. Karachi, Pakistan	Fatal	6	2		0	4		0	Aircraft crashed on takeoff killing 4 crewmembers and 7 people on ground.

				Injuries			Fatalities			
1967	Type Model Airline	Location	Injury Index	Total Occup	Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	Remarks
03 06	Canadair C4 British Midland (G)	E. Midlands Arpt.	None	3	0	0	0	0	0	0	Nose gear collapsed on landing.
03 05	Short Skyvan Aer Alpi (I)	Venice	None	3	0	0	0	0	0	0	Aircraft overran runway on landing. Came to rest inverted in shallow water off-shore. 3 crewmen escaped through nose cowl which was torn off during impact.
02 23	Douglas DC-3 Flugfelag (TF)	Danmarkshaun	None	3	0	0	0	0	0	0	Landing gear collapsed during ski landing on ice.
02 18	Fokker F-27 ATI (I)	Nr. Rome	None	43	0	0	0	0	0	0	Aircraft hit by lightning in nose. Nose gear failed to extend. Safe landing made on foamed runway.
02 16	Vickers Viscount AUA (OE)	Vienna Arpt.	None	?	0	0	0	0	0	0	Gear up landing. No injuries.
01 21	Douglas C-54 Air Ferry (G)	Nr. Frankfurt	Fatal	2	0	0	0	2	0	0	Aircraft crashed into trees during ILS approach.

1966	Type Model Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
12 20	Britannia Lloyd Int. (G)	Stunsted	None	4	0	0	0	0	0	0	Nose gear collapsed on touch and go.
12 17	Vickers Viscount Air Canada (CF)	Edmonton, Alberta	None	40	0	0	0	0	0	0	Prop separated inflight. Landed safely.
12 16	Caravelle Air France (F)	Athens	Serious	62	0	0	1	0	0	0	Engine fire occurred during climbout. Smoke entering cabin through punctures in fuselage. Aircraft landed safely. Fire extinguished by airport fire equipment. Passengers evacuated through right front door using escape rope and then outside ladder. 1 passenger broke his leg when he jumped out door with his luggage.
12 08	Britannia BEIAL (G)	Istanbul	None	119	0	0	0	0	0	0	Aircraft veered off runway into muddy area. Nose gear collapsed.
11 26	Caravelle Alitalia (I)	Ciampino, Rome	None	?	0	0	0	0	0	0	Overran runway on landing during training flight.
11 21	Boeing 707 BOAC (G)	Bedford	None	6	0	0	0	0	0	0	Aircraft damaged on hard landing during training flight.
11 19	Curtiss C-46 (N)	Keflavik Arpt., Iceland	None	2	0	0	0	0	0	0	Aircraft veered off runway on aborted takeoff. Gear collapsed.
09 10	Vickers Viscount Channel (G)	Palma	None	77	0	0	0	0	0	0	Nose gear collapsed on hard landing.
08 31	Britannia Britannia Airways (G)	Ljubljanna, Yugoslavia	Fatal	117	1		18	6		92	Aircraft crashed during instrument approach.
08 17	Douglas DC-3 Gulf Aviation (G)	Azaiba (Oman)	None	20	0	0	0	0	0	0	Aircraft crashed on takeoff. Destroyed.
08 05	Douglas DC-8 KLM (PH)	Tokyo, Japan	Fatal	64	0	0	0	1	0	0	Captain died of heart attack while aircraft on final. Copilot able to take over and land safely.
08 02	Convair 440 Lufthansa (D)	Nuremburg, Ger.	Serious	38	1		3	0	0	0	Nose gear collapsed on landing.
06 20	Curtiss C-46E (CF)	Lk. Peribonce, Quebec	Fatal	2	0	0	0	2	0	0	Aircraft crashed enroute into lake. Cause undetermined.
06 03	Vickers Viscount AUA (OE)	Salzburg, Austria	None	?	0	0	0	0	0	0	Nose gear collapsed on landing.
05 17	Vickers VC10 BOAC (G)	Nr. Bombay	None	?	0	0	0	0	0	0	Struck flock of birds during approach. 2 engines failed.
05 11	Ambassador Dan Air (G)	Beauvais Arpt., France	None	69	0	0	0	0	0	0	Right main gear collapsed on landing.
04 26	Convair 440 Lufthansa (D)	Copenhagen, Den.	None	34	0	0	0	0	0	0	Convair collided with taxiing Heron during takeoff run. Continued takeoff and made safe landing.
04 26	DeHavilland Heron Falck's Flight Service (OY)	Copenhagen, Den.	None	12	0	0	0	0	0	0	

1966	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
04 14	Ambassador Dan Air (G)	Beauvais Arpt., France	None	59	0	0	0	0	0	0	Aircraft overran runway on landing. Substantial damage.
03 10	Douglas DC-6 Trans Mediterranean (OD)	Mt. Parnon, Greece	Fatal	5	0	0	0	5	0	0	Crashed into mountain enroute.
03 10	Ambassador BKS (G)	Ouston	None	35	0	0	0	0	0	0	Damaged during takeoff due to abrupt rotation.
03 08	Lockheed 749 Aviation Charter Enterprises (G)	Khormaksar Arpt., Aden	None	5	0	0	0	0	0	0	Nose gear failed to extend for landing. Landing made with nose gear up. Fire broke out and smoke filled cockpit. Crew evacuated and fire extinguished.
03 05	Boeing 707 BOAC (G)	Mt. Fuji, Japan	Fatal	124	0	0	0	4	7	113	Aircraft broke up inflight due to extreme turbulence.
03 04	Douglas DC-8 Canadian Pacific (CF)	Tokyo, Japan	Fatal	72	0	0	8	3	7	54	Aircraft collided with approach lights during ILS. Crashed against sea wall and came to rest near threshold of runway. Aircraft destroyed by impact and post crash fire.
02 18	Douglas DC-GB BIAS (OO)	Milan, Italy	Fatal	4	0	0	0	3	0	1	Aircraft crashed during ILS approach. Destroyed by impact and post crash fire.
02 06	Vickers Viscount Air Inter (F)	Enroute to Paris.	None	64	0	0	0	0	0	0	Prop separated inflight. Fragments punctured fuselage. Rapid decompression resulted. Landed safely.
01 30	Boeing 707 TWA (N)	Frankfurt, Ger.	?	?	0	0	?	0	0	?	Pilot aborted takeoff when warning horn sounded. Overran runway. Minor damage. Passengers evacuated promptly.
01 28	Convair 440 Lufthansa (D)	Bremen, Germany.	Fatal	46	0	0	0	2	2	42	Aircraft stalled during attempted go around. Destroyed.
01 24	Boeing 707 Air India (UT)	Mt. Blanc, France	Fatal	117	0	0	0	4	7	106	Aircraft descended below MOCA. Crashed into Mt. Blanc. Destroyed.

1965	Type Model Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 17	Douglas DC-3 Skyways Coach (G)	Le Treport, France	None	32	0	0	0	0	0	0	Aircraft ditched in shallow water 50 yards offshore. Passengers and crew able to wade ashore. No injuries. Aircraft broken up by tide and surf.
12 10	Douglas DC-3 (CF)	Lynn Lk. Arpt., Manitoba	None	21	0	0	0	0	0	0	Forced landing made shortly after takeoff due to control problems.
11 26	Vickers Vanguard BEA (G)	Belfast, N. Ireland	None	112	0	0	0	0	0	0	Aircraft veered off runway during landing roll. Substantial damage.
11 26	Vickers Viscount BEAC (G)	Jersey Arpt., G.B.	None	79	0	0	0	0	0	0	Nose gear collapsed on landing.
11 10	Vickers Viscount Alitalia (I)	Sardinia	None	35	0	0	0	0	0	0	Nose gear collapsed on landing.
10 27	Vickers Vanguard BEA (G)	London, G.B.	Fatal	36	0	0	0	3	3	30	Aircraft crashed while executing missed approach during ILS attempt. Aircraft destroyed by impact and post crash fire.
10 23	Vickers Viscount Condor Flugdienst (D)	Munich	None	68	0	0	0	0	0	0	Aircraft veered off runway during landing. Gear collapsed. Aircraft destroyed.
10 10	Britannia British Eagle Int. (G)	Gam, Maldive Is.	None	120	0	0	0	0	0	0	Aircraft struck ground during attempted missed approach. Extensive damage, but no injuries sustained by occupants.
08 14	Vickers Viscount Lufthansa (D)	?	None	?	0	0	0	0	0	0	Nose gear collapsed on landing. No injuries.
08 02	Viking 1B Invicta Airways (G)	Manston Arpt.	None	3	0	0	0	0	0	0	Aircraft nosed over during ground loop on takeoff run.
07 20	Vickers Viscount Cambrian (G)	Nr. Liverpool	Fatal	2	0	0	0	2	0	0	Aircraft went out of control during final and crashed into factory. Cause unknown. 2 workers in factory fatally injured.
07 11	Avro 748 Series 1 Skyways Coach (G)	Lympue Arpt.	Minor	52	0	0	0	0	0	0	Aircraft made hard landing. Wing separated from fuselage. Aircraft rolled and came to rest inverted. No serious injuries.
07 08	Douglas DC-GB Canadian Pacific (CF)	Nr. 100 Miles House B.C.	Fatal	52	0	0	0	3	3	46	Device exploded in aircraft inflight. Destroyed.
07 04	Argosy 222 BEA (G)	Costalba di Pecora-ra, Italy	Minor	2	0	0	0	0	0	0	Aircraft crashed during instrument approach. Aircraft destroyed. Crew suffered minor in-juries.
06 11	Boeing 727 DLH (D)	Hamburg, Germany	None	?	0	0	0	0	0	0	Nose gear failed to extend for landing.
05 16	Boeing 707 BOAC (G)	Tehran, Iran	Minor	93	1	0	0	0	0	0	Aircraft made hard landing. Copilot sustained back injury.
05 06	Fokker F-27 Braathens SAFE (LN)	Sola Arpt.	None	?	0	0	0	0	0	0	Landed with nose gear retracted.

1965	Type Model Airline	Location	Injury Index	Tot Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
04 21	Boeing 707 Air France (F)	Lisbon, Portugal	None	152	0	0	0	0	0	0	Aircraft damaged substantially in hard landing.
04 14	Douglas DC-3 British United (G)	Nr. Jersey Arpt.	Fatal	27	0	1	0	3	0	23	Aircraft crashed during instrument approach. Aircraft destroyed. All occupants but stewardess fatally injured.
04 11	Boeing 707 Air France (F)	Kompongcham, Cambodia	None	83	0	0	0	0	0	0	Aircraft landed at military base instead of Phom-Penh airport. Runway too short and aircraft overran the end. Substantial damage.
03 25	Avro 748 Series 1 BKS (G)	Leeds/Bradford Arpt.	None	45	0	0	0	0	0	0	Aircraft substantially damaged due to hard landing.
03 25	Douglas DC-3 BKS (G)	Leeds/Bradford Arpt.	None	3	0	0	0	0	0	0	Aircraft struck trees during instrument approach. Safe landing made.
03 21	Hawker Siddeley 748 Series 2 BKS (G)	Leeds/Bradford Arpt.	None	44	0	0	0	0	0	0	Skidded into snowbank on side of runway during landing. Substantial damage.
03 17	Dart Herald EPA (CF)	Nr. Upper Musquodoboitt, N.S.	Fatal	8	0	0	0	2	1	5	Aircraft experienced inflight structural failure.
03 16	Douglas DC-3 (CF)	Blanc Sablon, Quebec	Serious	9	1	0	0	0	0	0	Aircraft veered off runway during takeoff. 1 crewmember seriously injured. Substantial damage.
03 03	Douglas DC-3 Morton Air Services (G)	Zurich, Switz.	None	2	0	0	0	0	0	0	Ground looped on landing. Substantial damage.
02 17	Douglas DC-3 British Midland (G)	Leeds/Bradford Arpt.	None	31	0	0	0	0	0	0	Overran runway on landing. Substantial damage.
02 11	Nord 262 Air Inter (F)	?	None	?	0	0	0	0	0	0	Aircraft damaged on landing.
02 08	Viking Airnautic (F)	Calvi, Corsica	None	10	0	0	0	0	0	0	Gear collapsed on takeoff. No injuries.
02 03	Curtiss C46 Air Cameroun (F)	Garona, Cameroans	Fatal	4	0	0	0	2	1	1	
01 17	Vickers Viscount Condor Flugdienst (D)	Santa Cruz, Teneriffe	None	65	0	0	0	0	0	0	Nose gear collapsed on landing.
01 10	Caravelle Sabena (OO)	Cologne, Germany	None	37	0	0	0	0	0	0	Aircraft veered off runway. Gear collapsed.

1964	Type Model Airline	Location	Injury Index	Tot Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
12 30	Fokker F-27 Braathens SAFE (LN)	Fornebu Arpt., Norway	None	38	0	0	0	0	0	0	Aircraft veered off of runway on landing. Substantial damage.
11 29	Douglas DC-4 BIAS (OO)	Stanleyville, Congolese Republic	Fatal	14	0	0	8	3	0	3	Aircraft struck oil drum on runway. Damaged horizontal stabilizer. Crashed out of control after takeoff. Passengers in rear of cabin thrown out through torn off cargo door. Fire after impact.
11 23	Boeing 707 TWA (N)	Rome, Italy	Fatal	73	0	0	17	5		43	Pilot aborted takeoff due to engine failure, veered to edge of runway. No. 4 engine struck ground vehicle after overrunning runway. Came to rest with fire on board. Shortly after aircraft exploded into flame. Completely destroyed.
11 21	Douglas DC-3 EPA (CF)	Lourdes de Blanc, Soblon, Quebec	None	4	0	0	0	0	0	0	Attempted go around after hard landing. Crashed 3/4 mile beyond runway. Aircraft destroyed. No injuries.
11 05	Comet 4B BEA (G)	Malaga Arpt., Spain	None	74	0	0	0	0	0	0	Aircraft veered off runway on landing. Substantial damage.
10 25	Boeing 707 Air France (F)	Majungo, Madagascar	None	?	0	0	0	0	0	0	Intentional gear up landing.
10 14	Douglas DC-3 British Midland (G)	Derby Arpt.	None	39	0	0	0	0	0	0	Gear collapsed during hard landing.
10 14	Vickers Viscount Air Canada (CF)	?	None	?	0	0	0	0	0	0	Landed with nose gear retracted.
10 06	Vickers Vanguard BEAC (G)	Glasgow Arpt.	None	95	0	0	0	0	0	0	Nose gear collapsed on hard landing.
10 02	Douglas DC-GB UTA (F)	El Goteron Trevelez Granada	Fatal	80	0	0	0	3	4	73	Aircraft crashed into mountain enroute. Cause undetermined.
09 29	Douglas DC-3 British Midland (G)	Guernsey Arpt.	None	16	0	0	0	0	0	0	Props of both engines struck ground on landing.
09 28	Douglas DC-7 Caledonian (G)	Istanbul	Minor	97	0	0	0	0	0	0	Aircraft undershot runway during instrument approach. Collided with ILS antenna. Left wing sheared off. Fire started after impact.
09 23	Vickers Viscount THY (TC)	Lod Arpt. Israel	None	?	0	0	0	0	0	0	Gear collapsed on landing roll.
09 16	Douglas DC-3 Eldorado (CF)	Nr. Ft. Smith, NWT	None	4	0	0	0	0	0	0	Aircraft struck trees during approach. Landed safely.
08 29	IL-18 TABSO (LZ)	Vienna Arpt.	None	97	0	0	0	0	0	0	Overran runway on landing.
07 30	Bristol 170 Air Fret (F)	Southend Arpt.	None	3	0	0	0	0	0	0	Gear collapsed on landing.

1964	Type Model Airline	Location	Injury Index	Tot Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
07 15	Boeing 720 DLH (D)	Nr. Peterschorf Ansbach, Ger.	Fatal	3	0	0	0	3	0	0	Aircraft went out of control in attempted roll during training flight. Broke up in midair.
06 13	Vickers Viscount TCA (CF)	Toronto, Ont.	Serious	44	0	0	1	0	0	0	During final approach aircraft lost power on both left engines. Swung to the left and struck ground on infield of airport. 1 passenger seriously injured; others received minor injuries.
06 02	Lockheed 188C KLM (PH)	Amsterdam	None	6	0	0	0	0	0	0	Aircraft damaged on hard landing during training flight.
05 26	Britannia 312 BOAC (G)	Bermuda	None	122	0	0	0	0	0	0	Left main gear collapsed during taxi.
05 25	Curtiss C-46 (CF)	Hudson Hope Arpt., B.C.	None	43	0	0	0	0	0	0	Ground looped on landing. Substantial damage. No injuries.
05 23	Vickers Viscount Cambrian (G)	Barcelona, Spain	None	63	0	0	0	0	0	0	No. 2 prop separated inflight. Punctured cabin caused rapid decompression. Larded safely. No injuries.
04 18	Douglas DC-3 Sabena (9Q)	Kasongo Arpt.	Minor	?	0	0	0	0	0	0	Ground looped on landing. No serious injuries.
04 06	Viking 1 Autair (G)	Stansted Arpt.	None	4	0	0	0	0	0	0	Gear collapsed on takeoff.
03 28	Vickers Viscount Alitalia (I)	Monte Summa-Vesuvius	Fatal	45	0	0	0	3	2	40	Crashed into Mt. Vesuvius during approach at Naples.
03 22	Comet 4 Malaysian Airways (G)	Singapore	Minor	68	0	0	0	0	0	0	Right main gear collapsed on landing. Fire broke out in right wing area. Emergency evacuation carried out. Escape chute fitted to main door melted in flames but rest of occupants able to jump clear. Some suffered sprained ankles. Aircraft destroyed.
03 17	Caravelle SAS (OY)	Copenhagen	None	?	0	0	0	0	0	0	Nose wheels separated from gear during landing roll.
03 11	Douglas DC-7 KLM (PH)	Geneva Arpt.	None	31	0	0	0	0	0	0	Aircraft overran runway on landing. Collided with blast fence. No injuries. Substantial damage.
03 10	Douglas DC-4 (CF)	Montreal	None	2	0	0	0	0	0	0	Gear raised prematurely during landing practice. Substantial damage.
03 09	Comet 4 BOAC (G)	Tehran, Iran	None	57	0	0	0	0	0	0	Touched down tail first. Substantial damage.
02 29	Britannia 312 British Eagle Int. (G)	Nr. Innsbruck, Austria	Fatal	83	0	0	0	3	5	75	Aircraft crashed into mountainous terrain during descent. Destroyed by impact.

1964	Type Model Airline	Location	Injury Index	Tot Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
02 03	Douglas DC-3 Turkish Airlines (TC)	Nr. Ankara, Turkey	Fatal	3	0	0	0	3	0	0	Aircraft crashed during instrument approach. Destroyed by impact.
02 02	Comet 4 BOAC (G)	Nr. Nairobi	None	69	0	0	0	0	0	0	During approach 9 miles from airport aircraft gear contacted ground. Climbed away and made safe landing at airport. Minor damage.
01 09	Douglas DC-3 Austin (CF)	Nr. Rupert Rr., Quebec	Serious	2	2	0	0	0	0	0	Aircraft made forced landing off airport when both engines failed. Pilots seriously injured.
01 09	Douglas DC-4 (G)	Nr. Lyons Arpt.	None	3	0	0	0	0	0	0	Mail plane crashed in field near airport. No injuries.
01 08	Carvair Aer Lingus (EI)	Stansted Arpt., Essex	None	3	0	0	0	0	0	0	Nose gear collapsed on landing.

APPENDIX C

1975 PRELIMINARY AIR CARRIER ACCIDENTS UNITED STATES (INCOMPLETE)*

1975	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
12 27	McDonnell Douglas	DC-10	Capitol Airways	International Oakland, Calif.			0	0	10	0	0	0	Approaching Oakland from Honolulu at FL320, decompression forced emergency descent to FL160. 10 of 183 passengers taken to hospitals for treatment of nausea, headaches earaches, and other effects.
12 22	McDonnell Douglas	DC-8-51	Braniff	Kennedy, N.Y.		127	0	0	0	0	0	0	In taxiing for takeoff, ran off onto snow-covered ground and collapsed nose-gear. Passengers evacuated via mobile lounge without injury.
11 29	McDonnell Douglas	DC-9-30	Ozark	Lambert-St. Louis, Mo.		32	0	0	0	0	0	0	On landing in heavy rain and gusty cross wind, aircraft hydroplaned and weathervaned. The right main gear went off runway and mired in mud. Occupants deplaned through forward passenger exit without injury. (Incident)
11 26	McDonnell Douglas	DC-10-10	American	Airborne 30 NM W. Carleton, Mich.		194	0	1	14	0	0	0	Made emergency descent from 34,953 to 33,000' to avoid collision with TWA Lockheed 1011 cruising at FL-350 in opposite direction with 114 aboard. The aircraft came within 20-100' of each other. 24 occupants of DC-10, including 10 cabin attendants were taken to a hospital. 3 passengers were seriously injured.

*Preliminary Accident/Incident Resume Reports of the National Transportation Safety Board must be qualified as follows: "Preliminary information, subject to change. Pertinence to accident/incident not positively established at this time."

(1) Not scheduled air carrier

1975	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
11 12	Boeing	B-727-200	Eastern	Raleigh-Durham N. Carolina	Serious	139	0	0	1	0	0	0	During landing in rain squall aircraft struck ground short of runway and bounced onto runway separating main gear and No. 3 engine. 1 passenger received serious injury during the subsequent emergency evacuation.
11 7	McDonnell Douglas	DC-9	Delta	Knoxville, Tenn.	None	31	0	0	0	0	0	0	Incident. Aircraft ran off end of runway, requiring passenger evacuation from left stairway and right emergency egress slide.
11 3	Douglas	DC-10-10	Trans-International	Airborne 50 NM West Calgary, Can.	Serious	272	0	1	2	0	0	0	Clear air turbulence encountered at FL330. Two passengers were severely injured and one stewardess received minor injury.
10 16	Douglas	DC-10-10	United	Seattle-Tacoma	Serious	132	0	0	14	0	0	0	During taxi-out emergency evacuation initiated due to APV smoke and fire. 13 passengers received minor injuries and 1 passenger serious injury during egress.
10 11	Boeing	727-023	American	Dulles, Wash. D.C.	Minor	90	0	0	2	0	0	0	Nose gear failed to extend in approach to Wash. National. Diverted to Dulles and landed. Passengers evacuated via two escape slides and aft stairway. Two passengers injured during evacuation.
9 27	Canadair	CL-44	Unknown L-VISY (Argentina)	Miami, Fla.	Fatal	8	2	0	0	1	0	2	Attempted to abort take-off, crashing into canal wall and caught fire.
9 27	Dassault-Breguet	Falcon	Federal Express (1)	Warwick, R.I.	None	3	0	0	0	0	0	0	During take-off attempt from closed runway on cargo flight, struck nose of Allegheny DC-9, a pick-up truck and an American B-727.

1975	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
9 22	McDonnell Douglas	DC-8-51	Delta	Texico, Texas	Serious	105	0	0	2	0	0	0	Encountered wake turbulence from Delta Lockheed 1011 six miles ahead at flight level 370. Two female passengers in aft lavatories were injured. One 78-year old fracturing right ankle, and the other injured knee and sprained finger.
9 20	McDonnell Douglas	DC-8-63	Airlift International	JFK, N.Y.	None	4	0	0	0	0	0	0	Aircraft struck runway lights, ILS monitor, approach light piers, and ILS localizer antenna on takeoff. Proceeded to Miami, with additional damage to tires.
9 17	McDonnell Douglas	DC-10	American	Banning, Calif.	None	135	0	0	0	0	0	0	Engine shut down enroute due to fire warning.
9 15	Boeing	747	Pan American	Puerto Rico	Serious	170	0	0	1	0	0	0	Encountered severe turbulence at flight level 350. One female passenger, exiting lavatory, received compound fractures of left leg.
9 14	Boeing	707-131B	Trans World	Edwardsville Illinois	None	73	0	0	0	0	0	0	After take-off, the No. 4 engine forward thrust reverser panel separated from the engine.
9 11	Boeing	747	Trans World	London, England	None	151	0	0	0	0	0	0	On take-off, tire and part of wheel assembly separated from aircraft, which continued on to New York without incident.
9 8	Boeing	747-123	American	San Juan, P.R.	Minor	160	0	0	1	0	0	0	On landing final approach, outboard section of left inboard trailing edge foreflap separated, striking fuselage. Aircraft landed and one passenger sustained reported minor head contusions.
9 4	Lockheed	1011	Eastern	Orlando to N.Y. (enroute)	None	245	0	0	0	0	0	0	Pressurization failure during climb to flight level 170. 26 passengers checked at hospital with 25 released and one remaining for observation.
8 30	Fokker	F-27	Wien Alaska	St. Lawrence Island, Alaska	Fatal	31	0	0	19	2	1	7	Crashed on approach. 3 crew and 7 passengers killed.

1975	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries			Fatalities			Remarks
							Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	
8 24	Boeing	747	United	San Francisco to Honolulu (enroute)	None	268	0	0	0	0	0	0	Enroute engine fire. Landed without incident.
8 23	Boeing	727	American	Buffalo, N.Y.	None	116	0	0	0	0	0	0	Left main landing gear collapsed after landing. Aft left galley door reported jammed. Two forward and right rear slides deployed and rear stairway also used to evacuate 108 passengers.
8 16	Boeing	727-232	Delta	Portland Maine	None	90	0	0	0	0	0	0	Fire during taxiing for take-off. 83 passengers and 7 crew members evacuated via rear stairs without injury.
8 8	McDonnell Douglas	DC-8-51	Delta	Wilmington, Del.	Serious	7	0	1	0	0	0	0	One cabin attendant thrown to floor in turbulence at flight level 370 while securing seat belt in stewardess jump seat, receiving fractured lumbar vertebrae.
8 8	Curtiss	C-46-F	Rich International	Boringuen, P.R.	None	2	0	0	0	0	0	0	Powerplant failure on both engines. Aircraft ditched in 50 ft. of water.
8 7	Boeing	727	Continental	Denver, Colo.	Serious	131	3	4	25	0	0	0	Crashed on take-off. The fuselage broke open near the cockpit, and just forward of the tail. 55 occupants examined and 25 hospitalized, one in serious condition.
8 3	McDonnell Douglas	DC-9	Delta	Buffalo, N.Y.	Minor	90	0	2	3	0	0	0	Two cabin attendants and three passengers received minor injuries during in-flight turbulence at flight level 270.
7 28	Boeing	707	Air France	Over Atlantic	Serious	136	0	1	0	0	0	0	Cabin attendant received fractured leg during in-flight turbulence at flight level 350.
7 25	McDonnell Douglas	DC-10-10	Continental	Seattle, Wash.	None	199	0	0	0	0	0	0	One engine shutdown required in landing. All passengers deplaned normally.

1975	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries			Fatalities			Remarks
							Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	
7 24	Boeing	727	American	Los Angeles California	None	56	0	0	0	0	0	0	Take-off aborted when right MLG sway brace failed.
7 18	McDonnell Douglas	DC-8	Capitol	Smyrna, Tenn.	None	3	0	0	0	0	0	0	Ran off runway on landing roll.
7 15	McDonnell Douglas	DC-10-30	National	Miami to N.Y. (enroute)	Fatal	71	0	0	0	0	0	1	Passenger fatally burned in lavatory fire.
7 12	Boeing	707	Trans World	So. Las Vegas Nevada	Serious	95	0	0	1	0	0	0	Passenger in aisle fractured ankle when thrown by turbulence.
7 12	Grumman	G-73	Cholk's International	Bimini, Bahamas	None	15	0	0	0	0	0	0	Impacted sailboat while taxiing.
7 11	DeHavilland (air taxi)	DH-114	Prinair(2)	San Juan Peurto Rico	Minor	11	0	0	1	0	0	0	On take-off, one propeller blade separated and slashed into fuselage, disabling flight and engine controls. Take-off was aborted and passengers deplaned.
7 9	Convair	580	North Central	Sioux City Iowa	None	22	0	0	0	0	0	0	In-flight engine explosion, followed by landing. All passengers deplaned by normal exits.
6 24	Boeing	727-225	Eastern	Jamaica, N.Y.	Fatal	126	0	2	9	4	2	107	On instrument approach, struck approach lights 2400 ft. from runway. Wind shear reported.
6 16	Martin	404	Southeast	Key West, Fla.	None	17	0	0	0	0	0	0	In-flight engine fire, followed by landing. Passengers evacuated through rear stairway and forward slide.
6 14	Lockheed	L-1011	Trans World	Los Angeles Calif.	Serious	233	0	0	3	0	0	0	Fire on engine start. Captain announced evacuation over PA system. 50 passengers evacuated from left rear slides, two passengers reporting back injuries and one an arm abrasion.
6 13	Fairchild	FH-227	Air New England	New Bedford Mass.	Minor	27	0	0	5	0	0	0	Overshot instrument landing, coming to rest 210 ft. beyond runway. Not stated whether injuries from impact or evacuation.

1975	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
6 8	Boeing	737	Frontier	Eagle, Colo.	Serious	8	0	0	1	0	0	0	Water tank failure shorted pressure controller with loss of cabin pressure. Passenger with prior medical history suffered collapsed lung.
6 24	Boeing	727-225	Eastern	Jamaica, N.Y.	Fatal	126	0	2	9	4	2	107	On instrument approach, struck approach lights 2400 ft. from runway. Wind shear reported.
5 20	Convair	580	Frontier	Gunnison, Colo.	Serious	53	0	1	0	0	0	0	In-flight turbulence. Stewardess injured back.
5 7	Boeing	707	Pan American	St. John's Newfoundland	Fatal	184	0	0	0	0	0	1	Cabin pressurization failure. "On reaching flight level 200, one passenger, a 71-year-old man with a cardiac problem slumped over in his seat and died."
5 6	Boeing	727	Northwest	Jamaica, N.Y.	None	47(?)	0	0	0	0	0	0	Struck by Delta 727 while being pushed from gate.
5 6	Boeing	727	Delta	Jamaica, N.Y.	None	35(?)	0	0	0	0	0	0	Taxied into Northwest aircraft at gate.
4 19	Lockheed	1011	Trans World	Phoenix, Ariz.	None	88	0	0	0	0	0	0	Blew 6 main gear and nose wheel tires in landing. Brakes engaged on landing. No injuries.
3 31	Boeing	737-247	Western	Casper, Wyo.	Serious	99	0	0	4	0	0	0	Instrument approach. Over-ran snow covered runway on landing, collided with ditch. Passengers evacuated. "Minor bruises, bumps, sprains," and "broken wrist to passenger on ground assisting another passenger."
3 26	DeHavilland	HGC-6	Air Central	Savoy, Ill.	Fatal	1	0	0	0	1	0	0	Crashed during instrument take-off. Aircraft control locks had not been removed.
3 21	McDonnell Douglas	DC8-63F	Flying Tiger	Las Vegas, Nev.	Serious	175	0	1	1	0	0	0	Turbulence. Stewardess serious injury and minor injury to 1 passenger.

1975	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
2 28	McDonnell Douglas	DC-10	American	Los Angeles	None	145	0	0	0	0	0	0	Right rear door came open in flight after takeoff. Lost slide/raft.
2 18	Boeing	707-123B	American	Longview, Texas	None	7	0	0	0	0	0	0	Training flight. Nose landing gear failed on touch-and-go landing.
2 16	Douglas	DC-6B	Pacific Alaska	Fairbanks, Alaska	Fatal	3	0	0	0	3	0	0	Unscheduled cargo flight. Lost engine after takeoff.
2 9	British A.C.	BAC-111	O'Harrah(1) So.Shore Corp.	Lake Tahoe Nev.	Serious	45	0	1	5	0	0	0	(general aviation, FAR Part 91). Crashed on takeoff after striking snow. Evacuated via L. forward door slide and 2 overwing exits. 1 serious injury and 4 minor to passengers; 1 cabin attendant minor injury.
1 14	Boeing	727-25	Eastern	Miami, Fla.	None	1	0	0	0	0	0	0	Being prepared for quick turnaround. Fire in area of hydraulic reservoir.
1 17	Lockheed	10T1	Eastern	San Juan, P.R.	None	76	0	0	0	0	0	0	Fire Damage in cargo compartment. Detected when unloading cargo after arrival.
1 8	Boeing	727-222	United	Birmingham, Ala.	None	88	3	5	80	0	0	0	Struck trees during instrument landing approach. Normal deplaning at gate after 2nd approach.
1 2	Douglas	DC-4B	Transvaal Corp.	Tucson, Ariz.	Minor	3	3	0	0	0	0	0	Ferry flight. Failed to become airborne.
1 1	Douglas	DC-3	Air O'Hara Ltd. (1)	35 N.E. Ft. Lauderdale, Fla.	None	3	0	0	0	0	0	0	Feathered No. 2 engine, unable to hold attitude. Ditched in calm sea. Sank in 3-4 minutes.

APPENDIX D

1975 AIR CARRIER ACCIDENTS
NATO COUNTRIES (EXCLUDING U.S.)
(DATA INCOMPLETE)*

							Injuries			Fatalities			
1975	Type	Model	Airline	Location	Injury Index	Total Occup	Flight Deck	Crew	Pass	Flight Deck	Crew	Pass	Remarks
12 22	Boeing	707	Trans World	Milan, Italy	Serious	133	2	1	23	0	0	0	Crashed on second instrument approach in fog. Captain fractured ribs, First Officer fractured 2 vertebrae, Stewardess fractured nose, and 23 passengers had minor injuries in the impact. No evacuation information yet available.
11 20	Hawker Siddeley	125		Dunsford, England	Fatal	6	1	0	1	0	0	0(6)	Crashed as a result of bird ingestion after striking flock of birds on takeoff. Pilot and 1 passenger severe injuries; 6 fatalities in car hit.
11 12	McDonnell Douglas	DC-10-30	ONA	J.F.K., N.Y.	Minor	139	Unknown			0	0	0	Struck flock of seagulls on take-off (30-40 up to 15 lb each), No. 3 engine separated during stop and aircraft destroyed by fire. Some minor injuries reported during evacuation.
10 7	McDonnell Douglas	DC-10	UTA	Noumea, New Caledonia	Minor	125	0	0	0	0	0	0	No injuries among 125 passengers. Blew tire on landing and overran runway.
9 30	DeHavilland	Twin Otter	Northern Air Thunderbird	Deose Lake, Can.	Fatal	7	0	0	0	2	0	5	Fatal to 2 crew members, 5 passengers.

*In none of above cases are data available at this time concerning occupant injuries or emergency egress.
1975 data incomplete.

1975	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries: Flight Deck	Injuries: Crew	Injuries: Pass	Fatalities: Flight Deck	Fatalities: Crew	Fatalities: Pass	Remarks
9 15	Hawker Siddeley	Trident	British Airways	Bilbao, Spain	Unk.	110		Unknown			Unknown		Aborted takeoff due to deceleration in heavy rain. Ran off runway.
9 14	Vickers	Viscount	Alidair	Guernsey	None	78	0	0	0	0	0	0	Nose gear collapsed on landing.
8 15	Vickers	Viscount	British Airways	Belfast	None	78	0	0	0	0	0	0	No. 3 engine failure, aborted takeoff.
7 25	Boeing	707	British Airways	Prestwick	Unk.	5		Unknown			Unknown		Training flight. Swung to left and aborted takeoff. Fire in no. 1 engine, compressor failure no. 2 engine.
7 20		Herald	British Island	Gatwick	Unk.	45		Unknown			Unknown		Descended suddenly on takeoff. Difficulty with main passenger door and emergency exits. All evacuated left front crew door.
6 18	Boeing	747	Qantas	Over Greek Airspace	Unk.	Unk.		Unknown		0	0	0	Encountered violent hail and turbulence and flight returned to London Substantial damage.
6 12	Boeing	747	Air France	Bombay, India	Unk.	392		Unknown		0	0	0	Right main gear tires blew on takeoff and aborted with 374 passengers and 18 crew. Resulting fire destroyed aircraft. All passengers safely evacuated.
5 16	Boeing	747	British Airways	Prestwick, Scotland	Minor/None	6	0	0	0	0	0	0	On landing approach right inboard foreflap separated from aircraft. Crew training flight.
5 11	Lockheed	L-1011	British Airways	London, England	Minor/None	162	0	0	0	0	0	0	On auto-pilot landing nose pitched violently up with tail contact.
5 7	Boeing	707	Pan American	St. Johns Canada	Fatal	184	0	0	0	0	0	1	Pressurization failure. 71 year old with cardiac problem died.
5 2	Boeing	747	British Airways	Toronto Canada	Minor/ None	217	0	0	0	0	0	0	On landing approach section of right outboard foreflap failed and separated.Aircraft landed safely. 197 passengers; 20 crew.

1975	Typé	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
4 23	McDonnell-Douglas	DC-9	Air Canada	En route Montreal	Unk.	55		Unknown			Unknown		Upon leveling at 7,300 M (24,000') loud noise. Diverted to Ottawa. Part detached from right engine.
4 9	Fokker	F-28	Itavia	Bergamo, Italy	Unk.	?		Unknown			Unknown		Stalled and crashed on initial climb. Passengers deplaned through slide/rafts.
3 22	Boeing	747	British Airways	Toronto, Canada	Minor/ None	224	0	0	0	0	0	0	On landing approach section of left inboard upper flap failed and separated. Aircraft landed safely. 206 passengers and 18 crew.
3 9	Boeing	707	TWA	Lisbon, Portugal	Minor/ None	55	0	0	0	0	0	0	Scheduled passenger flight swung off runway on takeoff. Minor damage. Crew of 9; 46 passengers.
2 19	Yak	40FG	General Air	Saarbucker, Germany	Minor/ None	16	0	0	0	0	0	0	On landing to avoid overshooting intentionally went off runway to right, colliding with trees.
2 18	McDonnell Douglas	DC-10	THY	Dusseldorf, Germany	Minor/ None	Unk.	0	0	0	0	0	0	On final approach right outboard flap vane failed and aircraft went into strip nose down right bank. After flaps retracted to 22" control was regained with safe landing.
1 30	Fokker	F-27	THY	Yesilkoy, Turkey	Fatal	42	0	0	0	2	2	38	Scheduled passenger flight crashed into Sea of Marmara while initiating missed approach after runway lights failed briefly during IFR landing. Destroyed.
1 27	Short Skyvan		Calm Air	La Brochet, Canada	Minor/ None	2	0	0	0	0	0	0	Nosewheel broke through snow during landing and failed. Substantial damage.
1 25	Fokker	F-27	Moersk Air	Vagar, Denmark	Minor/ None	26	0	0	0	0	0	0	Ran off ice and water covered runway to left of runway. Destroyed.

1975	Type	Model	Airline	Location	Injury Index	Total Occup	Injuries Flight Deck	Injuries Crew	Injuries Pass	Fatalities Flight Deck	Fatalities Crew	Fatalities Pass	Remarks
1 15	McDonnell Douglas	DC-9	KLM	Casa Blanca Morocco	Minor/ None	51	0	0	0	0	0	0	Late touchdown. Skidded to stop, Blowing 2 tires.
1 21	McDonnell Douglas	DC-9	SAS	Billund, Denmark	Minor/ None	3	0	0	0	0	0	0	Trainee lost control in check-out flight on landing. Came to rest 400 M. beyond end of runway. Substantial damage.
1 8	McDonnell Douglas	DC-8	Spantax	Ankara, Turkey	Minor/ None	5	0	0	0	0	0	0	Nose gear collapsed on landing. Substantial damage.
1 4	Vickers	Vanguard	British Airways	Milan, Italy	Minor/ None	4	0	0	0	0	0	0	Nose gear failed to extend in landing.

APPENDIX E

The following provides an example of the systems analysis approach necessary to completely and objectively analyze hardware and concepts as prepared in 1971 [Snyder and Robbins, 1971 (22)]. While the present study includes over double the concepts and there have been major advances in several of the systems evaluated at that time, this section is included without modification as an illustration of the systems approach as applied to evaluation of air transport technology.

SYSTEMS ANALYSIS OF CRASH IMPACT AND ESCAPE CONCEPTS

D. Hurley Robbins, Ph.D.

The objective of this section of the report is to present a systems study of the various concepts and hardware relating to crash impact protection and escape from the viewpoint of safety, reliability, maintainability, human factors, and technological considerations. An event-oriented flow diagram of crash impact and escape from an aircraft is presented to aid in assessing the feasibility of the various concepts and hardware under evaluation.

A. Event-Oriented Systems Study

In order to provide a framework to determine the function level of each of the concepts included in this study, an event-oriented flow chart of the crash and escape event has been prepared (See Figure 55). The various events of a crash are included from system installation to egress after a crash. Each item can critically affect survival in event of a crash.

The first item deals with system installation and configuration maintenance. If a device is improperly installed or maintained, survival of one or many is endangered. For instance, an improperly charged airbag inflation device could malfunction resulting in an undeployed restraint system. The occupant could receive an impact injury and become immobile. Preflight briefing and crew training has been included as the next event. Many studies have shown the benefit of a briefing on passenger use of restraint systems. Crew training must be adequate to insure proper use of exits.

When a survivable crash event is imminent, the crew may be aware or unaware. In documented cases, the crew has been unaware or unable to take action regarding a certain crash. In these cases, automatic arming of explosively-formed exits would be necessary.

Passenger warning can be effective in preparing occupants for a crash. Benefits include proper positioning and bracing for the most effective use of restraint systems. Also, the techniques of egress could be established to enhance its efficiency.

Because of the variety of seating configurations which may be found in the subject aircraft, front-, side-, and rear-facing seating have been listed separately. In addition, the out-of-position occupant is considered. Given current restraint systems technology and the differences in human impact tolerance to blows from different directions, the design goals may very well be different in each case.

The crash event itself certainly influences the survival problem. The optimum case is probably a crash on flat and open terrain. A high-wing aircraft has been observed to offer considerably less time for escape than a low-wing aircraft in event of a ditching. Rough terrain most likely increases the likelihood of high impact G-loadings, thus also affecting survival.

During the impact the occupants may range from uninjured to fatally injured. An immobile passenger presents nearly the same egress problem as a fatally injured passenger as he may block available exits thus preventing the escape of other passengers.

The post-crash environment strongly affects egress. Smoke and flames hinder most normal physical and psychological functions. The presence of automatic or live instructions can aid dramatically in egress.

Because of restraint system use, egress from these protective devices is included as a separate event. It is possible that time could be lost pushing airbag material out of the way in leaving seating positions.

Protection from smoke, fumes, and/or fire is believed to be important to survival. A few minutes added breathable air in a cluttered and smoky cabin could possibly be the difference between survival and asphyxiation.

Obviously, the exits must be opened to provide egress. Customarily, the crew opens normal and emergency exits. Occasionally, a structural failure provides a safe exit. Because of documented cases where not enough normal exits were available, the option for automatically produced exits is included.

It is often the case that some exits are unavailable. This is particularly the case when a fire exists outside the aircraft and when structural damage has jammed the doors.

Particularly in the case of darkness and smoke the routes to available exits can be difficult to locate. Audio visual and/or tactile signals can improve ability to egress quickly.

When an occupant reaches an exit, egress can be provided by several techniques. As some have proved more effective than others, a variety of egress techniques are included.

The Subject Systems

A total of seventy-four systems have been chosen for inclusion in the safety, maintainability, human factors, reliability, and technological analyses which follow. These are gathered from the previous sections of the report and can be grouped roughly in the following categories: 1. airbag inflation devices; 2. crash impact sensors; 3. airbag materials; 4. airbag coating materials; 5. crash impact restraint systems; 6. smoke hood concepts; 7. aisle and path markers; 8. warning and public address systems; and, 9. other technology. Most of these concepts are discussed at length in preceding chapters. Restraint systems concepts other than the airbag and its components have not been discussed previously and are included for purposes of comparison. The list is given in Table XIV. The number with each system is used in the tables which follow for purposes of identification.

TABLE XIV.

LIST OF IMPACT PROTECTION AND ESCAPE SYSTEMS

Airbag Inflation Devices

1. Stored gas system.
2. Stored gas system with modulated flow.
3. Augmented air system.
4. Augmented air system with staging.
5. Liquid-cooled, solid propellant system.
6. Solid-colled, solid propellant system.
7. Aspirator systems.

Crash Impact Sensors

8. Mechanical sensor.
9. Sensor using signals from inertial navigation system.
10. Radar proximity sensor.
11. Sonar proximity sensor.

Airbag Materials

12. Nylon
13. Polyester
14. Glass
15. Cotton

Airbag Coating Materials

16. Natural rubber
17. Butyl
18. Neoprene
19. Polyvinyl chloride (PVC)
20. Polyurethane
21. E.P.D.M.
22. Hypalon

Restraint Systems

23. Inflating occupant restraint system for passenger use in rear-facing seats
24. Inflating occupant restraint system for passenger use in side-facing seats
25. Inflating occupant restraint system for crew use in front-facing seats.
26. Rear-facing seats with lap belt
27. Passive net system (Nissan)
28. Passive blanket system (Hamill)
29. Front-facing seat with upper torso harness
30. Troop seat

Smoke Hood Concepts

31. Boeing mask
32. John Hand hood
33. Racine Gove Company hood
34. Sierra Engineering Company hood
35. Life Support Systems hood. (A) Elastic neck seal type
36. Life Support Systems hood. (B) Lanyard neck seal type
37. Scott-O-Vista mask
38. Mine Safety Appliance Company. (A) 88180 cansister device
39. Mine Safety Appliance Company. (B) Self-rescuer.
40. North American Rockwell fire hood concept

41. North American Rockwell fire mask concept
42. Schjeldahl hood. (A) Drawstring model
43. Schjeldahl hood. (B) Septal neck seal model.
44. Experimental FAA (Schjeldahl) hood. Self-contained air supply.
45. Bureau of Mines (Westinghouse/Schjeldahl) portable breathing apparatus. Chlorate candle.
46. FAA (Schjeldahl) hood. Advanced concept.

Aisle and Path Markers

47. Chemical illumination
48. Charge activated electro-illumination
49. Ultraviolet illumination
50. Phosphorescent illumination
51. Incandescent illumination
52. Self-luminescence (tritium)
53. Tactile markers
54. Floor level markers
55. Pulsating markers

Warning and Emergency Public Address Systems

56. Alarm bell
57. Bull horn
58. Solid state device
59. Operational TWA visual/aural system

Other Technology

60. ELSIE
61. Telescape
62. Escape rope
63. External platform slide entry
64. Integrated escape system
65. Folding slide
66. Cargo door
67. Ablative-coated exit
68. Passenger conveyor
69. Inflating slide/liferaft
70. Double slide
71. In-flight egress by paracone.
72. In-flight egress by rapidjet.
73. In-flight escape by capsule-chute
74. In-flight escape by fuselage parachute

B. System Safety

A variety of factors must be included to conduct the preliminary hazard analysis and to estimate the safety of the subject systems. The seventy-four crash impact and escape concepts are rated with respect to twenty- five criteria such as noise level, human error potential, as given in Table XV, etc. The rating scheme for each of the criteria is defined in Table XVI. As an example of the use of Table XV consider the noise level of a stored gas airbag inflation device. Noise level can be rated as: 1. no problem; 2. possible temporary threshold shift; and, 3. possible permanent hearing impairment. In Table XV the stored gas air bag inflation device received a noise level rating of "2" indicating a possible temporary threshold shift on the basis of experiments carried out using human volunteer test subjects.

C. Reliability Considerations

The analysis of reliability is tied closely to the event-oriented flow chart shown in Figure 55. The specific items which will be included in the reliability study are:

a. required function and failure definition (coupled with the flow-chart)
b. critical time periods in exercise of function
c. external environmental stresses under which each element must function; e.g. temperature range from -65°F to 200°F
d. effects of storage, shelf-life, packaging, transportation, handling, and maintenance; e.g. evaluation of components which deteriorate with age
e. identification of reliability critical items which significantly affect ability of systems to function (coupled with the flowchart).

It has not been found possible to develop a numerical rating system for the seventy-four subject systems. Rather, in Table 10 each of the systems is handled individually with brief verbal evaluations used for each of the reliability items.

D. Maintainability Considerations

Each system and subsystem has been subjected to a preliminary maintainability analysis with respect to the following items:

a. simplified maintenance activities

b. major repairs by depot level maintenance;
c. necessary inspection; and
d. projected requirements for facility, personnel, tools, etc.

It has been possible to develop a numerical rating system to assess maintainability. The definition of the rating system is included with the analysis on Table XVIII.

E. Human Factors Considerations

The human factors considerations which are involved in evaluating system performance include nearly all conceivable aspects of human function and performance. Both physiological and psychological stresses are likely to be at peaks emphasizing the detail which must be included in this evaluation. The seventy-four systems are rated with respect to seventeen criteria ranging from ease of use to anthropometric considerations. The rating scheme for each of the criteria is defined in Table XIX and the actual analysis given in Table XX.

F. Technological Aspects

Factors relating to hazards, reliability, maintainability, and human performance must be considered to form an estimate of a system's ability to perform properly. Other engineering and technological factors which do not fit in the above categories must also be included to prove the feasibility of a system for the intended application. Therefore, the following considerations will be included:

a. durability,
b. lightness,
c. compactness,
d. integration of all equipment within the aircraft without restricting crew functions,
e. automatic functions,
f. common equipment permanently installed in aircraft,
g. engineering state-of-the-art.

The rating scheme for each of these criteria is defined on Table XXI. and the analysis given.

G. System Results

When the tables in this section of the report are studied, particular potential performance patterns are observed for the various groups of life support systems which have been evaluated. In the text which follows, summary safety, reliability, maintainability, human factors, and technical feasibility paragraphs are written for the following groups of systems: 1. airbag inflation devices; 2. crash impact sensors; 3. airbag materials; 4. airbag coating materials; 5. restraint systems; 6. smoke protective devices; 7. aisle and path indicators; 8. emergency warning and public address systems; 9. emergency exits; 10. interior egress aids; 11. exterior egress aids, and, 12. in-flight egress.

A variety of comparisons can be made with regard to the various airbag inflation devices. Reliability is a consideration whether the system is in use or stored. The propellant and aspirator systems are estimated to possess higher reliability than stored gas systems because of problems with leakage. All inflation devices require careful handling because of the danger of inadvertent actuation. Special maintenance procedures would be necessary. All these systems have proven capability for accomplishing bag inflation based on prototype development occurring within the past few years. However, the bulkiness and weight must be assessed as an important variable in an aircraft application. The stored gas systems suffer the greatest penalty in this context.

A penalty is paid in introducing these systems with respect to several human factors. The fact that inflation noise is known to result in a temporary threshold shift in hearing could reduce the ability of the user to respond to oral commands and emergency information post-crash. In addition, systems using propellants and pyrotechnic components can produce thermal, toxicological, pyrotechnic, and also the associated psychological hazards. Air bag inflation systems should be classified at least as Hazard Level II devices.

Crash impact sensors are a reliability critical item. They depend on a well-defined G-signal representing a crash or the proximity of a hazard which could result in a crash. This has been one of the major problems in the introduction of inflating restraint systems in automobiles and less information is available defining the crash impact event in aircraft. Although it appears that accurately functioning, maintenance-free sensing devices can be fabricated, research on this item is essential before serious consideration of passive restraints for jet transport application.

The fabric material in an air bag would appear to be one of the smaller problems. Materials with adequate weight-to-strength ratios, high and low temperature resistance, and storability are available. Although a glass fabric has many ideal properties for this application, rip-stop nylon is lighter and more extensible.

Likewise, the material with which an airbag is coated offers few problems. Neoprene, the most likely candidate, has excellent storage and temperature characteristics.

Comparisons are made in the tables presented in this chapter between a variety of restraint systems. With respect to reliability, it is not essential to supplement a rear-facing passenger seat with an airbag. Introduction of the airbag may hamper egress from the seat. Side-facing seating configurations need added research to determine placement of the airbag for impact protection.

It should be noted that the sensor, the inflation device, and bag placement are all reliability critical items needing additional study before introduction in front-facing configurations for crew use. Reliable bag placement is particularly important in this application because of the necessity of crew function in controlling the aircraft during an emergency landing incident which can cover a time period of several seconds. The sensor, deployment technique, and placement are equally important in passive net systems. In conclusion, active restraint systems such as the rear-facing seat with lap belt and the front-facing crew seat with integrated upper torso belt restraint system all substitute simple hardware and an increased human error potential (the act of fastening belts) for the technologically complex passive restraint hardware.

The introduction of passive restraint systems requires more sophisticated maintenance procedures than the operational active systems. For example, automatically deployable systems should be checked for ready status before each flight. In addition, the passive systems require careful handling during maintenance because of explosive, pyrotechnic, and propellant components.

Several general technological items should also be mentioned. Belt systems are lighter in weight and are more compact demonstrating a distinct advantage over current generation passive restraint systems. Also, the effectiveness of belts in operational applications has been proven many times over when they are used, maintained, and installed properly. Inflating occupant restraint systems and passive nets have yet to be field tested, but operational prototypes have been extensively laboratory tested.

Inflating restraint systems possess several disadvantages and one major advantage over active belt systems when studied from the viewpoint of human factors. The disadvantages are: 1. possible hearing impairment in the post-crash environment hindering communication; 2. possible visibility decrement during and post-crash due to the bag material; and, 3. a potential for psychological stress in the presence of a propellant or explosive device. The advantage is that the passive nature of this restraint decreases the potential for human error.

The preliminary hazard analysis also yields several items which could be performance decrements for airbags. These are: 1. potential noise hazard; 2. hazard level II device; 3. presence of energy sources, explosive components, and/or propellants; 4. potential for inadvertent actuation; 5. presence of pressure vessels; and, 6. increased maintainability requirements.

Several of the smoke protective devices evaluated in this study appear to be reliable, durable, and relatively maintenance free while being possibly somewhat difficult to use. Some components are known to degrade with storage, but with periodic inspection, individual units could be replaced. All systems are light and compact and could be easily adapted for use in current operational aircraft. The Schjeldahl, Scott-O-Vista, and Mine Safety Appliance Co. systems are production items while the North American Rockwell and FAA advanced systems are concepts. The remainder of the systems have been developed as prototypes.

Human factors considerations represent the most important items in developing a decision regarding introduction of smoke protective devices in operational aircraft. The first item concerns the apparent decrement in visibility which occurs with several of the systems. The Schjeldahl, North American Rockwell fire mask, FAA systems possess the most desirable properties in this regard. The second item concerns ease of donning. All systems pose some problem in donning. At least a briefing is required and, especially for individuals with glasses, practice could be helpful. The third item concerns toxicity. Most smoke protective devices are useful to minimize toxic hazard potential in a crashed aircraft during egress. However, they present a toxic hazard of their own during prolonged use. Devices providing a self-contained air supply such as the advanced FAA prototype offer an advantage in this area.

A preliminary hazard analysis yields a few items of concern with respect to smoke protective devices. Among these items are: 1. toxicity problems; 2. inadvertent activation of systems using a stored breathable air source; 3. vulnerability to tampering and prolonged storage; and 4. some difficulty involved in system use.

Aisle and path markers offer an inexpensive, easily maintainable, durable, light, and compact aid to egress. Most of the systems studied are production items with the exception of pulsating path markers which are concepts with respect to aircraft application and tactile markers which are undergoing prototype development. In considering human factors, it can be concluded that aisle and path markers can be a useful aid provided they are positioned for the greatest effectiveness and visibility. It should be noted, however, that tactile markers may be difficult to use. A preliminary hazard analysis yields a few items as follows: 1. possible short term toxicity estimated particularly with chemical luminescence and self-luminescence; 2. energy sources exist in most systems which must be isolated from tampering and impact, 3. electrical systems can be a source of a fire hazard; and, 4. most systems are vulnerable to tampering.

Emergency warning and public address systems appear to present more of a reliability problem than aisle and path markers. Two specific problems are with power failure and with the design of crash resistant electro-mechanical components. However, the technology is available to solve these problems. Systems of this nature are believed to offer few if any problems with maintenance, and they are durable, light and compact. A preliminary hazard analysis yields few problems.

The systems include under the general heading "other technology" can be placed into four general classifications. These include: 1. exits; 2. external aids to egress; 3. internal aids to egress; and, 4. in-flight egress. Each of these groups are discussed individually.

All four of the exit concepts studied (ELSIE, external platform slide entry, cargo door, ablative coated exit) appear to be worthy candidates for further study and possible introduction into transport aircraft. Accident experience bears out the desirability of introducing exits in addition to those known to be available in actual cases. All four systems have been developed as prototypes or are already in operational use.

Reliability appears to be a primary concern, especially with ELSIE and the external platform slide entry. Deployment during normal flight would be dangerous and a failsafe activation system is necessary. The cargo door could be subject to jamming, a problem with most normal exits if fuselage deformation occurs, limiting its reliability. The ELSIE concept offers a distinct advantage in that case.

These systems are all relatively easy to use with ELSIE being the most difficult to activate. As it is presently conceived, this system requires two crew members to initiate actuation enhancing its fail-safe characteristics but increasing the chance for post crash confusion. Crew training and briefing would be required before each flight. Besides the hazard associated with explosive devices, ELSIE could present a noise problem, temporarily influencing passenger and crew hearing, and thus affecting communication during egress. This potential problem, most likely minor, should be investigated.

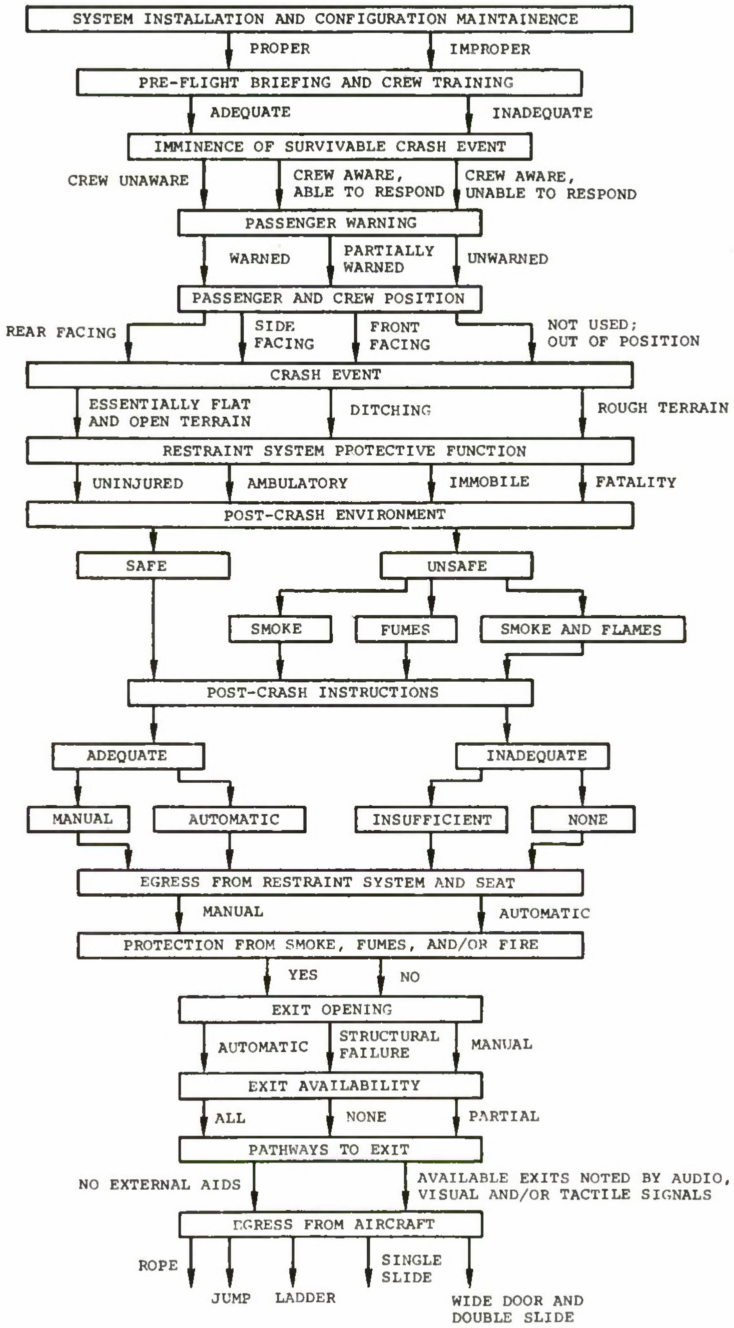
External egress aids include the telescape device, the escape rope, the folding slide, the slide/raft combination, and the double slide. These devices are all in service in operational aircraft with the exception of telescape which has been fabricated and tested as a prototype and the folding slide which has been proposed as a concept.

Most of these systems present a reliability problem with respect to deployment with the exception of the escape rope. All systems are technically feasible but some are mechanically quite complex. The deployment and structural characteristics of inflating structures such as escape slides need additional study based on the experiences in the recent Boeing 747 evacuation at San Francisco International Airport. The folding slide offers the greatest problems with deployment because of possible deformation occurring during fuselage distortion. Again the systems present few problems with respect to human factors with the exception of the escape rope and telescape, which are physically difficult to use and may present a hazard when improperly used.

Internal aids to egress which have been evaluated include an integrated passenger escape system and a passenger conveyor. These systems are complex and expensive, requiring much development and testing. A cost effectiveness study should be carried out to ascertain if these systems are economically feasible. The current investigators feel that they are not. Both systems require a flexible logic control in order to deliver passengers to the best available exits. In addition, both systems are subject to many crash impact hazards ranging from power loss to mechanical malfunction to fuselage deformation. The integrated passenger escape system has one characteristic worthy of note. It attempts to provide crash impact protection, smoke protection, and egress in one package. This systems approach is believed necessary in any approach to the overall problem of crash impact protection and escape.

In-flight egress is an extremely difficult problem with transport aircraft. The four systems (paracone, rapidjet, capsule parachute and fuselage parachutes) are all complex and expensive systems for which much research and development work must be carried out. To determine whether implementation of any of these systems is economical from the cost-effectiveness point of view, further study is necessary.

Figure 55. Crash Impact and Escape Flow Diagram



CONSIDERATION	AIRBAG INFLATION DEVICES	CRASH IMPACT SENSOR	AIRBAG MATERIAL	AIRBAG COATING MATERIALS	RESTRAINT SYSTEMS
	1 2 3 4 5 6 7	8 9 10 11	12 13 14 15	16 17 18 19 20 21 22	23 24 25 26 27 28 29 30
	stored gas stored gas - mod. flow augmented air aug. air - staging liq. cool - solid prop. solid cool - solid prop. aspirator	mechanical inertial guidance radar proximity sonar proximity	nylon polyester glass cotton	natural rubber butyl neoprene P.V.C. polyurethane E.P.D.M. hypalon	pass. IORS (rear face) pass. IORS (side face) crew IORS (front face) rear face seat + l.b. passive net passive blanket front face seat - A.F.H. troop seat
a. Durability	2 2 2 2 2 2 2	1 1 1 1	2 2 2 2	2 2 2 2 2 2 2	2 2 2 2 2 2 2 2
b. Lightness	2 2 1 1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1 1 1 1	2 2 2 1 2 2 1 1
c. Compactness	2 2 2 2 2 2 2	1 1 1 1	2 2 2 2	1 1 1 1 1 1 1	2 2 2 1 2 2 2 2
d. Installation restricts crew function	1 1 1 1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1 1 1 1	1 1 1 1 1 1 1 1
e. Automatic	1 1 1 1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1 1 1 1	1 1 1 2 1 1 2 2
f. Permanent installation	3 3 3 3 3 3 3	1 1 1 1	3 3 3 3	3 3 3 3 3 3 3	2 2 1 3 2 2 1 3
g. Engineering state of art	1 1 2 2 2 2 2	2 4 2 2	1 1 1 1	1 1 1 1 1 1 1	4 4 2 1 2 2 1 1

a. Durability
1. life of aircraft
2. possible replacement

b. Lightness
1. no decrement to aircraft weight
2. probably 15 lb. per system or more

c. Compactness
1. no decrement
2. more than 6 in.^{3} per system

d. Integration with aircraft non-restrictive to crew function
1. yes
2. no

e. Automatic
1. yes
2. no

f. Permanent installation in aircraft
1. yes
2. partial
3. no

g. Engineering state of art
1. production item
2. prototype development
3. mockup
4. concept

N = not applicable
i = insufficient information

CONSIDERATIONS	SMOKE HOOD CONCEPTS	AISLE AND PATH MARKERS	WARNING AND P.A.	OTHER TECHNOLOGY
	31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46	47 48 49 50 51 52 53 54 55	56 57 58 59	60 61 62 63 64 65 66 67 68 69 70 71 72 73 74
	Boeing mask John Hand hood Racine Glove Co. Sierra Eng. Co. LSS - Elastic seal LSS - Lanyard Scott-O-Vista M.S.A.C. - canister M.S.A.C. - self-rescue N.A.R. fire hood N.A.R. fire mask Schjeldahl - drawstring Schjeldahl - septal FAA - air supply B.M. - PBA hood FAA adv. concept	chem-illum. electro-illum. ultra-violet phosphorescent incadescent self-illum. (tritium) tactile markers floor level markers pulsating markers	alarm bell bull horn solid-state device TWA visual/aural	ELSIE telescape escape escape rope ext. plat. slide entry S.B. - escape harness folding slide cargo door ablative coat. exit pass. conveyor slide/raft double slide in-flight/paracone in-flight/rapid jet in-flight/capsule in-flight/parachute
a. Durability	2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	2 2 2 1 1 1 1 1 1	1 1 2 1	1 2 2 2 2 1 1 2 i 2 2 2 2 2 2
b. Lightness	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1	1 1 1 1	i 2 1 2 2 2 1 2 2 2 2 2 2 2 2
c. Compactness	1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1	1 1 1 1 1 1 1 1 1	1 2 1 1	1 2 2 2 2 2 1 1 2 2 2 2 2 2 2
d. Integration within aircraft non-restrictive to crew function	2 2 1 1 1 1 2 2 2 1 1 1 1 1 2 1	1 1 1 1 1 1 1 1 1	1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
e. Automatic	2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	1 1 1 1 1 1 1 1 1	2 2 2 2	2 2 2 2 2 2 2 1 2 2 2 2 2 2 2
f. Permanent installation in aircraft	3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	3 2 3 3 1 3 3 3 1	1 3 3 1	1 3 3 3 2 1 1 2 1 3 3 1 1 1 1
g. Engineering state of art	2 2 2 2 2 2 1 1 1 4 4 1 1 2 2 4	1 1 1 1 1 1 2 1 4	1 1 4 1	2 2 1 1 4 4 1 1 4 1 1 4 4 4 4

a. Durability
1. life of aircraft
2. possible replacement

b. Lightness
1. no decrement to aircraft weight
2. probably 15 lb. per system or more

c. Compactness
1. no decrement
2. more than 6 in.^{3} per system.

d. Integration within aircraft non-restrictive to crew function
1. yes
2. no

e. Automatic
1. yes
2. no

f. Permanent installation in aircraft
1. yes
2. partial
3. no

g. Engineering state of art
1. production item
2. prototype development
3. mockup
4. concept

N = not applicable
i = insufficient information

FACTOR	AIRBAG INFLATION DEVICES						
	1	2	3	4	5	6	7
	atored gas	stored gas - mod. flow	augmented air	aug. air - staging	liq. cool - solid prop.	solid cool - solid prop.	aspirator
a. Noise	2	2	2	2	2	2	2
b. Visibility	1	1	1	1	1	1	1
c. Ability to hear	2	2	2	2	2	2	2
d. Ease of use	2	2	2	2	2	2	2
e. Human tolerance to impact	1	1	1	1	1	1	1
f. Possible thermal hazard	1	1	2	2	2	2	1
g. Possible toxicological hazerd	1	1	2	2	2	2	2
h. Possible pyrotechnic hazard	1	1	2	2	2	2	2
i. Possible visual hazard	1	1	1	1	1	1	1
j. Space to carry out function	2	2	2	2	2	2	2
k. Illumination	2	2	2	2	2	2	2
l. Normal ingress and egress	1	1	1	1	1	1	1
m. Non-restrictive LS and protective equipment	1	1	1	1	1	1	1
n. Psychophysiological stress	2	2	2	2	2	2	2
o. Fail-safe design	1	1	1	1	1	1	1
p. Simplicity	1	2	1	1	1	1	2
q. Anthropometric considerations	2	2	2	2	2	2	2

FACTOR	CRASH IMPACT SENSORS			
	8	9	10	11
	mechanical	inertial guidance	radar proximity	sonar proximity
a. Noise	1	1	1	1
b. Visibility	1	1	1	1
c. Ability to hear	1	1	1	1
d. Ease of use	2	2	2	2
e. Human tolerance to impact	1	1	1	1
f. Possible thermal hazard	1	1	1	1
g. Possible toxicological hazerd	1	1	1	1
h. Possible pyrotechnic hazard	1	1	1	1
i. Possible visual hazard	1	1	1	1
j. Space to carry out function	2	2	2	2
k. Illumination	2	2	2	2
l. Normal ingress and egress	1	1	1	1
m. Non-restrictive LS and protective equipment	1	1	1	1
n. Psychophysiological stress	2	2	2	2
o. Fail-safe design	1	1	1	1
p. Simplicity	3	4	4	4
q. Anthropometric considerations	2	2	2	2

FACTOR	AIRBAG MATERIALS			
	12	13	14	15
	nylon	polyeater	glass	cotton
a. Noise	1	1	1	1
b. Visibility	2	2	2	2
c. Ability to hear	1	1	1	1
d. Ease of use	2	2	2	2
e. Human tolerance to impact	1	1	1	1
f. Possible thermal hazard	1	1	1	1
g. Possible toxicological hazerd	i	i	1	i
h. Possible pyrotechnic hazard	1	1	1	2
i. Possible visual hazard	1	1	1	1
j. Space to carry out function	2	2	2	2
k. Illumination	2	2	2	2
l. Normal ingress and egress	1	1	1	1
m. Non-restrictive LS and protective equipment	1	1	1	1
n. Psychophysiological stress	2	2	2	2
o. Fail-safe design	1	1	1	1
p. Simplicity	1	1	1	1
q. Anthropometric considerations	2	2	2	2

FACTOR	AIRBAG COATING MATERIALS						
	16	17	18	19	20	21	22
	natural rubber	butyl	neoprene	P.V.C.	polyurethane	E.P.D.M.	hypalon
a. Noise	1	1	1	1	1	1	1
b. Visibility	2	2	2	2	2	2	2
c. Ability to hear	1	1	1	1	1	1	1
d. Ease of use	2	2	2	2	2	2	2
e. Human tolerance to impact	1	1	1	1	1	1	1
f. Possible thermal hazard	1	1	1	2	1	1	1
g. Possible toxicological hazerd	i	i	1	1	i	i	1
h. Possible pyrotechnic hazard	2	2	1	1	2	2	1
i. Possible visual hazard	1	1	1	1	1	1	1
j. Space to carry out function	2	2	2	2	2	2	2
k. Illumination	2	2	2	2	2	2	2
l. Normal ingress and egress	1	1	1	1	1	1	1
m. Non-restrictive LS and protective equipment	1	1	1	1	1	1	1
n. Psychophysiological stress	2	2	2	2	2	2	2
o. Fail-safe design	1	1	1	1	1	1	1
p. Simplicity	1	1	1	1	1	1	1
q. Anthropometric considerations	2	2	2	2	2	2	2

FACTOR	RESTRAINT SYSTEMS							
	23	24	25	26	27	28	29	30
	pass. IORS (rear face)	pass. IORS (side face)	crew IORS (front face)	rear face seat + l.b.	passive net	passive blanket	front face seat-A.F.H.	troop seat
a. Noise	2	2	2	1	1	1	1	1
b. Visibility	2	2	2	1	1	1	1	1
c. Ability to hear	2	2	2	1	1	1	1	1
d. Ease of use	2	2	2	2	2	2	2	2
e. Human tolerance to impact	1	1	1	1	1	1	1	1
f. Possible thermal hazard	1	1	1	1	1	1	1	1
g. Possible toxicological hazerd	1	1	1	1	1	1	1	1
h. Possible pyrotechnic hazard	1	1	1	1	1	1	1	1
i. Possible visual hazard	1	1	1	1	1	1	1	1
j. Space to carry out function	2	2	2	2	2	2	2	2
k. Illumination	2	2	2	2	2	2	2	2
l. Normal ingress and egress	1	1	1	2	1	1	2	2
m. Non-restrictive LS and protective equipment	1	1	1	1	1	1	1	1
n. Psychophysiological stress	2	2	2	1	2	2	1	1
o. Fail-safe design	1	1	1	2	1	1	2	2
p. Simplicity	4	4	4	2	4	4	2	2
q. Anthropometric considerations	2	2	2	2	2	2	2	2

N = not applicable
i = insufficient information

FACTOR	SMOKE HOOD CONCEPTS															
	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
	Boeing mask	John Hand hood	Racine Glove Co.	Sierra Eng. Co.	LSS - Elastic seal	LSS - Lanyard	Scott-O-Vista	M.S.A.C. - canister	M.S.A.C. - self-rescue	N.A.R. fire hood	N.A.R. fire mask	Schjeldahl - drawstring	Schjeldahl - septal	FAA - air supply	B.M. - PBA hood	FAA adv. concept
a. Noise	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
b. Visibility	2	3	3	i	i	i	i	2	2	i	1	2	1	1	i	1
c. Ability to hear	i	1	i	i	i	i	i	1	1	i	1	1	1	1	i	1
d. Ease of use	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
e. Human tolerance to impact	i	1	1	1	1	1	i	i	i	1	1	1	1	i	i	1
f. Possible thermal hazard	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
g. Possible toxicological hazard	2	2	2	2	2	2	2	2	2	2	1	2	2	1	i	1
h. Possible pyrotechnic hazerd	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
i. Possible visual hazard	i	i	i	i	i	i	i	2	2	i	1	1	1	1	i	1
j. Space to carry out function	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1
k. Illumination	i	1	1	1	1	1	i	i	i	1	1	1	1	1	i	1
l. Normal ingress and egress	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1
m. Non-restrictive LS and protective equipment	3	i	i	i	i	i	i	3	3	i	2	2	2	2	i	2
n. Psychophysiological stress	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
o. Fail-safe design	i	1	1	i	1	1	i	i	i	1	1	1	1	1	i	i
p. Simplicity	2	1	1	1	1	1	2	2	2	1	1	1	1	2	3	2
q. Anthropometric conaiderations	2	1	1	1	1	1	2	2	2	1	1	1	1	1	2	1

FACTOR	AISLE AND PATH MARKERS								
	47	48	49	50	51	52	53	54	55
	chemo-illum.	electro-illum.	ultra-violet	phosphorescent	incadescent	self-illum. (tritium)	tactile markers	floor level markers	pulsating markers
a. Noise	1	1	1	1	1	1	1	1	1
b. Visibility	2	2	2	2	1	2	i	2	2
c. Ability to hear	1	1	1	1	1	1	1	1	1
d. Ease of use	1	1	1	1	1	1	2	1	1
e. Human tolerance to impact	1	1	1	1	1	1	1	1	1
f. Possible thermal hazard	1	1	1	1	1	1	1	1	1
g. Possible toxicological hazard	1	1	1	1	1	2	1	1	1
h. Possible pyrotechnic hazerd	1	1	1	1	2	1	1	1	1
i. Possible visual hazard	1	1	1	1	1	1	1	1	1
j. Space to carry out function	1	1	1	1	1	1	2	1	1
k. Illumination	1	1	1	1	1	1	2	1	1
l. Normal ingress and egress	1	1	1	1	1	1	1	1	1
m. Non-restrictive LS and protective equipment	1	1	1	1	1	1	1	1	1
n. Psychophysiological stress	2	2	2	2	1	2	2	2	2
o. Fail-safe design	1	1	1	1	1	1	1	1	1
p. Simplicity	1	1	1	1	1	1	1	1	1
q. Anthropometric conaiderations	1	1	1	1	1	1	1	2	1

FACTOR	WARNING AND P.A.			
	56	57	58	59
	alarm bell	bull horn	solid-state device	TWA visual/aural
a. Noise	1	1	1	1
b. Visibility	1	1	1	1
c. Ability to hear	2	1	1	2
d. Ease of use	3	3	3	3
e. Human tolerance to impact	1	1	1	1
f. Possible thermal hazard	1	1	1	1
g. Possible toxicological hazard	1	1	1	1
h. Possible pyrotechnic hazerd	1	1	1	1
i. Possible visual hazard	1	1	1	1
j. Space to carry out function	1	1	1	1
k. Illumination	1	1	2	1
l. Normal ingress and egress	1	1	1	1
m. Non-restrictive LS and protective equipment	1	1	1	1
n. Psychophysiological stress	2	2	2	2
o. Fail-safe design	1	1	i	2
p. Simplicity	3	3	4	4
q. Anthropometric conaiderations	1	1	1	1

FACTOR	OTHER TECHNOLOGY														
	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
	ELSIE	telescape	eacape rope	ext. plat. alide entry	S.B. - escape harness	folding slide	cargo door	ablative coat. exit	pass. conveyor	slide/liferaft	double slide	in-flight/paracone	in-flight/rapid jet	in-flight/capsule	in-flight/parachute
a. Noise	i	1	1	1	1	1	1	N	i	1	1	i	i	i	i
b. Visibility	1	1	1	1	1	1	1	1	1	1	1	i	3	3	1
c. Ability to hear	i	1	1	1	i	1	1	1	i	1	1	i	i	i	i
d. Ease of use	3	2	2	2	2	2	2	1	2	2	2	3	2	3	3
e. Human tolerance to impact	1	2	2	2	2	2	2	1	2	1	1	2	2	2	2
f. Possible thermal hazard	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
g. Possible toxicological hazard	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
h. Possible pyrotechnic hazerd	1	1	1	1	1	1	1	1	1	1	1	1	1	i	i
i. Possible visual hazard	1	1	1	1	1	1	1	1	1	1	1	i	2	2	1
j. Space to carry out function	1	3	3	3	3	3	1	1	3	3	3	3	3	3	3
k. Illumination	2	1	1	1	2	1	1	2	2	1	1	2	1	2	2
l. Normal ingress and egress	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
m. Non-restrictive LS and protective equipment	1	1	1	1	3	1	1	1	3	1	1	3	3	3	3
n. Psychophysiological stress	2	2	2	2	2	2	2	N	2	2	2	3	3	3	3
o. Fail-safe design	1	2	2	2	i	2	2	1	i	2	2	1	i	i	i
p. Simplicity	4	2	1	2	2	2	2	1	3	2	2	4	2	4	4
q. Anthropometric conaiderations	1	2	2	2	2	2	2	1	2	2	2	2	2	1	1

N = not applicable
i = insufficient information

CONSIDERATION	AIRBAG INFLATION DEVICES						
	1 stored gas	2 stored gas - mod. flow	3 augmented air	4 aug. air - staging	5 liq. cool - solid prop.	6 solid cool - solid prop.	7 aspirator
a. Simplified maintenance in using unit	1	1	1	1	1	1	1
b. Major repairs by depot level personnel	1	1	1	1	1	1	1
c. Inspections	1	1	1	1	1	1	1
d. Projected requirements for facility, personnel, tools, etc.	2	2	2	2	2	2	2

CONSIDERATION	CRASH IMPACT SENSOR				AIRBAG MATERIAL			
	8 mechanical	9 inertial guidance	10 radar proximity	11 sonar proximity .	12 nylon	13 polyester	14 glass	15 cotton
a. Simplified maintenance in using unit	1	1	1	1	1	1	1	1
b. Major repairs by depot level personnel	1	1	1	1	1	1	1	1
c. Inspections	1	1	1	1	2	2	2	2
d. Projected requirements for facility, personnel, tools, etc.	2	2	2	2	1	1	1	1

CONSIDERATION	AIRBAG COATING MATERIAL						
	16 natural rubber	17 Butyl	18 neoprene	19 P.V.C.	20 polyurethane	21 E.P.D.M.	22 hypalon
a. Simplified maintenance in using unit	1	1	1	1	1	1	1
b. Major repairs by depot level personnel	1	1	1	1	1	1	1
c. Inspections	2	2	2	2	2	2	2
d. Projected requirements for facility, personnel, tools, etc.	1	1	1	1	1	1	1

CONSIDERATION	RESTRAINT SYSTEMS							
	23 pass. IORS (rear face)	24 pass. IORS (side face)	25 crew IORS (front face)	26 rear face seat + l.b.	27 passive net	28 passive blanket	29 front face seat - A.F.H.	30 troop seat
a. Simplified maintenance in using unit	1	1	1	1	1	1	1	1
b. Major repairs by depot level personnel	1	1	1	1	1	1	1	1
c. Inspections	1	1	1	2	1	1	2	2
d. Projected requirements for facility, personnel, tools, etc.	2	2	2	1	2	2	1	1.

a. Simplified maintenance in using unit

1. yes
2. no

b. Major repairs by depot level personnel

1. yes
2. no

c. Inspections

1. before each flight
2. periodic

d. Projected requirements for facility, personnel, tools, etc.

1. available
2. new equipment, personnel, or facility required

N = not applicable
i = insufficient information

CONSIDERATION	SMOKE HOOD CONCEPTS															
	31 Boeing mask	32 John Hand hood	33 Racine Glove Co.	34 Sierra Eng. Co.	35 LSS - Elastic seal	36 LSS - Lanyard	37 Scott-O-Vista	38 M.S.A.C. - canister	39 M.S.A.C. - self-rescue	40 N.A.R. - smoke hood	41 N.A.R. - smoke mask	42 Schjeldahl - drawstring	43 Schjeldahl - septal	44 FAA - air supply	45 B.M. - PBA hood	46 FAA Adv. concept
a. Simplified maintenance in using unit	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
b. Major repairs by depot level personnel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
c. Inspections	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
d. Projected requirements for facility, personnel, tools, etc.	1	1	1	1	1	1	1	2	2	1	1	1	1	1	2	1

CONSIDERATION	AISLE AND PATH MARKERS									WARNING AND P.A.			
	47 chem. illum.	48 electro-illum.	49 ultra-violet	50 phosphorescent	51 incadescent	52 self-illum. (tritium)	53 tactile markers	54 floor level markers	55 pulsating markers	56 alarm bell	57 bull horn	58 solid-state device	59 TWA visual/aural
a. Simplified maintenance in using unit	1	1	1	1	1	1	1	1	1	1	1	i	1
b. Major repairs by depot level personnel	2	2	2	2	2	2	2	2	2	2	2	2	2
c. Inspections	2	2	2	2	1	2	1	2	2	1	1	1	1
d. Projected requirements for facility, personnel, tools, etc.	1	1	1	1	1	1	1	1	1	1	1	1	1

CONSIDERATION	OTHER TECHNOLOGY														
	60 ELSIE	61 telescone escape	62 escape rope	63 ext. plat. - slide entry	64 S.B. - escape harness	65 fold. slide	66 cargo door	67 ablative coat. exit	68 pass. conveyor	69 slide/raft	70 double slide	71 in-flight/paracone	72 in-flight/rapid jet	73 in-flight/capsule	74 in-flight/parachute
a. Simplified maintenance in using unit	i	1	1	1	2	1	1	1	1	1	1	2	2	2	2
b. Major repairs by depot level personnel	i	2	2	2	2	2	2	2	2	2	2	1	1	1	1
c. Inspections	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
d. Projected requirements for facility, personnel, tools, etc.	2	1	1	1	i	1	1	1	2	1	1	2	2	2	2

a. Simplified maintenance in using unit

1. yes
2. no

b. Major repairs by depot level personnel

1. yes
2. no

c. Inspections

1. before each flight
2. periodic

d. Projected requirements for facility, personnel, tools, etc.

1. available
2. new equipment, personnel, or facility required

N = not applicable
i = insufficient information

Item No. (See Table 7.)	Item	Required Function	Failure Definition	Critical time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
66	Cargo door	Fuselage cargo door, swing -out nose or tail, used for rapid egress of maximum number of passengers	Opening mechanism fails or structure buckles preventing actuation	Immediately post-crash or whenever emergency evacuation required	None known	Would provide additional exit but not essential system. Integrity of fuselage at swing points is most critical factor
67	Ablative exterior coating	Provide heat shield to protect overwing egress pathway	Fails to retain ablative characteristics, provides undue penalty affecting flight characteristics	Egress in post-crash exterior fire	None known	Not a critical item but may increase egress survivability. Effect on flight characteristics may be critical factor
68	Passenger conveyer belt	To provide passenger with means to locate and reach nearest emergency exit	Jams, failing to operate. Inflicts injuries on passengers jammed between belt and seat. Sends passengers in wrong direction (to non-useable exits)	Emergency egress, post-crash egress	None known	Not essential system for egress Structural failure during crash may render inoperative; directional control may be imperative
69	Slide/raft	Emergency egress to ground or water	Failure to deploy, punctures, inadvertently actuates	, Immediately -post-crash or whenever emergency evacuation required	None known. Periodic inspection recommended	Provides critical egress function. Mechanical deployment failure critical

Item No. (See Table 7.)	Item	Required Function	Failure Definition	Critical time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
71	In-flight egress paracone	In-flight emergency egress	Fails to deploy; Deploys but fails to slow down	Immediately following identification of in-flight catastrophic event and decision to egress by flight crew	Information not available	Integrity of post-event cabin area and deployment
72	In-flight egress rapidjet	Rapid egress without donning equipment. Egress in 6 sec. intervals	Inability to reach escape hatch due to aircraft attitude; jamming of restraint container and parachute	Immediately after decision to egress by crew	Information not available	Psychological reluctance to jump into hatch without assurance of system function Mechanical failure
73	In-flight egress capsule	Provide method (presently non-existent) for in-flight egress from disabled aircraft for passengers and crew not equipped with parachutes	Failure of capsule ejection ordnance; failure of drogue or parachute; non-survivable ground impact	Immediately after -decision by crew to egress	Information not available	Must function for survivable
74	In-flight egress fuselage parachute	As above by lowering intact fuselage. No action required by passengers	Failure of drogue and parachute initiating device	Immediately after decision by crew to egress	None known	Must function for survival

Item No. (See Table 7.)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage And Handling	Reliability Critical Items
53	Tactile markers	Provide tactile sensors for egress where vision poor or not existant	Failure to remain stable in place, incorrect positioning	Must be available immediately post-crash	No adverse effects known	Shape provides direction of exit indication. Markers must be correctly installed to remain in place
54-55	Floor level and pulsating aisle markers	Provide visual references for evacuation	Do not work	Immediately post-crash	None known	Pulse sequence; Energy source
56, 59	Alarm bell	Warn of emergency	Fails to work, or warning light fails	Prior to, during and/or subsequent to crash, ditching, or in-flight emergency	None if properly packaged	Energy source; Electrical circuits
57	Bull Horn	To provide portable emergency P.A. system	Power failure	Whenever required as emergency communication system due to failure of primary means	Battery deterioration	Energy source; Electrical circuits
58	Solid-state communications system	Provide portable communication between crew members	Does not receive or transmit; garbled signal, inadequate volume	Whenever required as emergency communications system due to failure of primary means	Unknown	Energy source; Electronic circuits
60	ELSIE	Provide instantaneous emergency exits	Does not sever exit	Can be initiated prior to ditching or for post-impact egress	Information not known	Failure of any of five major components

Item No. (See Table 7.)	Item	Required Function	Failure Definition	Critical time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
61	Telescape	Fast egress from emergency door exits	Fails to extend; fails to reach ground at useful angle; jams	Immediately post-crash, or when emergency egress required	Hardware can be stored indefinitely; gas source may leak; seal deteriorate	Not essential item. Can provide important function gas storage container and collapsing tubular alignment critical for proper function
62	Escape Rope	Allow egress from cabin overhead exits or flight deck windows	Tangled; support fails; can not be located	Immediately post-crash, or when emergency egress required	Can be stored without decrement for extended time under proper humidity and temperature	Serves critical need where jump from exit would be injurious. Strength and stowage critical
63, 65, 70	Inflatable Escape Slide	Provide fast reliable emergency egress from exit to ground	Failure to deploy or inadvertent inflation	Immediately post crash or when emergency egress required	Designed for long-term stowage; gas source requires recharge	Necessary for emergency egress. Mechanical (puncture) failure; failure of inflation source
64	S.B./Escape Harness	Automatic egress in emergency evacuation or post-crash	Inadequate restraint fit or failure of power system due to fuselage damage	Imediately post-crash or when emergency egress required	Insufficient data available on this concept	Not essential for egress. Failure of restraint, power system, or linkage would render nonusable
65	Mechanical Folding Slide	Serves as either walkway or stairs for emergency egress	Fails to deploy, jams, fails to reach ground	Immediately post-crash or whenever emergency evacuation required	None known	Not essential for egress. Failure to deploy or jamming may be critical factors

Item No. (See Table 7.)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
26	Rear-facing seat plus lap belt	Provide occupant crash protection	Seat structural failure, lap belt failure, or failure where seat is attached to aircraft	Must function during crash	Components must be maintained properly and frayed belts replaced	Strength of critical seat structural members, lap belt and attachments. Requires user action
27, 28	Passive net restraint system (Nissan, Hamill)	Provide occupant crash protection	Does not deploy or improperly positioned	Must function during crash	Most components can be handled and stored easily with careful installation and maintenance. This is a hazard level II device	The most susceptible items in this system are the crash sensor and the electro-mechanical actuation trigger. Function necessary for crash protection
29	Front-facing seat plus Air Force lap belt and shoulder harness with inertia reel	Provide occupant protection in crash without reducing crew ability to function	Seat structural failure, belt or harness failure, or failure where seat is attached to aircraft.	Must function during crash	Components require minimum attention except for restraint belt maintenance	Strength of components. Requires user action
30	Troop seat	Provide occupant protection in crash	Component failure	Must function during crash	Components require minimum attention except for restraint belt maintenance	Strenght of components. Requires briefing and user action

Item No. (See Table 7.)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
31-37, 40, 42, 43	Smoke hoods (rebreather) 3-6 min. duration	Protect against toxic fumes, smoke flame, and heat, and provide sufficient air for emergency egress without significant impairment of visual acuity or hearing	Leaks, obstructs vision, impairs hearing, or fails to protect against flame, smoke, or toxic fumes. Fails to retain air.	3-6 minutes post crash for donning and egress	Tears along fold lines, in reuse, deterioration	Function necessary for egress in smoke and fire
38, 39	M.S.A.C. smoke mask and canister	Removes large smoke particles	Defective nose clip; separated hose clip; canister hose leak	Post-crash egress	Canister hose deterioration, material deterioration	Function of possible assistance - in egress in smoke and fire
41	N.A.R. smoke mask	Filter smoke	Filter dried out	Post-crash egress	Outer container seal may break, drying out filter	Function of possible assistance for egress in smoke and fire
44-46	Smoke hoods (self-contained or generated air supply of long duration)	Filter smoke, wash out CO_2 or provide supply of gas, automatically	Filter dried out, air cylinder fails to work, failure of gas generator	Post-crash donning and egress	Deterioration of materials, loss of gas from cylinder, deterioration of chemicals	Function necessary for egress in smoke and fire
47-52	Emergency Illumination Systems	Provide emergency aisle, pathmarker, and exit illumination	Does not provide adequate level of illumination	Must function post-crash for emergency egress	Most components can be easily stored and handled	Must function post-crash in order for crew and passengers to egress

Item No. (See Table 7.)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
1,2, 3,4	Stored gas and augmented air inflation devices	Airbag inflation sources	No gas supplied	Must function before or during crash	Possible gas leakage. Pressure monitor necessary.	Function necessary for crash protection.
5,6, 7	Propellant and aspirator inflation devices	Airbag inflation sources	No gas supplied	Must function before or during crash	It is estimated that these devices can be stored and handled without reducing function	Function necessary for crash protection
8,9, 10,11	Crash impact sensors	Provide electrical signal to airbag inflation device	No signal provided	Must function before or during crash	All devices are prototypes. Insufficient field data is available	Device depends on well-defined signal defining imminence or occurrence of accident. This data is not available.
12,13 14,15	Airbag material	Contain inflation gas and serve as protective cushion	Material failure (tear or rip)	Must function before or during crash	Materials with adequate properties are available	Function necessary for crash protection
16-20	Airbag fabric coating materials	Reduce airbag porosity and heat transfer from inflation gasses	Coating material chosen which is subject to environmental degradation reducing function	Must function before or during crash	Materials with adequate properties are available	Not a reliability critical item

Item No. (See Table 7.)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
23	Airbag for passengers on near-facing seats using standard lap belts	Provide occupant crash protection	Does not inflate or improperly positioned	Must function during crash	Most components can be handled and stored easily with careful installation and maintenance. This is a Hazard Level II device	Not a reliability critical device. A rear-facing seat with lap belt provides protection without supplemental air bag
24	Airbag for passengers on side-facing seats	Provide occupant crash protection	Does not inflate or improperly positioned	Must function during crash	Most components can be handled and stored easily with careful installation and maintenance. This is a Hazard Level II device	Function necessary for crash protection. Because prototypes offering side impact protection are in the early developmental stage, the variables governing reliable air bag positioning have not yet been defined
25	Airbag for crew on front-facing seat	Provide occupant crash protection without reducing crew ability to function.	Does not inflate or improperly positioned	Must function during crash	Most components can be handled and stored easily with careful installation and maintenance. This is a hazard level II device	Function necessary for crash protection. Because of the necessity for crew function during and post-crash, the bag must be positioned very reliably. This is not possible wity current generation systems

HAZARD	AIRBAG INFLATION DEVICES							CRASH IMPACT SENSOR				AIRBAG MATERIAL				AIRBAG COATING MATERIAL							RESTRAINT SYSTEMS							
	1 stored gas	2 stored gas - mod. flow	3 augmented air	4 aug. air-staging	5 liq. cool - solid prop.	6 solid cool - solid prop.	7 aspirator	8 mechanical	9 inertial guidance	10. radar proximity	11 sonar proximity	12 nylon	13 polyester	14 glass	15 cotton	16 natural rubber	17 butyl	18 neoprene	19 P.V.C.	20 polyurethane	21 F.P.D.M.	22 hypalon	23 pass. IORS (rear face)	24 pass. IORS (side face)	25 crew IORS (front face)	26 rear face seat + l.b.	27 passive net	28 passive blanket	29 front face seat - A.F.H.	30 troop seat
a. Noise level	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1
b. Hazard level	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
c. Length of service	i	i	i	i	1	1	1	i	i	i	i	1	1	1	1	2	2	1	1	2	1	1	i	i	i	1	i	i	1	1
d. Flammability	1	1	1	1	i	i	i	1	1	1	1	2	2	1	3	3	3	1	1	2	3	1	1	1	1	1	i	i	1	1
e. Short term toxicity	1	1	2	2	2	2	2	1	1	1	1	i	i	1	i	i	i	1	1	i	i	1	1	1	1	1	1	1	1	1
f. Irritability	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
g. Thermal radiation	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
h. Isolate energy sources	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
i. Hazards of propellants	2	2	2	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
j. System environmental constraints	2	2	2	2	2	1	2	1	1	1	1	2	1	1	1	2	2	1	2	2	2	2	1	1	1	1	1	1	1	1
k. Use of explosive devices	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
l. Compatibility of materials	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m. Effect of electrical phenomena	2	2	2	2	2	2	2	1	2	2	2	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
n. Inadvertent actuation	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	3	3	3	1	3	3	1	1
o. Use of pressure vessels	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1
p. Crash safety	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
q. Safe operation and maintenance	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
r. Training for O and M	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	1	1
s. Egress, rescue, survival	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
t. Fire ignition and propagation	1	1	1	1	i	i	i	1	1	1	1	2	2	1	2	2	2	1	1	2	2	1	1	1	1	1	1	1	1	1
u. Shock resistance	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
v. Layout and lighting requirements	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
w. Fail-safe design	2	2	2	2	2	2	2	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	3	3	3	1	3	3	1	1
x. Vulnerability	i	i	i	i	1	1	1	i	i	i	i	1	1	1	1	2	2	1	1	2	1	1	i	1	i	1	i	i	1	1
y. Human error potential	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	3	4	4

N = not applicable
i = insufficient information

HAZARD	SMOKE HOOD CONCEPTS																AISLE AND PATH MARKERS									WARNING AND P.A.				OTHER TECHNOLOGY														
	31 Boeing mask	32 John Hand hood	33 Racine Glove Co.	34 Sierra Eng. Co.	35 LSS - Elastic seal	36 LSS - Lanyard	37 Scott-O-Vista	38 M.S.A.C. - canister	39 M.S.A.C. - self-rescue	40 N.A.R. fire hood	41 N.A.R. fire mask	42 Schjeldahl - drawstring	43 Schjeldahl - septal	44 FAA - air supply	45 B.M. - PBA hood	46 FAA Adv. concept	47 chemo-illum.	48 electro-illum.	49 ultra-violet	50 phosphorescent	51 incadescent	52 self-illum. (tritium)	53 tactile markers	54 floor level markers	55 pulsating markers	56 alarm bell	57 bull horn	58 solid-state device	59 TWA visual/aural	60 ELSIE	61 telescape	62 escape rope	63 ext. plat. - slide entry	64 S.B. - escape harness	65 fold. slide	66 cargo door	67 ablative coat. exit	68 pass. conveyor	69 slide/liferaft	70 double slide	71 in-flight/paracone	72 in-flight/rapidjet	73 in-flight/capsule	74 in-flight/parachute
a. Noise level	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1	i	1
b. Hazard level	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	2	4	4	4	4
c. Length of service	2	2	2	2	2	2	2	2	2	2	i	2	2	2	i	i	1	1	1	1	1	1	1	1	1	1	1	i	1	1	1	1	1	1	1	1	i	i	1	1	1	2	1	1
d. Flammability	i	i	i	i	i	i	i	i	i	i	i	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	2	1	1	1	1	2	2	2	2	2	2
e. Short term toxicity	i	i	i	i	i	i	i	i	i	i	1	2	2	1	1	1	2	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
f. Irritability	i	i	1	i	i	i	i	i	i	i	1	1	1	1	i	i	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	i	1	1	i	i	1	1	i	i	i	1
g. Thermal radiation	1	1	1	1	1	1	1	1	1	i	1	1	1	1	i	1	1	1	1	1	1	1	1	1	1	1	1	i	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
h. Isolate energy sources	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1	2	2	2	2	2	2	1	2	2	2	1	1	2	2	2	1	2	2	2	2	1	2	2	2	2	1	2	2
i. Hazards of propellants	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	1	2	3	2	1	1	1	2	2	3	1	3	3
j. System environmental constraints	i	i	i	i	i	i	i	2	2	i	2	1	1	1	i	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	i	i	1	1	i	1	1	i	i	i	i
k. Use of explosive devices	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	i	1	i	i
l. Compatibility of materials	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1
m. Effect of electrical phenomena	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	i	1	1	1	1	1	1
n. Inadvertent actuation	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	1	1	1	1	1	1	1	1	1	2	1	1	2	3	3	1	2	2	2	2	N	3	2	2	3	3	3	3
o. Use of pressure vessels	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	1	2	2	N	1	2	2	i	1	i	1
p. Crash safety	1	1	1	1	1	1	1	i	i	1	1	1	1	i	i	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	i	1	1	2	2	2	1	3	1	1	i	i	i	i
q. Safe operation and maintenance	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	2	1	i	i	1	1	i	1	1	2	2	2	2
r. Training for O and M	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	i	1	1	1	3	2	2	3	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2
s. Egress, rescue, survival	i	i	i	i	i	i	i	i	i	i	1	1	1	1	i	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1	1	1	i	1	1	3	3	3	1
t. Fire ignition and propagation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1	1	2	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	i	1	1	i	i	i	i
u. Shock resistance	1	1	1	1	1	1	1	i	i	1	1	1	1	i	i	1	1	1	1	1	1	1	1	1	1	1	2	i	1	1	2	1	1	i	2	2	1	2	1	1	i	i	i	i
v. Layout and lighting	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
w. Fail-safe design	3	1	1	1	1	1	1	3	3	1	1	1	1	1	i	3	2	2	2	2	2	2	1	2	2	1	1	2	1	3	3	1	2	3	3	2	1	3	2	2	3	3	3	3
x. Vulnerability	2	i	i	i	i	i	i	2	2	i	2	i	i	2	2	i	2	2	1	1	2	1	2	1	1	1	2	2	1	1	2	2	2	2	2	2	1	i	2	2	2	2	2	2
y. Human error potential	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	i	1	1	1	1	1	1	4	1	1	6	6	6	6	6	6	6	5	3	3	6	1	3	5	5	6	4	6	6

N = not applicable
i = insufficient information

TABLE XV PRELIMINARY HAZARD ANALYSIS RATING SYSTEM

a. Noise level
   1. No problem
   2. Possible temporary threshold shift
   3. Possible permanent hearing impairment

b. Hazard level
   1. Negligible
   2. Controllable hazard (marginal)
   3. Will cause injury without immediate action (critical)
   4. Failure will cause injury (catastrophic)

c. Length of service
   1. Estimated five year life based on manufacturer's data.
   2. Less than 5 years

d. Flammability
   1. Low
   2. Medium
   3. High

e. Short term toxicity
   1. None
   2. Moderate (could be dangerous in combination with other toxic gases)
   3. Dangerous (qualitative estimate)

f. Irritability
   1. None
   2. Moderate
   3. Disablizing

g. Thermal radiation
   1. None
   2. Moderate
   3. Disablizing

h. Isolate energy sources
   1. None present
   2. Necessary

i. Hazards of propellants
   1. None present
   2. Designed for safe handling
   3. Prototype systems for which data has not yet been developed.

j. System environmental constraints
   1. Operates the same under all required conditions of temperatures, pressure, and humidity
   2. Performance varies with temperature, pressure and/or humidity

k. Use of explosive devices
   1. None present
   2. Hazard level II when installed

l. Compatibility of materials
   1. No problems known
   2. Possible problem

m. Effect of electrical phenomena (current, electrostatic charge, or electromagnetic fields)
   1. No problems known
   2. Hazard level II, III, or IV

n. Inadvertent activation
   1. No problems known
   2. Research accomplished to solve problems
   3. Research Needed

o. Use of pressure vessels
   1. None present
   2. Necessary component (Hazard level II)

p. Crash safety
   1. Operable after and during survivable crash
   2. Marginal operation after or during survivable crash
   3. Not operable after or during survivable crash

q. Safe operation and maintenance

1. No problems known
2. Hazard level II (at least) at all times during operation and maintenance

r. Training for operation and maintenance

1. None required
2. Special training required for proper use

s. Egress, rescue, survival

1. Enhanced with use of system
2. Unaffected by use of system
3. Hazardous with use of system

t. Fire ignition and propagation sources

1. None present
2. Possible source present

u. Shock resistance

1. Designed for operation in shock environment
2. Susceptible to shock damage

v. Layout and lighting requirements

1. No special requirements
2. Special lighting and/or layout required for use

w. Fail-safe design

1. Not needed
2. Required and data available for design purposes
3. Required and data needed

x. Vulnerability

1. Invulnerable
2. Vulnerable to tampering and/or prolonged storage

y. Human error potential

1. Automotive device, no training needed
2. Manual device, no training needed
3. Automatic device, briefing required
4. Manual device, briefing required
5. Automatic device, briefing and training required
6. Manual device, briefing and training required

TABLE XIX. HUMAN FACTORS RATING SYSTEM

a. Noise

1. No problem
2. Possible temporary threshold shift
3. Possible permanent hearing impairment

b. Visibility

1. No decrement when using system
2. Partial decrement when using system
3. No visibility when using system

c. Ability to hear

1. No decrement when using system
2. Partial decrement when using system
3. No hearing when using system

d. Ease of use

1. No experience or briefing necessary
2. Briefing necessary before use
3. Briefing and training necessary before use

e. Human tolerance to impact

1. No injuries with proper system use
2. Possible injuries even with proper system use

f. Possible thermal hazard

1. No
2. Yes

g. Possible toxicological hazard

1. No
2. Yes

h. Possible pyrotechnic hazard

1. No
2. Yes

i. Possible visual hazard

1. no
2. yes

j. Space to carry out functions

1. No restriction on user mobility or function based on crash impact protection and emergency egress flowchart
2. Possible partial restriction on passenger/crew egress or crew function in operating aircraft
3. System use precludes other activity

k. Illumination

1. Needed for system use
2. Not needed for system use

l. Normal ingress and egress

1. Unaffected by system
2. Requires user action to activate system

m. Non-restrictive life support and protective equipment

1. Mobility and/or communication enhanced by use of system
2. Mobility and/or communication unaffected by use of system
3. Mobility and/or communication reduced by use of system

n. Psychophysiological stress

1. No increased psychophysiological stress associated with system use
2. Minor psychophysiological stress associated with system use
3. Potential inability to function

o. Fail-safe design

1. Yes
2. No

p. Simplicity

1. No movable parts
2. Moving mechanical parts
3. Complex electro-mechanical device
4. Complex electro-mechanical device with associated electronic circuitry.

q. Anthropometric considerations

1. Minor design consideration
2. Major design consideration (system function strongly dependent on anthropometric variables)

APPENDIX F

The following is a list of manufacturers of the various aisle and emergency egress illumination systems discussed in Section 5.

CHEMO-ILLUMINESCENCE

American Cyanamid Company
Organic Chemicals Division
Bound Brook, New Jersey 08305

Remington Arms Company
939 Barnum Avenue
Bridgeport, Connecticut 06602

ELECTRO ILLUMINESCENCE

Grimes Manufacturing Company
515 N. Russell Street
Urbana, Ohio 43078

Honeywell, Inc.
Honeywell Plaza
Minneapolis, Minnesota 55408

MLM Electronics
130. E. River Drive
Willingboro, New Jersey 08046

Plumly Industries
Ft. Worth, Texas

Scott Aviation
Division of A.T.O., Inc.
225 Erie Street
Lancaster, New York 14086

Soderberg Manufacturing Company, Inc.
628 S. Palm Avenue
Alhambra, California 91803

Sylvania Products, Inc.
60 Boston Street
Salem, Massachusetts 01970

GASEOUS DISCHARGE SYSTEMS

A.C.R. Electronics, Inc.
112 Voice Road
Carle Place
New York, New York 11514

Birns and Sawyer, Inc.
1026 N. Highland Avenue
Los Angeles, California 90038

Electronic Lights, Inc.
Division of Kemlite Lab., Inc.
1701 N. Ashland Avenue
Chicago, Illinois 60622

Illumination Industries, Inc.
610 Vaqueros Avenue
Sunnyvale, California 94086

Kemlite Laboratories, Inc.
1819 W. Grand Avenue
Chicago, Illinois 60622

LTV Electro Systems, Inc.
P.O. Box 6030
Dallas, Texas 75222

Life Support Technology, Inc.
4820 S.W. Lloyd Avenue
Beaverton, Oregon 97005

MLM Electronics
130 E. River Drive
Willingboro, New Jersey 08046

Pichel Industries, Inc.
Division of Optics
693 S. Raymond Avenue
Pasadena, California 91105

Soderberg Manufacturing Company, Inc.
628 S. Palm Avenue
Alhambra, California 91803

Whelen Engineering Company
3 Winter Avenue
Deep River, Connecticut 06417

Zip Com Corporation
5620 West 12th Street
Littlerock, Arkansas 72204

ULTRAVIOLET PATHWAY MARKERS

Luminex, Inc.
P.O. Box 696
Santa Barbara, California 93102

SELF-LUMINOUS SOURCES (TRITIUM) AND PHOSPHORESCENT MARKERS

Conrad Precision
630 5th Avenue
New York, New York

U.S. Radium Corporation
Morristown, New Jersey 07960

INCANDESCENT SOURCES

Chicago Miniature Lamp Works
4453 North Ravenwood
Chicago, Illinois

General Electric
Nela Park
Cleveland, Ohio 44122

Grimes Manufacturing Company
515 North Russell Street
Urbana, Ohio 43078

Life Support Technology, Inc.
4820 S.W. Lloyd Avenue
Beaverton, Oregon 97005

LTV Electro Systems, Inc.
P.O. Box 6030
Dallas, Texas 75222

Pichel Industries, Inc.
693 S. Raymond Avenue
Pasadena, California 91105

Pile National Company
1334 N. Kostner Avenue
Chicago, Illinois 60651

Scott Aviation
Division of A.T.O., Inc.
225 Erie Street
Lancaster, New York 14086

Soderberg Manufacturing Company, Inc.
628 S. Palm Avenue
Alhambra, California 91803

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AG-221	ISBN 92-835-1218-9	UNCLASSIFIED

5. Originator	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organization 7 rue Ancelle, 92200 Neuilly sur Seine, France
6. Title	ADVANCED TECHNIQUES IN CRASH IMPACT PROTECTION AND EMERGENCY EGRESS FROM AIR TRANSPORT AIRCRAFT
7. Presented at	

8. Author(s)	9. Date
Richard G. Snyder	June 1976

10. Author's Address	11. Pages
The University of Michigan Ann Arbor, Michigan 48105 U.S.A.	320

12. Distribution Statement	This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors		14. UDC
Passenger aircraft	Aircraft fires	629.7.047:656.7.08
Transport aircraft	Escape systems	
Aviation safety	Crash landing	
Aviation accidents	Safety engineering	

15. Abstract

Analysis of all NATO member air transport accidents, 1964–1975, revealed that injuries and fatalities, when such information could be determined, were primarily due to the post-crash effects of fire, smoke and toxic fumes, and secondarily to crash impact. Future air transport design trends were reviewed, and approximately 150 advanced crash-impact and emergency-egress concepts, devices, and state-of-the-art techniques were evaluated. It was concluded that rear-facing passenger seats, the NASA Ames ($21+G_x$ $45+G_z$) airline seat, and the production Sheldahl smoke hood can provide significantly improved occupant protection, while high-energy emergency egress systems appear promising for future aircraft.

This AGARDograph was prepared at the request of the Aerospace Medical Panel of AGARD/NATO.

AGARDograph No.221
Advisory Group for Aerospace Research and Development, NATO
ADVANCED TECHNIQUES IN CRASH IMPACT PROTECTION AND EMERGENCY EGRESS FROM AIR TRANSPORT AIRCRAFT
Published June 1976
320 pages

Analysis of all NATO member air transport accidents, 1964–1975, revealed that injuries and fatalities, when such information could be determined, were primarily due to the post-crash effects of fire, smoke and toxic fumes, and secondarily to crash impact. Future air transport design trends were reviewed, and approximately 150 advanced crash-impact and emergency-

P.T.O.

AGARD-AG-221
629.7.047:656.7.08

Passenger aircraft
Transport aircraft
Aviation safety
Aviation accidents
Aircraft fires
Escape systems
Crash landing
Safety engineering

AGARDograph No.221
Advisory Group for Aerospace Research and Development, NATO
ADVANCED TECHNIQUES IN CRASH IMPACT PROTECTION AND EMERGENCY EGRESS FROM AIR TRANSPORT AIRCRAFT
Published June 1976
320 pages

Analysis of all NATO member air transport accidents, 1964–1975, revealed that injuries and fatalities, when such information could be determined, were primarily due to the post-crash effects of fire, smoke and toxic fumes, and secondarily to crash impact. Future air transport design trends were reviewed, and approximately 150 advanced crash-impact and emergency-

P.T.O.

AGARD-AG-221
629.7.047:656.7.08

Passenger aircraft
Transport aircraft
Aviation safety
Aviation accidents
Aircraft fires
Escape systems
Crash landing
Safety engineering

AGARDograph No.221
Advisory Group for Aerospace Research and Development, NATO
ADVANCED TECHNIQUES IN CRASH IMPACT PROTECTION AND EMERGENCY EGRESS FROM AIR TRANSPORT AIRCRAFT
Published June 1976
320 pages

Analysis of all NATO member air transport accidents, 1964–1975, revealed that injuries and fatalities, when such information could be determined, were primarily due to the post-crash effects of fire, smoke and toxic fumes, and secondarily to crash impact. Future air transport design trends were reviewed, and approximately 150 advanced crash-impact and emergency-

P.T.O.

AGARD-AG-221
629.6.047:656.7.08

Passenger aircraft
Transport aircraft
Aviation safety
Aviation accidents
Aircraft fires
Escape systems
Crash landing
Safety engineering

AGARDograph No.221
Advisory Group for Aerospace Research and Development, NATO
ADVANCED TECHNIQUES IN CRASH IMPACT PROTECTION AND EMERGENCY EGRESS FROM AIR TRANSPORT AIRCRAFT
Published June 1976
320 pages

Analysis of all NATO member air transport accidents, 1964–1975, revealed that injuries and fatalities, when such information could be determined, were primarily due to the post-crash effects of fire, smoke and toxic fumes, and secondarily to crash impact. Future air transport design trends were reviewed, and approximately 150 advanced crash-impact and emergency-

P.T.O.

AGARD-AG-221
629.7.047:656.7.08

Passenger aircraft
Transport aircraft
Aviation safety
Aviation accidents
Aircraft fires
Escape systems
Crash landing
Safety engineering

egress concepts, devices, and state-of-the-art techniques were evaluated. It was concluded that rear-facing passenger seats, the NASA Ames ($21+G_x$ $45+G_z$) airline seat, and the production Sheldahl smoke hood can provide significantly improved occupant protection, while high-energy emergency egress systems appear promising for future aircraft.

This AGARDograph was prepared at the request of the Aerospace Medical Panel of AGARD/NATO.

ISBN 92-835-1218-9

egress concepts, devices, and state-of-the-art techniques were evaluated. It was concluded that rear-facing passenger seats, the NASA Ames ($21+G_x$ $45+G_z$) airline seat, and the production Sheldahl smoke hood can provide significantly improved occupant protection, while high-energy emergency egress systems appear promising for future aircraft.

This AGARDograph was prepared at the request of the Aerospace Medical Panel of AGARD/NATO.

ISBN 92-835-1218-9

egress concepts, devices, and state-of-the-art techniques were evaluated. It was concluded that rear-facing passenger seats, the NASA Ames ($21+G_x$ $45+G_z$) airline seat, and the production Sheldahl smoke hood can provide significantly improved occupant protection, while high-energy emergency egress systems appear promising for future aircraft.

This AGARDograph was prepared at the request of the Aerospace Medical Panel of AGARD/NATO.

ISBN 92-835-1218-9

egress concepts, devices, and state-of-the-art techniques were evaluated. It was concluded that rear-facing passenger seats, the NASA Ames ($21+G_x$ $45+G_z$) airline seat, and the production Sheldahl smoke hood can provide significantly improved occupant protection, while high-energy emergency egress systems appear promising for future aircraft.

This AGARDograph was prepared at the request of the Aerospace Medical Panel of AGARD/NATO.

ISBN 92-835-1218-9

AGARD

NATO OTAN

7 RUE ANCELLE · 92200 NEUILLY-SUR-SEINE

FRANCE

Telephone 745.08.10 · Telex 610176

DISTRIBUTION OF UNCLASSIFIED AGARD PUBLICATIONS

AGARD does NOT hold stocks of AGARD publications at the above address for general distribution. Initial distribution of AGARD publications is made to AGARD Member Nations through the following National Distribution Centres. Further copies are sometimes available from these Centres, but if not may be purchased in Microfiche or Photocopy form from the Purchase Agencies listed below.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Coordonnateur AGARD – VSL
Etat-Major de la Force Aérienne
Caserne Prince Baudouin
Place Dailly, 1030 Bruxelles

CANADA
Defence Scientific Information Service
Department of National Defence
Ottawa, Ontario K1A OZ2

DENMARK
Danish Defence Research Board
Østerbrogades Kaserne
Copenhagen Ø

FRANCE
O.N.E.R.A. (Direction)
29 Avenue de la Division Leclerc
92 Châtillon sous Bagneux

GERMANY
Zentralstelle für Luft- und Raumfahrtdokumentation und -information
D-8 München 86
Postfach 860880

GREECE
Hellenic Armed Forces Command
D Branch, Athens

ICELAND
Director of Aviation
c/o Flugrad
Reykjavik

ITALY
Aeronautica Militare
Ufficio del Delegato Nazionale all'AGARD
3, Piazzale Adenauer
Roma/EUR

LUXEMBOURG
See Belgium

NETHERLANDS
Netherlands Delegation to AGARD
National Aerospace Laboratory, NLR
P.O. Box 126
Delft

NORWAY
Norwegian Defence Research Establishment
Main Library
P.O. Box 25
N-2007 Kjeller

PORTUGAL
Direccao do Servico de Material
da Forca Aerea
Rua de Escola Politecnica 42
Lisboa
Attn: AGARD National Delegate

TURKEY
Department of Research and Development (ARGE)
Ministry of National Defence, Ankara

UNITED KINGDOM
Defence Research Information Centre
Station Square House
St. Mary Cray
Orpington, Kent BR5 3RE

UNITED STATES
National Aeronautics and Space Administration (NASA),
Langley Field, Virginia 23365
Attn: Report Distribution and Storage Unit

THE UNITED STATES NATIONAL DISTRIBUTION CENTRE (NASA) DOES NOT HOLD STOCKS OF AGARD PUBLICATIONS, AND APPLICATIONS FOR COPIES SHOULD BE MADE DIRECT TO THE NATIONAL TECHNICAL INFORMATION SERVICE (NTIS) AT THE ADDRESS BELOW.

PURCHASE AGENCIES

Microfiche or Photocopy
National Technical
Information Service (NTIS)
5285 Port Royal Road
Springfield
Virginia 22151, USA

Microfiche
Space Documentation Service
European Space Agency
114, Avenue Charles de Gaulle
92200 Neuilly sur Seine, France

Microfiche
Technology Reports
Centre (DTI)
Station Square House
St. Mary Cray
Orpington, Kent BR5 3RF
England

Requests for microfiche or photocopies of AGARD documents should include the AGARD serial number, title, author or editor, and publication date. Requests to NTIS should include the NASA accession report number. Full bibliographical references and abstracts of AGARD publications are given in the following journals:

Scientific and Technical Aerospace Reports (STAR),
published by NASA Scientific and Technical
Information Facility
Post Office Box 8757
Baltimore/Washington International Airport
Maryland 21240, USA

Government Reports Announcements (GRA),
published by the National Technical
Information Services, Springfield
Virginia 22151, USA

Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London W1P 1HD

ISBN 92-835-1218-9

AGARD

NATO OTAN

7 RUE ANCELLE · 92200 NEUILLY-SUR-SEINE

FRANCE

Telephone 745.08.10 · Telex 610176

DISTRIBUTION OF UNCLASSIFIED AGARD PUBLICATIONS

AGARD does NOT hold stocks of AGARD publications at the above address for general distribution. Initial distribution of AGARD publications is made to AGARD Member Nations through the following National Distribution Centres. Further copies are sometimes available from these Centres, but if not may be purchased in Microfiche or Photocopy form from the Purchase Agencies listed below.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Coordonnateur AGARD – VSL
Etat-Major de la Force Aérienne
Caserne Prince Baudouin
Place Dailly, 1030 Bruxelles

CANADA
Defence Scientific Information Service
Department of National Defence
Ottawa, Ontario K1A OZ2

DENMARK
Danish Defence Research Board
Østerbrogades Kaserne
Copenhagen Ø

FRANCE
O.N.E.R.A. (Direction)
29 Avenue de la Division Leclerc
92 Châtillon sous Bagneux

GERMANY
Zentralstelle für Luft- und Raumfahrtdokumentation und -information
D-8 München 86
Postfach 860880

GREECE
Hellenic Armed Forces Command
D Branch, Athens

ICELAND
Director of Aviation
c/o Flugrad
Reykjavik

ITALY
Aeronautica Militare
Ufficio del Delegato Nazionale all'AGARD
3, Piazzale Adenauer
Roma/EUR

LUXEMBOURG
See Belgium

NETHERLANDS
Netherlands Delegation to AGARD
National Aerospace Laboratory, NLR
P.O. Box 126
Delft

NORWAY
Norwegian Defence Research Establishment
Main Library
P.O. Box 25
N-2007 Kjeller ,

PORTUGAL
Direccao do Servico de Material
da Forca Aerea
Rua de Escola Politecnica 42
Lisboa
Attn: AGARD National Delegate

TURKEY
Department of Research and Development (ARGE)
Ministry of National Defence, Ankara

UNITED KINGDOM
Defence Research Information Centre
Station Square House
St. Mary Cray
Orpington, Kent BR5 3RE

UNITED STATES
National Aeronautics and Space Administration (NASA),
Langley Field, Virginia 23365
Attn: Report Distribution and Storage Unit

THE UNITED STATES NATIONAL DISTRIBUTION CENTRE (NASA) DOES NOT HOLD STOCKS OF AGARD PUBLICATIONS, AND APPLICATIONS FOR COPIES SHOULD BE MADE DIRECT TO THE NATIONAL TECHNICAL INFORMATION SERVICE (NTIS) AT THE ADDRESS BELOW.

PURCHASE AGENCIES

Microfiche or Photocopy
National Technical
Information Service (NTIS)
5285 Port Royal Road
Springfield
Virginia 22151, USA

Microfiche
Space Documentation Service
European Space Agency
114, Avenue Charles de Gaulle
92200 Neuilly sur Seine, France

Microfiche
Technology Reports
Centre (DTI)
Station Square House
St. Mary Cray
Orpington, Kent BR5 3RF
England

Requests for microfiche or photocopies of AGARD documents should include the AGARD serial number, title, author or editor, and publication date. Requests to NTIS should include the NASA accession report number. Full bibliographical references and abstracts of AGARD publications are given in the following journals:

Scientific and Technical Aerospace Reports (STAR),
published by NASA Scientific and Technical
Information Facility
Post Office Box 8757
Baltimore/Washington International Airport
Maryland 21240, USA

Government Reports Announcements (GRA),
published by the National Technical
Information Services, Springfield
Virginia 22151, USA

Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London W1P 1HD

ISBN 92-835-1218-9