Technical Memorandum

CRASH POSITION INDICATOR/CRASH SURVIVABLE FLIGHT DATA RECORDER EJECTABLE VERSUS NONEJECTABLE

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27 July 1983

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NAVAL AIR TEST CENTER
PATUXENT RIVER, MARYLAND

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TM 83-1 SY	2. GOVT ACCESSION NO.: AD-A132329
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): CRASH POSITION INDICATOR/CRASH SURVIVABLE FLIGHT DATA RECORDER EJECTABLE VERSUS NONEJECTABLE	5. TYPE OF REPORT & PERIOD COVERED: TECHNICAL MEMORANDUM
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): DANIEL M. WATTERS	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: NAVAL AIR TEST CENTER, SYSTEMS ENGINEERING TEST DIRECTORATE, PATUXENT RIVER, MARYLAND 20670	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: NAVAL AIR TEST CENTER, NAVAL AIR STATION, PATUXENT RIVER, MARYLAND 20670	12. REPORT DATE: 27 JULY 1983
	13. NUMBER OF PAGES: 28
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

AIRCRAFT EJECTABLE AND NONEJECTABLE
CRASH POSITION INDICATOR (LOCATOR)
EMERGENCY LOCATOR BEACON
UNDERWATER LOCATOR BEACONS
CRASH SURVIVABLE FLIGHT DATA RECORDERS AND COCKPIT VOICE RECORDERS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

All U.S. military and air carrier aircraft are required to have on board Crash Position Indicator/Crash Survivable Flight Data Recorder/Crash Survivable Cockpit Voice Recorder (CPI/CSFDR/CSCVR) systems. All air carrier aircraft use nonejectable CPI/CSFDR/CSCVR systems. U.S. and Canadian military aircraft use both ejectable and nonejectable CPI/CSFDR/CSCVR systems. Ejectable systems are used on Navy, Marine Corps, and Coast Guard aircraft, primarily because of their overwater mission. Ejectable systems are more complex than nonejectable systems. The reliability, maintainability, and

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survivability record for both ejectable and nonejectable systems ranges from poor to excellent depending on system design, configuration, and testing. The Search and Rescue (SAR) record for ejectable systems is excellent while the SAR record for nonejectable systems has been relatively poor. The weight, volume, and power requirements for ejectable systems are generally less than for nonejectable systems. The System Safety of all systems is excellent except for the Mortar type (personal hazard if inadvertently ejected on the ground). The acquisition cost of ejectable systems are generally greater than for nonejectable systems. Ejectable CPI/CSFDR/CSCVR systems should be used on aircraft that operate over water. All other aircraft could use either ejectable or nonejectable systems.

PREFACE

The United States and foreign military air forces and air carriers use both ejectable and nonejectable type Crash Position Indicator/Crash Survivable Flight Data Recorder/Crash Survivable Cockpit Voice Recorder (CPI/CSFDR/CSCVR) systems on their aircraft. There has been considerable controversy concerning the relative merits of ejectable and nonejectable systems and in which aircraft each type should be used. These trade-off decisions are critical to the development, test, and evaluation (DT&E) process of new systems. This paper attempts to assess the technical design, operational cost, and crash survivability trade-off merits of both ejectable and nonejectable CPI/CSFDR/CSCVR systems. The conclusions are supported by the data contained herein, in the referenced documents, and by operational DT&E data supplied by individuals familiar with the systems.

APPROVED FOR RELEASE

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1. All U.S. military and air carrier aircraft are required to have on board Crash Position Indicator/Crash Survivable Flight Data Recorder/Crash Survivable Cockpit Voice Recorder (CPI/CSFDR/CSCVR) systems. This requirement is implemented in all large air carrier aircraft operating under U.S. Code of Federal Regulations, Title 14, Aeronautics and Space, Part 121. The requirement is only partially implemented on smaller air carrier and general aviation aircraft and on military aircraft. Only some military aircraft, primarily fixed wing multiengine, are equipped with CPI/CSFDR/CSCVR systems. Tables I and II list all known operational ejectable and nonejectable CPI systems. Tables III and IV list all known operational ejectable and nonejectable CSFDR/CSCVR systems for commercial and military aircraft, respectively.

Table I

EJECTABLE CPI SYSTEMS
MILITARY AND AIR CARRIER AIRCRAFT
ROTARY AND FIXED WING

Leigh Instruments Model Number	Military Nomenclature	Description	Battery	Frequency (MHz)	Aircraft Type(s)
BAU-4A	AN/URT-26(V)4	Surface Mtd. Airfoil	Ni-Cad	243	C-124, PBY
BAU-5		Doughnut	Ni-Cad	243	Bell 47
BAU-6		Surface Mtd. Airfoil	Ni-Cad	243	DHC-2 (UK)
BAU-9		Surface Mtd. Airfoil	Ni-Cad	243	DC-3, DHC-2, etc.
BAU-10		Surface Mtd. Airfoil	Ni-Cad	243, 121.5	DHC-6 (Peru)
BAU-12	AN/URT-506	Doughnut	Lithium	243	CH-113, CH-118, CH-47, CH-124, (G.P. Helo)
BAU-13		Doughnut	Lithium	243, 121.5	G.P. Helicopter
BAU-14		Surface Mtd. Airfoil	Lithium	243, 121.5	G.P. Fixed Wing
BAU-15	AN/URT-507	Surface Mtd. Airfoil	Lithium	243	CC-138, G.P.
BAU-16		Surface Mtd. Airfoil	Lithium	121.5	G.P. Fixed Wing
BAU-17		Doughnut	Lithium	121.5	G.P. Helicopter
BAU-18		Surface Mtd. Airfoil	Lithium	121.5	DHC-6
RBA-2	AN/USH-501	Airfoil	Ni-Cad	243	CC-106
RBA-6A, 36	AN/URT-26(V), 8	Airfoil	Ni-Cad	243	C-130A/B/D/E/H
RBA-7/A/B	AN/URT-26(V)3, 9	Airfoil	Ni-Cad	243	C-141
RBA-9C		Airfoil	Ni-Cad	243	F-104G
RBA-10	AN/URT-26(V)10	Airfoil	Ni-Cad	243	C-135, VC-137 (B-70)
RBA-15A, B	AN/URT-26(V)11	Airfoil	Ni-Cad	243	P-3A/B/C, C-2, E-2
RBA-17	AN/URT-26(V)18	Airfoil	Ni-Cad	243	T-43 (B737)
RBA-18	AN/URT-26(V)12	Airfoil	Ni-Cad	243	C9A (DC9)
RBA-19A-G	AN/URT-26(V)13	Airfoil	Ni-Cad	243	C5A
RBA-20	AN/URT-26(V)14	Airfoil	Ni-Cad	243	CC-130
RBA-21	AN/URT-26(V)16	Airfoil	Ni-Cad	243	CC-117
RBA-22	AN/URT-26(V)15	Airfoil	Ni-Cad	243	CC-115
RBA-[illegible]		Airfoil	Lithium	121.5	DHC-5 (Peru)
RBA-24	AN/URT-26(V)19	Airfoil	Lithium	243	E3A
RBA-35		Airfoil	Lithium	243	TA-501
RBA-36	AN/URT-26(V)2, 8	Airfoil	Ni-Cad	243	C-130A/B/D/E
RBA-38B		Airfoil	Lithium	243.5	MRCA
RBA-39		Airfoil	Lithium	121.5, 243	B-707 (Egypt)
RBA-40	AN/URT-26(V)20	Airfoil	Lithium	243	CC-137
RBA-41	AN/URT-26(V)21	Airfoil	Ni-Cad	243	CP-140
RBA-42		Airfoil	Ni-Cad	121.5, 243	Falcon
Collins Radio	AN/ASH-31(V)	Mortar	Lithium	121.5, 243	B-1

Table II

NONEJECTABLE CPI SYSTEMS
MILITARY AND AIR CARRIER AIRCRAFT
ROTARY AND FIXED WING

Manufacturer	Model	Description	Battery	Switch
Emergency Beacon Corp. 15 River Street New Rochelle, NY 10801	EBC-102A EBC-202B EBC-302V EBC-302 EBC-302VR	Metal case, potted components integral whip antenna mounting bracket, drop in. Claims 1,000 g shock.	Alk Alk Alk Alk Alk	Mechanical, external mass Oil damped pendulum
Garrett Mfg. Ltd. 255 Atwell Drive Rexdale, Ontario (Not in production)	RESCU 88 RESCU 88L RESCU 77 RESCU 99 DAL	Available in horizontal and vertical mounting. Two piece mounting clips. Vertical fin with antenna on each side.	Mag/Ni-Cad Li Li Ni-Cad	Aerodyne, three versions
Larago Electronics Mfg. Ltd. 3120 44th Ave. N. St. Petersburg, Fl 33714		Factory mount with latching side, exterior antenna or telescoping.	Alk/Mag	
Deft Laboratories 7 Adler Drive Syracuse, NY 13206	Sharc 7 Cessna ELT	Rectangular plastic case provided with Velcro attach kit long axis mounts vertical or horizontal.	Li	Magnet and Ball Inertia Switch, Inc.
Life Support Technology	Albie I Albie II Albie III		Alk Merc	10 g switch
Merl, Inc.		Same as Larago.		
Micro Electronics 911 Commercial Ave. Anacortes, WA 98221	Life-Pak 1800	Steel case, encapsulated, whip antenna, quick disconnect mounting bracket.	Li/Alk	Magnet switch with exterior magnet
Narco Avionics Commerce Drive Fort Washington, PA 19034	ELT-10 ELT-10C	Lexan case, factory mount with metal strap over unit exterior or portable antenna.	Alk Li	Technar Rolamite
Pathfinder Corp. 4518 Taylorsville Rd. Dayton, OH 45424 (Not in production)	2052-AF		Li	
Pacific Avionics	ELT-1	Fixed antenna.	Alk	Mechanical, exterior mass
Piper Aircraft Lock Haven, PA 17745	Locator	Same as Garrett.		
Pointer, Inc. 1445 W. Alameda Dr. Tampe, AZ 85282	Pointer II Model 3000 Model 3000A Model 2000 Model C4000	Sealed tube, mounts inside skin with attached antenna outside. Lexan box with factory mount exterior or portable antenna.	Merc/Li Mag Li Mag	Technar Rolamite
Radair Box 13018 Fort Worth, TX 76118 (Not in production)	Dart I Dart II			
Specter Systems	Auto Set			

Table III

CRASH SURVIVAL FLIGHT DATA RECORDERS AND COCKPIT VOICE RECORDERS FOR AIR CARRIER AIRCRAFT

Manufacturer	Model Number	Recording Type	Ejectable	Storage Media	Record Time	Aircraft used on[1]
Fairchild	A100 A100A	Voice Voice	No No	Mag. Tape Mag. Tape	30 min 30 min	All commercial transports worldwide plus corporate and many commuter aircraft
	500 600 700	Data	No	Metal Foil	300-400 hr 600-800 hr	ACT certified prior to September 1969 plus many corporate and commuter aircraft
	F800	Data	No	Mag. Tape	25 hr	ACT certified prior to and after September 1969 plus corporate and commuter aircraft
	F1000	Voice/Data	No	Mag. Tape	30 min Voice 30 min Data + 8 hr Data (excerpted)	Proposed CVDR for use on corporate and commuter aircraft
Lockheed	109	Data	No	Metal Foil	300 hr	ACT certified prior to September 1969
	209	Data	No	Mag. Tape	25 hr	ACT certified after September 1969
	319	Data	No	Mag. Tape	25 hr	Several commuter aircraft (combines recorder with flight data acquisition unit in one package)
Sunstrand	AV557A/B/C	Voice	No	Mag. Tape	30 min	Commercial air transports worldwide
	F542	Data	No	Metal Foil	300-400 hr 600-800 hr	ACT certified prior to September 1969
	573A	Data	No	Mag. Tape	25 hr	ACT certified after September 1969
	UFDR	Data	No	Mag. Tape	25 hr	ACT certified prior to and after September 1969 plus corporate and commuter aircraft
Leigh	Leads 300	Data and Data/Voice	No	Mag. Tape	15 hr	Several Canadian airlines aircraft certified prior to September 1969

NOTE: (1) Recorders (Flight Data) on aircraft certified prior to September 1969 were required to have five parameters (ARINC 542). Those certified after September 1969 are required to have 24 or more parameters (ARINC 573). Some Digital Recorders are also applicable to both ARINC 542 and ARINC 573 applications. Corporate aircraft are not presently required to have any recorders unless operated under FAR Part 121 but many are installed either by the factory (such as Gulfstream American, Learjet, Falcon, etc.) either as standard equipment or as customer option. Commuter turbojet aircraft operating under FAR Part 135 and carrying 10 or more passengers are required to be equipped with CVR's and may be equipped with FDR's; however, governmental requirements worldwide differ in this respect.

Table IV

CRASH SURVIVABLE FLIGHT DATA RECORDERS AND COCKPIT VOICE RECORDERS FOR MILITARY AIRCRAFT

Manufacturer	Military Number (Model No.)	Recording Type	Ejectable	Storage Media	Record Time	Integral CPI	Aircraft used on
Collins Radio	AN/ASH-31(V)	Voice/Data	Yes	Mag. Tape	30 min	Yes	B-1
Hamilton, Std.	AIRS	Data	No	BORAM/MNOS	30 min	No	U.S. Army prototype
Lear Siegler	(CSFDR 3246A)	Voice/Data	No	EEPROM	30 min	No	U.S. Air Force prototype
Leigh Inst.	AN/ASH-20(V) (RTC-6A)	Voice/Data	Yes	Mag. Tape	30 min	Yes	C-2A, E-3A, KC-130R, P-3A/B, E-2B
	AN/USH-501 (VEU-1)	Data	No	Mag. Tape	5.3 hr	No	CF-5
	AN/USH-502(V) (RTC-6A/F)	Voice/Data	Yes	Mag. Tape	30 min	Yes	CC-130, CC-115, CC-117, CC-137, CP-140
	EU-803C						
	(CVR-2)	Voice	No	Mag. Tape	30 min	No	MRCA
	(RTC-9H)	Voice/Data	Yes	Mag. Tape	1 hr	Yes	MRCA
	Leads 200						
	(RTC-9E/H)	Voice/Data	Yes	Mag. Tape	1 hr	Yes	F-104G, TA-501, Alpha Jet
	(RTD-3A/J)	Voice/Data	No	Mag. Tape	1 hr	No	F-104G, C-5F
	(RTC-40)	Voice/Data	Yes	Mag. Tape	Variable	Yes	Prototype
	(SSR)	Voice/Data	Yes	Bubble or BORAM/MNOS	Variable	Yes	Prototype
Lockheed	(LAS)	Voice/Data	Yes	Mag. Tape	30 min	Yes	C-5A
	(209)	Data	No	Mag. Tape	25 hr	No	C-130, C-141, SH-60B (test aircraft only)
Sperry-Gyro	(SCR300)	Voice/Data	No	Mag. Tape	90 min	No	F-4, Hawk, Tornado, Lynx, Sea King
Sperry-Univac	(SSFIR)	Voice/Data	No	BORAM/MNOS	30 min	Yes	U.S. Navy Prototype

EJECTABLE SYSTEMS

2. Ejectable CPI/CSFDR/CSCVR systems are usually contained in a module mounted in the aircraft skin or surface (vertical stabilizer or aft fuselage). Aircraft sensor and audio data are received and processed by internal avionics and transferred to the CSFDR/CSCVR for storage (15 to 30 min first-in-first-out record time). The CPI consists of a radio beacon transmitter/antenna system that will transmit an omnidirectional emergency signal (121.5 and/or 243 MHz) and powered by either a nickel-cadmium or lithium battery. One new ejectable CPL will provide a visual marker (strobe light) that time-shares battery power with the radio beacon. The CPL is activated upon ejection from the aircraft and is required to transmit the emergency signal for 48 hr minimum. The ejectable CPI/CSFDR/CSCVR is deployed from the aircraft by one or more of the following switch devices: frangible switch (nose, wings, and belly); water activated switch; electromechanical switch (ejection seat); and manual electromechanical switch (test and maintenance). There are two known types of ejectable CPI/CSFDR/CSCVR systems (see table I). References 1, 2, and 3 specifications cover ejectable CPI/CSFDR/CSCVR systems required by the U.S. Navy.

a. Airfoil Type AN/ASH-20(V). The airfoil is made of rigid closed cell foam covered by a fiberglass cloth/polyester resin skin. The skin is coated with 30 to 40 mils of intumescent coating for thermal protection and then painted with epoxy paint for environmental protection. The radio beacon transmitter, antenna, and manual shutoff switch are molded into the airfoil foam. The battery and CSFDR are removable from cavities in the airfoil. Figures 1 and 2 depict airfoil configurations for fixed and rotary wing aircraft, respectively. The airfoils are released from the aircraft by either an electromechanical or squib release device. Upon release, the fixed wing aircraft airfoil aerodynamically flies away from the aircraft at a retarded velocity. The rotary wing aircraft airfoil or "doughnut" tumbles away from the aircraft at a retarded velocity. The airfoil is designed to survive a hard ground impact and to float if deployed into water. References 4 and 5 cover the DT&E of two Advanced Development Model (ADM) solid state airfoil type CSFDR's.

b. Mortar Type AN/ASH-31(V). The mortar is made of an outer structural foamed-in-place fiberglass shell and an aluminum inner shell that houses the transmitter, batteries, and recorder. Figure 3 depicts the mortar deployable package. The deployable package is ejected from the aircraft by a squib actuated gas thruster (1,500 lb) at a separation velocity of 100 ft/sec. Upon separation, a parachute is deployed from the deployable package to retard impact velocity. The mortar is designed to survive a hard ground impact and to float if deployed into water.

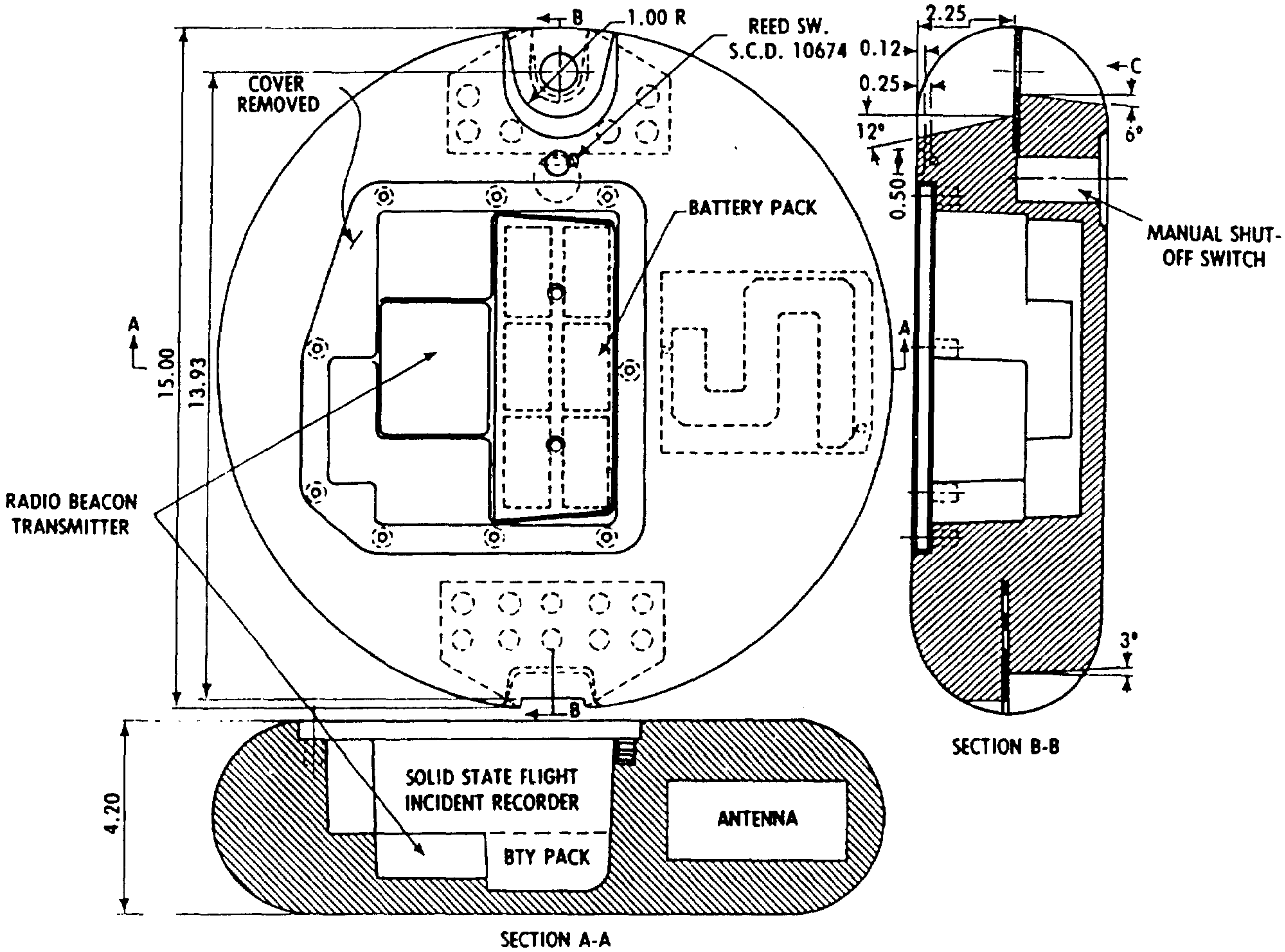


Figure 1
DEPLOYABLE FLIGHT INCIDENT RECORDER/CRASH
POSITION LOCATOR (FIR/CPL) FOR HELICOPTERS

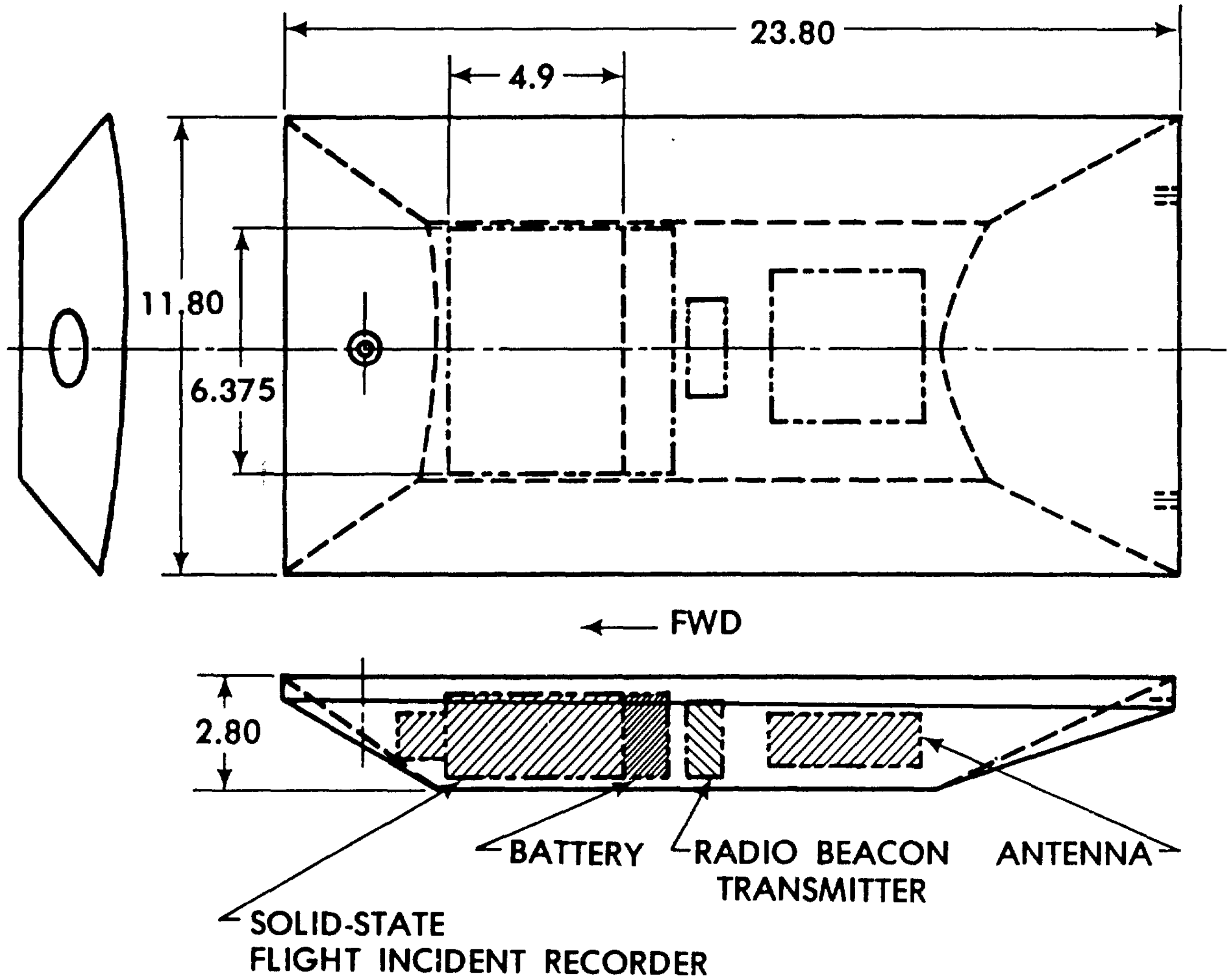


Figure 2
DEPLOYABLE FLIGHT INCIDENT RECORDER/CRASH POSITION LOCATOR (FIR/CPL) FOR FIGHTER/ ATTACK AIRCRAFT

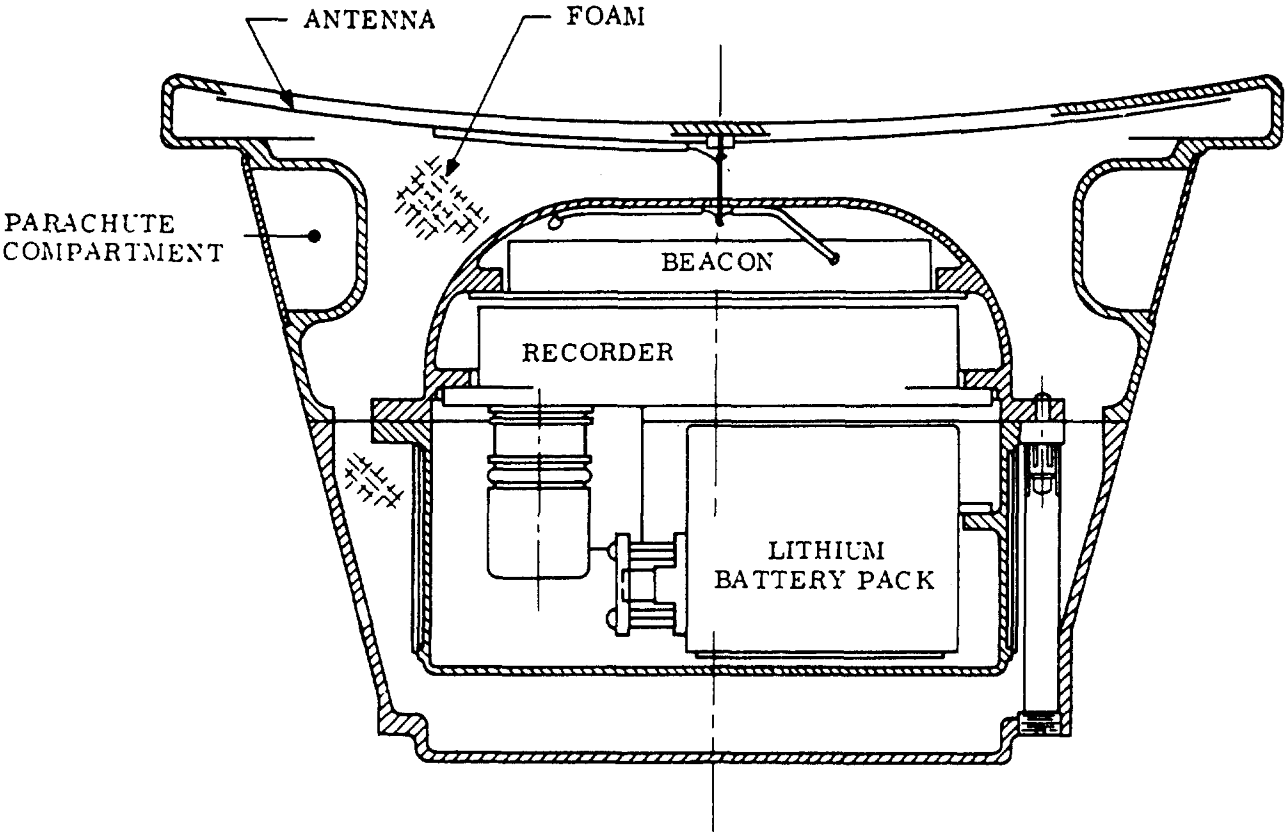
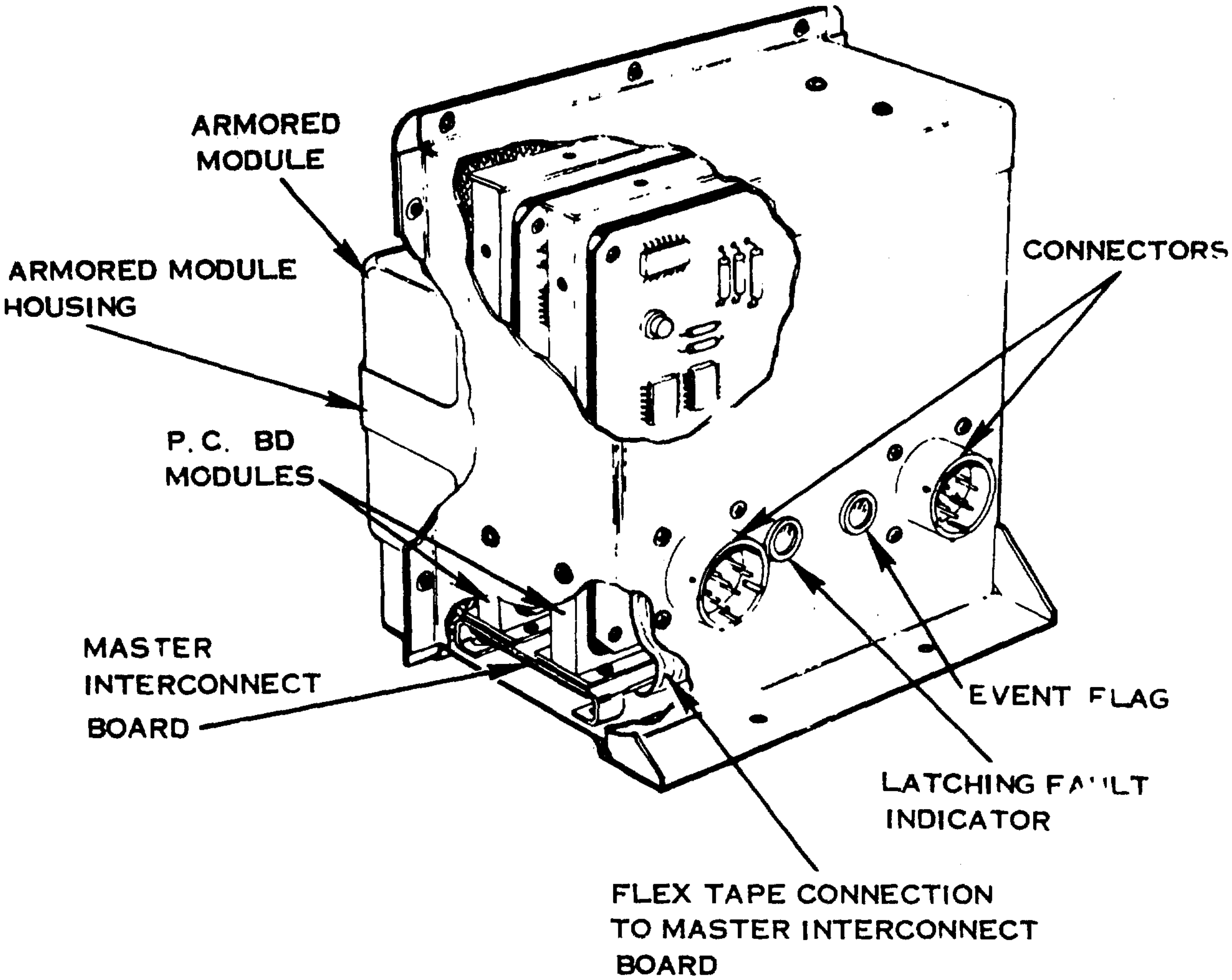


Figure 3
AN/ASH-31(V) MORTAR TYPE
DEPLOYABLE PACKAGE CONFIGURATION

NONEJECTABLE SYSTEMS

3. Nonejectable CPI/CSFDR/CSCVR systems are usually contained within a crash hardened case and mounted inside the aircraft as other avionics equipment. The CPI/ CSFDR/CSCVR systems are usually housed in separate crash hardened cases. CSFDR's store aircraft sensor parameter data (30 min to 25 hr first-in-first-out record time) and CSCVR's store aircrew audio data (15 to 30 min first-in-first-out record time). Nonejectable CPI/CSFDR/CSCVR systems function similar to ejectable systems except there is no ejection mechanism and the CPI does not have a strobe visual marker. Figure 4 depicts a nonejectable type CSFDR which includes both a Crash Survivable Memory Module (CSMM) with accompanying signal conditioning and memory controls in one package. Figure 5 depicts a cross section of the CSMM. Upon an aircraft crash, the nonejectable CPI/CSFDR/CSCVR will continue to record as long as power and signal inputs are supplied to the system. Although this has never happened during a major accident, it is a potential problem particularly during a minor accident or incident. Most nonejectable CSFDR/CSCVR systems are designed to operate using aircraft systems power; however, some are designed to operate using aircraft battery power.



ESTIMATED PRODUCTION CHARACTERISTICS
● WT 8.51 LBS ● SIZE 6.5" LONG 6.5" HIGH 6.8" WIDE ● VOLUME 207 IN^3 ● MATURE RELIABILITY-10,000 HOURS MTBF ● POWER CONSUMPTION - 25 WATTS MAX AT 28 VDC

Figure 4
AIRS PACKAGE

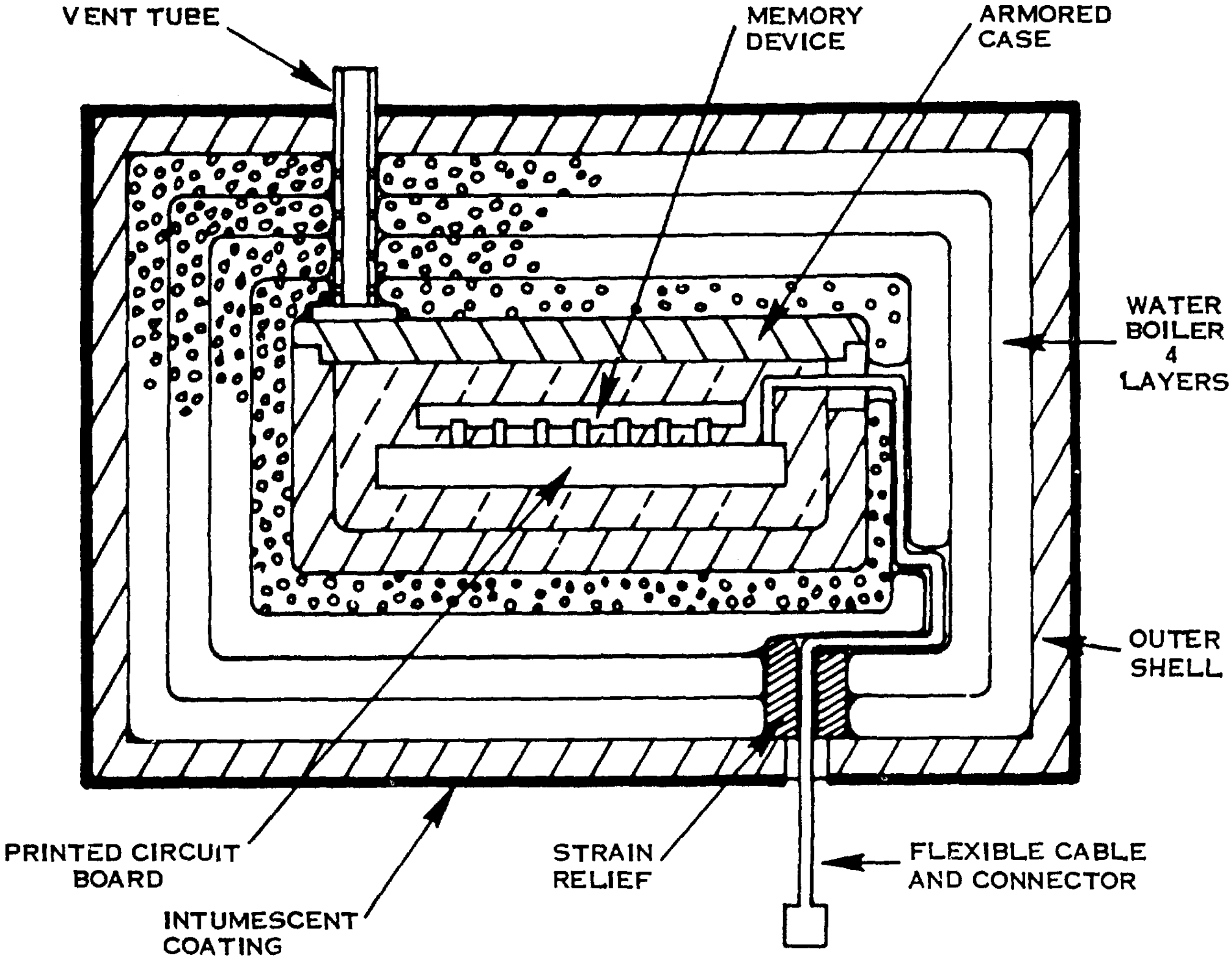


Figure 5
NONDEPLOYABLE TYPE AIRS CSFDR
SECTION OF PROTECTED MEMORY MODULE

CRASH POSITION INDICATOR/CRASH SURVIVABLE FLIGHT DATA RECORDER/CRASH SURVIVABLE COCKPIT VOICE RECORDER FUNCTION

4. There is little or no difference in the overall functional requirements of ejectable and nonejectable CPI/CSFDR/CSCVR systems. The function of the CPI is to transmit an emergency radio signal to assist in locating a downed aircraft, aircrewmen, and the CSFDR/CSCVR during Search and Rescue (SAR) operations. The function of the CSFDR/CSCVR is to record aircraft sensor parameters including aircrew audio for a period of time prior to an accident, incident, or crash. The number of sensor parameters recorded may vary from as few as 6 on analog metal foil type recorders to as many as 100 on digital type recorders. The total record time of CSFDR/CSCVR systems may vary from as little as 15 min to as much as 25 hr. There is, however, good accident analysis data that indicate 15 to 30 min of recorded air carrier data are sufficient and have become the standard for military aircraft recorders. The current CSFDR/CSCVR system designs are required to record approximately 24 sensor parameters (U.S. air carrier aircraft) for 25 hr and aircrew audio for 30 min and 50 sensor parameters (military aircraft) for 30 min and aircrew audio for 15 min. These new recorder designs are beginning to use data compression techniques to

conserve memory storage capacity, weight, volume, power, and ultimately cost. Finally, the CSFDR/CSCVR systems are required to function reliably during all flight operations; the CPI is required to function reliably after an accident incident or crash; and the CSFDR/CSCVR recorded or stored data are required to survive an accident, incident, or crash. Reference 6 covers the DT&E of an ADM solid state nonejectable type CSFDR.

EJECTABLE VERSUS NONEJECTABLE SYSTEMS

5. Before comparisons are made between ejectable and nonejectable CPI/CSFDR/CSCVR systems, aircraft operational requirements should be addressed. All civilian and military aircraft fly over and occasionally crash into both land and water. For example, domestic civilian and commercial and some military (U.S. Army and U.S. Air Force) aircraft fly primarily over land while international civilian and commercial and some military (U.S. Navy, U.S. Marine Corps, and U.S. Coast Guard) aircraft fly primarily over water. Approximately 7% of all U.S. and Canadian private and air carrier aircraft that operate and crash over North America crash into water (lakes, rivers, and coastal waters). Approximately 45% of all U.S. Navy/Marine Corps aircraft involved in major accidents crash into water (usually at sea). Most of these crashes occur in water of extreme depth that makes it difficult, if not impossible, to locate and recover an aircraft with a nonejectable CPI/CSFDR/CSCVR. Therefore, aircraft with a primary over-the-water operational requirement is driven toward ejectable, floatable CPI/CSFDR/CSCVR systems. Notwithstanding overriding operational considerations, there are some obvious and subtle advantages and disadvantages associated with the use of ejectable and nonejectable CPI/CSFDR/CSCVR systems. These advantages and disadvantages are categorized and summarized as follows:

a. Complexity, Reliability, and Maintainability. There are obviously considerable reliability differences between CPI/CSFDR/CSCVR system manufacturers. For example, some U.S. air carrier aircraft still carry obsolete-technology analog metal foil type CSFDR's that have poor reliability. Most aircraft, however, carry digital magnetic tape type CSFDR's that have good to excellent reliability. Therefore, for the purposes of this analysis, it will be assumed that the overall functional reliability of systems is equal or can be designed to be equal. The ejectable system, however, has more equipment that must function reliably, i.e., the ejection system itself. Consequently, one reliability problem peculiar to ejectable systems has been inadvertent deployments. The U.S. Navy/Marine Corps aircraft with ejectable CPI/CSFDR/CSCVR systems (220 total) experienced approximately 60 (27.4%) inadvertent ejections between 1979 and 1982 (reference 7). It was determined that approximately 60% of these inadvertent ejections were caused by inadvertent manual deploy switch operation, 35% induced by incorrect maintenance procedures, and 5% induced by component reliability failures; i.e., 95% were human operational errors while only 5% were true reliability errors. Nonejectable systems, of course, do not have any of these ejection problems. A similar reliability problem peculiar to nonejectable CPL's or Emergency Locator Transmitters (ELT's) is inadvertent activations or false alarms. A sample of 361 incidents of ELT's or General Aviation aircraft between 1979 and 1981 indicated 99 (27.2%) false alarms (reference 8). It was found that the most common causes of these false alarms were accidental operation of the control or remote switch, switch malfunction, and inadequate installation/handling. Also, nonejectable CSFDR/CSCVR systems may have an "over reliability" problem in that, upon an accident or crash, the system(s) will continue to record until the engine(s) stop or until a special sensor stops the recording. Continued recording after an accident or crash could, in time, erase the critical data required for crash analysis.

b. Survivability. The overall survivability requirements for both ejectable and nonejectable CPI/CSFDR/CSCVR systems are the same; i.e., the CPI radio beacon transmits after the accident or crash and all the data stored in the CSFDR/CSCVR are recoverable for analysis after the accident or crash. The primary difference between ejectable and nonejectable systems is the test requirements and consequent design requirements for survivability. The survivability test requirements established by the U.S. Federal Aviation Administration (FAA) for air carrier aircraft, as contained in TSO-C51a (reference 9), have been the U.S. standard for private, air carrier, and military systems. The survivability test requirements for nonejectable systems are generally more severe than those for ejectable systems in the areas of penetration resistance, static crush, and fire protection. The theory behind these differences is that nonejectable systems remain with the crashed aircraft and are subjected to more severe mechanical and thermal environment than do ejectable systems that depart the aircraft and clear the crash and fire. As a result of the more stringent survivability test requirements, nonejectable systems must be designed with crash hardened armor, as shown in figure 5, thus, increasing weight, volume, power requirements, and cost. Subsequent testing, evaluation, and analysis indicate that some of the TSO-C51a survivability test requirements are not realistic. Consequently, a revision to TSO-C51a, as drafted in reference 10, has been proposed. This revision more logically defines the survivability requirements as related to the real crash environment and in terms of testability. The net effect of the TSO-C51a revision increases mechanical and thermal severity, particularly for the ejectable type CPI/CSFDR/CSCVR systems. Obviously, there is limited empirical data on CPI/CSFDR/CSCVR survivability. U.S. air carrier (FAR Part 121) aircraft are not required to carry CPI's or ELT's but are required to carry Underwater Locator Beacons (ULB's) with CSFDR's that transmit at 37.5 kHz. U.S. general aviation aircraft are required to carry ELT's but no CSFDR's or CSCVR's. A Crash Research Institute analysis (references 11 and 12) of U.S. and Canadian general aviation aircraft crashes containing nonejectable CPI or ELT systems indicates that approximately 65% survive; i.e., the CPI/ELT activates and transmits after the crash. The primary reason for nonoperation of the nonejectable CPI/ELT systems was determined to be caused by mechanical/thermal destruction/damage. It should be noted that a nonejectable CPI/ELT/ULB on an aircraft submerged in water is virtually useless for SAR aircraft location; i.e., HF/VHF/UHF radio beacon signals transmitted through water cannot be received by SAR aircraft radio equipment. A similar analysis of U.S. and Canadian military aircraft crashes containing ejectable CPI/ELT systems (references 7 and 13) indicates that approximately 99% survive. These data also include CPI survival from inadvertent deployments. There is only one known case of an ejectable CPI not surviving a crash (U.S. Navy P-3B crash into a stone mountain face). Ejectable CPI's over water do not present a radio beacon transmission and SAR radio reception problem because the CPI floats and transmits an omnidirectional VHF or UHF signal at ranges up to 50 miles. Empirical crash survivability data for CSFDR/CSCVR systems are even more limited than that for CPI systems. The U.S. National Transportation Safety Board (NTSB) compiled crash survivability data (1959 to 1973) on 509 U.S. air carrier aircraft crashes with nonejectable CSFDR/CSCVR systems (reference 14). Of the 509 crashed systems, 409 (81%) fully survived, 33 (6%) partially survived, and 67 (13%) either did not survive or were not recovered. The NTSB data indicate that the location of nonejectable CSFDR/CSCVR systems in the aircraft is critical to recorded media survivability, i.e., media survivability is increased considerably if the CSFDR/CSCVR is located as far aft in the aircraft as possible. There are no known cases of an ejectable CSFDR/CSCVR not surviving a crash. The best sample (reference 15) comes from Federal Republic of German F-104G aircraft crashes with ejectable CSFDR/CSCVR systems. Out of 10 (1977 to 1981) catastrophic high-speed crashes into land, all ejected CSFDR/CSCVR systems survived and the data were recovered and analyzed.

c. SAR. The SAR requirements for both ejectable and nonejectable CPI/CSFDR/CSCVR systems are the same. Obviously, successful SAR operations are highly dependent on proper CPI radio beacon activation/transmission and the ability of the SAR aircraft to receive the radio signal, find and visually locate the downed aircraft, and recover survivors and the CSFDR/CSCVR systems. There is a considerable difference between ejectable and nonejectable system capability to adequately accomplish the SAR mission. Ejectable CPI systems have an excellent activation/survivability/transmission record. The problem with ejectable systems has been the inadvertent deployments that require unnecessary recovery, sometimes repair, and reinstallation of the ejected package. Nonejectable CPI systems, on the other hand, have a poor activation/survivability/transmission record. The primary reasons for this poor record are inadequate actuation sensors (usually acceleration switches), poor crash survivability, and inability to transmit VHF/UHF emergency signal through wreckage obstruction or through water (into water crash). Therefore, ejectable systems have a clear advantage over nonejectable systems for SAR operations.

d. Weight, Volume, and Power Requirements. As with any avionics equipment, it is a design and operational objective to minimize weight, volume, and power requirements of CPI/CSFDR/CSCVR systems. Commercial nonejectable magnetic tape systems are relatively heavy (30 to 50 lb), voluminous (1,600 to 2,400 $in.^3$), drawing 60 to 100 W power. Existing ejectable systems tend to weigh less (20 to 35 lb), be less voluminous (1,200 to 1,800 $in.^3$), and require less power (40 to 70 W). New ejectable and nonejectable systems using digital solid state technology and new lightweight crash protection materials have reduced system weight, volume, and power requirements considerably, i.e., weight (10 to 20 lb), volume (600 to 1,000 $in.^3$), and power (15 to 30 W).

e. System Safety. The only safety considerations for CPI/CSFDR/CSCVR systems are batteries (CPI operation) and ejection systems. Many CPI systems use lithium batteries because of their long storage life (up to 5 years) and their lightweight and small volume. Some lithium batteries (not currently in CPI systems) have proven to be hazardous by exploding under high temperature conditions. Considerable DT&E has been accomplished in this area and it was found that lithium batteries present no hazard if they are designed and tested to current specifications. All lithium batteries currently used in military CPI systems have been qualified under TSO-C97 or similar military specifications. Another perceived hazardous component is the explosive squib release mechanism used on some ejectable systems. The squibs used on ejectable systems are completely enclosed devices of the type that have been used on aircraft for years and, in fact, pose no hazard to aircraft or personnel. One real hazard does exist, however, with the mortar type ejectable system. When fired or ejected, the deployable package departs the aircraft at about 100 ft/sec. Therefore, if ejected inadvertently while the aircraft is on the ground, the package could be hazardous or fatal to nearby personnel. For this reason alone, the U.S. Navy does not use the mortar type CPI/CSFDR/CSCVR ejectable systems.

f. Cost. Acquisition costs (including DT&E and installation) tend to be higher for ejectable CPI/CSFDR/CSCVR systems due to their additional complexity. Cursory cost analysis indicates that the acquisition cost of a nonejectable magnetic tape system should be less than $20,000 per system while an ejectable magnetic tape system should be less than $30,000 per system. Digital solid state memory technology has initially increased these acquisition costs because of their state-of-the-art development; however, costs should decrease as more semiconductors and systems are produced. It should be noted that solid state technology has increased reliability, maintainability, survivability, and operability while reducing weight, volume, and power requirements.

g. Cost/Benefits. Several cost/benefit analysis of CPI/CSFDR/CSCVR systems on U.S. Navy aircraft have established very high net results. These positive net cost/benefits are derived primarily from projected reductions of aircraft and aircrew losses, SAR missions, and recovery operations through the use of recorded flight data. Obtaining information immediately after an aircraft accident or incident permits rapid determination of cause and immediate implementation of appropriate corrective action to prevent recurrence. One cost/benefit analysis (reference 16) indicates that preventing the loss of just one aircraft more than pays for equipping the entire fleet with CPI/CSFDR/CSCVR systems and complementary maintenance monitoring systems. In addition to providing significant economic benefits, such system capabilities can enhance fleet operational readiness by reducing or not requiring the grounding of aircraft. In all cost/benefit analysis, little, if any, attention has been given to SAR operations. CPI/ELT radio beacon transmissions from a downed aircraft can reduce SAR flying hours. In cases where the approximate location of a downed aircraft is unknown and even when a wide area must be searched, fewer SAR flying hours are required through the use of CPI/ELT locating. CPI/ELT transmission and SAR aircraft receiving provide rapid location of surviving aircrew. CPI/ELT systems allow rapid location of severely injured aircrewmen without the use of a Personnel Locator Beacon (PLB). PLB's may not be carried by all aircrewmen or the PLB may be separated from the aircrewmen or the aircrewmen may be injured such that the PLB cannot be activated. SAR operations indirectly derive benefits from the CSFDR/CSCVR systems since recorded information can be used to reduce accidents/incidents and thus a reduction in SAR missions. The ejectable CPI/CSFDR/CSCVR provides more cost effective benefits to the SAR operation due to its high reliability, survivability, and water recovery capabilities. Further quantifying of the cost/benefits resulting from CPI/CSFDR/CSCVR systems on aircraft should be conducted.

CONCLUSIONS

6. The following conclusions are summarized from the detailed discussions in paragraph 5. These conclusions are further summarized in table V.

a. Aircraft operational requirements (over land and water) are overriding considerations in whether an aircraft should be equipped with an ejectable or nonejectable system. Aircraft that operate primarily over water or at sea should be equipped with ejectable systems. Aircraft that operate primarily over land may be equipped with either an ejectable or nonejectable system.

b. Ejectable systems are more complex than nonejectable systems because of the deployment mechanisms (ejection switches and release devices) required for ejectable systems.

c. System reliability and maintainability (R&M) is generally dependent on system design, installation, and testing. It is more difficult to attain higher levels of R&M for ejectable systems because of their complexity. The R&M record for ejectable CSFDR/CSCVR systems in-service is relatively poor while the R&M record for nonejectable CSFDR/CSCVR systems ranges from poor to excellent depending on the system. The R&M record for both ejectable and nonejectable CPI systems ranges from poor to excellent depending on the system. Current ejectable systems have an inadvertent deployment problem that is attributed to poor maintainability and human errors. Nonejectable metal foil analog type CSFDR's and some magnetic tape CSCVR's have poor reliability while most digital CSFDR's and CSCVR's have good to excellent reliability. Nonejectable CPI's or ELT's have an inadvertent activation or false alarm problem that is attributed to poor R&M and human errors.

d. The survivability record of ejectable CPI/CSFDR/CSCVR systems are excellent (99 to 100%), while the survivability record for nonejectable systems range from poor for CPI systems (65%) to fair for CSFDR/CSCVR systems (87%).

e. Successful SAR operations are dependent on the survival, activation, and proper function of the CPI during and after a crash. Successful SAR operations are also dependent on the proper function of the SAR aircraft VHF/UHF radio and direction finding systems. The SAR record for ejectable CPI systems is excellent while the SAR record for nonejectable CPI systems is poor. The poor nonejectable CPI record is attributed to poor system survivability and reliability.

f. Ejectable CSFDR/CSCVR systems generally weigh less, are smaller, and require less power than nonejectable systems because nonejectable systems have heavy armor that encloses power dissipating electronics. Ejectable CPI systems generally weigh more and are larger than nonejectable CPI systems because ejectable systems are enclosed in airfoil and/or flotation devices. Power requirements for ejectable and nonejectable CPI systems are essentially the same.

g. The system safety of both ejectable (airfoil type) and nonejectable systems is excellent. The mortar type ejectable system is considered to be hazardous to personnel should this system be inadvertently ejected while the aircraft is on the ground or deck.

h. The acquisition cost of ejectable CPI/CSFDR/CSCVR systems is about one third more than the cost of nonejectable systems. The higher cost for ejectable systems is attributed to the additional complexity, ejection hardware, and installation. The new nonvolatile solid state CSFDR/CSCVR systems will cost more than existing magnetic tape systems; however, costs of solid state systems will decrease with increased production of solid state memory devices.

i. There are substantial cost/benefits associated with CPI/CSFDR/CSCVR systems on military aircraft. The primary cost/benefit is the reduction of aircraft and aircrew losses through the use of recorded data from aircraft accidents and incidents. Substantial cost/benefits can be realized in SAR and aircraft recovery operations.

Table V

EJECTABLE AND NONEJECTABLE CSFDR/CSCVR/CPI SYSTEM CHARACTERISTIC COMPARISON MATRIX

System Characteristic	Ejectable CSFDR/CSCVR	Nonejectable CSFDR/CSCVR	Ejectable CPI	Nonejectable CPI
System Complexity	More	Less	More	Less
Reliability Record	*Poor	*Poor-Excellent	Excellent	Poor
Maintainability Record	Poor	Poor-Excellent	Poor	Poor
Survivability Record	Excellent	Fair	Excellent	Poor
SAR Record	N/A	N/A	Excellent	Poor
Weight/Volume/Power	Less	More	Equal	Equal
System Safety	Airfoil-Excellent Mortar-Poor	Excellent	Airfoil-Excellent Mortar-Poor	Excellent
System Cost	More	Less	More	Less

*The predicted reliability of state-of-the-art solid state CSFDR/CSCVR systems is 6,000 to 10,000 hr MTBF.

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