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OFFICE OF NAVAL RESEARCH

FINAL REPORT

LIFE SUPPORT AND PROTECTION REQUIREMENTS FOR THE HEAD/NECK REGION OF NAVY AIRCREWMEN

December 1986

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LIFE SUPPORT AND PROTECTION REQUIREMENTS FOR THE HEAD/NECK REGION OF NAVY AIRCREWMEN

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Foreword and Acknowledgements

This report was prepared for the Naval Air Systems Command and the Office of Naval Research as part of a program to examine the problems of aircraft escape and survival for Navy aircrewmen. Mr. George R. Mutimer, of the Naval Air Systems Command, was instrumental in establishing project objectives and served as Technical Monitor. Dr. Donald P. Woodward, of the Office of Naval Research, served as Contract Monitor during the course of the project. We are most appreciative of their support and help.

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Prologue

The goal of Navy engineering personnel concerned with the design of aircrew systems always has been to provide aircrewmen with maximum protection while at the same time preserving the freedom of the "shirt-sleeve environment." The full expression of this goal was exemplified in the F-111B cockpit capsule, with the capsule offering maximum protection and still allowing significant freedom of movement. In the pursuit of the goal, however, the solution became the goal and when the goal, i.e. the capsule, faded into disfavor so did most of the earlier dream of a shirt-sleeve environment.

Recent experience with advanced fighter aircraft such as the F/A-18 and the F-16 make it abundantly clear that the earlier goal of unfettering the aircrewman must be reinstated. Many feel that the penalties for wearing the current oxygen mask, the anti-exposure suit, flotation gear, etc., outweigh the advantages. In addition, programs are afoot to reconfigure the protective helmet to accommodate more programs (and more weight). These programs include head-up displays, night vision devices, gunsights, and both laser and chemical protection. With these additions to the protective helmet, penalties can only increase. Problems of comfort, fatigue, and restriction of movement will be exacerbated.

The penalties associated with the current life support and protection system are in large measure due to lack of a systems approach to protecting aircrewmen. Engineering design is directed to component improvement rather than to problem solution. Indeed, the Navy organizational structure virtually precludes a systems approach to problem solution. For example, drowning is a problem. There is no office or individual responsible for the problem of drowning. A flotation garment is a solution. There _are_ offices and individuals responsible for the development and improvement of flotation garments. Real improvements in crewman protection require that we transcend this solutional-centric posture and look more to the problems. This requires offices and individuals who are responsible for solving the problems of drowning, exposure, head injury, hypoxia, etc. and not for developing new and improved water wings, poopy suits, helmets, and 02 masks.

This study was started under my direction and with Naval Air Systems Command/Office of Naval Research support as a modest attempt to examine some of the bases for current life support concepts and the manner in which current systems are used. The initial project question was "Does an aircrewman need to wear his helmet at all times?" In other words, what is the timeline of impact risk during Navy missions?

The study subsequently broadened to become a general review of life support and protection needs. The study plan called for returning to "square one" and reexamining the full spectrum of protection requirements with a goal of bringing new attention to the problems per se. By so doing, it was hoped that established personal equipment approaches would not be blandly accepted and that consideration might be given to alternative solutions, possibly in the form of revised aircraft subsystems design.

Available resources required that the study be necessarily small compared to the overall task of "aircrew protection." The first step, described here, covers head, eye and respiratory protection and considers the priority and timing of these needs only. The study provides no absolute answers for protection issues but is intended instead to foster the recognition that there may be alternatives to current solutions and that most of these current solutions are at a point of diminishing return. A systems approach to the development of an Aviation Life Support System, supported by diverse data as presented here, should benefit Navy aircrewmen and contribute to mission effectiveness in the future.

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Section I

Naval Aviation by the Year 2000

The success of naval aviation in meeting the operational challenges of the year 2000 and later will rest on the research and development efforts of today. The strategic imperative of Western superiority in aviation requires a constantly expanding technology base. The utilization of new technologies from fields such as materials processing, adaptive computer control, high-temperature propulsion, and advanced electronic display systems will enable the United States to continue to produce superior aircraft. This is recognized in the Statement of Work for a Navy multi-mission aircraft considered for the 1990's which states that "Maximum benefits and payoffs are likely only if advanced technologies are integrated into new total system concepts."

The rewards accruing from use of new technologies can be seen in the latest Navy aircraft, the F/A-18. This aircraft, incorporating aerodynamic high lift devices and digital electronic flight controls, brings true multi-mission capability into a single vehicle (Lockard, 1984). The excellent combat capabilities of the F/A-18, managed by a single pilot, are the result of application of new technologies plus use of "total system concept" principles during the design phase. Under this concept, all components and factors bearing on the production of an integrated weapon system are incorporated in the design process. The integrated weapon system is defined as the aircraft, avionics, weapons, support systems, and crew. These elements must be matched perfectly and must make maximum use of advanced technologies if total system capabilities are to be achieved.

Each subsystem within an aircraft serves a specific purpose and also interacts with other subsystems to play a complex role in determining the ultimate effectiveness of the aircraft as an airborne weapon. For maximum effectiveness, each subsystem must incorporate new technologies, as feasible, and must relate to other subsystems as determined by the total system concept. The need for technology advance in subsystems such as aircraft propulsion is easily recognized. It is perhaps not as obvious that the same need exists for aviation crewmembers and for their Aviation Life Support System (ALSS).

The development of an Aviation Life Support System must be done in the context of crewman performance requirements and the operational flight environment. The workload placed on crew-members by high performance military aircraft is imposing. The pilot of a single-place aircraft is responsible for aircraft maneuvering control, navigation under all types of weather and lighting, aircraft subsystems management, and completion of all mission assignments. Each of these broad categories includes a host of lesser responsibilities. In all, the tasks can become insurmountable if not taken into account during the design of the aircraft and associated subsystems. In particular, the ALSS cannot impede performance of these tasks.

Then there is the matter of the flight environment. Aviation missions take place under a range of atmospheric and altitude conditions, with violent accelerations and force fields the norm, and with a velocity range extending to Mach 2 and beyond. There also is the possibility of enemy action or some aircraft mishap, either of which can require emergency escape and thus place the crewmember in a new and even more hostile environment.

Newer aircraft, such as the F/A-18, incorporate many advanced technologies for pilot support. Standard cockpit "housekeeping chores" required in other aircraft, such as fuel transfer management, are automated (Lockard, 1984). In addition, aircraft subsystems are self-monitoring and provide automatic reversion to a back-up mode when a fault is detected.

The advancement of life support technology for newer aircraft such as the F/A-18 is every bit as important as the advancement of other support systems. Life support assemblies also should reflect the "total system concept." Castine and Naber, of the Naval Air Development Center, recognized the need for a systems-oriented approach to the development of life support systems when they said in 1978:

> Navy fighter pilots are presently equipped with a collection of non-integrated protective clothing and devices which have been designed to meet specific hazards with little regard to in-flight acceptance or overall mission effectiveness. Each item of the pilot's protective equipment may be generally considered adequate when evaluated on the individual component level. However, when the equipment is utilized collectively, the pilot is severely restricted, especially during the in-flight portion of the mission profile. The requirement to wear several pieces of protective equipment designed to meet specific hazards has restricted the aircrewman's performance and efficiency, and has reduced overall mission effectiveness.

The problems described by Castine and Naber must be resolved in the next-generation Aviation Life Support System.

Section II
Aviation Life Support

Problems relating to the physiology of flight, although recognized from the days of the French balloon flights during the 1800's, did not impact military aviation until World War I, when aircraft were built capable of achieving altitudes in the order of 25,000 feet. By the 1920's, difficulties of flight at altitudes above 15,000 feet caused consideration to be given to the use of supplemental oxygen. By 1921, oxygen tanks were being carried in military aircraft, with the oxygen supplied to the pilot through a pipe stem hooked over his lip (West et al, 1972).

As use of on-board oxygen became practical, aircrewmen entered into a more hostile flight environment. Prolonged exposure to intense cold, reduced pressure, and the many hazards of high altitude operations brought attention both to training and to protection. Special clothing for flight above 15,000 feet was developed. Aviation Life Support, tracing its nascency to the 1920's, grew steadily during the period of the 30's and developed into a full professional discipline during World War II.

As the performance of present-day aircraft continues to advance, there is a need for ever-improved life support and protection systems for aircrewmen. The speed, range, maneuverability, and altitude capabilities of modern aircraft require crewmen to wear a variety of separate personal equipment assemblies (Mohr, 1985), with the list always increasing. Mohr cites protective assemblies in current use as including head impact protection, flash blindness protection, noise protection, hypoxia protection, thermal burn protection, pressure protection, immersion protection, G protection, and chemical agent protection.

The impressive performance capabilities of modern military aircraft require use of an emergency escape system, which imposes its own set of protection needs. An escaping crewmember is exposed to a high acceleration directed parallel to the spinal column to catapult the cockpit seat and occupant from the aircraft, with an acceleration magnitude from 10 to perhaps more than 20 G_z, depending on seat design, occupant mass, ejection airspeed, and other variables (Brinkley and Raddin, 1985). When ejection airspeed is in the range of 500 to 600 knots, aerodynamic deceleration forces, experienced next by the crewmember, may be as high as 30 to 40 G_x. Following these forces, it would seem that subsequent decelerations caused by parachute opening shock and abrupt encounter with the ground would pale into insignificance. However, all of these forces must be taken into account by the designers of life support systems. The totality of the life support demands represents an impressive challenge.

The Navy program for development and improving the Aviation Life Support System (ALSS) is planned and administered by the Naval Air Systems Command (AIR-931, AIR-411, and AIR-531) and executed by the Navy Laboratory System, with the Naval Air Development Center in a prominent position. The goals of the program are "to enhance the combat effectiveness of the Navy's aircrews and to improve aircrew survivability during emergencies, or when it becomes necessary to abandon the aircraft" (DeSimone, 1984). The program is broad in scope and addresses problems ranging from new parachute technologies to on-board oxygen generation.

The Navy ALSS Program draws information concerning the need for new equipment and improvement in existing items from a number of Navy activities. Fleet reports of aviation problems, investigations of accidents and incidents, maintenance records, feedback from Aviation Physiology Training Units, and technology advances made within Navy laboratories provide the information which serves the ALSS R&D effort. The types of information serving as R&D "drivers" were characterized several years ago by DeSimone (1980) as:

0 Overwhelming accident statistics indicating deficiencies in escape provisions in all platforms

0 Recently acquired POW data addressing SAR (search and rescue)

0 Emphasis on logistics considerations which have been long neglected

0 Special requirements dictated by aviation capable ships

0 The need to unburden the aviator of present heavy, bulky protective systems affecting efficiency in normal flight and mission accomplishment

0 New platform systems performance capability exceeding physiological capability

0 The need for realistic CB protective systems

DeSimone concluded that life support research addressing these issues can "provide the capability to realize the full combat potential of new weapon systems, thus insuring operational superiority, not parity."

Section III
Project Objectives

The formulation of specific objectives for the project described here began as the Navy VFMX aircraft development program was undergoing intensive planning and review at the Naval Air Systems Command as a possible replacement both for the F-14 fighter and the A-6 medium attack aircraft. The VFMX aircraft, as planned, would expand and significantly improve the combat effectiveness of Navy and Marine Corps Air Wings for the period 1995 and beyond. The advanced capabilities considered for the VFMX caused concern that the state of the art of life support components might not match the missions and flight regimes envisioned for the VFMX. For this reason, consideration was given to a general review of life support technology and its adequacy for 1995 aircraft missions.

A number of discussions were held with the Technology Director for Life Support, Naval Air Systems Command, as project objectives and procedures were formulated. Two topics of broad concern to the Technology Director served to guide these discussions. These concerns were:

Man - The Weak Link?

Experience with the newest and most capable military aircraft, such as the Air Force F-16 and the Navy F/A-18, indicates aircraft technology may have progressed to the point where man can no longer keep pace. In earlier systems, the motivation and adaptability of the pilot was a key factor underlying mission success. Now, while the pilot remains a critical element, there is evidence that certain of his qualities can prevent the aircraft system from achieving its full design potential.

The Air Force F-16 Program has directed attention to the problem of G-induced loss of consciousness (GLOC), which has resulted in a number of crashes due to pilot incapacitation. While GLOC has been encountered in a variety of aircraft, losses due to its occurrence have been verified only in the F-16 (Burton and Whinnery, 1985). GLOC, which differs significantly from blackout - a loss of vision under acceleration, results in a period of total incapacitation lasting an average of 15 seconds, according to the experimental results of Burton and Whinnery, with reduced performance capability both preceding and following the episode. The duration of the episode and the initiation of recovery presume, of course, that the G-force is "dumped" as incapacitation occurs.

G-induced loss of consciousness apparently results from both the magnitude of acceleration forces and their rate of onset. The onset rate is critical both (1) to inducing GLOC and (2) to eliminating any symptomatic warnings to the affected crew. It is, perhaps, the lack of warnings which is most insidious and critical.

Newer aircraft such as the F-16 and the F/A-18 are considerably more maneuverable than their predecessors. These aircraft can maintain higher acceleration forces and enter an acceleration profile more rapidly than earlier aircraft. The F-16, for example, is capable of an extremely rapid entry into an acceleration maneuver (6G/sec onset) and can, as expressed by an F-16 pilot, "Hold 9G's all day long" (AsMA Panel Session, 1986).

A survey of Navy fighter and attack pilots (Johanson et al, 1985) indicates the F/A-18 aircraft has a much higher rate of GLOC per flight hour than other Navy aircraft and apparently resembles the F-16 in this regard. Again we have an aircraft capable of sustaining high acceleration forces and rapid G-onset rates.

The F-16 and the F/A-18 both are excellent combat aircraft, in part as a result of their extreme maneuverability. The worth of these aircraft is tempered, however, when the pilot cannot keep pace. In the acceleration dimension, the pilot has become the weak link in the aircraft's system. Research being conducted under Air Force auspices (Alexander et al., 1985) is addressing the problem of the aircrewman as a limiting factor in fighter aircraft performance. The Air Force approach envisions a new flight suit ensemble, a 57 degree semi-supine seat, and aircraft-mounted ancillary equipment. The crewman is essentially encapsulated in his flight ensemble, with many traditional cockpit functions and components integrated directly into this new flight suit. Aircraft escape will require use of a new seat/propulsion concept. Analyses indicate that this crewman protection system, with the semi-supine seat, will allow aircraft turns imposing greater than ten G acceleration forces.

Compartmentalization of ALSS Development.

The life support dimensions of concern in naval aviation should be expressed in functional terms relating to the ability of an aviator to be fully capable of completing all mission assignments, to stay alive, and to remain in one piece. On first consideration, there would appear to be an insurmountable number of issues involved in protecting aircrewmen in high performance aircraft. However, some order can be brought to this review when it is recognized that there are in fact only three classes of life support requirements. These are the maintenance of performance integrity, physiological integrity, and body integrity.

Maintaining performance integrity implies the design of an ALSS which will not interfere with required crewman activities and which will sustain and support performance capability under all probable inflight stresses. A life support system should not compromise an aviator's performance by restricting any cockpit activities and, indeed, should if possible support and enhance the crewman's performance potential.

Physiological integrity means simply keeping the crewman alive and in good functioning condition. Here we refer to the provision of oxygen, maintenance of proper atmospheric pressure, exclusion of toxic gases, and provision for thermal control. In an aircraft under normal flight conditions, these requirements are easily met. However, maintaining these variables within appropriate ranges during conditions of emergency descent and during periods of survival under unusual and hostile environments may be quite another matter.

Providing for body integrity is mainly a matter of counteracting the unusual force environments in which an aircrewman may be placed. Impact protection can be provided in a number of ways, at present principally through restraint harnesses and protective helmets. Protection against high wind velocities during emergency escape currently is achieved through limb restraint systems which lock prior to or during ejection. High-G protection is provided through an anti-G inflatable garment. All of these systems work rather well with present aircraft. Whether they represent the optimum means for meeting life support requirements for aircraft such as the F-16, the F/A-18, and future, higher performance aircraft is a matter for consideration.

Total Systems Approach. The development of a life support system must be done in a coordinated, total systems manner to insure that support and protection are provided to the aircrew throughout the complete range of environments/environmental stressors associated with all aircraft missions. The life support system is but one functional element in a larger weapon system. It must operate as an integral element, supporting all other elements through its support of the aircrew. Every component within the life support system must contribute to overall system performance and must not interfere with the functioning of any other component. As noted earlier by Castine and Naber (1978), components not only must be adequate when evaluated on an individual basis but must also be adequate when employed as a total, multi-element ensemble system.

Specialization/Compartmentalization. A life support research and development program which begins in an effort to insure that a crewman will retain his ability to perform cognitive actions under all mission conditions, i.e. to think clearly, must at some point address the issue of impact protection. The ability to perform cognitive actions certainly is impaired if the head suffers impact blows of any severity. If head impact increases in severity, serious injury and even death may result. Obviously, head impact protection is a priority concern in the development of a life support system.

An obvious solution for the problem of impact protection for the head is a hard-shell helmet. This is the current solution of choice for such diverse activities as football, motorcycling, ice hockey, and military aviation. It is such an obvious choice that the means subsumes and embodies the requirement. The requirement labeled "impact protection" fades and is supplanted by the means "helmet," which comes to have a system identity of its own. As head injury problems arise or are foreseen with new aircraft and new missions, one is not able to turn to the specialist on "impact protection." In the real world of engineering design and hardware development, such an individual would be difficult to find. Instead, one turns to the "helmet engineer." The task now is not one of reviewing techniques for increased head impact protection but rather one of considering ways in which the helmet might be improved or redesigned to meet the needs of a new aircraft. If there is a problem in head protection, one now examines ways to "fix" or "improve" the helmet. Nor is this focus on means as opposed to requirements solely an engineering design issue. Even the customer organization and logistics organizations work towards holding the "norm," i.e. the helmet, as a consequence of usage experience and familiarity (customers) and of the turmoil and costs of change/replacement (logistics). The problem is considerably greater than that of the engineering organization in isolation.

The same transposition of requirement and means occurs for all life support system components. "Respiration support" becomes "oxygen mask;" "burn protection" becomes "fire-retardant clothing assemblies;" and so on. An engineering community, by the very nature of its organization, highly specialized expertise and interests, and time demands rarely has the luxury, even for a major new aircraft program, of performing a systems analysis of support and protection requirements and then developing an optimized and carefully tailored life support system for the new vehicle. It is far more likely that existing components will be modified and upgraded as deemed necessary and then incorporated into the new aircraft.

The lack of a system design concept is reflected in the procedures followed by specialist engineers, i.e. the "helmet engineer." Each specialists designs his component to provide maximum protection, not optimum, and is not likely to assume the risk of providing lesser protection for his body part (head, torso, etc.) in order to gain overall improvement for the total crewman. This modus operandi is driven by the existing organization in the military/industrial complex wherein, as noted earlier, there are helmet experts, but few if any head injury experts, i.e., if there is another way to protect the head other than with the hard-shell helmet, the system is not programmed to find it. The result is that solutions to protection problems developed in earlier times become immutably "tried and true" and new problems are addressed with updates rather than new solutions. There is a need for a system and individuals who will define or redefine the protection/performance problems caused by known threats and address these with a total systems concept that will allow for judicious trade-off of component solutions within the context of a total design approach. An Aviation Life Support System developed under this philosophy would best achieve the Navy goal of supporting combat effectiveness while at the same time providing requisite protection and support for crewmen.

Aviation Life Support System Requirements Review

The thrust of this project was to examine the life support and protection needs of Navy aircrewmen flying high-performance aircraft equipped with automated escape systems. The examination was conducted retrospectively, drawing principally on an examination of aircraft mishaps and supported by structured interviews with aviation personnel. The survey of information was intended to be of adequate depth to allow a broad review of life support requirements but not to be in such detail that an indepth examination of a specific life support dimension could be made. The need for respiration support thus is a legitimate topic; the precise specification of an oxygen delivery system is not.

Scope of Project. Three boundary conditions were defined to establish the scope of this project. These conditions were:

1. Attention would be given only to life support and protection requirements for the head and neck body region of an aircrewman. In functional terms, the project was to focus on support of cognition, respiration, vision, and audition. Under these conditions, head protection was one of the most important topics. No consideration, however, was to be given to issues of limb flail, torso protection, or injury potential of extremities.

The restriction of project attention to the head and neck region allowed the project to address one of the most important problems in life support, i.e., a comprehensive definition of the need for head impact protection. This restriction also was intended to keep project efforts to a manageable level, with the understanding that procedures would be established which could easily be expanded to cover full body life support requirements if desired at some later period.

2. The project was to develop a broad base of information sources relating to the need for life support. These sources included combat mishap data, records of accidents during peacetime operational and training missions, and information from operational squadrons describing current flight activities, with particular attention given to Air Combat Maneuvering. Consideration also was given to including information on capabilities of advanced aircraft, such as the X-29A forward-swept wing vehicle, and future mission scenarios, which would bring in issues of laser weapons and chemical warfare. However, these latter sources were deemed beyond the project scope at this time.

3. The project would be oriented to requirements per se and not to current life support equipment configurations. There was no attempt to conduct systematic evaluations of current items of equipment. In the real world, of course, it is difficult to examine protection requirements without considering protection equipment. Therefore, equipment issues were described as relevant to the central theme of life support requirements. However, the orientation at all times was toward the human and not toward equipment.

Project Questions. The project was oriented around five broad questions of interest. Answers to these questions, to the extent that answers can be developed, provide a rationale and basis for the concept of protecting an aircrewman during military missions. It was recognized, of course, that these questions, phrased so broadly, could never be answered in absolute detail. The intent of the project was first to assess the extent to which these questions represented valid lines of inquiry, i.e. "Could they be answered?", and, next, to develop some measure of quantitative support for an answer to each question. The five questions of interest were:

0 What are the life support and protection needs of Navy aircrewmen?

0 What is their relative importance?

0 When is the need experienced?

0 What differences exist between peacetime and combat needs?

0 How well do existing support and protection systems work?

Section IV
Data Base Development

The questions addressed in this project required information from a number of sources. Three data bases were developed, as follows:

<u>Combat Mishaps</u>	-	137 cases
<u>Operational and Training Mishaps</u>	-	310 cases
<u>Squadron Data</u>	-	19 aircrewman interviews

Each data base is described in detail later.

The principal source of information, as seen above, consisted of aircraft mishap reports covering both combat and peacetime missions. Information concerning each mishap was recorded in sufficient depth to conduct a broad statistical survey of life support and protection requirements. For the most part, information is not sufficiently detailed or precise to allow an in-depth investigation of specific accidents. For example, combat data is based on interviews and questionnaires completed in most cases some years following the actual event. Thus, when an aviator records his airspeed at time of ejection as "400 kts," he is providing his best statement of this flight parameter, based on recall of a rapid and traumatic episode. There is little question but that the actual airspeed might have been 350 or 450 knots. The likelihood of it being 250 knots, however, is considered slim. In any event, when working with summary rather than discrete data, errors of estimate tend to counterbalance and one can presume that the summary estimate is reasonably correct.

Relation to Other Navy Data Bases

The information on operational and training mishaps was provided by the Naval Safety Center, Norfolk, Virginia. The mishap printouts include parameters describing the event as well as certain conclusions developed by investigating boards and the staff of analysts at the Naval Safety Center. Information from these printouts was re-entered into the BioTechnology computer system in order that it might be used easily in conjunction with information in the other data bases.

The data base describing peacetime events developed by BioTechnology parallels, in some limited measure, the development of the Aircrew Automated Escape Systems and Aircrew Life Support Systems Equipment In-Service Usage Data Analysis Project, an on-going effort by Mr. Frederick C. Guill of the Naval Air Systems Command and associates at the Naval Weapons Engineering Support Activity (NAVWESA), Washington, DC. The NAVWESA data base is a more comprehensive effort which draws on computer tapes furnished by the Naval Safety Center. It is supported by other information sources such as the 3-M (maintenance and material management) system for all Navy aircraft escape systems. This data base has been used for studies of adequacy of reporting systems, for in-depth reviews of unique aircraft escape events, and for evaluations of specific items of life support equipment.

The BioTechnology project described here began as a review of biomedical problems encountered by Navy aircrewmen in emergency aircraft escape under combat conditions. Data describing recent peacetime operational and training missions was included to increase the breadth and meaningfulness of conclusions. Should the approach described here be extended in the future, however, consideration should be given to direct linkage with data bases maintained at the Naval Safety Center and at the Naval Weapons Engineering Support Activity.

Data Entry

Combat. Navy aircrewmen forced to eject during combat operations in Southeast Asia represent a unique and invaluable data resource with which to evaluate the procedures and equipment used for protection during aircraft escape, survival, and rescue. Of the Navy aircrewmen who ejected at that time, 39 percent were recovered, mostly during open water rescues; 33 percent were missing or listed as killed in action; and 28 percent became prisoners of war. In February and March 1973, American prisoners of war held by the North Vietnamese were repatriated. Among this group were 137 Navy aircrewmen who had ejected from fixed-wing aircraft. Subsequent to their official debriefing, each of these repatriated POWs was sent the Aviator's Combat Casualty Report Form developed by BioTechnology. Ultimately, responses were obtained from all of the POWs. A detailed report of information provided through this form, supplemented by medical injury information provided by the Naval Aerospace Medical Institute, can be found in Every and Parker (1976).

Information from the combat casualty form was entered in a new data base specifically designed for the current review of aircrewman life support requirements. Appendix A presents the data entry form used both for combat and non-combat aviation mishaps. The scope of the combat mishap data base is shown in Table 1.

Table 1
Scope of Combat Mishap Data Base

<u>Size</u>

137 combat mishaps in Southeast Asia

<u>Population</u>

U.S. Navy aircrewmen who spent time as Prisoners of War

<u>Period Covered</u>

1964 through 1973

Aircraft	Number
A-4	42
A-6	12
A-7	6
F-4	27
F-8	12
RF-8	4
RA-5	9
	112

Note: Total number of aircraft (112) is less than number of mishap crewmen (137).

<u>Operational and Training Mishaps</u>. Computer records of aircraft mishaps occurring during the full range of peacetime missions were provided by the Aeromedical Division, Naval Safety Center. These records, derived from mishap tapes maintained at the Naval Safety Center, contain a brief narrative of the occurrence, event parameters (airspeed, altitude, etc.), and certain conclusions prepared by analysts within the Aeromedical Division.

The records cover all ejection mishaps which occurred between 1980 and 1984. For present purposes, only information pertaining to trainer, fighter and attack aircraft equipped with ejection seats was used. The computer entry form employed for these data is shown in Appendix A.

Table 2
Scope of Operational and Training Mishap Data Base

<u>Size</u>

310 mishap crewmen during peacetime operational and training missions

<u>Population</u>

Student Naval Aviators, Naval Aviators, Naval Flight Officers, and Marine Corps Aviators flying fighter, attack, reconnaissance, or trainer aircraft with ejection seats.

<u>Period Covered</u>

1980 through 1984

Aircraft	Number
A-4	53
A-6	26
A-7	60
F-4	29
F-5	1
F-8	3
F-14	26
F-18	3
	201

Note: Above aircraft include trainer and reconnaissance versions

Squadron Data. While data from aircraft mishaps is of great value in determining the requirement for life support systems, these data should be supplemented by additional information obtained from the ultimate user, Navy aircrewmen. There are two reasons for obtaining information directly from aircrewmen:

1. The possibility exists that minor injury events occur during training missions which are not recorded in the usual aviation medical reporting channels. For example, the rapidly changing force fields experienced during Air Combat Maneuvering might produce a minor neck sprain or injury but at a level not considered medically significant by the aviator. Nonetheless, this information would be of value when defining inflight protection requirements.

2. The aircrew are the ultimate users and, in a sense, the "buyer" of an Aviation Life Support System. Their expressed needs and preferences should be taken into account, particularly if the system is to be used as designed. The acceptance accorded a support system will be higher if it is based in part on inputs from, and reflects, the felt needs of the aircrew population.

Information from aircrewmen was obtained at the Fleet-Readiness squadron, VF-101 - Oceana NAS, Virginia. The questionnaire used at VF-101 is presented as Appendix B. Table 3 shows the scope of the squadron questionnaire data base.

Table 3

Scope of Squadron Questionnaire Data Base

Size

19 questionnaire and interview responses

Population	Number
Naval Aviator	12
Naval Flight Officer	4
Naval Aviator/Flight Surgeon	1
British Exchange Pilot	1
U.S. Air Force Exchange Pilot	1

Survey Date

4 December 1985

Aircraft

F-14

Data Retrieval

The three data bases used in this project were structured in the computer so that summary statistics and cross-tabulations could be obtained quickly. The plan was to provide information bearing on basic project questions directly and with little requirement for data manipulation. All data bases are relational and can be examined together during a single data query. If desired, individual cases can be brought on-screen at any time. This is particularly useful if the circumstances of a mishap, i.e. the narrative, need to be examined more closely.

Section V
Results and Discussion

Design for Combat or Non-Combat?

An important question faced by the designers of Navy aviation equipment, particularly that used to support aircrewmen, is "Do you design for combat or for non-combat?" There is little question but that flight conditions met during combat differ from those of peacetime in magnitude of effects. Table 4 compares the emergency escape airspeed and altitude conditions for the combat and non-combat (operational and training) missions described in this study. The difference in airspeed is particularly striking, showing a mean escape speed in combat of over 400 knots as compared with a mean peacetime speed of less than 200 knots. This is but one factor illustrating that the conditions normally encountered during combat ejections are appreciably more severe than those encountered during non-combat ejections. In an earlier study (Every and Parker, 1976), it was found also that the severity of resulting combat ejection injuries was often compounded during the landing, escape, and evasion phases of survival. In all, an emergency escape during combat is a much different matter than that during a peacetime operational or training mission.

The question of design emphasis is not easily answered. A case can be made for emphasizing peacetime training conditions. Design for combat certainly will be more demanding, more costly, and might add weight to the aircraft. The case for peacetime design also is buttressed by the fact that, while the Navy has had only three combat ejections (Syrian strike in 1983) in the ten year period from 1976 through 1985, there have been 773 non-combat ejections (Thornton, 1986). There is an inherent logic in designing for the most frequent event. Final consideration should be given, however, to the fact that Navy aircraft are justified and designed as combat weapon systems.

Table 4

Comparison of Escape Conditions for
Combat Versus Non-Combat Missions

	Combat (N = 137)	Non-Combat (N = 310)
Airspeed		
Minimum	100 kt	0 kt
Maximum	725	550
Mean	410	188
Altitude		
Minimum	100 ft	0 ft
Maximum	20,000	26,000
Mean	4,722	3,962

Protective Benefit of Current Aviation Life Support Systems

A program to develop guidelines for an Advanced Life Support System should be based on a benchmark describing the performance of today's system. How well does the current Aviation Life Support System work?

The Naval Air Systems Command has an abundance of data describing the performance and particularly the problems associated with individual items of life support equipment. There is no single measure, however, which describes how well today's ALSS functions in the totality.

The data entry phase of the present project afforded an opportunity to make some decisions concerning overall head/neck region ALSS performance. As each mishap record was entered into the peacetime "training and operational mishap" data base, covering the period 1980 through 1984, a judgment was made as to the protection provided by that specific ALSS during the mishap. Criteria used for these judgments were:

Provided Significant Protection - A definite statement was made in the accident report concerning the positive protective benefit of some ALSS component, such as "The helmet prevented serious head injury during aircraft tumbling."

Useful/As Advertised - The ALSS got the aviator through an emergency escape alive and with no or only minor injuries. No evidence of component failure was noted.

Some Problems - Some component failed or some difficulty in equipment operation was noted. This could range from simple failures such as "Survival radio failed" to a breakdown of a myriad of ALSS items.

Played No Part - Operation of the ALSS was irrelevant under accident circumstances. This would be the case if there was no opportunity or no attempt to eject.

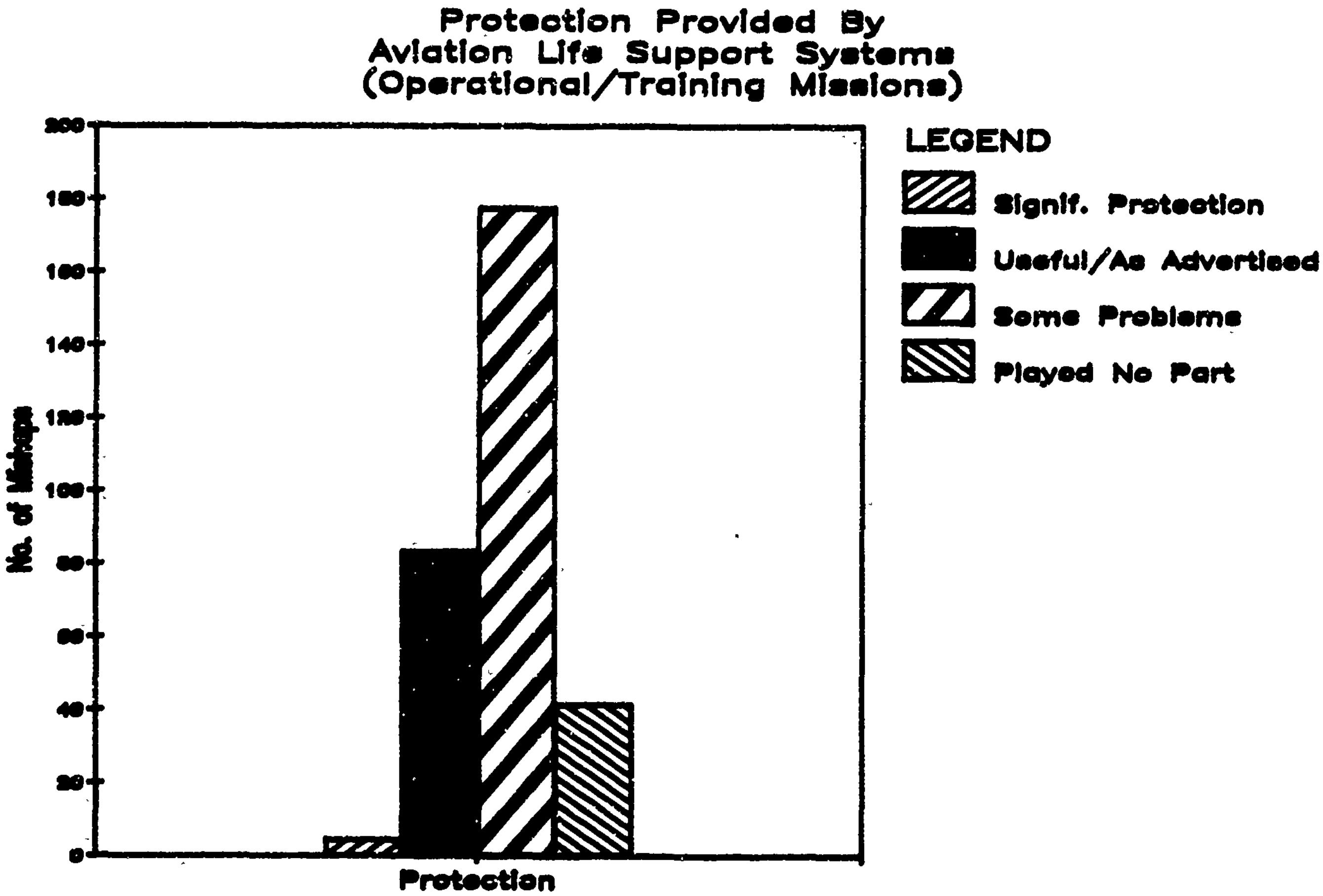


Figure 1

Results of the scoring of ALSS performance, based on the 310 aircraft mishaps, are presented in Figure 1. Note that in 178 instances, or 58 percent of the mishaps, some problem with the ALSS was discussed. In 84 cases (27 percent), the system was judged to have been useful and to have operated as advertised.

The above findings lead to two comments. First, problems with life support system components should not be surprising. The assignment to protect an aviator during emergency escape from an out-of-control aircraft traveling at several hundred knots is most difficult, bordering on the impossible. And, one must remember that the systems have averaged approximately an 85 percent success rate over the years in bringing aviators through this episode alive. Second, ALSS design must be an on-going process. As problems can be identified and categorized, they should be used to trigger new requirements reviews, new approaches, and new design concepts. Aircraft performance and escape environments will only become more imposing as new fighter and attack aircraft appear.

Priority Design Requirements

The first step in developing a design concept for any Aviation Life Support System is to ensure a life sustaining environment. If the aircraft flies above 10,000 feet, supplemental oxygen must be available; for high altitude flight, protection must be provided against the cold temperature; and so on. These life support requirements are well established and need not be addressed here.

A major objective of this study was to identify design requirements above and beyond the basic. Are there conditions/ factors inherent in modern aircraft operations which are not addressed adequately by present support and protection systems? In particular are there unusual forces to be considered when an aircraft is in distress and/or an emergency escape must be made? At such times, the need for performance support and for protection of an aircrewman may be greatest.

Since operational experience seldom is adequately documented, analyses of Navy aircraft accidents serve as a primary source of information concerning design requirements for a life support system. In this study, accidents occurring both in combat and during peacetime were reviewed. Each accident report was studied to determine whether there was any indication of the operation of some environmental force which impaired the performance or which threatened or caused injury to the aircrewman. In many instances, both for combat and non-combat reports, the information indicated that the forces encountered were those normally anticipated for crew operation of the aircraft and for emergency egress. In a typical combat scenario, the aircraft was hit by hostile fire, the pilot immediately recognized that aircraft damage was severe and further flight impossible, and an ejection was initiated. In a scenario such as this, no unanticipated forces or conditions (fire, violent accelerations, etc.) were encountered during the initiation and execution of emergency escape. Forty-six of the 137 combat cases were of this type.

Emergency escape from an aircraft during a peacetime operational or training mission yields, as one would expect, fewer unusual conditions than found in reports of combat escape. In a peacetime mission, the pilot generally has more time to review the situation, to slow the aircraft, and to accomplish a relatively routine ejection. A summary narrative of one peacetime emergency egress episode reads:

> During normal flight, aircraft engine quit, apparently because fuel flow ceased due to undetermined cause. Relight attempts and manual fuel with RAT extended were unsuccessful. Crew ejected - sustained minimal injuries.

There were 251 reports of non-combat emergency escape, out of a data base containing 310 cases, in which the circumstances were much like those in the above narrative, i.e. no violent accelerations or other unanticipated conditions.

Tabulation of the 118 combat reports and the 70 non-combat reports in which some unusual force was reported to have been encountered is presented in Table 5. The same findings are shown as percentages in Figure 2. Again, it should be remembered that these results cover 115 (84 percent) of the combat episodes and only 70 (23 percent) of the peacetime operational and training episodes. These disparate percentages illustrate the more severe conditions of combat - the greater number of instances in which some environmental force or condition threatens to impair performance or to cause injury.

Table 5 shows that for both combat and non-combat where there were environmental conditions, there are two which predominate. These are (1) acceleration forces, in which violent or unusual aircraft acceleration forces impair the aircrewman in his escape efforts or which cause injury; and (2) fire, or smoke indicating fire, either in or in the immediate vicinity of the cockpit area. An example of the operation of acceleration forces, taken from a summary narrative of a non-combat episode, shows:

> During Air Combat Maneuvering, the aircraft experienced several slat malfunctions resulting in asymmetric flight, including a 360 degree uncommanded roll. Pilot ejected at 9500 feet; nose down spin. Unable to reach face curtain; pinned against canopy with head bent forward. Used handle.

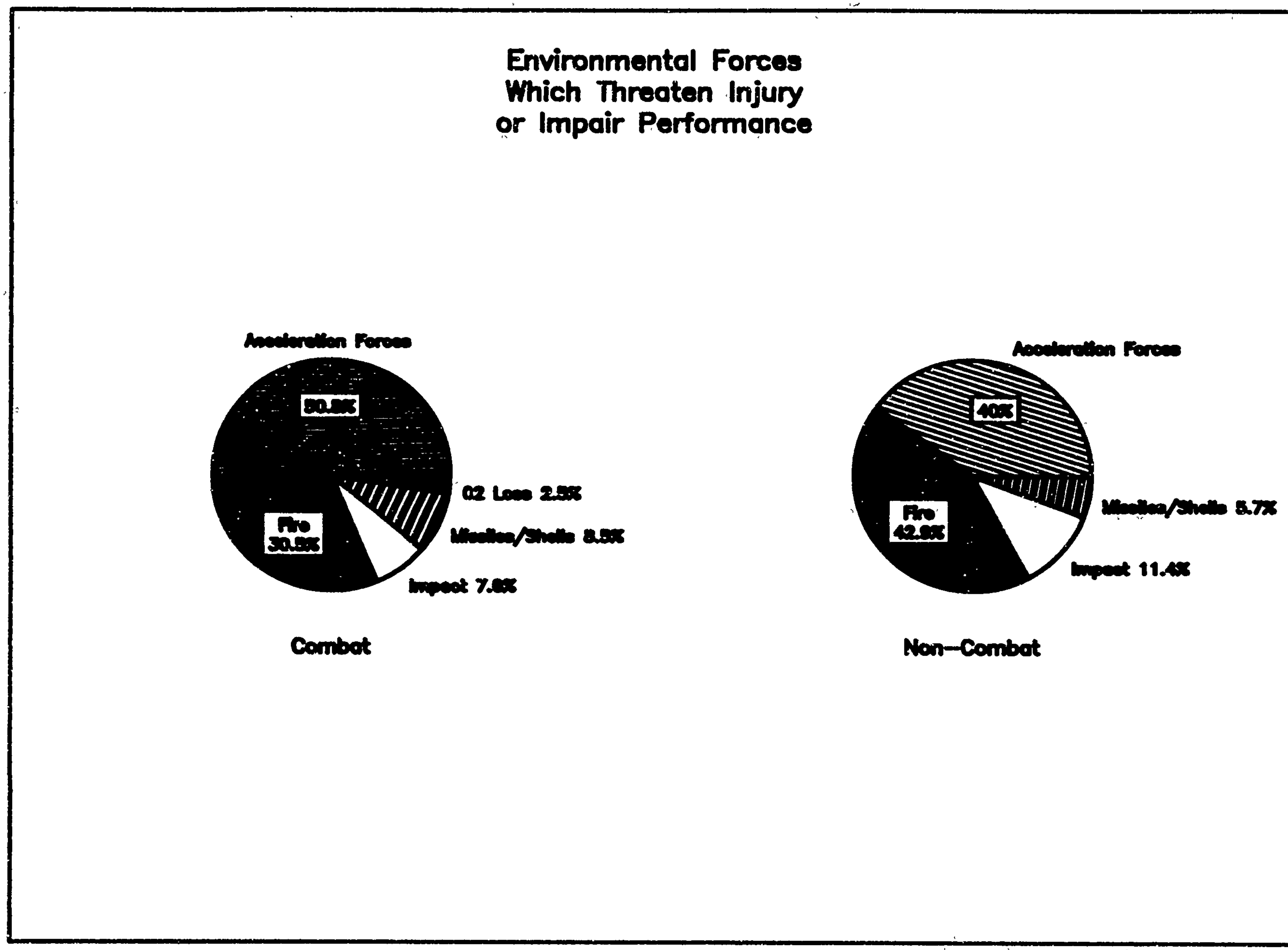

Environmental Forces
Which Threaten Injury
or Impair Performance
Acceleration Forces
50.8%
02 Loss 2.5%
Missiles/Shells 8.5%
Fire
30.5%
Impact 7.8%
Combat
Acceleration Forces
40%
Missiles/Shells 5.7%
Fire
42.9%
Impact 11.4%
Non-Combat

Figure 2

Table 5

Instances in Which Environmental Forces Threatened Injury or Impaired Performance During Emergency Egress Incidents

Combat Data Base (N = 137)	Instances
No unusual force noted	19
Acceleration forces	60
Fire in or around cockpit	36
Missile/shell penetration of cockpit	10
Impact with cockpit structures	9
Oxygen loss	3
Non-Combat Data Base (N = 310)	
No unusual force noted	251
Acceleration forces	28
Fire in or around cockpit	30
Missile/shell penetration of cockpit	4
Impact with cockpit structures	8

Most acceleration reports describe a problem in the ability of the pilot to reach the face curtain/ejection handle or note serious impact against cockpit structures as a result of the acceleration forces.

The second serious environmental condition is fire. In combat conditions, where the aircraft might have been just struck by a missile, the presence of cockpit fire is not surprising. It is more surprising that fire events are fairly frequent during non-combat aircraft emergencies. The following summary of a peacetime episode illustrates this:

While flying number 3 position in a 3-plane formation, pilot noted fire warning light, followed by a electric and hydraulic malfunctions/warning lights/smoke in the cockpit. Pilots in other aircraft confirmed that aircraft was on fire. Pilot ejected.

Penetration of the cockpit by missiles or shell fragments is an anticipated outcome during combat missions. Indeed, there were 10 such episodes reported. It is more surprising to find, however, that four cases involving cockpit penetration by shell fragments were included in the non-combat data base. The following narrative taken from report of a peacetime training mission illustrates this:

> Aircraft struck by ricocheting 20 mm shell following training attack. Shell entered cockpit and canopy exploded. Forward cockpit pilot unconscious. Aft pilot initiated command ejection. Both successful. Much equipment damage/ many injuries.

It is apparent that any protection offered an aircrewman from cockpit battle damage during combat might have protective benefit for peacetime training missions as well.

Aircrew Assessment. Crewmen who regularly fly military missions are in an excellent position to assess their protection needs and to make recommendations concerning a life support system. User inputs are an essential part of any design process and provide a separate source of information to complement that offered by accident analyses.

The questionnaire completed by aircrewmen assigned to an East Coast Fleet Readiness Squadron asked for a rating of life support and protection dimensions in terms of importance (Appendix B), with dimensions specified as listed:

1. Protection of head from impact
2. Provision of oxygen (in pressurized cockpit)
3. Protection/maintenance of vision
4. Protection from fire
5. Restraint against aircraft maneuvering forces
6. Protection/restraint against emergency escape forces
7. Maintenance of auditory communication(s)
8. Protection from cockpit fragment/shell penetration
9. Control of cockpit temperature
10. Protection from cockpit noise

Results of the ratings by aircrewmen are presented in Figure 3. This figure shows that the three items considered most important by aircrewmen are "Protection/maintenance of vision," "Protection/restraint against emergency escape forces," and "Maintenance of auditory communications." It is interesting to note that two of these three items deal with maintenance of sensory capabilities. It would appear that the primary concern of an aircrewman is one of ensuring that his fighting capabilities are not degraded, i.e., it is most important that his sensory capabilities be maintained. Issues concerning body integrity, such as "Protection from fire" and "Protection from shell penetration" are considered of lesser importance.

Injury Patterns

Injuries sustained by aircrewmen during combat and peacetime missions and during aircraft emergencies provide useful informa-

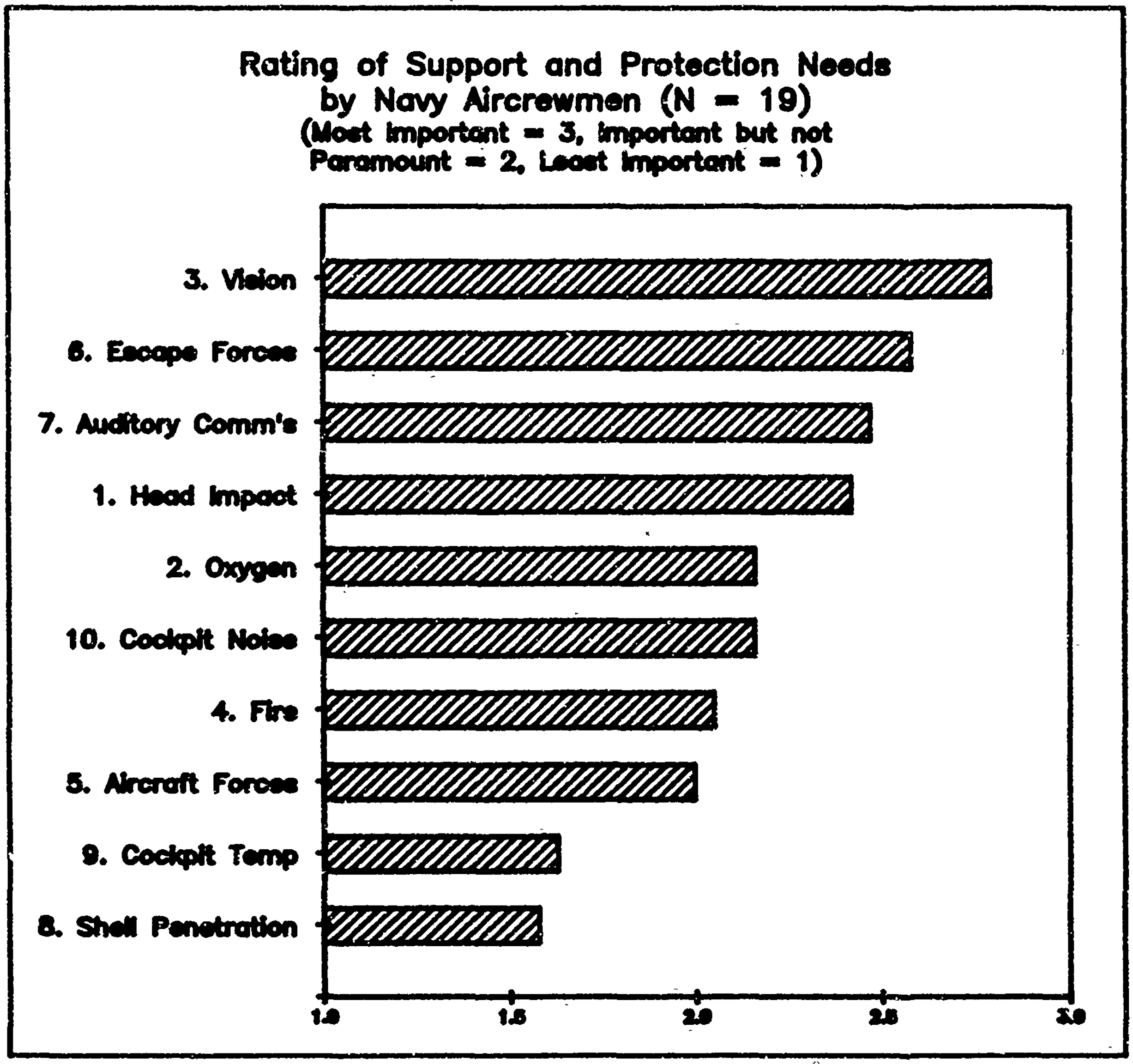


Figure 3

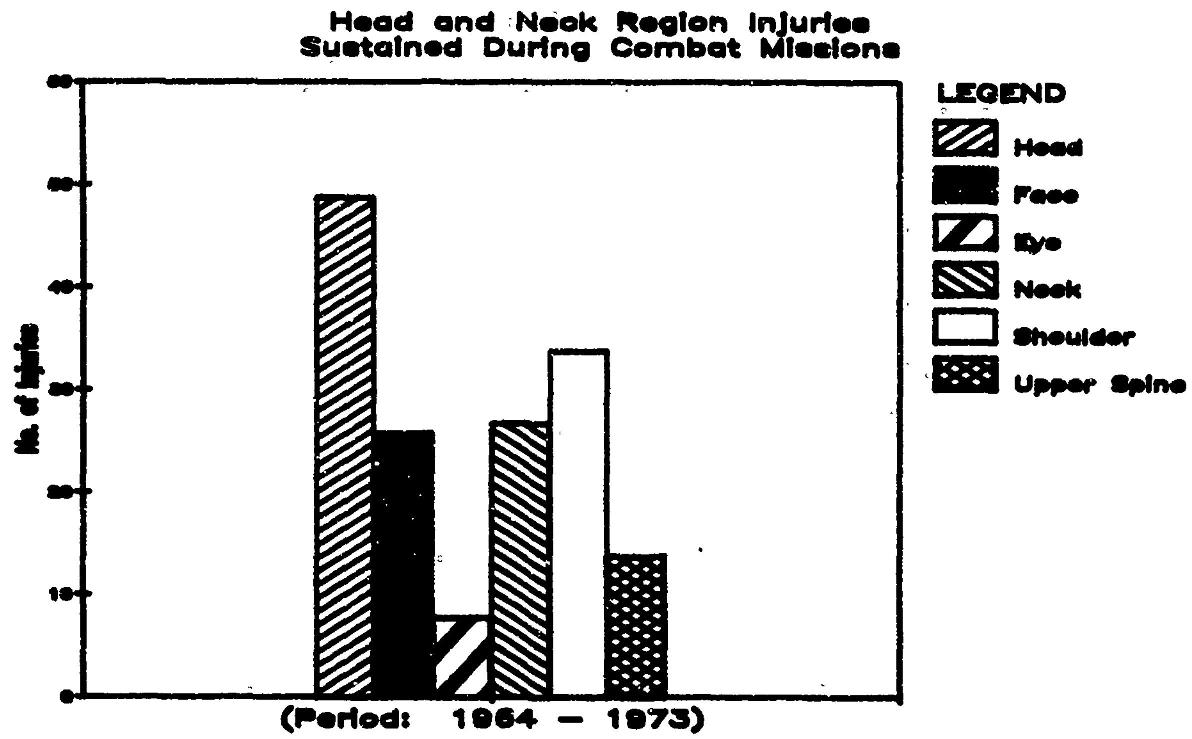
tion concerning the nature and magnitude of forces acting on the aircraft and the crewmember. While a primary purpose of a life support system is to prevent injury, the fact is that injuries do occur. Information concerning these injuries, and particularly any injury patterns that might be discerned, can be of considerable value in the development of new life support concepts.

The location of injuries suffered by aircrewmen in the head and neck region during both combat and non-combat missions is shown in Figure 4. Under conditions of combat, in which an aircraft might sustain serious structural damage, violent and unusual aircraft acceleration forces can result. It is not surprising, therefore, that injuries to the head (cuts, contusions, etc.) resulting from impact with cockpit structures represent the most frequently noted injury in the head and neck region.

During peacetime, Figure 4 shows that injuries to the head are not as dominant, with a greater proportion of shoulder and neck injuries being noted. A possible explanation for this shift is that the hardshell helmet is more effective against head injuries in the lower speed peacetime environment, particularly where the mean aircraft escape speed is less than 200 kts.

Aircrewman Condition

The condition of an aircrewman during an emergency is a matter of some concern, particularly if it becomes necessary for the crewman to assist in the rescue process. Richards (1982) reviewed Medical Officer's Reports from the Naval Safety Center covering 249 over-water ejections (1974-1979) and found that in this sample 84 percent successfully coped with survival stresses and were recovered alive. The majority of these crewmembers (N = 208), however, did encounter problems during the water survival phase that could have made them a fatality. In another study of 646 Navy aircraft mishaps, Voge (1985) found that in the survival phase - from clearance of the aircraft to arrival of rescuers - a


Head and Neck Region Injuries
Sustained During Combat Missions
LEGEND
Head
Face
Eye
Neck
Shoulder
Upper Spine
(Period: 1964 — 1973)

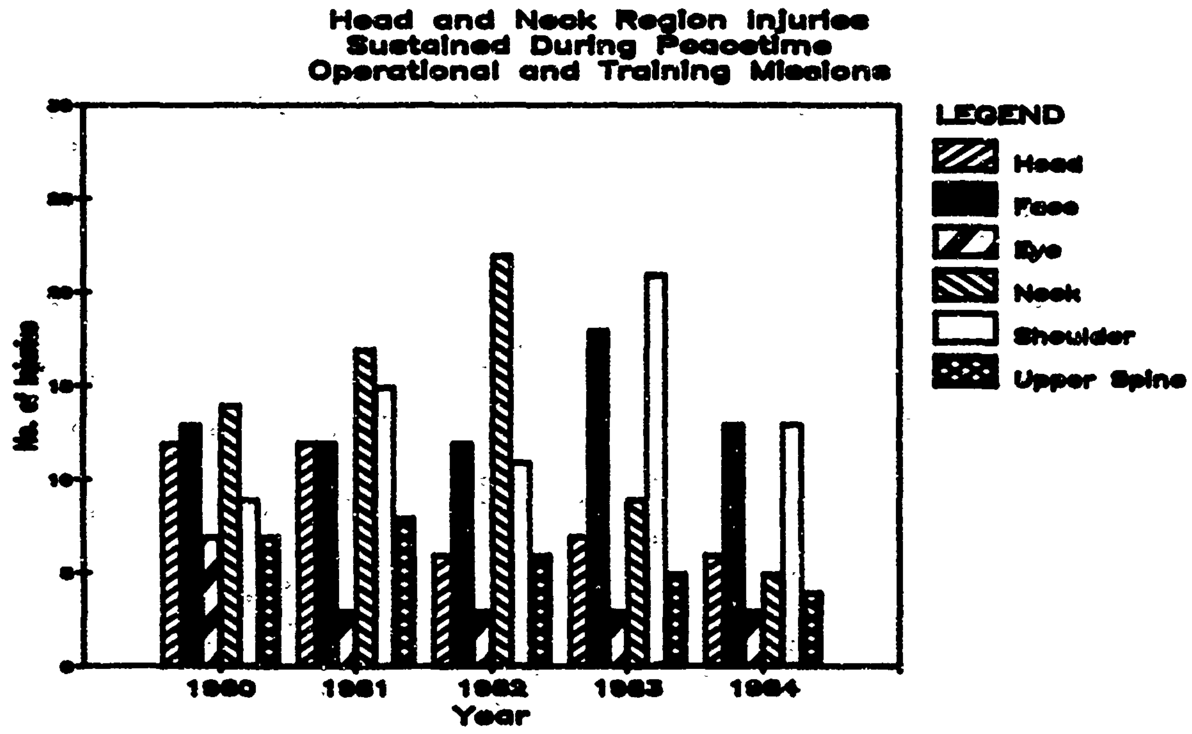

Head and Neck Region Injuries
Sustained During Peacetime
Operational and Training Missions
LEGEND
Head
Face
Eye
Neck
Shoulder
Upper Spine
1980
1981
1982
1983
1984
Year

Figure 4

significant problem was failure of the aircrewman to use accepted procedures. In a study of survival under combat conditions, Every and Parker (1973) reported a number of injury conditions which complicated rescue operations. In roughly 30 percent of the combat episodes, the survivor sustained a major injury.

In all of the studies cited above, difficulties were noted during survival and rescue phases. Causes for these difficulties included unanticipated conditions, failure to follow procedures, and injuries suffered by the crewman.

Injury condition of the aircrewman was a key item of interest in the present review of aircraft mishaps. During the initial input of combat data, project personnel were struck by the number of times the aircrewman was noted as "unconscious at some time during the emergency, emergency escape, or subsequent survival period." A comparison of the dimension of "unconscious" for combat escape versus escape occurring under peacetime conditions is of interest. Table 6 shows the number of combat and non-combat episodes of unconsciousness and the relation of these events to egress airspeed. Note that the rate of unconsciousness in combat (23 percent) is more than twice that found during peacetime mishaps (10 percent). This undoubtedly is due to the severity of combat emergencies as well as the increased airspeed at the time of ejection (average 410 kts versus 188 kts for peacetime). The clear relationship between occurrence of an unconscious episode and egress airspeed is shown in Figure 5. The "best fit" curve, based on an exponential regression analysis, shows the increasing likelihood of unconsciousness with increasing airspeed.

Table 6

Reported Loss of Consciousness
During Aircraft Emergency Escape

Number of Episodes

Combat - 32 of 137 (23 percent)

Non-Combat - 30 of 310 (10 percent)

Effect of Speed at Time of Ejection

Speed (kt)	No. of Cases*	Unconscious	Percent
0-100	75	5	7
101-200	137	10	7
201-300	75	7	9
301-400	61	9	15
401-500	65	19	29
501-600	15	6	40
601-700	5	1	20
701-800	2	2	100
Unknown	12	3	--

*Combat and Non-Combat cases combined

Impaired consciousness of aircrewmen, whether occurring during training missions or during or following aircraft emergencies, is receiving great attention today. New aircraft are capable of accelerative forces which extend well beyond human tolerance. The F-16 aircraft, for example, can maintain a 9 G turn indefinitely

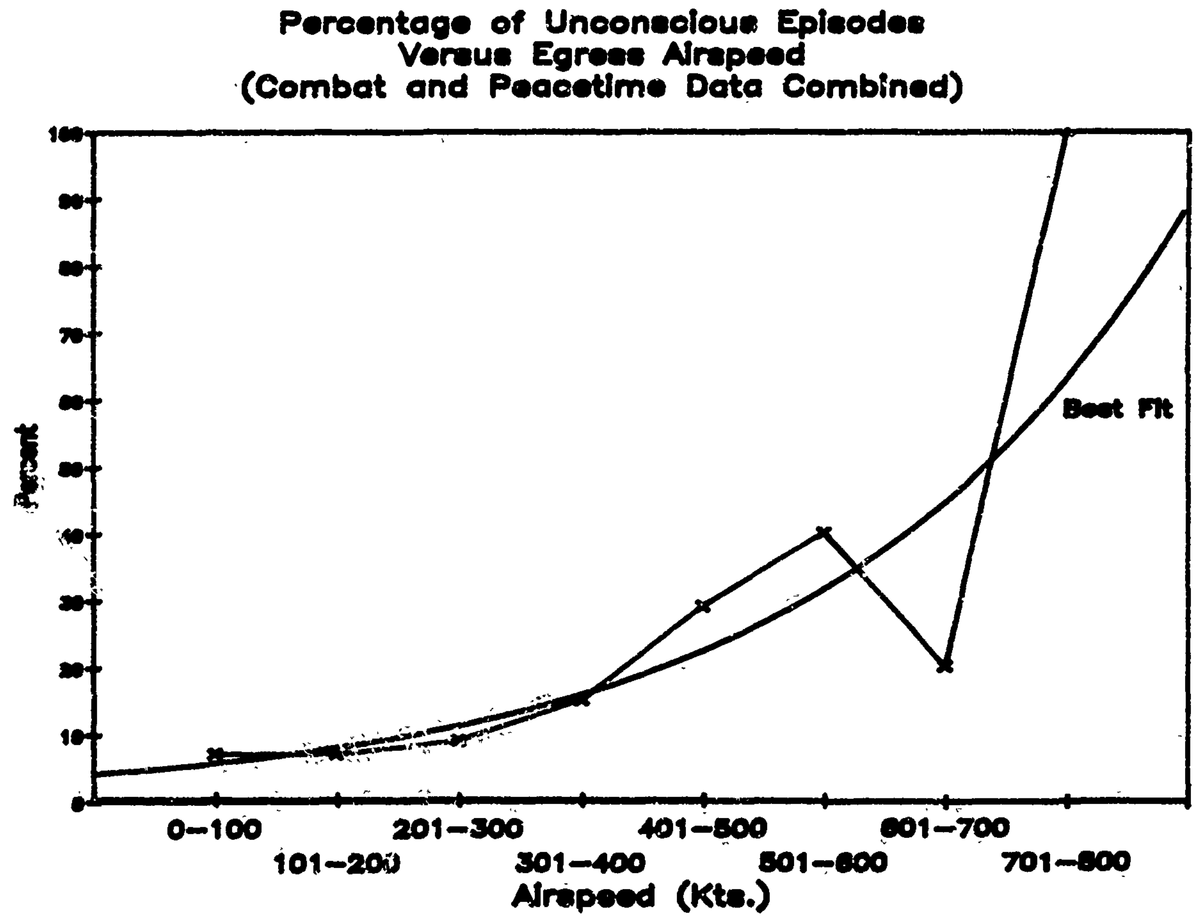


Figure 5

with a 6 G/sec rate of onset. High G turns at this level can be accomplished in several aircraft, although aircraft losses due to GLOC (G-induced loss of consciousness) have been verified only for the F-16 (Burton and Whinnery, 1985). These authors report a 12 percent rate of GLOC in Air Force aircrew incidents involving 12 different types of aircraft. This exactly matches the 12 percent rate found in a survey of naval aviators by Johanson et al. (1985).

The relatively low incidence of loss of consciousness noted above is supported by the present limited survey of F-14 aircrewmen in which most pilots said they never experienced "black-out" during ACM missions and only rarely experienced "grey-out" involving restriction and fuzziness of vision (response tallies shown in Appendix B). The incidence might increase, however, should these pilots transition from the F-14 aircraft to the F/A-18 with its high thrust-to-weight ratio and high G-onset rates. Johanson et al. (1985) found that reports of GLOC experiences per 10,000 hours for F/A-18 pilots were three times as frequent as those for F-14 pilots.

The episodes of altered consciousness noted during both combat and non-combat emergency escapes, plus the GLOC experiences of crewmen flying today's high-G performance aircraft, are quite relevant for the design of future life support systems. Any period during which consciousness is lost or cognitive functioning seriously degraded renders a pilot incapable of performing any precise sequence of activities. Recent studies have shown that a GLOC event can produce a period of total incapacitation lasting as long as 20 seconds, if G is "dumped" upon onset of incapacitation, followed by a significant reduction in capability that might well last for several minutes (Burton and Whinnery, 1985). The rise in in-flight GLOC episodes, coupled with the number of cases where loss of consciousness was identified during an aircraft emergency, justify a consideration of the requirements placed on an aircrewman during aircraft maneuvers as well as during aircraft escape and subsequent survival. The life support system should contribute to performance enhancement during acceleration manuevers by protecting against GLOC. The system also should not place undue performance demands on an aircrewman during aircraft emergencies.

Richards (1982), in a study of aircrew survival issues following emergency escape over water, found considerable variability in post-egress procedures taught to aircrew members by different training activities. On the basis of considerable experimentation, including live jump testing, Richards identified a standardized sequence of over-water post-egress actions to be followed in emergency escape, as shown in Table 7.

Table 7

Recommended Sequence of Over-Water Post Egress Actions by a Crewmember Following Emergency Escape

High-Altitude Post-Egress Procedure	Low-Altitude Post-Egress Procedure	
1	1	Inflate LPA
2	2	Deploy RSSK
3	3	Prepare to release canopy release upon water impact
4		Exercise descent options
5	4	Avoid the parachute canopy
6	5	Disentangle
	6	Exercise descent options

Descent Options (no priority)

- 0 Snap LPA lobes
- 0 Remove oxygen mask
- 0 Raise helmet visor
- 0 Activate 4-line release

(Richards, 1982)

As can be seen, this list of actions is reasonably demanding. The probability of successful escape and survival are enhanced if post-egress procedures are followed as shown.

Table 6 shows that almost one-quarter of all combat escape narratives list some period of unconsciousness. At whatever point in the escape sequence a loss of consciousness occurs, the result necessarily would be a lessened capability to follow the set of procedures identified by Richards. Survival chances would be correspondingly reduced.

The implications of the data on impaired consciousness and GLOC for life support system designers are straightforward. Systems should be made as automatic as possible. Any actions required of a crewmember during this period of stress and impaired capability may well be counterproductive. The age of micro-processors and automatic equipment operation must be reflected in life support system design to the fullest extent feasible.

The need for automatic systems is recognized by the Navy as shown by the introduction of the Sea Water Activated Release System (SEAWARS) into Fleet use in 1984. SEAWARS is an independent, self-contained device which automatically releases parachute canopy fittings upon sensing of sea water. It is designed to prevent the four to seven crewmember drownings due to parachute entanglement that occur each year following successful ejections. The value of this sytem was demonstrated amply in a 1985 rescue in which the operation of SEAWARS was credited with saving the life of an unconsciousness Navy pilot (Long, 1985).

The Timing of Life Support Requirements

A crewman manning a Navy aircraft usually is fully outfitted with all the protective and support equipment he might need at any point in his scheduled mission. An oxygen mask is worn even though the flight might be only to transport a fighter aircraft from one location to another. The hardshell protective helmet is worn throughout the mission. Protection is a full-time matter, even though full-time wear may exact some penalty in terms of general discomfort, increased fatigue, and reduced intra-cockpit mobility.

A central issue in this study was the identification of the timing of life support requirements. When does an aircrewman need protection? If a precise identification of need could be achieved, one might be more selective in meeting the need. A system would just provide protection when needed.

The philosophy of "protect only when necessary," if feasible, should represent a step toward a shirt-sleeve environment. A comment recorded from a VF-101 aviator stated "A shirt-sleeve environment would be fine as long as all necessary protection is provided, particularly for emergency escape."

In attempting to define the timing of life support needs, a number of measures were considered. The single best index of when protection is needed appears to be the mission phase during which aircraft emergencies and subsequent egress occur. This index has been plotted in Figure 6, presenting both combat and non-combat mishaps.

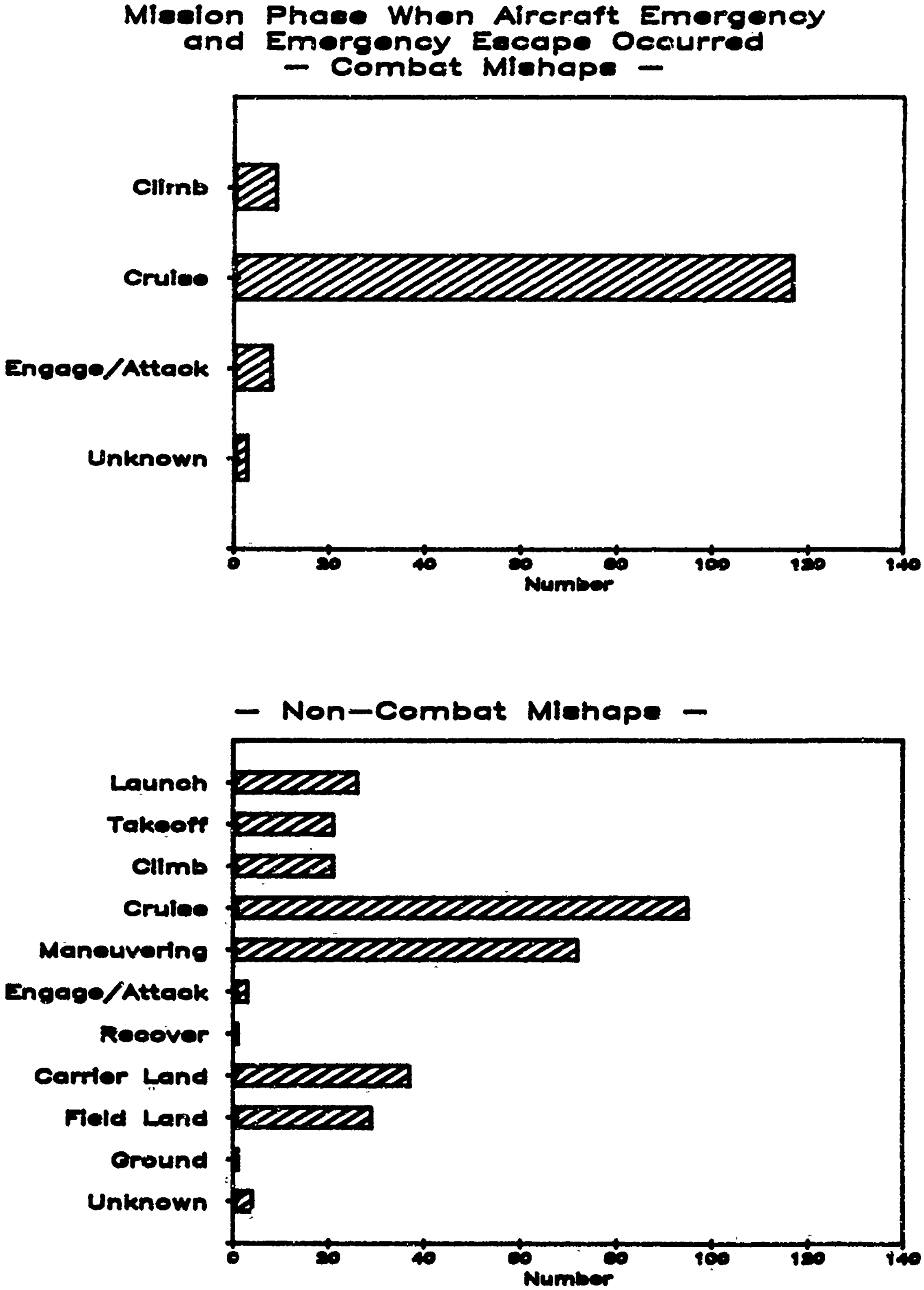

Mission Phase When Aircraft Emergency
and Emergency Escape Occurred
— Combat Mishaps —
Climb
Cruise
Engage/Attack
Unknown
0
20
40
60
80
100
120
140
Number
— Non-Combat Mishaps —
Launch
Takeoff
Climb
Cruise
Maneuvering
Engage/Attack
Recover
Carrier Land
Field Land
Ground
Unknown
0
20
40
60
80
100
120
140
Number

Figure 6

The data in Figure 6 describing combat episodes shows that by far the greatest number of mishaps occurred during the cruise phase. There appear to be two reasons. First, most aircraft were damaged by SAM missiles when either approaching or departing the target area. As soon as the aircraft was deemed uncontrollable, the pilot and crew ejected and subsequently became prisoners of war. Second, a large number of aircraft hit during the few minutes of the "engage/attack" phase crashed immediately, affording no opportunity for an aircrewman to become a POW.

The combat data in Figure 6 show no mishaps during "launch/attack" or "carrier/field landing" phases. Such events were considered operational mishaps and did not produce any POWs.

The phase during which non-combat mishaps occur is a more dispersed measure than found for combat. Again, Figure 6 shows that most episodes take place during the "cruise" phase. Close behind this is "maneuvering," which generally refers to Air Combat Maneuvering or similar training exercises in which the pilot/aircraft weapon system is pressed to limits of controllability. The one instance showing a mishap during the "ground" phase was purely and simply an equipment malfunction resulting in an unexpected ejection of an aircrewman.

The results seen in Figure 6 offer little support for the hypothesis that protection is needed only for very specific and limited phases of military missions, whether combat or non-combat. During the operational and training missions of peacetime, emergencies occur over the full range of mission phases. While protection needs may be more obvious during the violent maneuvering of ACM exercises, these needs cannot be neglected during other mission phases. In combat, as represented by Southeast Asia missions, most emergencies that resulted in POW situations occurred during the "cruise" phase, a rather extended period of flight. In all, results of this study do not suggest that the search for protection principles which are phase-specific will be profitable.

Head/Eye/Neck Protection

Physical protection of the head, eye, and neck region from impact is of paramount importance for an aircrewman. His information processing and cognitive capabilities, so vital to mission success, depend on physical and functional integrity of the head and eyes. Injuries to the neck can affect performance and even, under some conditions, produce unconsciousness.

The survey of environmental forces which impair performance or threaten injury, presented earlier in Figure 2, listed "Impact" as 7.6 percent for combat and 11.4 percent for non-combat missions. Impact forces, which might well be considered as one facet of the more frequently occurring "acceleration forces," do constitute a genuine hazard in aviation operations. Protection of some kind obviously is required. The real question is whether the hardshell helmet, with its burgeoning attachments, represents the best way to provide this protection in current and future aircraft.

Table 8 lists head/eye/neck injuries, plus instances of impaired vision, recorded for combat and non-combat. In by far the majority of occurrences, no injuries were noted. Where

Table 8

Head/Eye/Neck Injuries and Performance Impairment Recorded for Combat and Non-Combat Mishaps

Head Injuries	Combat (N=137)	Non-Combat (N=310)
Unconscious	32	30
Cut/Bruise	12	9
Concussion	4	1
Trauma	--	3
Fracture	1	--
None	88	267
Eye Injuries		
Hemorrhage	--	10
Burn	3	1
Laceration	--	4
Injury	1	4
None	133	291
Impairment of Vision		
Temporary blindness	5	--
Blurred	1	--
None	131	310
Neck/Upper Spine Injuries		
Cervical damage	7	5
Sprain/strain	14	43
Cut	9	10
Contusion	1	16
Burn	10	1

injuries or problems were listed, some patterns can be discerned. During combat it appears that the forces of the mishap and subsequent aircraft egress frequently operate to produce some period of unconsciousness. Impaired consciousness is by far the most likely outcome of trauma to the head region. For eye injuries, most frequent, at least in peacetime mishaps, is the hemorrhage caused by excessive acceleration forces. The most frequent injury to the neck/upper spine region is a sprain or strain, most likely caused by ejection forces and windblast. In the combat data base, ten instances of neck "burn" were recorded. Supporting narratives described fire in or around the cockpit area in seven of these ten cases.

The neck injuries recorded in the combat and non-combat data of this study all were associated with forces encountered during ejections from disabled aircraft. Serious neck injuries also can occur as a result of inflight maneuvering stresses. Schall (1983) describes an instance in which an F-4 instructor pilot injured his neck during a training mission and subsequently became partially paralyzed. The pilot sustained cervical fractures apparently when his helmet struck the cockpit canopy during an unanticipated negative G maneuver.

A study by Guill (1983) reviewed Naval Safety Center data for ejections occurring between 1 January 1969 and 31 December 1979, with particular attention given to neck injuries. During this time, 1,188 ejections were reported as having been accomplished within the escape system's performance envelope. For these ejections, 135 cases of moderate or severe neck injury were recorded, for an injury rate of just over 11 percent. This compares to neck/upper spine injury rates of 30 percent for combat and 24 percent for non-combat escapes found in the present study. These rates suggest a higher incidence of neck injury for non-combat ejections in the 1980-1984 time period (present study) when compared with the 1969-1979 data (Guill study). However, since the Guill study focused on neck injuries requiring grounding, hospitalization, or extended care and did not include lesser injuries (contusion, lacerations, abrasions, etc.), the difference in injury rates would appear to be artificial.

Head and neck injuries, including those to the eye, occur as a result of extreme forces encountered by an airman while attempting to fly a disabled aircraft and during the emergency escape phase. The injury rate undoubtedly would be higher were it not for the protective system now in use. The hard-shell helmet with its visor is the major component for protecting the head and eyes. The combat and the non-combat data bases provide information concerning the manner in which mishap forces act on helmets as well as the general performance of helmets during an aircraft mishap.

The results presented in Table 9 show that no significant problem is noted with the protective helmet in most combat and non-combat mishaps. In combat, the biggest problem is that helmets are lost at some point during the emergency. In examining these data, however, one should keep in mind that the combat information on which this table is based was provided some years after the event. Recollections concerning helmet performance may be hazy at best, especially if there was some period of unconsciousness.

Table 9

Helmet Performance Problems
Noted for Combat and Non-Combat Mishaps

Problems	Combat (N=137)	Non-Combat (N=310)
Lost	16	52
Rotated	6	22
Damaged/Failed	2	24
Discarded	6	3
Burned	--	1
Maintenance Error	--	1
Helmet Noted to Have Performed Well	3	7
None	104	200

In non-combat mishaps, the major problem once again is that the helmet was lost at some point. The remaining two problems of significance are that the helmet was severely damaged or failed and that it rotated during egress, thereby producing or threatening head injury. In both data bases, there are specific instances in which the helmet was noted to have performed well, implying, if not stated definitely, that use of the helmet prevented the crewman from suffering a head injury.

The mishap reports seen in Tables 8 and 9 reflect the performance of protective helmets during aircraft emergencies involving crew escape. A better understanding of helmet adequacy is obtained when the above data are supplemented by reports from the user population, i.e. squadron aircrewman comments concerning problems encountered in the day-to-day wear of these helmets. Table 10 summarizes problems described by aviators in Fleet

Readiness Squadron VF-101. Due to the small number of crewmen interviewed (19), differences in the number of times a problem category was cited are of no great significance.

Table 10

Helmet Problems
Identified by Aircrewmen
(N = 19)

Problems	No. of Reports
Poor hearing protection	6
Comfort (hot spots, chinstrap, etc.)	5
Field of vision (rotates in ACM, etc.)	5
Weight	3
Fit (sizing problems)	3
Vision restriction	3
Visor operation (2 hands)	3
No problems	1

It is interesting to note, however, that 18 of the 19 crewmen (95%) did note one or more problems with the current helmet. These problems can be summarized as relating to "hearing protection," "comfort," "vision restriction," and "operation of the visor system."

The helmet problems found during aircraft emergencies as well as those cited by aircrewmen are issues which should be addressed by life support equipment designers when new helmets, such as that under consideration to support night vision devices, are fabricated. Progress with respect to the problems noted in this report will not be easily achieved. Adding additional systems, such as night vision devices, to the existing helmet configuration could greatly exacerbate the problems already identified.

Provision of Oxygen

One of the most direct requirements placed on an Aviation Life Support System is to provide oxygen during high altitude flight. In meeting this requirement, the crewman's personal oxygen system is redundant since the pressurized cockpit provides an adequate oxygen supply under routine circumstances. The requirement for a personal system thus must be evaluated in terms of support provided during a variety of emergency scenarios versus the comfort and vision-restriction problems caused by wearing an oxygen mask.

An emergency at high altitude requiring immediate escape from an aircraft is a situation in which an aircrewman would need a continuing supply of oxygen until he descends to an altitude where atmospheric pressure, and consequent oxygen supply, is sufficient to sustain consciousness. High altitude in this case would seem to refer to 30,000 feet and above. At 30,000 feet, an individual suddenly decompressed to ambient pressure, as would be the case in emergency egress, would have a time of useful consciousness ranging from 45 sec. to 1 min., 15 sec. (West et al., 1972). Since the crewman's time to free fall to 14,000 feet, the altitude at which the automatic parachute ripcord release assembly (APRRA) operates, is 60 sec., one can presume there would be no loss of useful consciousness during an emergency escape at 30,000 feet if the crewman has no personal oxygen supply during the descent. If parachute opening were to take place immediately after ejection, however, there could be loss of useful consciousness.

Data showing altitude of ejection for both combat and non-combat emergency escapes are presented in Table 11. This table shows that the highest escape altitude recorded for combat was 20,000 feet. For non-combat mishaps during this period, there were a total of seven ejections between 24,000 and 26,000 feet. For the data base of this study, the incidence of escape in the 24,000 - 26,000 foot range is in the order of two percent. Data from the Naval Safety Center (Thornton, 1986), however, do list two ejections from Navy aircraft in 1969 at 30,000 feet.

Table 11

Emergency Escapes from Aircraft
at Altitudes of 20,000 Feet and Higher

Altitude	Combat (N=137)	Non-Combat (N=310)
20,000 - 20,999	6	1
21,000 - 21,999	--	--
22,000 - 22,999	--	1
23,000 - 23,999	--	--
24,000 - 24,999	--	3
25,000 - 25,999	--	2
26,000 - 26,999	--	2

The above data show very few Navy ejections at high altitude. In fact, the typical ejection occurs at 4,000 to 5,000 feet (Table 4). The case for emergency bailout oxygen therefore does not appear to be strong. There are, however, other emergency conditions to be considered. One of these is the case in which an aircrewman must escape from an aircraft which is in the water and sinking. Is an emergency supply of oxygen necessary in those situations where an aircraft has just gone into the water? Here, there are limited numbers on which to base a decision. The last Navy underwater ejection occurred in 1975, with only nine such ejections occurring from 1957 until 1975. There have been 12 underwater egress events from Navy ejection seat aircraft from 1964 through 1984 (Thornton, 1986).

Data for non-combat mishaps in the present study show that approximately 50 percent of all emergency escapes result in a parachute landing in the open sea (Table 12). Open sea conditions can be quite severe, often with waves continuously breaking over the survivor. Parachute entanglement or other equipment problems can make survival tenuous, although survival prospects are better since the introduction of the automated parachute release system (SEAWARS). In any event, under the circumstances of an open ocean landing, emergency oxygen could be quite useful. The following brief narrative, taken from one of the non-combat mishaps, illustrates:

> CV arrestment. Aircraft engaged No. 4 cross deck pendant. Purchase cable parted due to two-blocking of engine. Aircraft departed angle deck below flying speed. Crew ejected safely. Pilot regained consciousness underwater. No trouble breathing with A-13A mask.

Table 12

Type of Terrain Encountered
Following Emergency Aircraft Escape
Under Non-Combat Conditions

Terrain	Number
Open sea	152
Lake	8
Shallow water	5
Swamp	8
Hard ground	43
Soft ground	34
Flight deck	7
Trees	16
In/near fireball	2
Desert	18
Mountains	4
Rocks	4
Dense woods	1
Runway	8
Total	310

Having reviewed data concerning oxygen requirements for emergency situations, it is appropriate to consider the advantages and disadvantages of oxygen use for normal flight conditions. The provision of a continuous supply of oxygen through the current delivery system is not without its penalties. Table 13 lists problems recorded with the oxygen mask during both combat and non-combat ejections. As with the protective helmet, most mishap reports list no problem with the oxygen mask. Where problems are identified, the most frequent occurrence is loss of mask at some point during the emergency. In non-combat events, dislodging of the mask also is a frequent event. Both problems point to mask retention as a key issue with the current delivery system.

Table 13

Problems Recorded for Oxygen Masks in Combat and Non-Combat Mishaps

Problems	Combat (N=137)	Non-Combat (N=310)
Lost	14	36
Damaged/Failed	6	21
Dislodged	--	17
Inadvertent Release	--	12
Discarded	3	10
Not in Place	2	4
Entanglement/Disconnect Difficulty	--	4
Fire	--	2
Improper Use	--	2
Performed Well	1	3
None	111	199

The present oxygen mask is designed for full mission use. However, interviews with squadron personnel show wide variation in the extent and manner of actual use. For example, some crewmen wear the oxygen mask only during takeoff and landing and for radio communications. Inasmuch as use now is not continuous, squadron personnel were queried concerning preferences for a system which provides oxygen only as needed versus the current system designed for continuous use. Results are presented in Table 14 and show that aircrewmen apparently would prefer a system which provides oxygen only as needed, much as that in commercial airline operations today.

Table 14

Aircrewman Preference Concerning
System Providing Oxygen Only as Needed
(N = 19)

Choice	Number Expressing This Preference
"As Needed" System Desirable	12
Prefer Current System of Continuous Oxygen	5
No Preference	2

Section VI
Summary and Conclusions

This project examined the life support and protection needs of Navy aircrewmen flying high-performance aircraft equipped with automated escape systems. A principal objective was to develop a broad base of information relating to the need for life support. From this information, guidelines supporting a future Aviation Life Support System were developed. In order to retain a reasonable project scope, attention was given only to life support and protection requirements for the head and neck body region of an aircrewman.

The project was oriented to requirements per se and not to current life support equipment configurations. Although it is difficult to examine protection requirements without considering protection equipment, no systematic evaluation of current items of equipment was conducted.

A second project objective was to develop an information management system whereby a designer might have rapid access to the full range of information necessary to support life support design decisions. Three data bases were constructed describing (1) combat aircraft mishaps, (2) peacetime operational and training aircraft mishaps, and (3) responses of Navy aircrewmen to a structured questionnaire/interview session covering life support and protection issues. The data base structure is relational and allows all data bases to be examined together during a single data query. Examination of the three data bases supports the following conclusions:

Aviation Life Support and Protection Requirements

Results of this study reinforced findings of previous investigations that the conditions of a combat emergency aircraft escape are different and considerably more severe than those under peacetime conditions. Average combat escape speed was 410 knots, more than 200 knots greater than the average non-combat speed of 188 knots. However, even with these differences there appear to be two protection requirements which stand out for both combat and peacetime emergencies.

Acceleration Forces. Many mishap reports show that violent or unusual aircraft acceleration forces during the period of emergency caused injury or, more likely, impaired the aircrewman in his escape efforts. These reports frequently show a problem in the ability of a crewman to reach the face curtain or ejection handle or that injury was caused by impact against cockpit structures as a result of acceleration forces. In combat, acceleration forces were recorded as causing a serious problem in 44 percent of the mishaps. For non-combat mishaps, acceleration forces were recorded for only nine percent of the events. Even so, this environmental force remains as one of the two most important.

The findings concerning acceleration forces indicate that a first order requirement for any Aviation Life Support System is to provide appropriate restraint against the unusual forces encountered in aircraft emergencies and during emergency escape. Use of dynamic restraint, capable of drawing a crewman back into a normal seated position during periods of negative G when he cannot reach lower controls, is an avenue. Consideration also might be given to head restraint, instead of relying so much on the hard-shell helmet, for protection against buffeting impact during violent accelerations.

A number of Navy development programs are addressing problems of crewman restraint in newer aircraft (Vollmer and DeSimone, 1984). These include a passive arm restraint, an aircraft minus 0.7Gx acceleration sensitive inertia reel locking mechanism, and improved minus Gz restraint. A restraint system employing inflatable bladders designed to reduce head rotation and displacement during impact has been developed in a joint Army/Navy effort.

Fire. It is not surprising that under combat emergency conditions fire, or heavy smoke, in or around the cockpit area is encountered frequently. Combat records show that fire or dense smoke was reported in 26 percent of the mishaps. Many times, this occurred immediately after missile damage. In non-combat mishaps, fire or smoke was reported in ten percent of the cases. Considering that battle damage usually is not found in non-combat mishaps, this rate is higher than might be anticipated.

Fire within the cockpit is very serious. Results of this study show that this situation occurs with sufficient frequency to be given careful consideration in the design of any new ALSS. Since it may not be possible to preclude fire due to the nature of aircraft operations and the fuels used, great care should be taken that all life support items are fully fire resistant. Use of a cockpit fire retardant gas, if feasible, might also offer protective benefit.

Crewman Condition

The condition of an aircrewman during an aircraft emergency is a matter of concern, particularly since he may need to deploy or activate items of survival equipment during descent as well as assist in the rescue process. Injury condition of aircrewmen was a particular item of interest during this study. One of the most important findings was the number of instances in which some period of "impaired consciousness" or "unconscious" was listed for crewmen. Twenty-three percent of all combat mishaps recorded some period of unconsciousness. These lasted from a matter of seconds to, in one case, a duration of four days. Under non-combat conditions, even when Air Combat Maneuvering is involved, the frequency of unconsciousness drops to ten percent, a rate still considered high.

The fact that unconsciousness is a frequently found condition in aircraft emergencies, occurring in roughly one-quarter of all combat episodes, is a finding of consequence for the design of life support equipment. Once the decision to eject is made and escape initiation completed, all actions should take place on an automatic basis. The more that is required of a crewman, the lower the chances for a successful escape. A 1982 report (Richards) shows that Navy aircrewmen are trained to accomplish six or more actions during the period of descent following an ejection. Since then, the SEAWARS automatic parachute release system has been introduced into the Fleet, representing a significant step toward reducing the number of required crewman activities and thereby improving chances for a successful emergency escape and survival.

Timing of Life Support Requirements

A central issue in this study was the identification of the timing of life support requirements. The question asked was "Does an aircrewman need to wear all of his protective equipment at all times?" If a precise identification of need could be achieved, one might be more selective in meeting the need.

Results show that injuries to aircrewmen, particularly head impact injuries, while not evenly distributed, do occur during all phases of a mission. Impact protection appears to be required at all times. This is not the case, however, for the oxygen mask. A review of oxygen mask requirements, supported by comments of aircrewmen, indicate a system whereby oxygen is provided on an "as-needed basis" might be preferable to the current system of continuous delivery.

Impact Protection

Protection of an aircrewman from impact injury to the head, eye, and neck region is of greatest importance. Mission success depends on physical and functional integrity of the head and eyes. Protection of the neck is necessary to sustain performance capability and consciousness. At this time, protection for this body region is provided through continuous wear of a hard-shell helmet, designed primarily to withstand impact forces and now serving a variety of additional purposes.

Mishap data document that the current helmet does protect an aircrewman from impact injury in many instances. In operational and training mishaps, the helmet was noted as "damaged" or "failed" in eight percent of the cases. The forces that caused this helmet damage would have been transmitted directly to the head without helmet protection. In addition, in two percent of the cases the helmet was noted as having "performed well," presumably having prevented serious impact injury. Thus in at least ten percent of these events, the helmet is serving a very useful purpose.

The converse side of the picture shows many problems with hard-shell helmets. In non-combat mishaps, the helmet is either lost or rotates, causing injury, at some point during 24 percent of these events. In addition, squadron personnel report many difficulties with the helmet involving hearing protection, comfort, and restriction of vision.

Designing an improved system to provide impact protection for the head and eye region represents possibly the most difficult task facing life support engineers. The current hard-shell helmet achieves its design goal of providing impact protection to some extent, but certainly not completely. Unfortunately, it also serves as a mounting platform for a variety of devices such as visors, oxygen masks, communications devices, earcups, and possibly even night vision systems. Abandoning the helmet for a seat-mounted rigid-restraint system would leave no place for these devices. In addition, any fixed restraint or impact protection system will adversely affect vision. The problem will not be easily solved.

Protection of Neck Region

Injuries to the neck, as they occur both in combat and in peacetime training missions, are classified principally as sprain/strain injuries. The unusual acceleration forces found with a disabled aircraft and during emergency escape appear to be the cause, suggesting issues of restraint rather than impact protection. Severe neck injuries, including cervical fractures, can result solely from torsional forces. Huelke et al. (1979) describe a review of highway trauma events in which 78 cases were identified as cervical fractures and/or dislocations sustained by inertial or acceleration loading of the neck and not by direct impact to the head or neck. Such outcomes may be even more likely in aviation due to the higher speeds and greater acceleration forces.

Reports of escape from disabled aircraft during combat list a number of neck "burns" suffered by crewmen. These appear to be the result of cockpit fires rather than being abrasive burns caused by harness straps or similar items. These instances lend additional support to the case for fire protection made earlier.

Oxygen Delivery System

The provision of oxygen to an aircrewman, an obvious necessity, is complicated by the fact that two systems are in use. The pressurized cockpit provides an adequate oxygen supply under routine circumstances even at high altitude. The life support issues concern the requirement for a personal oxygen supply to supplement the cabin supply and the best method for delivering this oxygen.

The customary justification for a personal oxygen system is in the possibility of sudden decompression or emergency escape at high altitude. Results of this study indicate the circumstances of combat and non-combat mishaps rarely, if ever, require use of oxygen. Maximum ejection altitude noted for combat is 20,000 ft. and for non-combat 26,000 ft. In an ejection at the higher of these altitudes, presuming some free-fall period prior to parachute deployment, there should be no loss of useful consciousness due to lack of oxygen.

Use of personal oxygen during an underwater emergency escape also is cited as justification for this system, although there is no official Navy requirement for an underwater breathing capability in Navy aircraft. This justification is tenuous. The last Navy underwater ejection occurred in 1975. Between 1964 and 1984, there have been 12 instances of underwater egress from a sinking aircraft in which the personal oxygen supply may or may not have been essential to survival. In any event, the new automatic inflation system for personal flotation may make underwater egress easier.

There is, however, the case of the crewman who parachutes into the open ocean. Here, a personal oxygen system may be of considerable value as high waves break over the survivor and he deals with possible equipment problems. Several cases in the non-combat data base document use of the current emergency oxygen system during the initial stages of survival.

In normal conditions of use, a number of problems are encountered with current oxygen systems and masks. Aviators, by and large, are not fond of the mask. One aircrewman, perhaps with a touch of hyperbole, referred to the oxygen mask as "the worst piece of equipment in the airplane." Most problems focus on the comfort of the mask and the fact that it tends to slip under G loading and interfere with a crewman's field of view. In addition, there is the matter of fire in the cockpit, which occurs not infrequently and could be made more dangerous by a cockpit oxygen supply.

Consideration should be given to a personal oxygen delivery system which is available on an "on-demand basis." Aircrewmen indicate they would prefer such a system. This system would be available for emergencies; it could be worn continuously during an extended high altitude flight to provide nitrogen washout as a precaution in the event of sudden decompression; and it could be used when an aircrewman desires a period of 100 percent oxygen to alleviate fatigue symptoms.

Problems of discomfort and interference with field of view would be lessened with an on-demand system. There also might be, according to aircrewman reports, a positive benefit on mission performance if the mask were not worn during critical mission periods. However, emergency oxygen should be available, and the delivery system in place, when a crewman makes a parachute entry into open ocean.

Information Management

Design of an advanced aviation life support system to meet the needs of Navy aircrewmen in future aircraft must draw on many sources. The specification of life support and protection needs should reflect the full range of operational and emergency situations experienced or anticipated in the future and should also draw on the experiences and expressed preferences of aircrewmen. The design task will be more efficient and more effective if needed information is immediately available and in a format which can be readily used.

A major objective of this study was to develop a prototype information management system incorporating data from diverse sources and allowing immediate access to these data as project questions dictated. Data bases were developed describing (1) combat mishaps, (2) peacetime operational and training mishaps, and (3) responses of Navy aircrewmen concerning life support and protection issues. The information system was structured to provide information bearing on project questions directly and with little requirement for data manipulation. The three data bases are relational and can be examined together during a single data query. Summary statistics and cross-tabulations can be obtained quickly. If desired, individual cases and narratives can be brought on-screen at any time during the course of an inquiry.

The information management system developed in this study was used to examine a number of topics concerning life support and protection of aircrewmen. The system will allow the examination of more such topics, if desired. For maximum utility, data bases describing (1) the characteristics and capabilities of next generation Navy aircraft and (2) scenarios under which Navy aircraft might operate in the future, including missions under biological and chemical warfare conditions might be added. With incorporation of these data bases, and continuing improvement in the computer procedures for data management, this information system should offer significant support to the community of life support designers and engineers.

Life Support and Protection Requirements Overview

The findings of this study are based on information taken from several data sources: (1) reports of emergency escape from Navy aircraft under the combat conditions of Southeast Asia, (2) reports of peacetime operational and training emergency ejections, and (3) structured interviews with aircrewmen flying the F-14 fighter aircraft. The primary question addressed was "What can we conclude now, based on these diverse data sources, as to what the principal dimensions of an advanced life support and protection system for Navy aircrewmen should be?"

An overview of the derived life support and protection requirements is presented in Table 15. In keeping with project constraints discussed earlier, these requirements are directed solely to the head, eye, and neck region of an aircrewman.

The first consideration with any advanced Aviation Life Support System (ALSS) must be the impact of the system on crewman performance. Completeness of protection must not be achieved at the expense of the crewman's ability to operate aircraft systems and to perform at maximum effectiveness under combat conditions. If possible, the ALSS should contribute to performance. A system in which the ALSS increases crewman tolerance to maneuvering acceleration forces, for example, might be considered as contributing to crewman performance.

Table 15

Overview of
Life Support and Protection Requirements
- Head, Eye, and Neck Region -

General Requirements

0 Performance and sensory capabilities

- Maintenance/enhancement of vision, audition, and cognition

0 Acceleration forces

- Protection against unexpected, excessive and sustained forces

0 Fire

- Provision of both fire protection and fire retardent systems

0 Automation

- Use of automated systems as feasible to counter effects of periods of altered consciousness

Specific Requirements

0 Head and neck impact protection

- Protection during all mission phases with consideration of alternatives to hard-shell helmet

0 Oxygen provision

- Consideration of new delivery systems as well as on-demand provision of oxygen.

The need to maintain performance capability was expressed as paramount in interviews with aircrewmen. They were particularly concerned that any system not operate to degrade the primary sensory modalities, i.e., vision and hearing. Their responses made it clear that maintenance or even enhancement of sensory efficiency, with its obvious importance for combat effectiveness, took precedence over other and more direct issues of protection.

Protection against direct threats (high acceleration forces, fire, impact, etc.) should be addressed within a coordinated total systems approach in which the protective qualities of any single component of the ALSS do not lessen overall ALSS performance. A component which protects the head from impact injury cannot increase the risk of neck injury when the crewman operates in a high G environment. Each protective component must operate as an integral element in a larger system, supporting all other elements.

The requirements shown in Table 15 represent a point of departure for consideration of a new ALSS. Since the project focused on head, eye, and neck protection only, issues such as body thermal control during water survival and limb flail during emergency egress, while of great importance, are not addressed. In addition, advanced scenarios in which laser weaponry might be employed were not reviewed. The importance of such issues, however, is recognized.

The life support and protection requirements identified in this study represent a step toward development of an advanced Aviation Life Support System. With a priority listing of requirements, a systems approach can be employed in which design attention is given to requirements rather than to upgrading of existing equipment. Through such a systems approach, the performance of an Aviation Life Support System of the year 2000 should complement and support the aircraft operating at that time. The result will be a complete weapon system with a synergism among all operating subsystems.

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APPENDIX A

BioTechnology, Inc. Data Base
Data Entry Form

Date Entered
/ /

AVIATION LIFE SUPPORT SYSTEMS
- Event -

Name: (No Entry)
Rank: (No Entry)
Aircraft:
Mission:
Occupants:
Airspeed: kts
Attitude:
Mishap Severity:
Location:
Temp Air: Deg.F
Recovery Time: Min.

Case No.:
Date of Mishap: / /
Class:
Mission Phase:
Crewman:
Altitude: ft
Ejt Method:
In Envelope?:
Terrain:
Temp Water: Deg.F
Rec. Vehicle:

Brief Narrative:

- Injury Circumstances - Pg 2

Emergency Escape Phase, if any, in which injury occurred:
Body Integrity Factors: Windblast:
Physiological Integrity:
Performance Integrity:
Injury Severity:

- Injury Dimensions -

Cause

Head:
Upper Spine:
Vertebra:
Shoulder:
Eye:
Face:
Neck:
Vision:
Hearing:

- Reported Equipment Performance -

	Type	Direction	Performance
Ejection Seat:			
Helmet:			
Visor:			
Oxygen Mask:			
Oxygen System:			
Canopy:			
Face Curtain:			
Radio:			
Parachute:			

What was the role of the ALSS in this event:

Significant Protection:
Useful/As Advertised:
Some Problems:
Played No Part:

APPENDIX B

Questionnaire/Interview Form
used with East Coast Fleet Readiness Squadron

Demographic Information

Navy DAta

Squadron	(Not relevant for this report)
Rank	(Not relevant for this report)
Designator (Please Check)	
Naval Aviator	13
Naval Flight Officer	4
Other	2

Flight Experience

Total Flight hours	Mean = 2139 hrs
Aircraft currently flown	F-14
Other aircraft (More than 100 hrs)	

Personal Data

Age	Mean = 32 years
Height	Mean = 71"
Weight	Mean = 171 lbs

Head Protection

1. During Air Combat Maneuvering, how frequently does your head strike some part of the cockpit?

   Never 2 Frequently 5
   Rarely 10 Every Flight 2

2. During what phase of a flight do you feel you most need head protection? (Check one or more)

   Takeoff 3 Climb 0 Cruise 0
   ACM/Attack 4 Descent 0 Land 1
   Emergency Escape 17 Parachute Descent/Landing 13
   None 0

3. What helmet do you wear now? Navy Form Fit = 18; Other = 1

4. How do you rate your helmet for:

   Weight: Too heavy 3 Heavy but ok 8
   Not noticeably heavy 4 No problem 4

   Stability: Unstable 0 Some rotation 5
   Slight rotation 8 Very stable 6

   Comfort: Very uncomfortable 1 Some problems 4
   Fairly comfortable 10 Quite comfortable 4

5. What particular problems do you have with your helmet?

   Poor hearing protection (6); comfort (5); field of vision (5); weight (3); fit (3); vision restriction (3); visor operation (3); no problems (1).

6. Have you ever suffered a head injury during a flight?

   Yes 0 No 19

   If yes, describe: ______________________________

7. Would you be happy without a hard-shell helmet if all necessary support and protection were provided in some other manner?

   Yes 14 No 3 Undecided 2

Oxygen/Respiration

1. When do you use your oxygen mask? (Check as many as desired)

   At all times 7 Takeoff and landings 11
   During ACM/attack 11 Only for radio use 5
   Occasionally 0 Other (Describe) No entries

2. If the microphone were elsewhere, how often would you wear the oxygen mask?

   The same 5 Less 13 Never 1

3. How would you feel about a system which provides oxygen only when needed?

   Desirable 12 No real preference 2
   Prefer current system of continuous oxygen 5

Vision

1. What problems do you have now during a mission with vision or vision protection?

   Visor operation/availability/vision through (9); vision obstruction, 02 mask, helmet (4); problems with visors and glasses (4); none (2)

2. How frequently do you use the sun visor (during day missions)?

   Continuously 10 Only in ACM/Attack 1
   Occasionally 6 Never 2

Vision (Cont'd.)

3. Have you ever had a canopy bird strike?

Yes 4 No 15

If yes, how many? Total of 8

4. Would you fly with night vision goggles?

Yes 5 No 4

If they could be used just as needed 6

Undecided 2 Other (explain) 2 (1) Would depend on the mission; (2) If lightweight and comfortable, yes.

5. Would you fly with a full-face helmet?

Yes 9 No 7 Undecided 3

Other (Explain) No entries

General

1. Have there been any instances in the past two years when something has happened during an ACM/attack mission that was not reported through normal medical channels (sore neck, etc.)?

   Yes 12 No 7 If yes, describe: Strained neck (8); back and shoulder muscle strains (harness) (4); pinched neck nerve (1); sore eyes (1)

2. Do you recall any instances when some feature of the life support system (helmet, visor, O2 mask, restraint, etc.) interfered with your flight performance?

   Yes 19 No 0 If yes, describe: Communications (comm. cord hangs up, comm. failure, etc.) (8); vision (O2 mask/helmet slip, etc.) (7); movement interference (restraint system locks, etc.) (7); equipment problems (O2 mask disconnects, etc.) (6).

3. On what percentage of ACM/attack missions do you experience any period of "blackout?" (Circle one)

0% = Never (14)	30 (1)	60	90
10 (4)	40	70	100% = Every flight
20	50	80	

4. On what percentage do you experience "grayout?" (Restricted vision, fuzziness, etc.)

0% = Never (2)	30 (3)	60	90 (1)
10 (8)	40	70 (1)	100% = Every flight
20 (1)	50 (2)	80	

5. Have you ever made an emergency ejection from an aircraft?

Yes 1 No 18

If yes, please indicate:

Type of aircraft: A7B

Type of ejection seat: ____________________

Approximate airspeed 150 kt and altitude 1500 ft

Please describe any problems, issues, or benefits with your life support system during the emergency escape.

Basically everything worked as advertised - raft had a slow leak, emergency radio did not work. Helmet interfered with head movements while in parachute descent and in raft due to bulky equipment.

Life Support Systems

1. Please review this list of life support issues and grade each of them for importance in the design of a new system for the aircraft of the 1990's.

   3 = Most important items

   2 = Important but not paramount

   1 = Items of least importance

<u>Mean Response</u>

<u>2.79</u>	Protection of head from impact
<u>2.58</u>	Provision of oxygen (in pressurized cockpit)
<u>2.47</u>	Protection/maintenance of vision
<u>2.42</u>	Protection from fire
<u>2.16</u>	Restraint against aircraft maneuvering forces
<u>2.16</u>	Protection/restraint against emergency escape forces
<u>2.05</u>	Maintenance of auditory communication(s)
<u>2.00</u>	Protection from cockpit fragment/shell penetration
<u>1.63</u>	Control of cockpit temperature
<u>1.58</u>	Protection from cockpit noise
	Other. Specify:

Unclassified

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

A Navy aircrewman flying high-performance aircraft faces a myriad of environmental and mission stresses. He is protected through use of an Aviation Life Support System (ALSS), the basic form of which has changed little through the years. This project examined primary life support and protection needs ~~of an aircrewman~~ as a first step toward the development of an advanced ALSS to match the missions and flight regimes of future.

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Navy aircraft. An information structure was developed which utilizes three data bases covering (1) reports of emergency escape from Navy aircraft under the combat conditions of Southeast Asia, (2) reports of peacetime operational and training emergency ejections, and (3) structured interviews with aircrewmen flying the F-14 fighter aircraft. In order to retain a reasonable project scope, attention was given only to life support and protection requirements for the head, eye, and neck body region of an aircrewman.

Analyses of the ~~data bases~~ information indicates ~~the first order of~~ that requirements include (1) maintenance or enhancement of ~~those~~ performance and sensory capabilities (vision, audition, and cognition) of critical importance for Navy missions, (2) protection against the unexpected, excessive, and sustained acceleration forces encountered in advanced aircraft, (3) provision of both fire protection and fire retardant systems and (4) use of automated systems as feasible to counter effects of periods of altered consciousness.