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HUMAN SURVIVAL IN AIRCRAFT EMERGENCIES

by Charles A. Yost and Ronald W. Oates

Prepared by
STENCEL AERO ENGINEERING CORPORATION
Asheville, N. C.
for

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HUMAN SURVIVAL IN AIRCRAFT EMERGENCIES

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ABSTRACT

A general study was performed to outline methods for the improvement of human survival in civilian aircraft emergencies. Survival condition criteria, accident statistics and human tolerance limits have been surveyed with respect to those aircraft used in two categories: certificated air carriers and general-private aviation (including official executive aircraft). The methods presented in this report for aircraft occupant survival improvement fall into the general areas of occupant protection through seat design and occupant restraint improvement to withstand impact accelerations which are applied to the aircraft.

FOREWORD

This volume briefly describes how survival in aircraft emergencies can be improved by optimum aircraft interior and seat system design to aid occupant restraint, support and protection. This effort is conducted under the Life Support and Protective Systems subprogram of the Human Factors Systems Program, a line item of the Congressional Authorization to the National Aeronautics and Space Administration.

As a follow-on effort the Ames Research Center, Moffett Field, California, is conducting for the Human Factors Program a developmental effort to design, develop, and evaluate a prototype seat/restraint system for improved crash and vibration protection. The latest developments in energy-absorption techniques, protective structures, and full-body emergency restraint methods will be applied to the problem.

ACKNOWLEDGMENTS

The research study described herein was conducted by Stencel Aero Engineering Corporation under NASA Contract NASw-1530. The work was done under the auspices of Dr. W. L. Jones, Director, Biotechnology and Human Research Division and technical direction of Mr. Allan Merkin, NASA Headquarters, Washington, D.C.

Aircraft and accident statistics have been provided by the FAA and interpreted by the writers for graphical presentation. Definition of the most adverse environments in which a human might survive have been abstracted from the FAA-Civil Aeromedical Research Institute work, from NASA reports and the Flight Safety Foundation, Inc. test data. In addition, a number of agencies and investigators have been consulted in an effort to gain in-depth information rapidly for this report. These contacts have included:

1. NASA- Biotechnology and Human Research Division, Washington, D.C.
2. FAA - Mr. J. J. Swearingen, and Mr. A. H. Hasbrook, Civil Aeromedical Research Institude, Oklahoma City, Oklahoma
3. FAA - Mr. J. J. Carroll, Supersonic Transport-Safety Washington, D. C.
4. CAB - Mr. B. R. Allen and Mr. Hollowell, Bureau of Safety, Washington, D.C.
5. Mr. J. Lederer and Mr. Hallas, Flight Safety Foundation, Inc., Phoenix, Arizona
6. Dr. L. S. Higgins, M.D., Technology, Incorporated, San Antonio, Texas
7. Mr. J. H. Enders, NASA, Aeronautics Division, Washington, D. C.

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SUMMARY

Survival in aircraft emergencies can be improved, generally speaking, by improved aircraft interior and seat design to aid occupant restraint and protection. This would reduce injuries and fatalities in those accidents in which the aircraft incurs substantial damage but nevertheless remains adequately intact for occupant survival.

This report emphasizes occupant seating and restraint improvement as related to:

(1) certificated air carrier transport aircraft having large passenger capacity.

(2) general/private aviation aircraft having a few occupants.

Aircraft accident statistics show that substantial damage is sustained in nearly 70 percent of all aircraft accidents but that the fuselage remains sufficiently intact for human survival. Occupants can be protected against injury in this type of accident by means of energy absorption seat designs, protective seat structure with improved full body restraint, and safety consciousness in interior cabin decor. Internal improvements would therefore have beneficial utilization in the majority of aircraft accidents and provide immediate areas for improvement.

INTRODUCTION

The Civil Aeronautics Board classifies an aircraft accident as the occurrence incident to flight in which, as a result of the operation of an aircraft, any person (occupant or non-occupant) receives fatal or serious injury,or any aircraft receives substantial damage. An aircraft accident incident to flight is further defined as an accident which occurs between the time an engine or engines are started for the purpose of commencing flight until the aircraft comes to rest with all engines stopped for complete or partial deplaning or unloading. It excludes death or injuries to persons on board which result from illness, altercations, and other incidents not directly attributable to flight operations. This report refers to an aircraft emergency as a situation in which an aircraft accident results.

The problem of improving the chance of human survival in aircraft emergencies arises out of the increasing numbers of persons using aircraft as well as the widely diversified performance and application of these aircraft. The provision of survival aids to meet an aircraft emergency have not kept pace with the capability of an aircraft to transfer people into environmental conditions beyond human tolerance. The problem is most acute in all fields of civil aviation where manufacturing and operating economics are strong factors.

This report presents concepts, analyses, and evaluation of practical survival methods that may be applied to civilian aircraft. Two categories of aircraft have been considered in the study: (1) certificated air carrier aircraft, and (2) general private aviation aircraft (including executive official aircraft.) Consideration is given to human tolerance, aircraft impact velocity and angle, the type of aircraft operation, the accident statistics that indicate predominate problem areas, and survival improvement concepts that can be applied inside of the aircraft to accomplish human protection.

The study as reported, proceeds first to define the extent of the survival improvement problem in terms of aircraft accident statistics; and in terms of physical factors such as velocity, acceleration, and human tolerance.

Thereafter, methods for survival improvement are presented that would be applied internal tc the aircraft to maintain conditions of occupant tolerance by means of seat design and occupant restraint.

SURVIVAL CRITERIA

Survivable Aircraft Accidents

There are many conditions that an occupant is exposed to and must withstand in order to survive an aircraft accident. Assuming the aircraft fuselage remains structurally intact, the passenger must be protected from severe impact forces, smoke, fire and fumes, and then he must be given a means for immediate evacuation. The first and foremost requirement to be met in order for the occupant to survive is that the aircraft fuselage must remain substantially intact. While fires must be supressed and the passengers must be protected from smoke and fumes,and then evacuated, none of these can be very useful without maintaining structural integrity of the occupant area.

This report deals primarily with the problem of protecting the aircraft occupants from severe impact forces. A survivable aircraft accident is therefore defined for this study as one in which the occupied cockpit and/or fuselage remain relatively whole after impact. The methods studied and presented in this report are therefore concerned with occupant structural protection; and improving the occupant seat and restraint structure so as to be compatible with human impact and acceleration tolerances.

Two aspects of survival criteria exist. One has to do with the aircraft structure capability and the other has to do with the occupant-seat structural capability. Since the imposed forces are dependent upon the velocity changes that occur with distance and time, it is possible to present the limits of structural capability in these terms. Similarly, the occupant has acceleration tolerances beyond which he sustains injury. An estimate of these limitations are given in Figure 1, and expressed in terms of velocity change and deceleration distance.

As shown in Figure 1, one real limit placed upon the occupant is that available distance under which he may be decelerated. This limit is placed upon the occupant by surrounding seats, by the cockpit envelope, or by the distance from the bottom of the seat to the floor. The occupant must be decelerated within this space limitation.

Data on the acceleration tolerance of typical aircraft occupants (men, women and children) is not available. While it is known that some persons have experienced and tolerated very high acceleration forces, with a wide variety of passengers a 10 g limitation would be reasonable for design. With a 10 g limitation for design and the space available to the seat for displacement it can be seen in Figure 1 that the relative occupant velocities with objects in the cabin should be limited to about 25 ft/sec. Velocities in excess of this amount are likely to cause injury to the passenger.

Crashworthiness

Figure 1 gives some idea of the limits for aircraft structure and for occupants under a crash environment. The aircraft longitudinal deceleration distance covers a wide range because of various horizontal sliding resistance conditions. Horizontal velocities in excess of about 180 ft/sec. might be tolerated by the aircraft provided it does not meet strong vertical obstacles, steep embankments, or have severe attitudes. Sliding action permits the deceleration distance in the longitudinal direction to be much larger than the actual length of the aircraft. Objects approached longitudinally may often result in the fuselage remaining relatively intact.

The ability of the aircraft fuselage to attenuate vertical velocity is fixed by the fuselage diameter. Vertical velocity tolerance is therefore much less than that for the longitudinal direction. The only means attenuating the vertical velocity is crushing of the aircraft diameter. In the case of most transports, perhaps four or five feet of fuselage can be deformed before the interior cabin floor structure reaches ground level. As illustrated in Figure 1, this deformation might allow a 30 or 40 foot per second vertical velocity to be tolerated and still maintain reasonable occupied fuselage structural integrity.

Approximate survivable impact conditions found in some transport crashes investigated by Av-Ser (reference 3 and 7) were as follows:

(1) 150 knots forward speed
(2) 15 degrees nose down pitch angle
(3) 30 degrees yaw angle to either side of the longitudinal axis of the aircraft.
(4) a resultant crash force angle within an arc extending from 15 degrees above to 45 degrees below the longitudinal aircraft axis in the vertical plane and parallel to the longitudinal axis.
(5) impact against and a deceleration on reasonably level terrain having the general density of plowed ground.

These conditions are generally in keeping with those outlined in Figure 1. The velocity and impact angle at which the fuselage commences to undergo severe destruction is shown in Figure 2. This is roughly compatible with the Av-Ser findings for survivable-unsurvivable conditions found in some transports; as well as being roughly compatible with Figure 1. To this date, very little test data is available that would allow a more exact definition of the survivable accident boundaries for aircraft structures.

Looking at Figure 2 it can be seen that the region for survivability extends up to an aircraft velocity of about 140 miles per hour for horizontal impact angles. As the flight path angle increases the toleration of the aircraft decreases, until at about 70 degrees, the tolerable velocity probably drops to near zero.

Occupant Flailing

Design improvement for occupant protection requires that space be available for the occupant to decelerate, and requires full restraint of the occupant in his seat (reference 3.4, 3.5). In current seats,particularly in general aviation, cabin conditions are prevalent that cause the occupant to become injured from impact with rigid structures.

Case histories show that 70 to 80 percent of all general aviation injuries in crash decelerations are a result of face or head impacts caused by upper torso and head flailing. Improved occupant restraint design incorporating upper torso restraint would immediately decrease the injury index in these survivable crashes.

To provide some idea of flailing sweep, Figure 3 shows the motions of fifth and ninety-fifth percentile subjects accelerated forward over a tight safety belt. Reference 2.2, 215. The subjects were displaced by a 1 g force so the sweep presented must be considered as a minimum strike distance. The impact velocity of the head during these test exceeded 12 ft/sec.

In actual crash conditions larger magnitudes of body movement can be expected since impact forces are likely to be greater than 1 g and the passenger seat belts would probably be loosely fastened. While it is not practical to allow amount of space needed so that the occupant could flail without impacting any structure, it is practical to restrain the occupant such that his head and torso are unable to flail. Shoulder and lap restraint alone would eliminate a large number of impact injuries.

Figure 3(b) illustrates the number of injuries that have been incurred on various parts of the body in a large number of light aircraft accidents. This injury pattern of 800 survivors in light aircraft accidents shows that, in light planes at least, the greatest number of injuries occur to the head and torso. This is almost entirely a result of body flailing at impact. The need to restrain the body above the waist is apparent and should be incorporated.

Human Body Structure

Bones provide the rigid framework for the body to carry loads and to protect the vital organs such as the heart, brain, and lungs from injury. The ligaments act to hold the bone joints together and cartilage furnishes elastic connective tissues which protect the bones at the joints from shock and give the skeleton more flexibility. Figure 4 illustrates the arrangement of the human skeleton, and identifies the major skeletal parts by their technical names.

The engineer is concerned with the body as a structural load carrying system for dynamic and static loads. The body, being a composite of flexibly connected rigid members, must be externally restrained to prevent excessive momentum or force to build up between the parts. For a seated aircraft passenger undergoing rapid decelerative forces, the body masses requiring restraint are the pelvis region, the upper chest area and the head. While restraint of the arms and legs would also be desirable, movement of these body parts and their possible injury are not directly fatal. While methods for such total restraint would be desirable, it would present much difficulty in practice.

The head mass must be restrained from fore and aft whiplash motions that can be developed on the 7 cervical vertebrae. Failure to restrain the head permits severe neck strains and head velocity conditions to develop.

The upper torso must be restrained to prevent pivoting motions about the pelvic regions. The majority of the body mass is in the upper torso, contained in the boundary of the rib cage and dorsal vertebrae, with the dorsal vertebrae acting as attach points for the ribs. This section therefore forms a relatively rigid structure for restraint support. Movement of the upper torso is therefore in a rigid fashion about the lumbar vertebrae and pelvic region when a lap restraint is employed. Without upper torso restraint, the torso momentum would transfer to the pelvic region.

The pelvic region must be restrained to avoid bending of the lumbar vertebrae and to prevent motion of the pelvic and foreleg masses. The lumbar vertebrae and the lower dorsal vertebrae receive very little support from the rib cage structure. Vertical compressive accelerations of the upper body are therefore almost wholely supported by this vertebrae column section and can be expected to experience more severe stresses than the upper portions of the back bone structure. Ruptured discs are fairly common and might therefore occur frequently in this section if it is not firmly supported.

The skeletal structure, as shown in Figure 4, and the distribution of masses and hinge regions of the body indicate a need for body restraint, during impact, extending from the pelvis region up to and including the head. The relative masses of the various body parts are approximated as listed in Figure 4. Reference 3.6 points out that shoulder straps fastened to the lap belt can apply forces that lift and reduce the lap belt effectiveness.

VELOCITY — DISTANCE — TIME
(SURVIVAL CRITERIA)

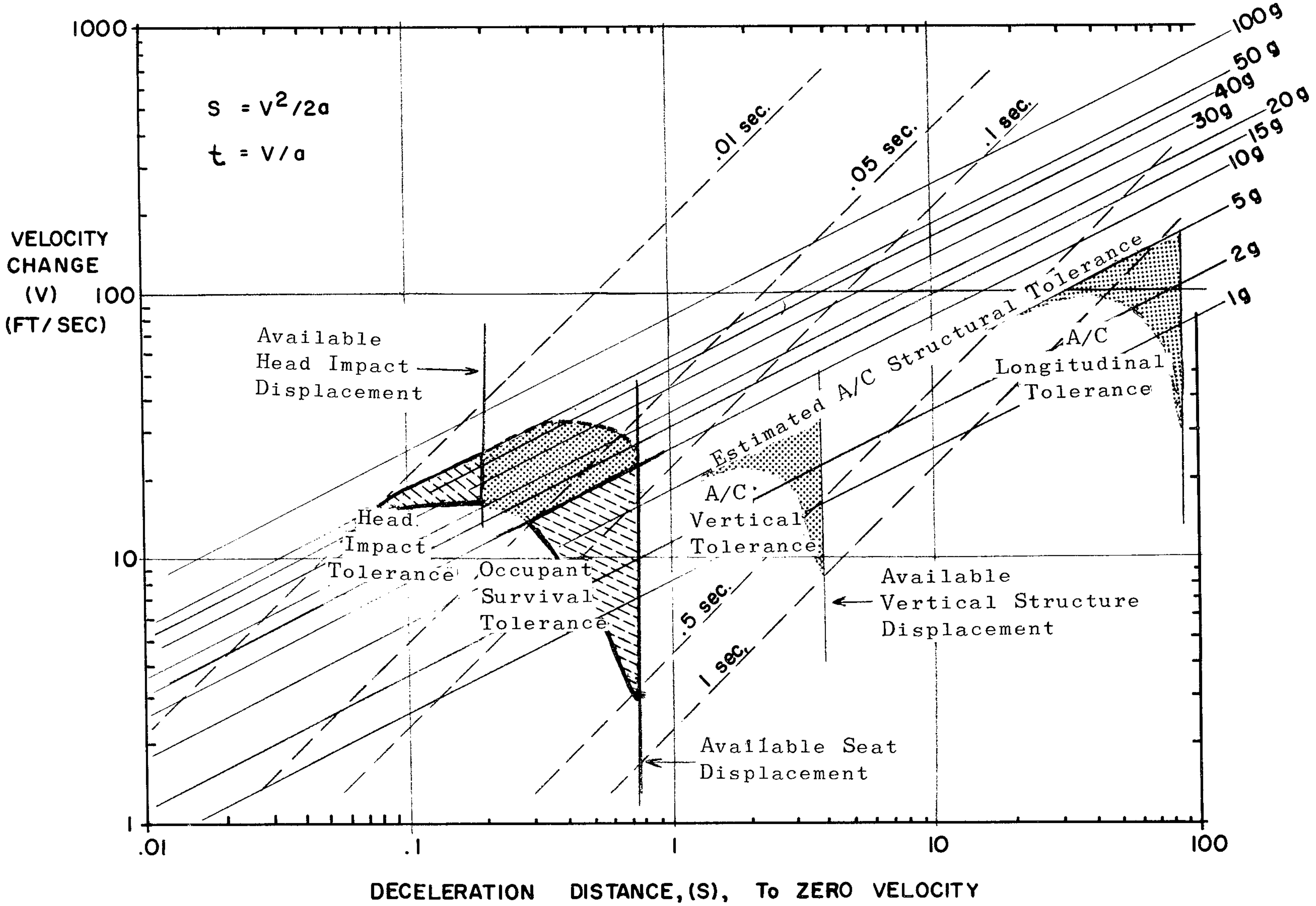


FIGURE 1

SURVIVABLE ACCIDENT BOUNDARY

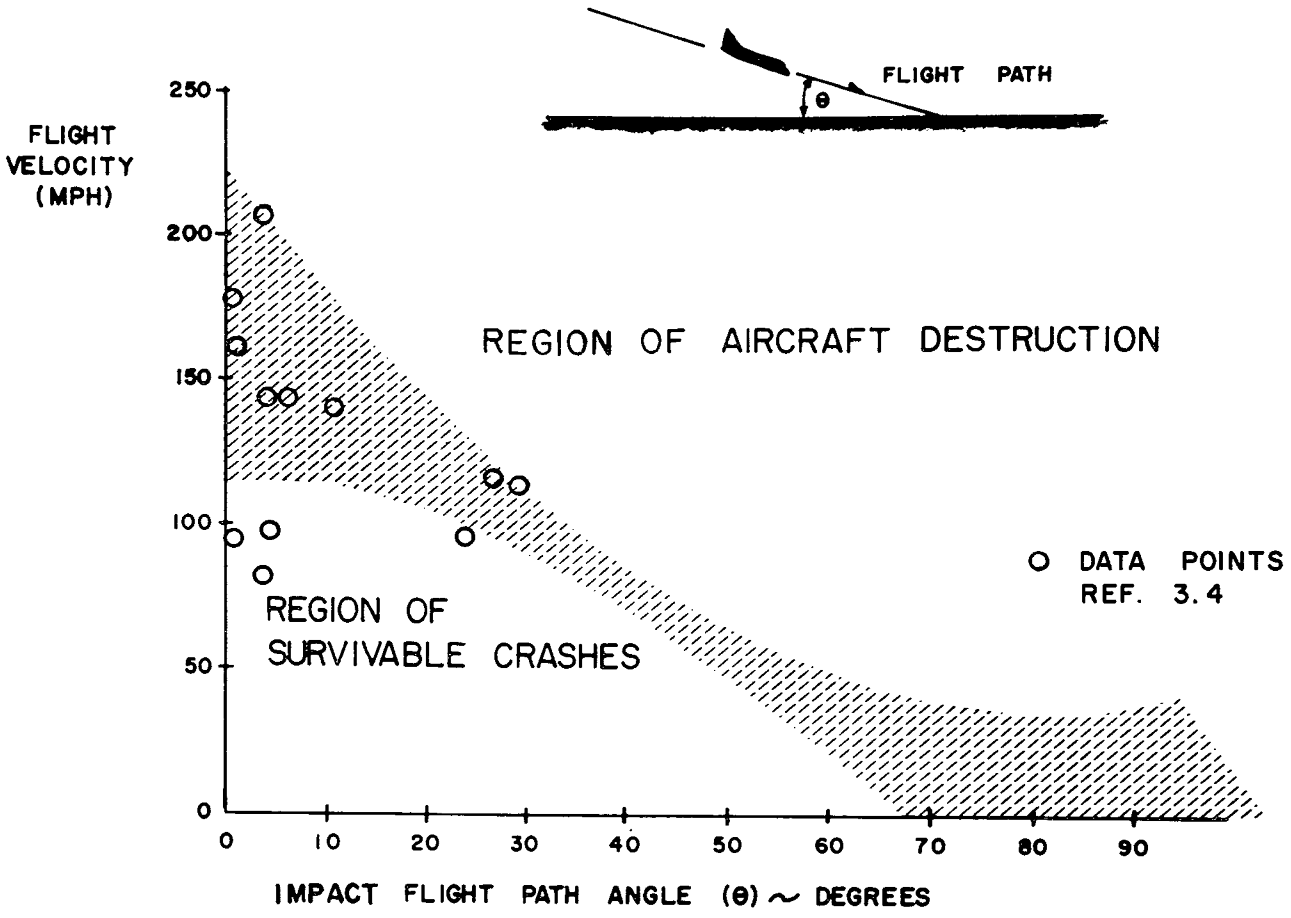
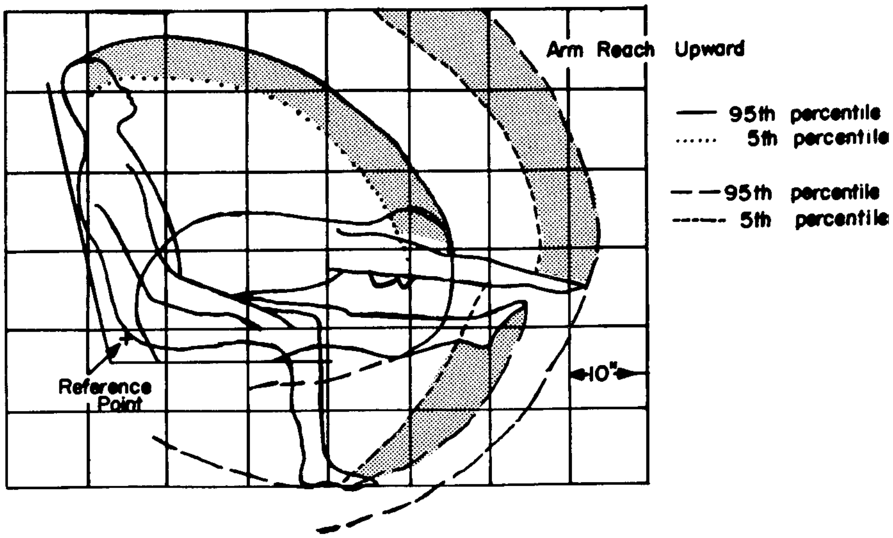


FIGURE 2

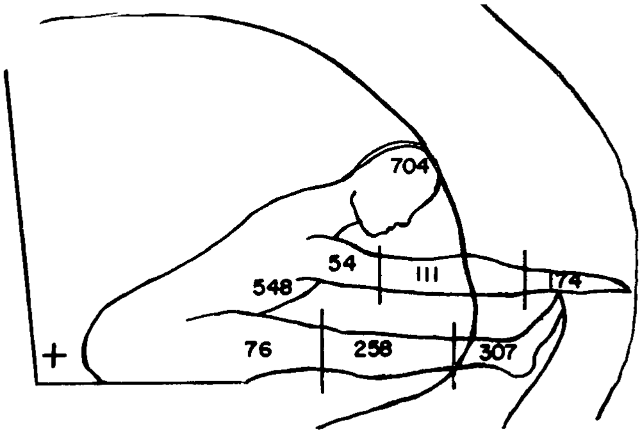
RESTRAINED HUMAN IMPACT ENVELOPE



(a)

REF: AM 62-13

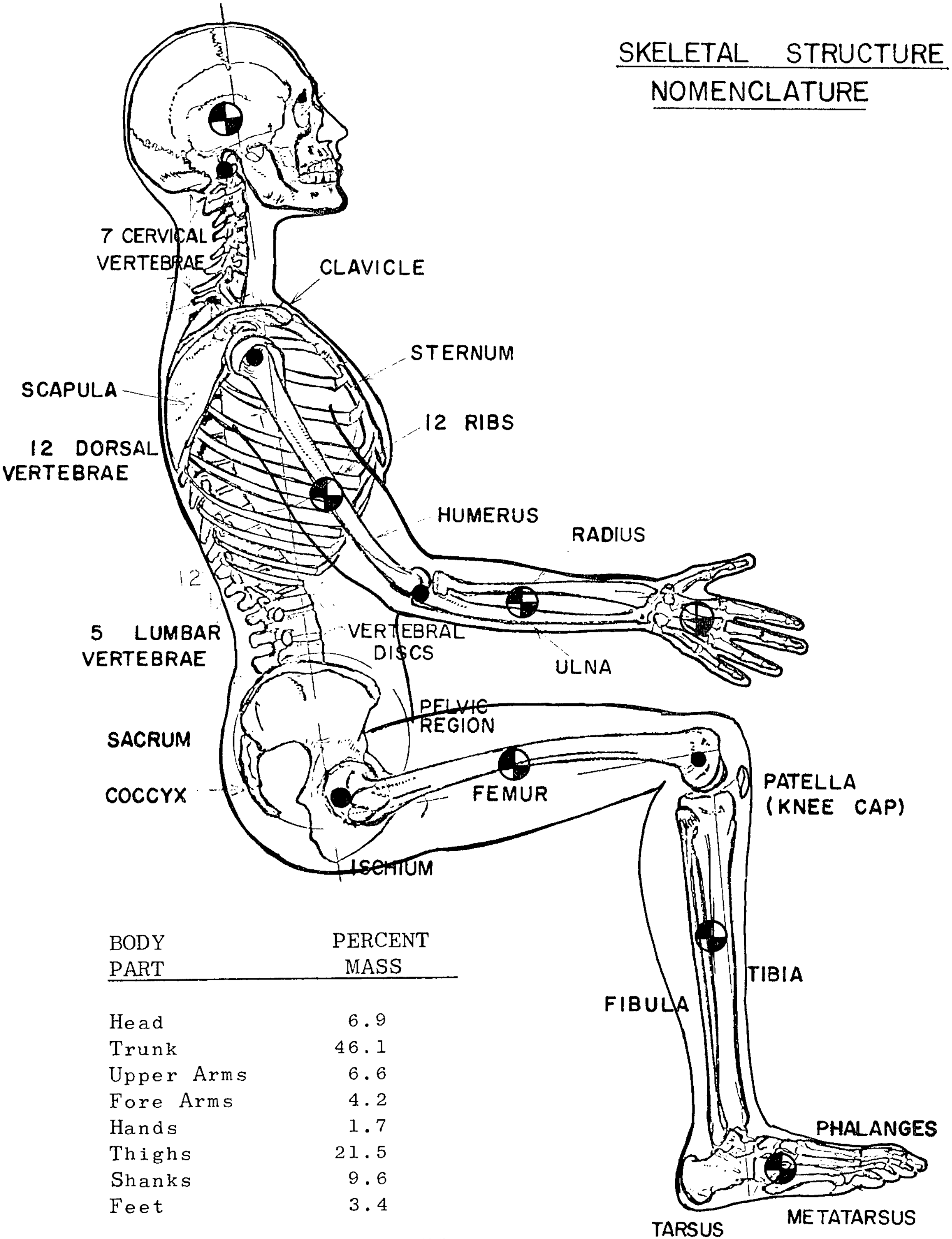
RESTRAINED HUMAN INJURY AREAS
LIGHT AIRCRAFT CRASHES



(b)

FIGURE 3

SKELETAL STRUCTURE NOMENCLATURE



BODY PART	PERCENT MASS
Head	6.9
Trunk	46.1
Upper Arms	6.6
Fore Arms	4.2
Hands	1.7
Thighs	21.5
Shanks	9.6
Feet	3.4
TOTAL	100.0

FIGURE 4

AIRCRAFT EMERGENCY SURVIVAL METHODS

Internal survival improvement methods in this report contain design objectives for occupant seating and restraint. Other areas for improvement, such as fire supression, smoke and fume protection and evacuation aids are not elaborated in this study.

There are a number of methods that could be applied in an aircraft emergency to protect the occupants from severe injury. Only a few of these methods can be applied at an acceptable price to the user. Figure 5 shows some of the methods that might be applied to assist survival in aircraft emergencies. These methods are presented in chart form. The kind of methods that could be applied are divided into three basic modes of flight: take-off, in-flight, and landing. The methods are further divided into applications to general aviation and commercial aviation, and executive aircraft. Those methods that appear reasonable to apply in a given flight mode and a particular type of aircraft are indicated by a solid dot.

AIRCRAFT EMERGENCY METHODS

METHOD	TAKE-OFF			IN-FLIGHT			LANDING		
	G	C	E	G	C	E	G	C	E
INTERIOR CRASH PROOFING	●	●	●				●	●	●
CRASH CAPSULES			●						●
FULL BODY RESTRAINT	●	●	●	●	●	●	●	●	●
ENERGY ABSORBING SEAT	●	●	●				●	●	●

C = COMMERCIAL AIR CARRIER
E = EXECUTIVE OFFICIALS
G = GENERAL AVIATION

FIGURE 5

INTERNAL FUSELAGE IMPROVEMENTS

Efforts to improve aircraft interiors are a result of accidents wherein the aircraft cabin has remained adequately intact for human survival but the occupants have, nevertheless, died or were seriously injured because of fumes, fire, inadequate seat tie-down/seat belt restraint, or impact with local hard objects placed too close for crash safety. A summary of notes by J.J. Carroll [4] and published reports by A. H. Hasbrook[7], combined with that data obtained by the Flight Safety Foundation, Inc.[3] point out that the interior design considerations for crash survival should include crashworthiness features such as:

(1) Secure seat tie-down and seat energy absorption properties.
(2) Secure occupant restraint.
(3) Removal of lethal objects and surfaces from the occupant-impact envelope.
(4) Secure attachment of interior furnishings.
(5) Suppression of smoke and fire.
(6) Quick routes for evacuation.

Much remains to be done toward defining quantitative values to meet these requirements. In this respect, aircraft manufacturers have pointed out the need for accident survival methods/criteria that is of definite argument based on clear evidence and of a quantitative nature for design and test.

Work at the Civil Aeromedical Research Institute (CARI) has been extensive in defining human body impact limits and injury levels.[2] The CARI work, combined with the aircraft crash test data of the Flight Safety Foundation, Inc.[3] provides additional views on how aircraft interiors may be designed to improve chances for occupant survival.

S. R. Mohler and J. J. Swearingen [2.2] estimate that possibly one half of all fatalities occurring annually in survivable aircraft accidents could be prevented if aircraft design were to include conditions for human tissue protection during impact. These authors further detail three principles for delethalization:

(1) Eliminate and/or redesign cabin objects which can cause puncture wounds upon bodily impact.
(2) Design and install a seat-restraint system (seat belt and shoulder harness) which will securely hold a human body under brief transient forces as high as 25 g.(Ref.3.6,1.1.4.3.1). Tolerance to impulsive loading under severe body restraint

may be taken as: (Ref. 3.6)
Longitudinal - 45 g for 0.10 sec.
25 g for 0.20 sec.

Lateral - 20 g for 0.10 sec.

Vertical - (Eyeballs down) 25 g for 0.10 sec.
(Eyeballs up) 15 g for 0.10 sec.

(3) Design instrument panels and all other areas of likely body contact so that upon impact the greatest amount of deformation and material rearrangement would occur in the structures and not in the human body.

Occupant Protection & Interior Design Methods

Improvements for the occupant in the aircraft interior are effective under flight conditions where the aircraft is in a velocity and attitude condition that would allow impact to occur without severe destruction of the fuselage. Granting such impact conditions, the interior improvements are concerned primarily with occupant protection; thus, the removal of dangerous furnishings, sharp or hard surfaces and loose objects that might impact with the occupant is compatible design for aircraft emergencies.

Occupant seating and restraint represents a major area of interior design that could be improved with immediate benefits for occupant protection. For emergencies, full body restraint is essential to keep the occupant from flailing and impacting with surrounding hardware. In large passenger aircraft, seat and restraint design improvements are most essential to meet take-off and landing emergencies. Certain types of aircraft that undergo severe jostling conditions in-flight would also be made more comfortable with a full body restraint system on the pilot.

Where an aircraft undergoes crash type conditions, the occupant protection can be improved by designing seats to absorb high energy pulses. Force limiting energy absorbing devices (Ref. 3.5) would reduce high peak forces and allow the seat to remain attached to the basic aircraft structure and maintain the occupant position in the seat at lower force levels. Such seat design would be immediately useful to all aircraft types. At the present time seats are not designed to absorb high energy impacts and therefore frequently come loose from the airframe structure.

Another form of protection for the occupant would be crash capsules. The nature of crash capsules would require them to be special structures within the airframe designed to resist and absorb impact at higher energy levels than the aircraft itself. Such devices do not appear economically practical for most aircraft; however, crash capsules may be useful for special executive application wherein a maximum protective security is more essential than the usual economic considerations for the aircraft.

Seat Design

The integral parts of a passenger seat system at the present time are the restraint belt, belt anchorage, seat portions which carry belt loads, cushion support and seat anchorages to the floor structure. Improvement is needed in the design of these components.

The use of ductile structures is desirable since this would allow deformations and attenuation precluding complete seat failure. Whenever practical, passenger seats should only be attached to a surface of structural continuity, such as the cabin floor. Attachments to differing structure surfaces, such as wall-floor combination structure, can deform differently to impose severe torsion on the seat ties, resulting in greater seat tiedown stresses and deformation damage.

Aircraft seat design provides one immediate improvement avenue for occupant safety. Seats may be improved by giving design attention to the following items:

(1) Minimize seat mass, particularly in the upper parts of the seat back to reduce impact acceleration moment forces.
(2) Avoid the exposure of hard structures where body impact may occur.
(3) Use ductile, energy absorbing materials for primary seat structure.
(4) Provide exo-skeletal seat structure for occupant protection.
(5) Provide crushable impact attenuating surfaces.
(6) Increase floor attachment joint flexibility to reduce bending stresses.
(7) Build in seat safety aids against smoke, fumes, heat, vision and decompression.
(8) Extend upper seat back above the head level for head protection.

Restraint Design

When an aircraft cockpit or cabin area remains relatively intact after a crash impact, definite improvements would be realized if the passenger or crew member were more adequately restrained.

Restraint design is an integral part of the seat system and needs design effort to:

(1) Improve belt latch resistance against accidental release. For instance, some belt latches are susceptible to accidental release.

(2) Provide restraint devices for upper torso and head in severe emergencies.

Head injuries take a heavy toll either directly by puncture wounds or indirectly by stunning blows. These injuries prevent rapid occupant exit before fire consumes the aircraft. Head and shoulder restraint is therefore essential to prevent excessive head travel and to provide a degree of safety to many who are at present killed or who suffer severe injuries to head or face.

Deceleration tests have demonstrated that when a man is well restrained by seat and shoulder harnesses, and in good condition he can tolerate crash force peaks from 15 to 45 g's (ref. 3.6). This substantiates the belief that people should survive impacts where the structures remain primarily intact since these structures fail at much lower g-forces.

COMMERCIAL MULTI-ENGINE TRANSPORT SAFETY IMPROVEMENT

General Statistical Information

A commercial air carrier is an operator who has been issued a Certificate of Public Convenience and Necessity by the CAB. The two main categories of air carriers are the Certificated Route Carriers and the Supplemental Carriers.

Figure 6 is a bar graph that shows each major type and number of aircraft in operation by the certificated route air carriers as of December, 1965. Boeing, Douglas, Lockheed and Convair Corporations provide the greatest majority of the currently used commercial aircraft. Of the 2104 fixed wing aircraft listed as held by the air carriers, only about 1875 are actually used for passenger operations. The number of commercial aircraft in active service (Figure 8) has only varied about 2½% since 1957. The service provided by these aircraft is shown in Figure 7 as accumulated by all the aircraft, and again in Figure 8 as an annual average allotted to each aircraft. Currently, the average transport aircraft travels 700,000 miles flies 2100 hours and makes 2200 departures per year.*

The annual number of commercial carrier accidents is small when compared to the large number of aircraft operations during that period. Figure 9 shows an average of about 80 accidents to occur annually, out of the four million flight depatures.

Taking into account the total number of accidents that occur annually, Figure 10 shows about one accident to occur per 50,000 departures, and coincidently, about one accident to occur per every 50,000 flight hours. This averages about 11,000 departures or flight hours per day, so that some kind of aircraft accident might be expected to occur every five days.

The reliability of aircraft transport systems is difficult to express in a simple manner because of numerous operating variables.

---

*The statistics found in this section were derived from the "FAA Statistical Handbook of Aviation" and from the Civil Aeronautics Board Annual "Statistical Review" and have been interpreted by the authors for presentation in this report.

Using the conglomerate of overall departure and flight time statistics and assuming all events to be equally probable, the reliability of the operating aircraft transport system could be expressed as:

(1) Reliability = 0.99998 that any one departure will be accident free, or perhaps

(2) Reliability = 0.99998 that any one hour of operation will be accident free.

This represents extremely good system reliability; however, it is a grossly simple interpretation and does not represent effects of individual case factors of time, distance, departures, maintenance, weather, etc. While the accident rate is extremely small, the massive quantities of air carrier operations still inevitably result in a significant total number of accidents and fatalities as shown in Figure 11.

There were 1642 fatalities in commercial aviation during the period from 1960 through 1964 as a result of 64 fatal accidents. These fatalities were distributed in categories as shown in Figure 12 and are summarized by Table 1.

TABLE 1

	Percent of all accidents	Percent of all fatal accidents	Percent of all fatalities
Take-off and Initial Climb	14	20	25
Enroute	26	45	60
Approach and Landing	50	30	15

AIRCRAFT IN OPERATION BY
CERTIFICATED ROUTE AIR CARRIERS
DEC. 1965

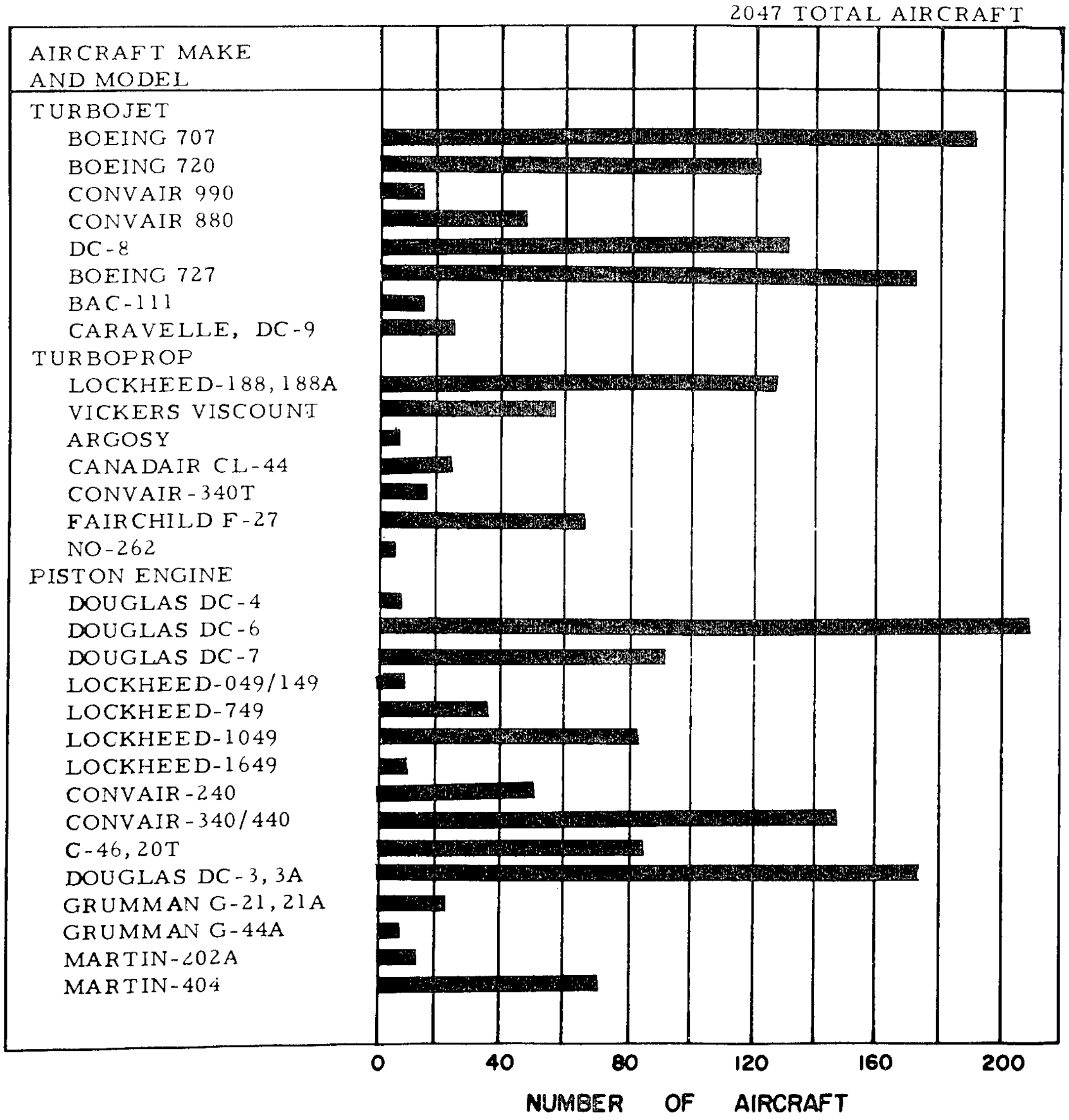


FIGURE 6

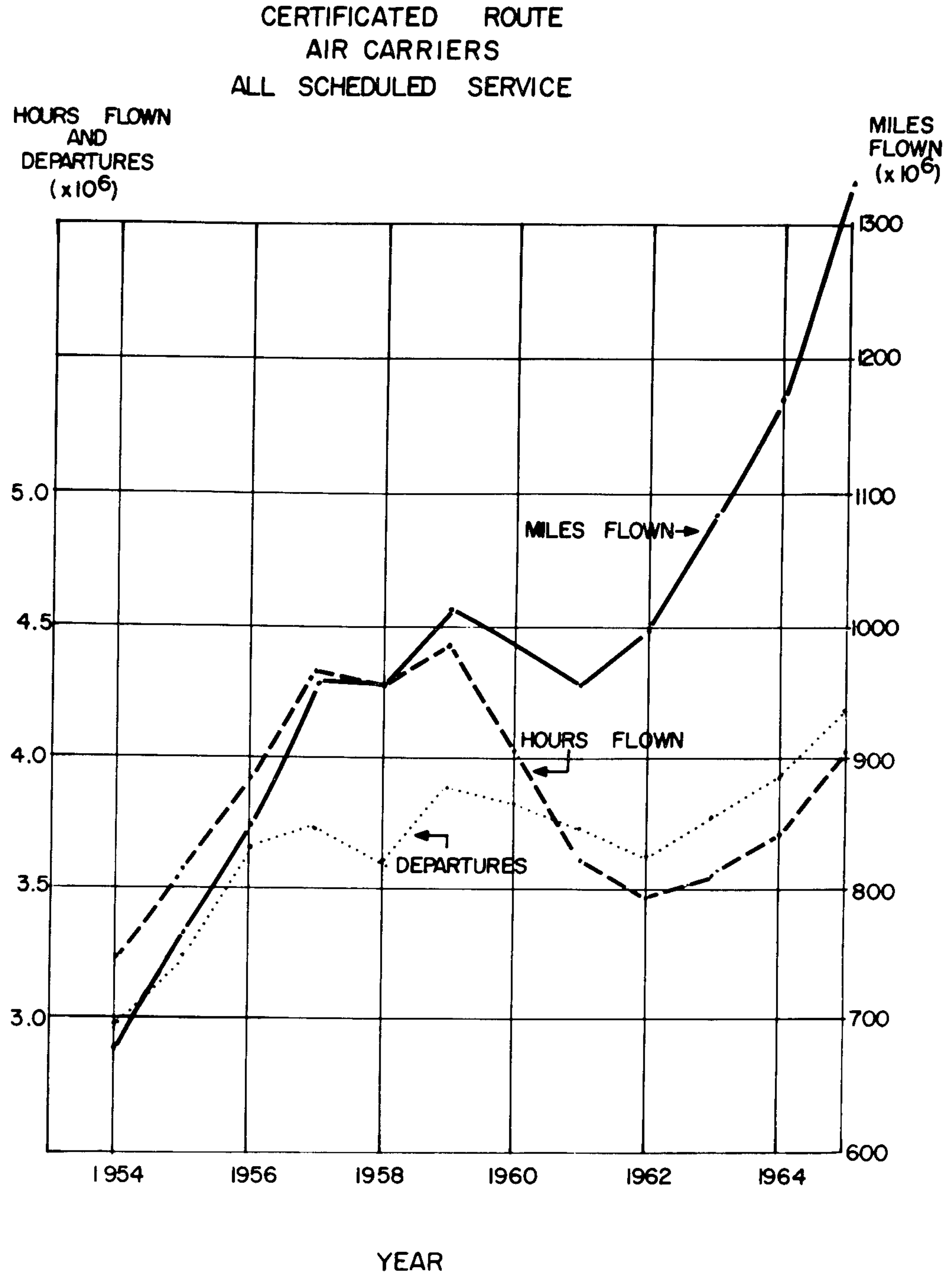

CERTIFICATED ROUTE
AIR CARRIERS
ALL SCHEDULED SERVICE
HOURS FLOWN AND DEPARTURES (x10^6)
MILES FLOWN (x10^6)
5.0
4.5
4.0
3.5
3.0
1300
1200
1100
1000
900
800
700
600
MILES FLOWN
HOURS FLOWN
DEPARTURES
1954
1956
1958
1960
1962
1964
YEAR

FIGURE 7

CERTIFICATED PASSENGER/CARGO
U.S. DOMESTIC & INTERNATIONAL AIR CARRIERS
OPERATIONS DATA

(REF. 1966 FAA STATISTIC HANDBOOK)

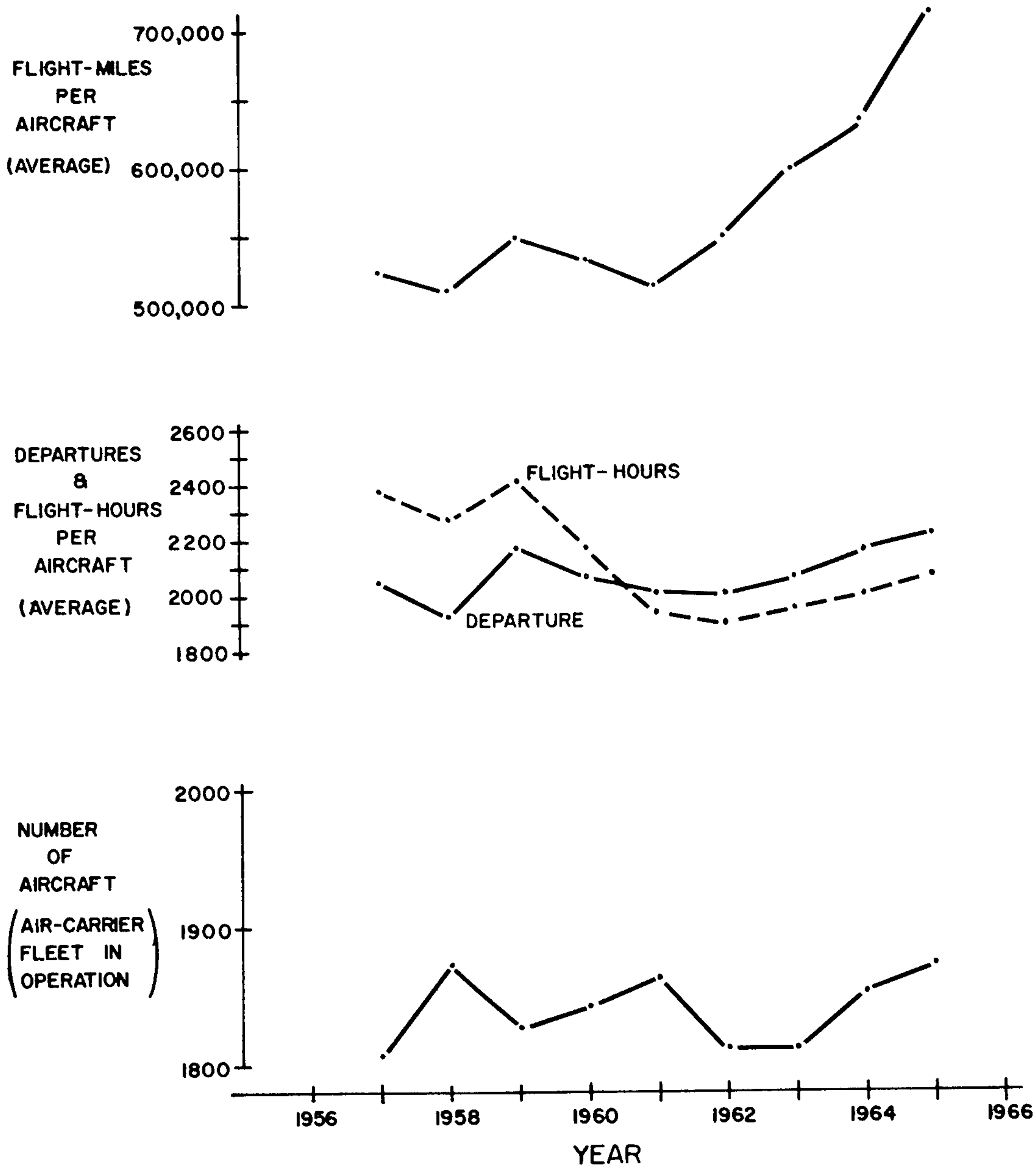
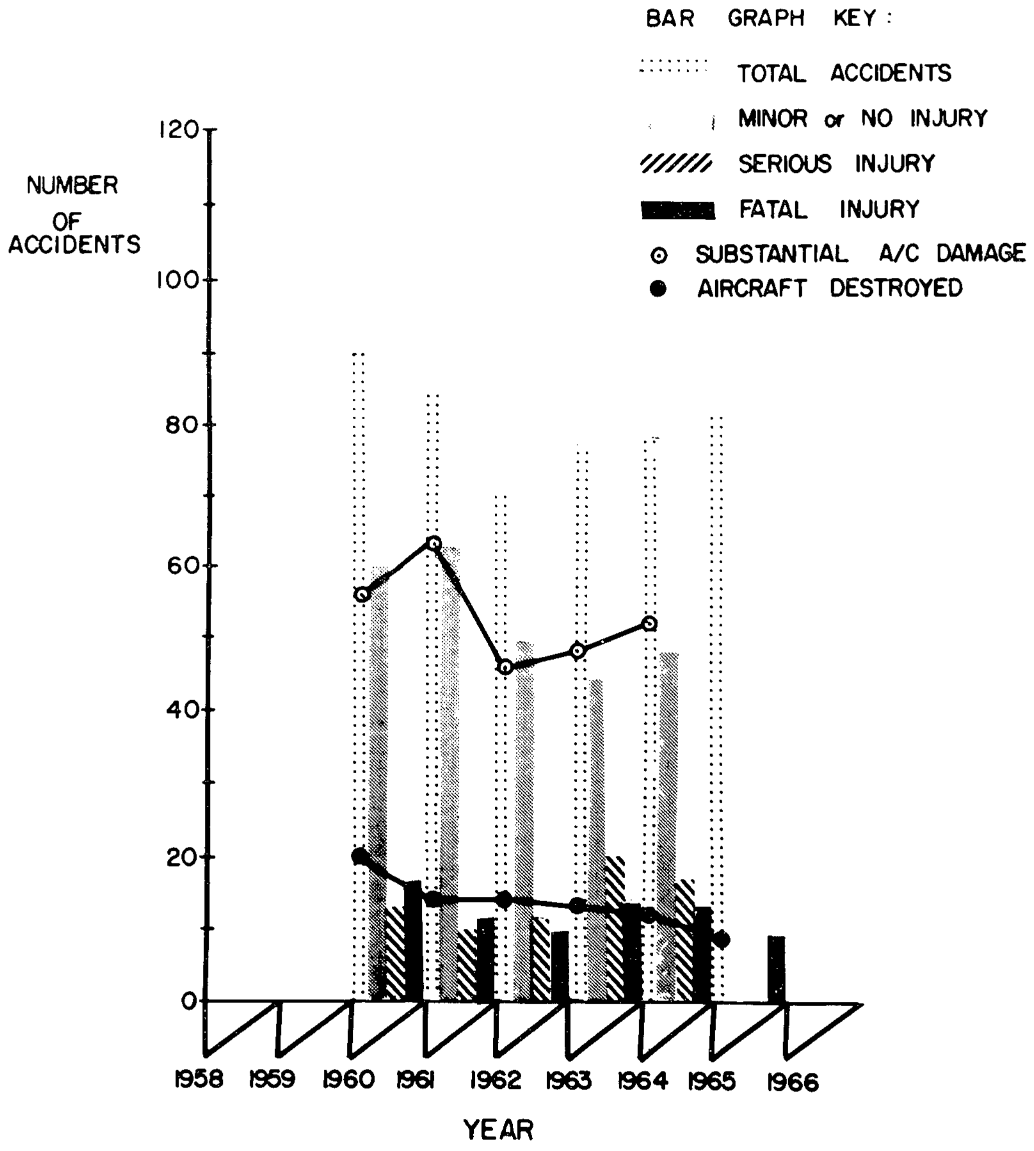


FIGURE 8



U.S. CERTIFIED ROUTE AIR CARRIERS

ALL OPERATIONS - NUMBER OF ACCIDENTS

FIGURE 9

CERTIFICATED PASSENGER/CARGO
U.S. DOMESTIC & INTERNATIONAL AIR CARRIERS
ACCIDENT RATE DATA

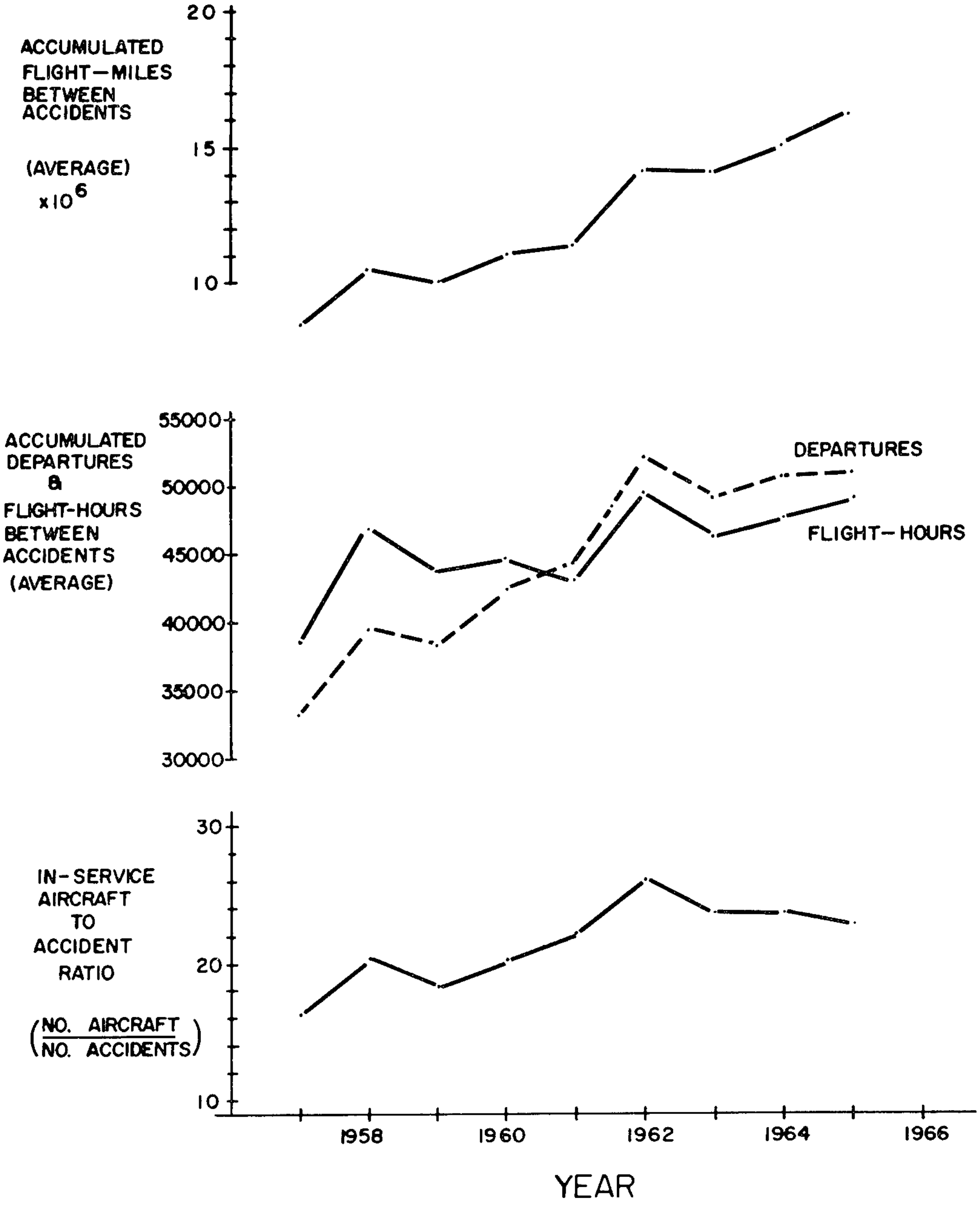


FIGURE 10

U.S. AIR CARRIERS
ALL OPERATIONS
FATALITIES PER FATAL ACCIDENT

1960-1965 INCLUSIVE

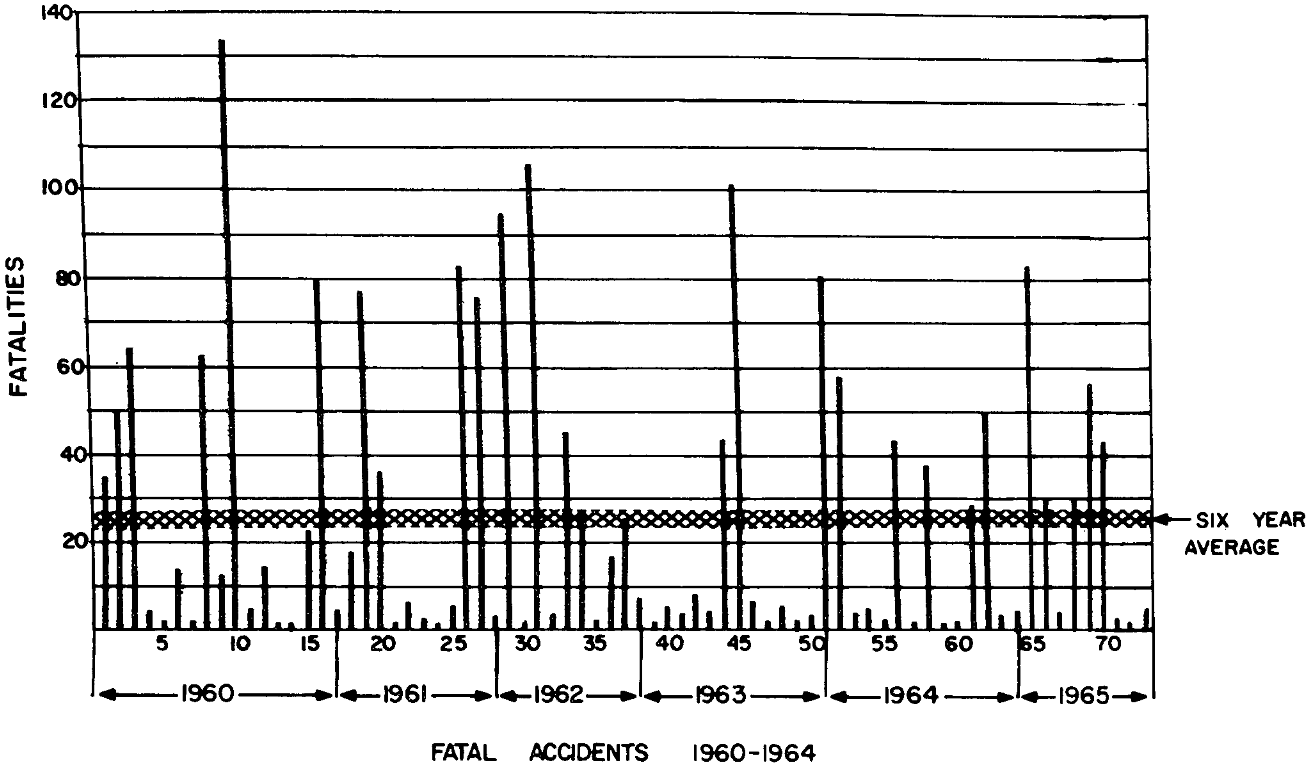


FIGURE 11

U.S. AIR CARRIER ACCIDENTS
1960-1964 INCLUSIVE

402 ACCIDENTS 64 FATAL ACCIDENTS 1642 FATALITIES

PHASE OF OPERATION			ACCIDENTS PER PHASE	PERCENTAGE OF ALL ACCIDENTS	FATAL ACCIDENTS	FATAL ACC. % PER PHASE	FATALITIES
STANDING	2.9%	GROUND	14	3.5	1	7.14	2
TAKE-OFF TAXI	4.0	TAXIING	20	4.9	2	10.0	2
TAKE-OFF RUN	4.7	TAKE-OFF	56	13.9	12	21.4	404
INITIAL CLIMB	7.6						
CLIMB TO CR.	3.5	ENROUTE	106	26.4	29	27.36	972
ENROUTE CRUISE	14.5						
ENROUTE DESCENT FROM CRUISE	6.9						
APPROACH	11.8	LANDING	204	50.8	20	9.8	262
LEVEL OFF & TOUCHDOWN	13.8						
GO-AROUND	2.2						
ROLL-OUT	18.1						
TAXIING FROM LANDING	4.0						
OTHER	6.0	UNKNOWN	2	.5	0	0	0
TOTALS			402	100%	64		1642

FIGURE 12

Transport Aircraft Seating & Restraint System Improvement

The number of transport aircraft emergencies is evident from the statistics of Table 1, Figure 11 and Figure 12. The multi-engine reciprocating and the jet engine aircraft are used primarily by commercial certificated air carriers and often carry over a hundred passengers each. The problem of improving survival in this class of aircraft is quite different from that associated with general aviation.

Passengers on any one transport flight may represent the whole spectrum of the population in age, health, size and occupation. A large number of persons seated in row fashion is also a characteristic of passenger transports that necessitates that the passenger remain seated and be protected in that position until such time that the aircraft has come to a stop and orderly evacuation can begin.

One of the most difficult problems confronting designers for improved protection of occupants is the fact that occupants vary over such a large range. The methods used to improve human survival during transport emergencies must therefore be compatible with all persons. The improvement of passenger seat design and restraint must take the wide variation of occupants into account. The techniques for energy absorption and restraint are thereby complicated.

The skeleton shown in Figure 4 represents the structure of an average adult as he might be seated in a passenger aircraft. The locations and relative masses are also shown for each major body segment. The body mass segment data is derived in part from a study on body segment parameters. Looking at the body as a non-rigid physical structure with mass centers and flexible joints, it is apparent that both upper and lower torso restraint is required to prevent spine bending and head-flailing motions that could cause serious injuries. The rapid motion of the head mass on the neck vertebrae structure and the strain developed by suddenly stopping this mass even without impact is the cause of many neck injuries. Similarly, acceleration forces acting to bend the spinal column impose severe compression and/or tension stresses on the vertebrae disc structure causing slipped disc and other forms of back injury.[13] Some form of restraint is required to prevent these body displacements, since muscle response and strength alone is inadequate to react to sudden impact forces.

Tests indicate that in some survivable crashes the local dynamic loads may reach 40 to 50 g's for short durations, measured in milliseconds.[3.6] If the seats are unable to absorb this sudden impulse they will break loose.

The maximum forces developed on seat structure are a result of relative velocity mass accelerations and floor structural deformations. These develop under conditions of aircraft runway overshoot, or impact under adverse attitudes in which the fuselage meets sudden resistance and undergoes structural failure.

The occupant held seated in the aircraft can experience high accelerations if he develops independent velocity changes over a very short distance. Elasticity of the fuselage structure and free unrestrained motions of the occupant allow relative velocity to build up between the seats and various parts of the aircraft. It is in the arresting of these relative internal velocities that such short duration, high g-level forced (40-50 g's) may develop in the seat structure.

There are two practical requirements that must be met for improved occupant protection. One is that the occupant's vital parts must be kept from building up differential velocities in excess of about 30 or 40 feet per second. In addition, these differential velocities must be stopped within a space of about 6-8 inches to prevent excessive acceleration loads on the occupant. Secondly, the body loads must be transferred into the seat by a restraint and cushion support system that does not have significant rebound.

The seat may be thought of as being composed of three basic parts. Those parts are: the legs, which should be energy absorbing in order to transfer large quantities of energy without developing high peak loads; a supporting frame with cushions which would act to protect the occupant; and thirdly, some form of body restraint which is able to maintain the occupant in position regardless of his size or shape.

Seats that are suitable for providing a large amount of energy absorption and occupant protection should be mounted as single units; that is, they should not be structurally tied into pairs and triplets as an integral unit as currently practiced in passenger aircraft. This is not to say that individual energy absorbing seat designs couldn't be grouped in close doublet and triplet type arrangements, but rather that these seats would have to have the capability of moving independently of one another under impact situations to avoid assymmetrical loading and to accomplish efficient energy absorption.

Features that could be incorporated in advance seat design are shown in Figure 13 entitled "Aircraft Seat Design Improvement for Impact". Some of the features pointed out in that figure are the high back protective head rests,the impact absorbing back structure, high energy dissipation cushions, high-energy dissipation stroking load limiting legs, and a full body restraint system. This may be compared with present seat designs which use rigid leg structures, lap belt restraint only, low energy absorption cushions, soft back structures and no head protection.

The simple technique of using the available seat spacing for stroking energy devices increases seat leg energy dissipation by a factor of about 6 without increasing the basic seat design strength. Using present seat design techniques and increasing the seat design strength to about 25 g's would only increase the energy absorption capabilities of present seats by about $2\frac{1}{2}$ times. By comparison, advanced energy absorption seat design, when increased to 25 g design strength level, would increase the energy absorption capability by a factor of 16. Such improvements are a result of allowing the seat to stroke in a controlled load limiting manner while absorbing energy throughout that stroke.

The ability to take advantage of an increased seat energy absorption capability lies in a full body restraint system that can transfer body loads into the seat in a simple practical manner.

Energy Absorbing Seat Development

One example of a light-weight, high-strength seat which is designed to offer maximum energy absorption is shown in Figure14. Energy absorption is provided by extensible attenuators in forward and vertical loadings. This seat is designed for impact attenuation for the dynamic load conditions of 20 g-vertical and 20 g forward within a 30 degree arc to either side, as well as for 10 g's laterally. This seat strength is based upon an occupant weight of 225 pounds.

Seat weight is kept to a minimum through the use of aluminum honeycomb construction in all structural panels. Less cushions and mounting tracks, the seat weights approximately 35 pounds.

Integrated Safety Seat

Referring to Figure 3a, it can be seen that a passenger who is restrained only by a seat belt is thrown forward from the waist up. The torso and head swings through an arc such that the head would impact into the front seat or panel objects. The legs also swing such that they would impact similar objects.

Figure 15 illustrates an integrated safety seat concept and one method whereby the body could be restrained from the waist to the head. The restraint method uses a body curtain which is stored on the top of the seat back beneath the upholstery. Ordinarily, the curtain is not used; however, in an emergency it would be a simple matter to reach above the head and pull the curtain down over the body and fasten it to the seat belt. This method of body restraint has the advantage of not interferring with the passenger comfort unless an emergency occurs. The curtain would be sufficiently porous and resilient to permit both breathing and force distribution. In addition to the face curtain, the seat shown in Figure 15 features energy-absorbing leg supports and a high seat back extending above the head level in order to protect the head from flying objects.

Energy absorbing supports are sufficiently rigid to resist normal passenger loads; however, under the much higher forces of a crash, the legs would deform and absorb energy in the process of seat stroking. Further study is required on this type of seating, both from the standpoint of detail structure and from the standpoint of accommodation.

Other features that might be considered in the design of a safety seat to meet passenger requirements include such things as air supply, food trays, ready-to-serve food packages, trash collection units, minor first-aid needs, smoke-heat-vision protective devices, and floatation gear.

Honeycomb Design for Impact Survival

Aluminum honeycomb is an effective mechanical energy absorber and is finding increased use in the control of forces to decelerate objects.[11] Materials such as sponge, solid rubber, cork, and paper wadding generally exhibit spring characteristics with an attendent rebound problem.

Aluminum honeycomb has the unique property of failing at a constant load with complete dissipation of energy that would otherwise be released in rebound. The initial peak at which compressive failure begins can be eliminated by pre-crimping the honeycomb core to produce slight initial compressive failure. When exposed to further loading the pre-crimped core proceeds to carry the crushing load at a near linear rate. Such control appears attractive in safeguarding human occupants in aircraft crash conditions.

As an example of aluminum honeycomb's ability to attenuate human impact loads, consider this representative case:

Assuming the impacting mass to be the human head with a weight of about twelve (12) pounds and assuming that the occupant is restrained by a seat belt, the head could be expected to impact a forward surface (instrument panel, seat back, etc.) at a velocity of over 40 ft/sec. Under these conditions, approximately 320 ft-lb of kinetic energy would be dissipated at head impact. Without a yielding material to absorb this energy, death is certain. However, rough calculations indicate that such an impact upon an aluminum honeycomb (3003 aluminum, 3/4 inch cell, and a .004 inch foil gage)[12] section with a thickness somewhat over 3 inches could be tolerated by the human head.

Kinetic energy at impact $= E_k = \frac{WV^2}{2g} = \frac{(11.5)(42)^2}{64.4} = 320$ ft.-lb.

The rate of deceleration is approximated by : $A = V^2/2S_c$

It appears practical to pad areas of likely body contact in all types of aviation vehicles with honeycomb or similar material to improve survival.

AIRCRAFT SEAT DESIGN IMPROVEMENT FOR IMPACT

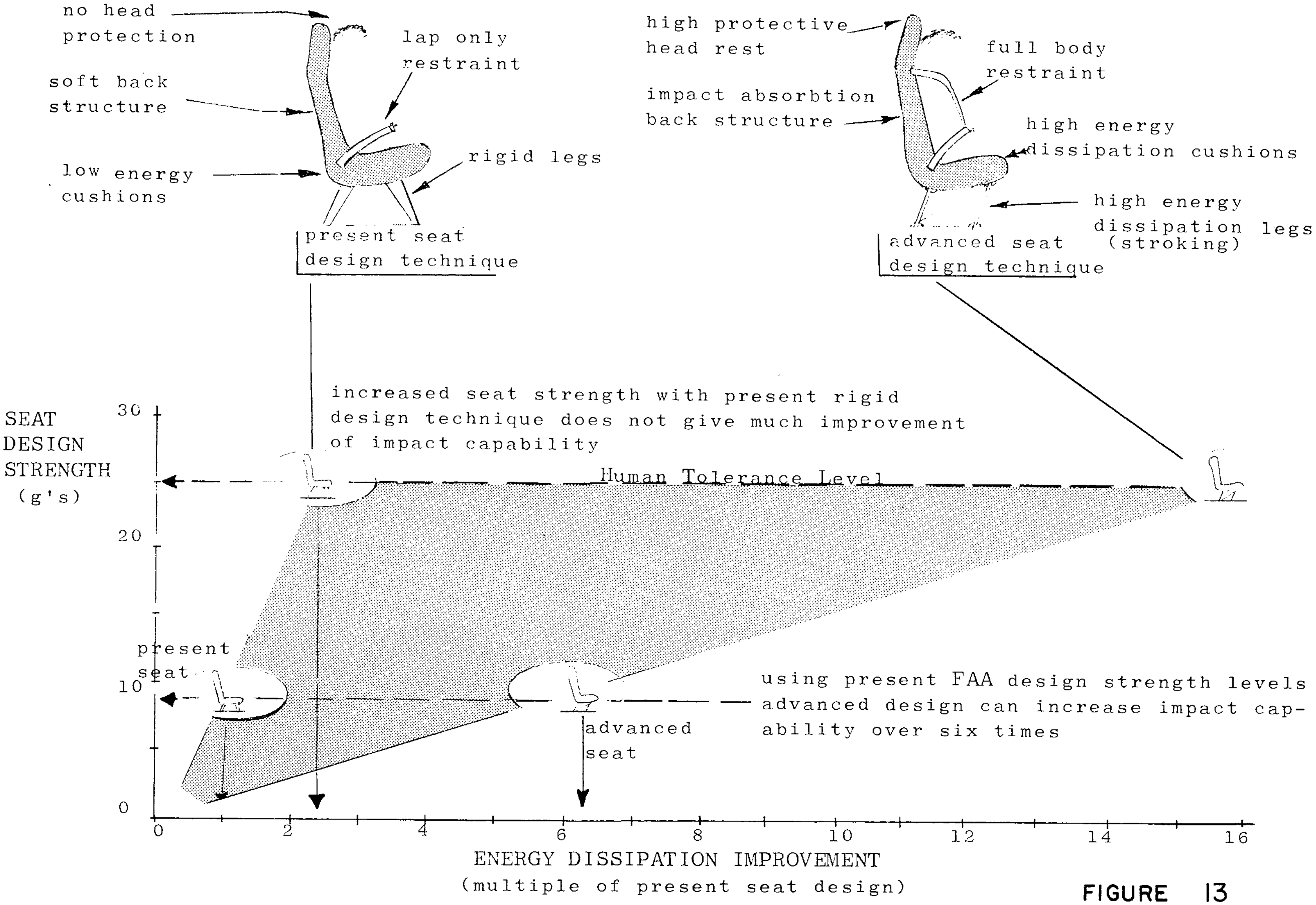
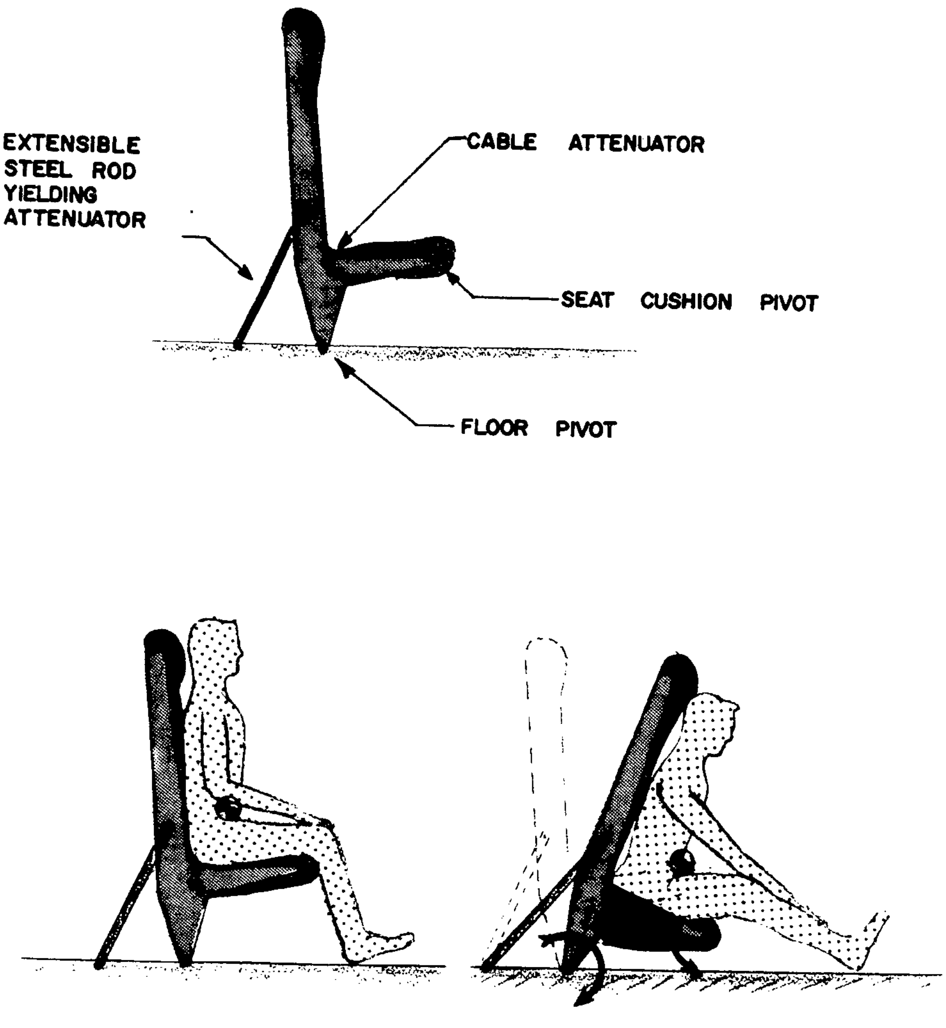


FIGURE 13

20-G ENERGY ABSORBING SEAT

(REF. U.S. NAVY CONTRACT N600 (19) 62456)
NET CUSHION HELICOPTER SEAT
STENCEL AERO ENGINEERING CO.



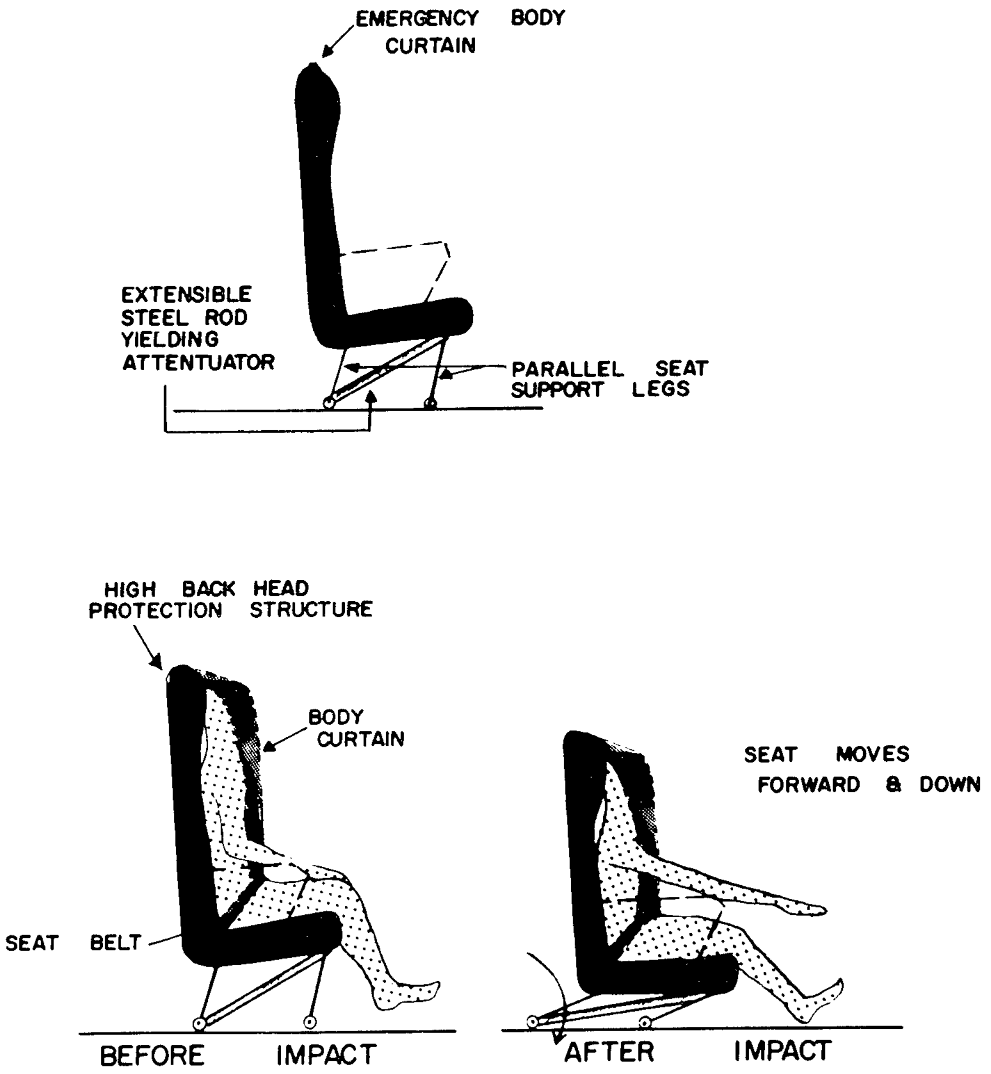
BEFORE IMPACT

AFTER IMPACT

FIGURE 14

INTEGRATED SAFETY SEAT

(ENERGY ABSORBING)



BEFORE IMPACT

AFTER IMPACT

FIGURE 15

GENERAL AVIATION SAFETY IMPROVEMENT

General Aviation Statistics

U.S. General Aviation includes all domestic civil flying other than scheduled and related flying of public airlines. Over the past several years the annual flying time of general aviation has been about four times the flying time of domestic public air carriers.

General aviation flying is categorized by five types: pleasure, business, aerial application, instruction and commercial/miscellaneous.

General aviation pleasure flying accounted for about 25% of the total flying hours and for one-half of the pilot fatalities in the 1962-63 period.

The second highest accident mortality rate is experienced in commercial air taxi service, fire control activities, and miscellaneous flying. While the time spent in commercial flying is nearly the same (25%) as in pleasure flying, the actual number of deaths was only about one-third that of pleasure flying.

Business flying has experienced a somewhat better accident record than commercial flying. Business flying utilizes aircraft to transport executives, sales personnel, etc., and accounts for roughly two-fifths of the total flying time in general aviation. In 1962-63 the fatality rate for business flying was 3.5 per 100,000 plane hours, or about 40 percent lower than for general aviation as a whole.

The instructional flying category consists of flight training of civilians under accredited instructor supervision. One-sixth of the total flying time was accounted for by instructional flying in 1962-63. However, this type of flying was responsible for only one-twentieth of all fatalities.

General aviation data presented in this section are for all flying categories and for all types of aircraft and includes over 90,000 aircraft of all types. This is twice the number of only ten years ago and the rapid growth continues. Figure 16 graphically portrays this rapid growth.

Annually, out of the general aviation aircraft, about one in 18 can be expected to have an accident of some type; one aircraft in 25 can be expected to receive substantial damage; one aircraft in 90 can be expected to be destroyed; and about one aircraft in 180 can be expected to include fatalities. The record of general aviation (Figure 16) shows that an accident occurs for every 4000 hours of accumulated flying time while the commercial air carrier record averages 50,000 flying hours between accidents.

Figure 17 shows the number of accidents currently at 5000 per year, of which 500 are fatal, and 1000 aircraft are destroyed. The actual number of fatalities has increased to over 1000 per year in apparent proportion with the increased number of aircraft. The rapid upward trend is shown in Figure 18.

A breakdown of general aviation accidents by phase of operation for year 1963 is shown in Figure 19. It is readily apparent that the largest single percentage of accidents occur during landing; however, only a small number of these end with fatalities. Most of the fatalities occur during normal cruise, or other in-flight conditions associated with bad weather, malfunction of systems, pilot error or unexpected collision.

GENERAL AVIATION — ALL TYPES AIRCRAFT

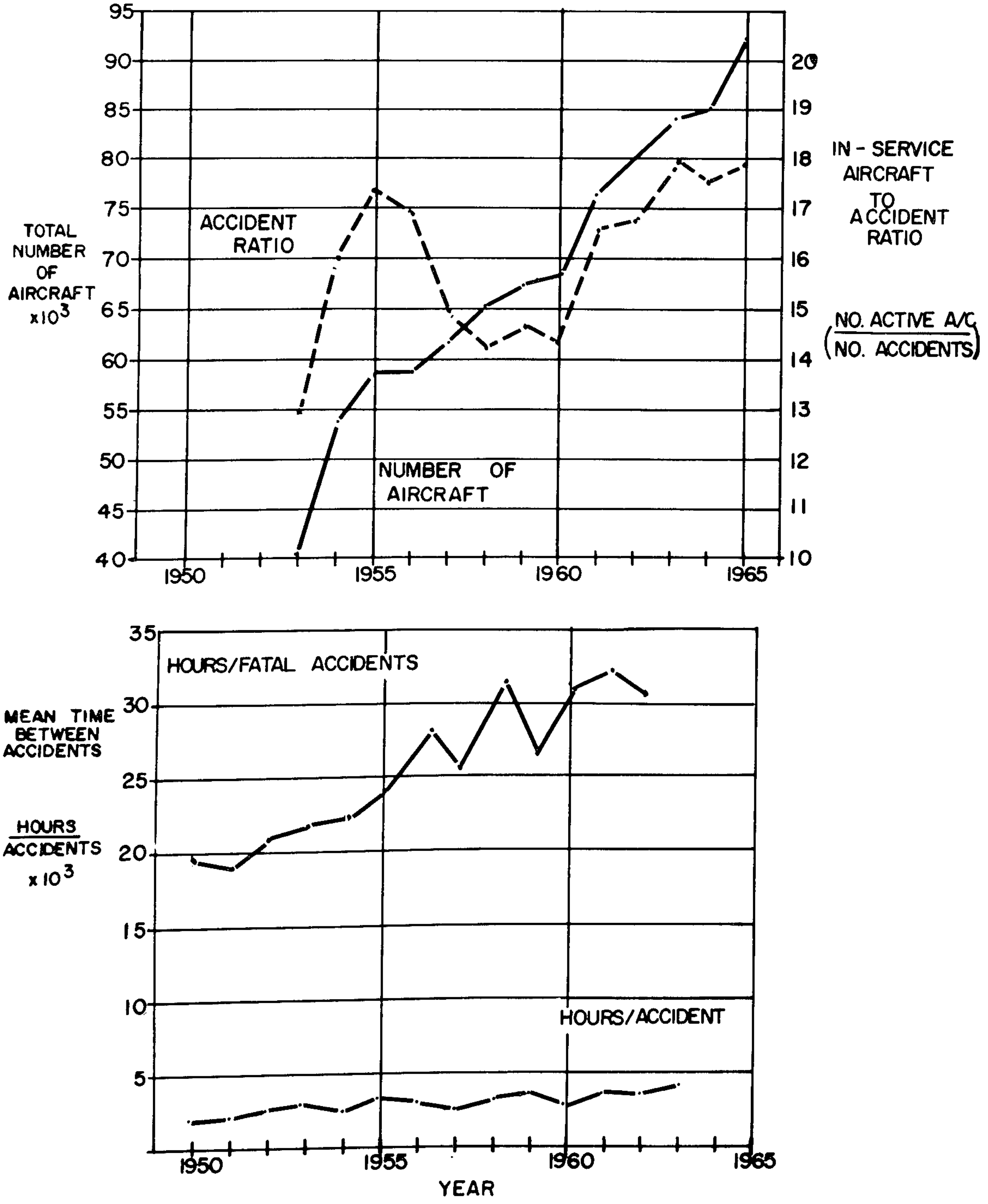


FIGURE 16

GENERAL AVIATION

ALL OPERATIONS - NUMBER OF ACCIDENTS

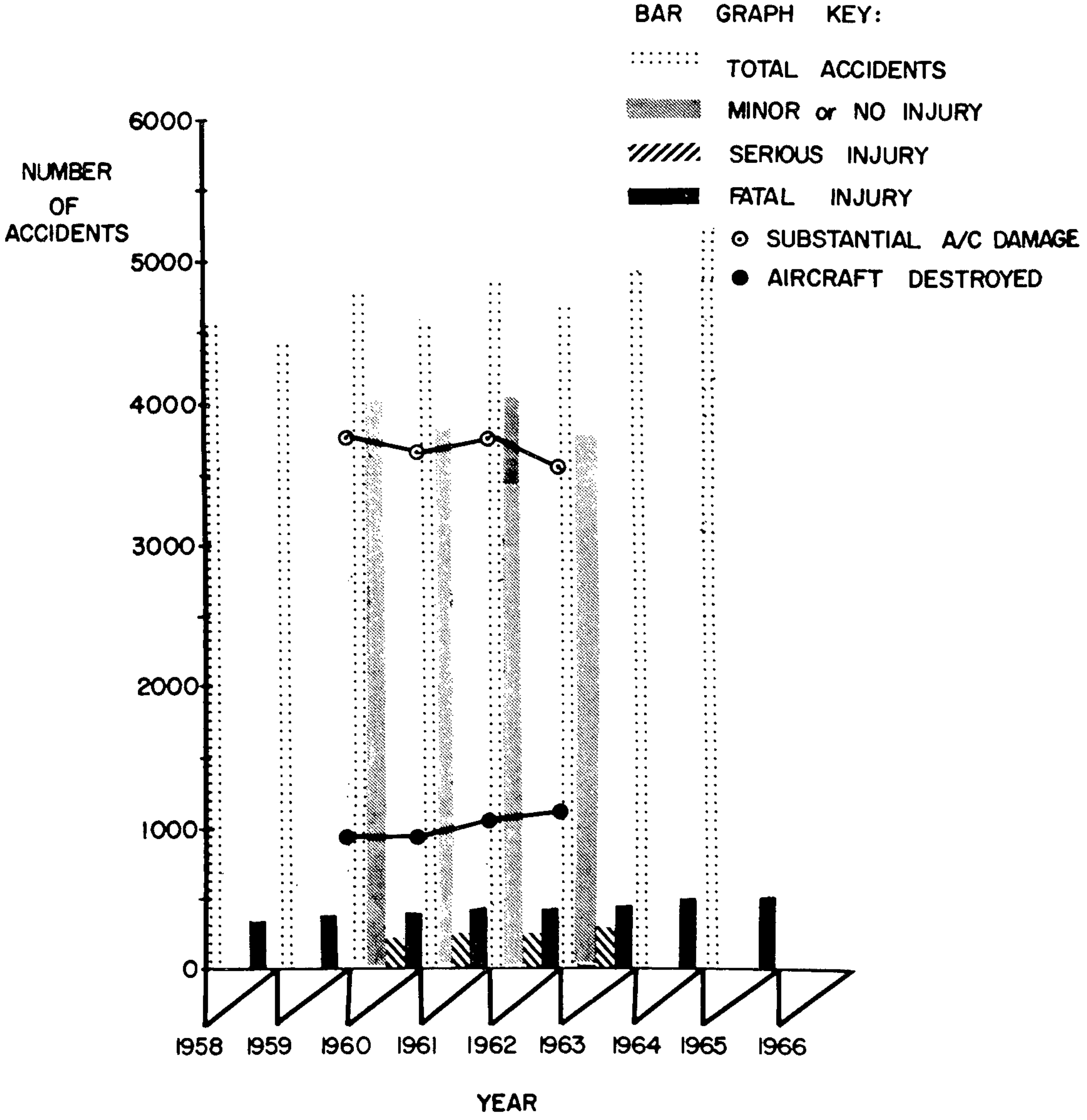


FIGURE 17

GENERAL AVIATION

ACCIDENT STATISTICS

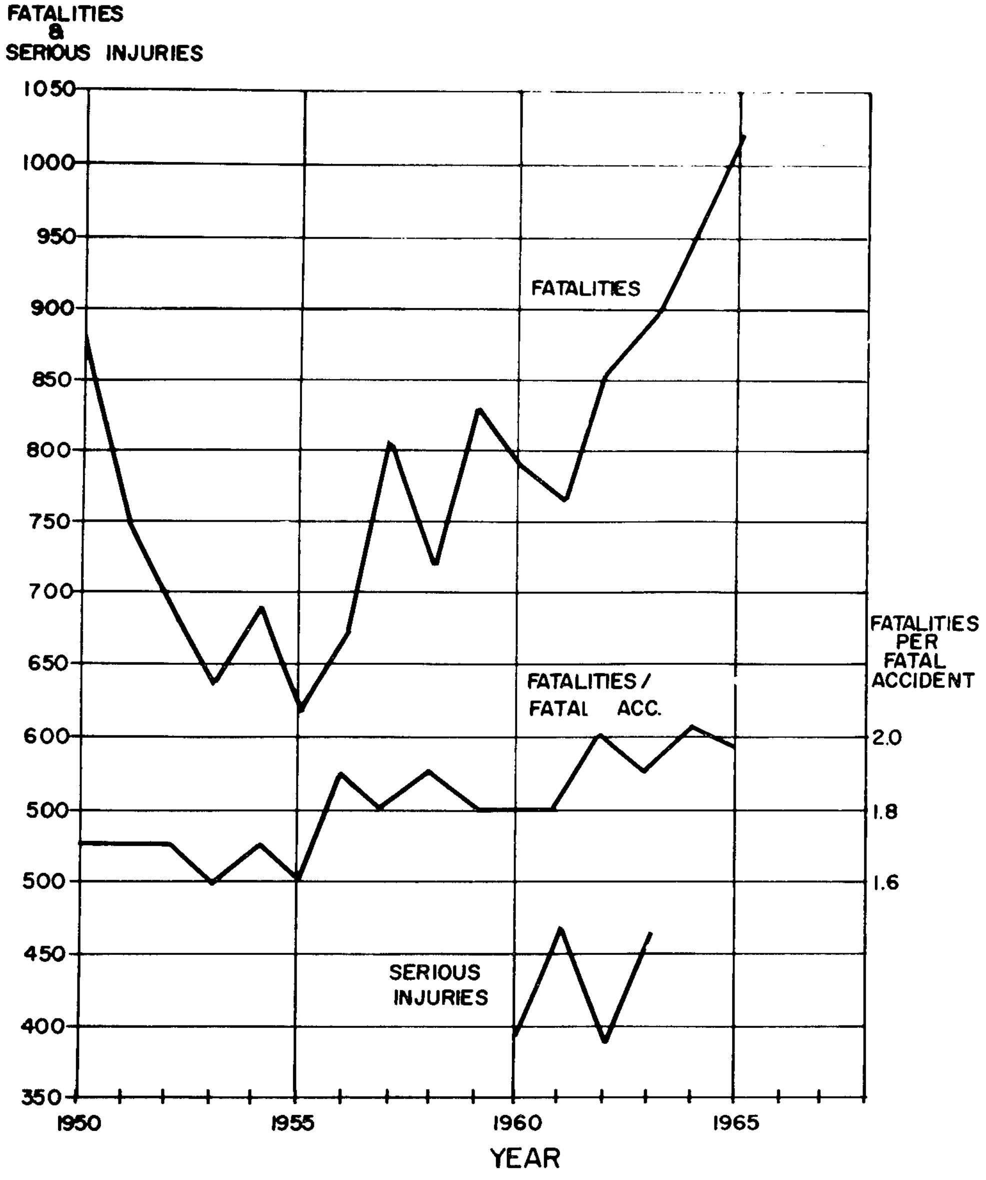


FIGURE 18

GENERAL AVIATION-ALL OPERATIONS

(63300 ACTIVE AIRCRAFT)

TYPICAL DISTRIBUTION OF ACCIDENTS BY PHASE-YEAR 1963

4690 ACCIDENTS—462 FATAL—295 WITH SERIOUS INJURY—3913 WITH MINOR INJURY

1097 AIRCRAFT DESTROYED—3550 AIRCRAFT SUBSTANTIALLY DAMAGED—43 MINOR DAMAGE

893 FATALITIES—462 SERIOUS INJURIES—7336 MINOR INJURIES

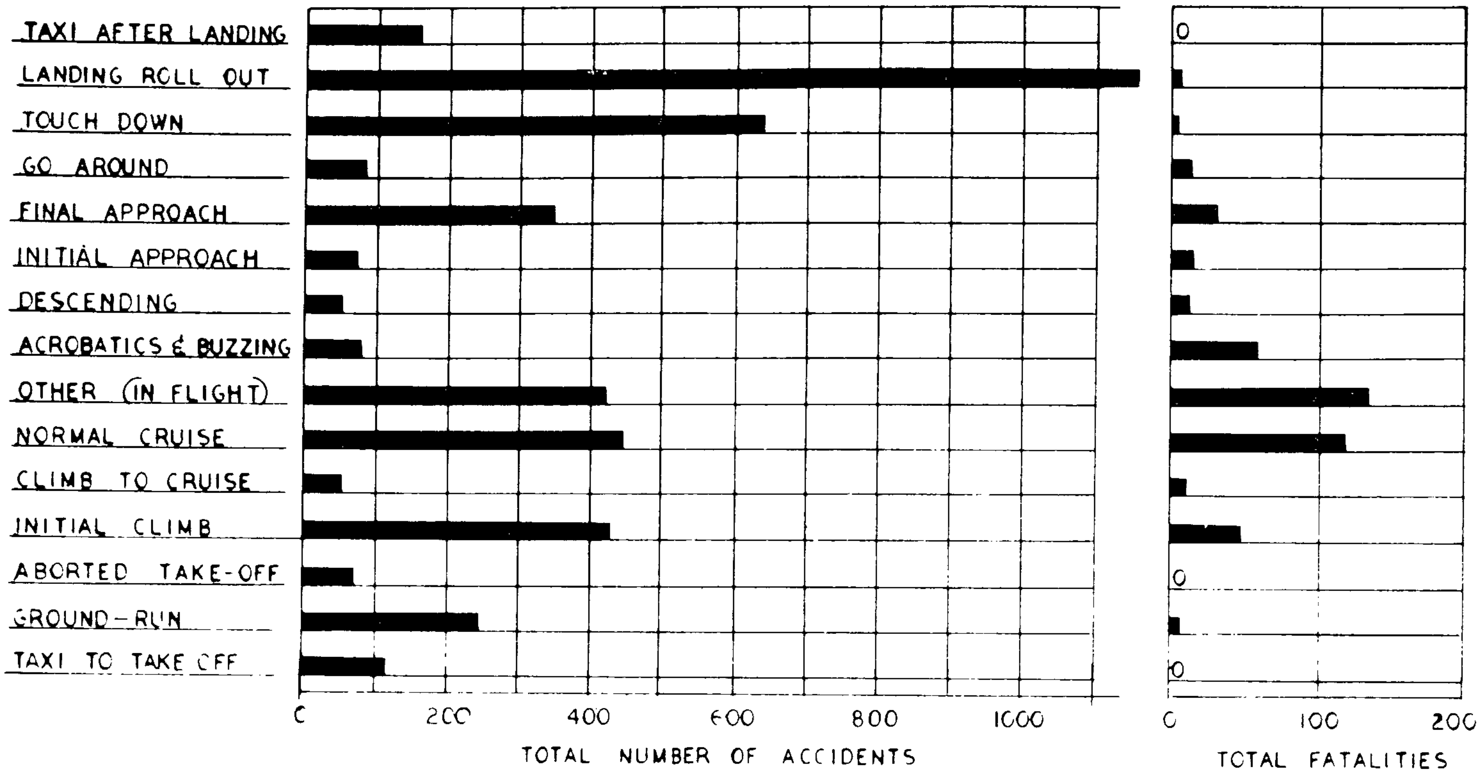


FIGURE 19

INTERNAL IMPROVEMENTS

Seat Attachment

Manufacturers of general aviation aircraft are obliged to observe the requirements of Federal Air Regulations Part 23, Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes. Under the design requirements specified herein the seat structure with an occupant restrained by belt or harness should be capable of ultimate forces as follows:

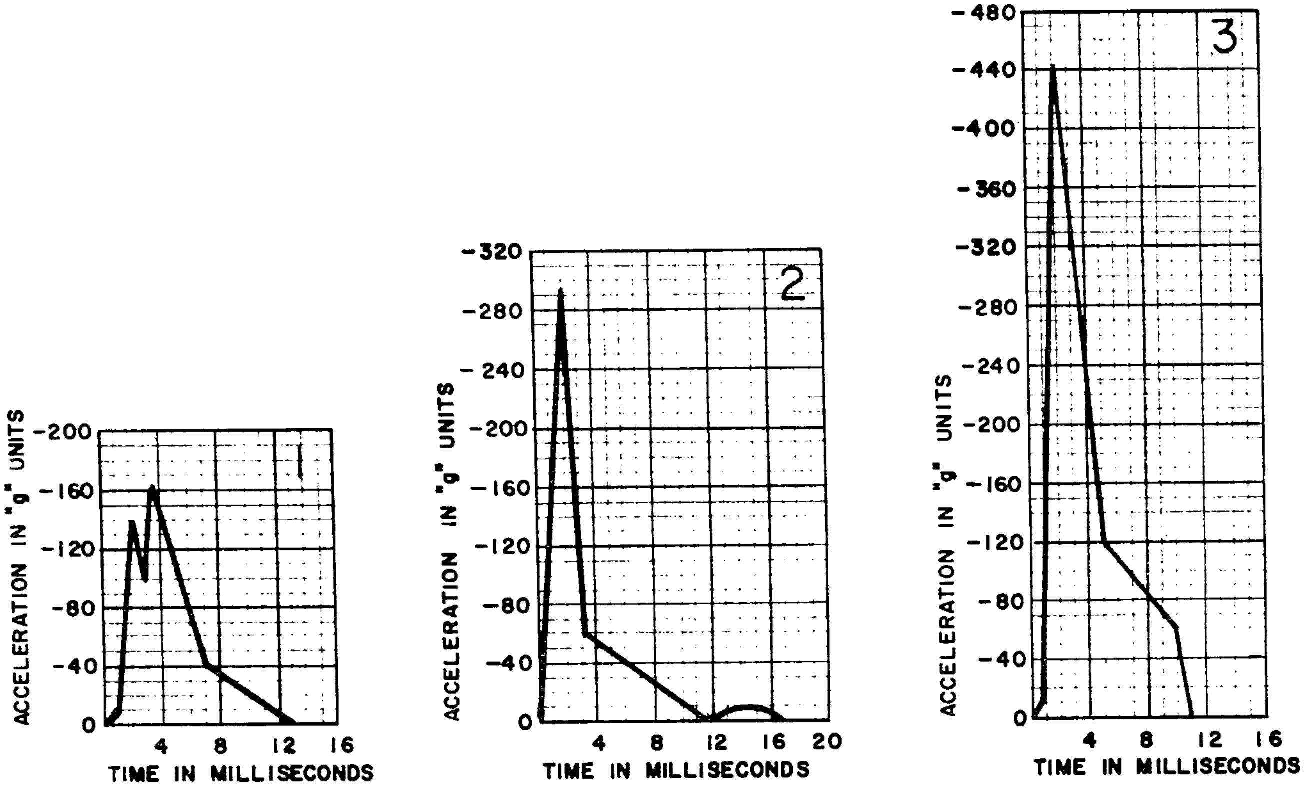
Upward	3.0 g	(4.5 g Acrobatic Category)
Forward	9.0 g	
Sideward	1.5 g	

These force limits apply to minor crash conditions and provide a reasonable chance of escaping serious injury, but under certain conditions much higher peak g's may be experienced. Seats may break loose under this loading and point out the need for an energy absorbing seat attachment.

The need for full body restraint is apparent from Figure 3 and from Figure 20, which shows g-force curves obtained from catapulting an instrumented dummy head against a typical unprotected light aircraft instrument panel. As noted, the lowest impact velocity produced a peak g value of over 160 g. The rigid panel did not deform so the head impacted the panel over a very small area. The forehead is the strongest part of the face, but it cannot withstand a force of 80 g's on one square inch of area without fracture. Therefore, all injuries depicted in Figure 20 would cause fatal head injuries.

HEAD IMPACT ACCELERATIONS

G-FORCE CURVES OBTAINED WITH HEAD IMPACTS ON A TYPICAL LIGHT-AIRCRAFT INSTRUMENT PANEL AT VELOCITIES OF (1) 17.6 FT/SEC, (2) 26.7 FT/SEC, AND (3) 42.2 FT/SEC.



REF. AM 66-12

FIGURE 20

HUMAN TOLERANCES

This section presents a number of graphical data related to human tolerances for acceleration, impact, temperature, and decompression. These data were gathered from the NASA SP-3006 "Bioastronautics Data Book" and FAA reports AM 66-12, and AM 66-18 written by J. J. Swearingen, of the Civil Aeromedical Research Institude. These particular graphs have been selected because of their direct relationship to aircraft accident survival.

The graphs in this section are provided mainly as supplementary survival criteria data.

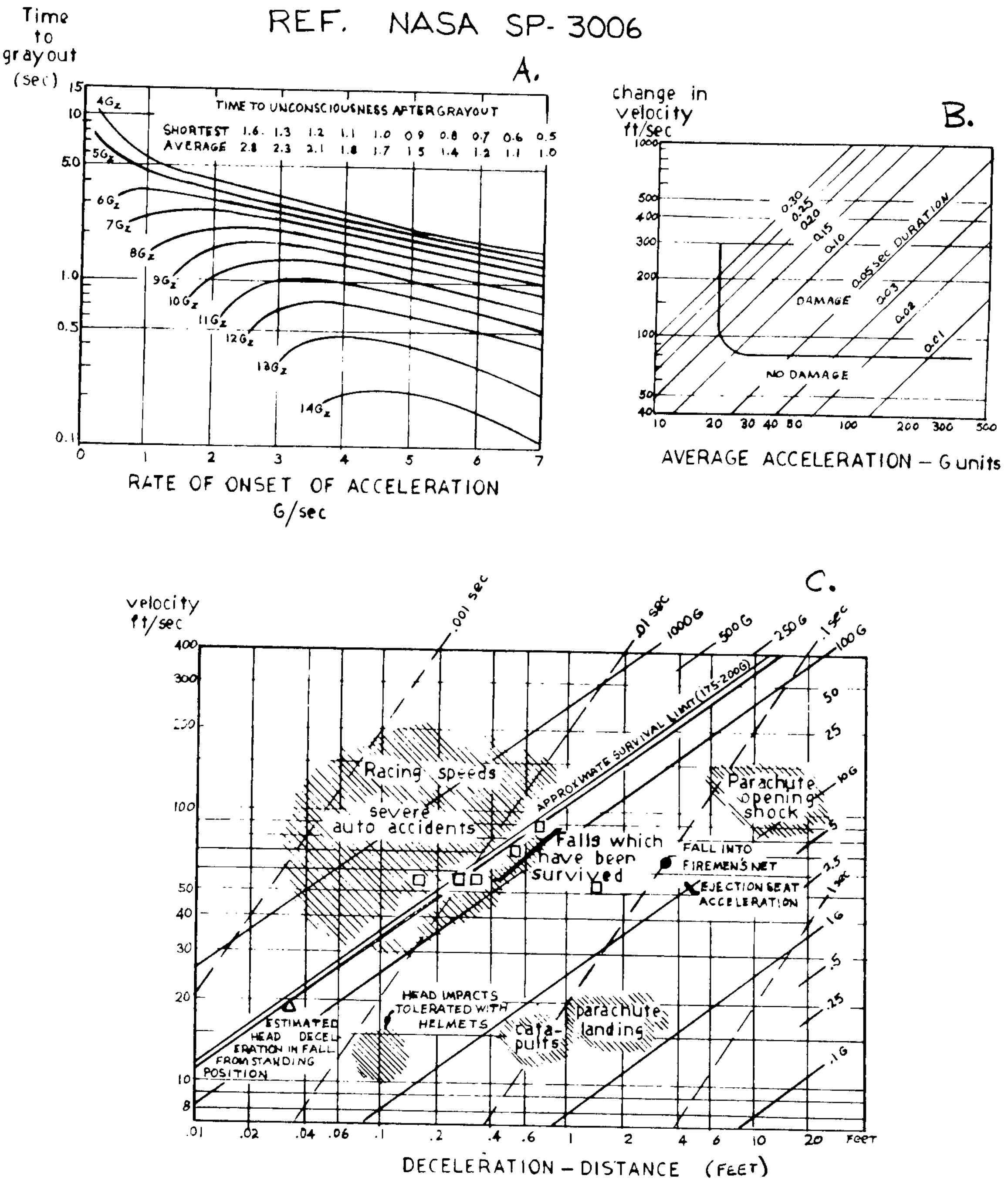
Figure A-8 shows the relationship of maximum acceleration and onset rate for stopping distances from 4 to 8 inches from a 30 ft/sec. impact velocity.[11] The most efficient use of stopping distance is produced by an infinite onset rate. This is represented by the minimum g, infinite onset point of each curve. A triangular time history is represented by the maximum g end point of each curve. The points between these two extremes represent trapezoidal time histories with specific onset rates and a finite crushing time at constant g. For protection of humans, the areas of high g and low onset rate are of interest. Superimposed on this figure are the approximate acceleration tolerances [10] for humans with acceleration duration time labeled for each data point.

For impact durations of less than 0.07 seconds, it is assumed that the body acts as a rigid mass with no fluid shifts occurring.[11] Thompson assumed that structural limits for body tissue are in excess of 200 g, and constructed the tolerance curve of Figure A-9. The magnitude of peak g may range up to 45 g for impacts of greater than 0.07 second duration, hence there is infinite slope for the tolerance curve in this area. For impacts of less duration time, up to about 200 g, the tolerance limit is represented by the criteria that $2V = 100$ ($V= 50$ fps) and for this area the tolerance curve is horizontal. The validity of this concept is indicated by the data points on Figure A-9.

Based on these test results, and shown in Figure A-10, A.B. Thompson states that the ultimate human limits to entire body impact is somewhere in the range of 45 and 55 psi impact force. The physiological shock yield point lies somewhere between 28 and 32 psi for transverse accelerations.

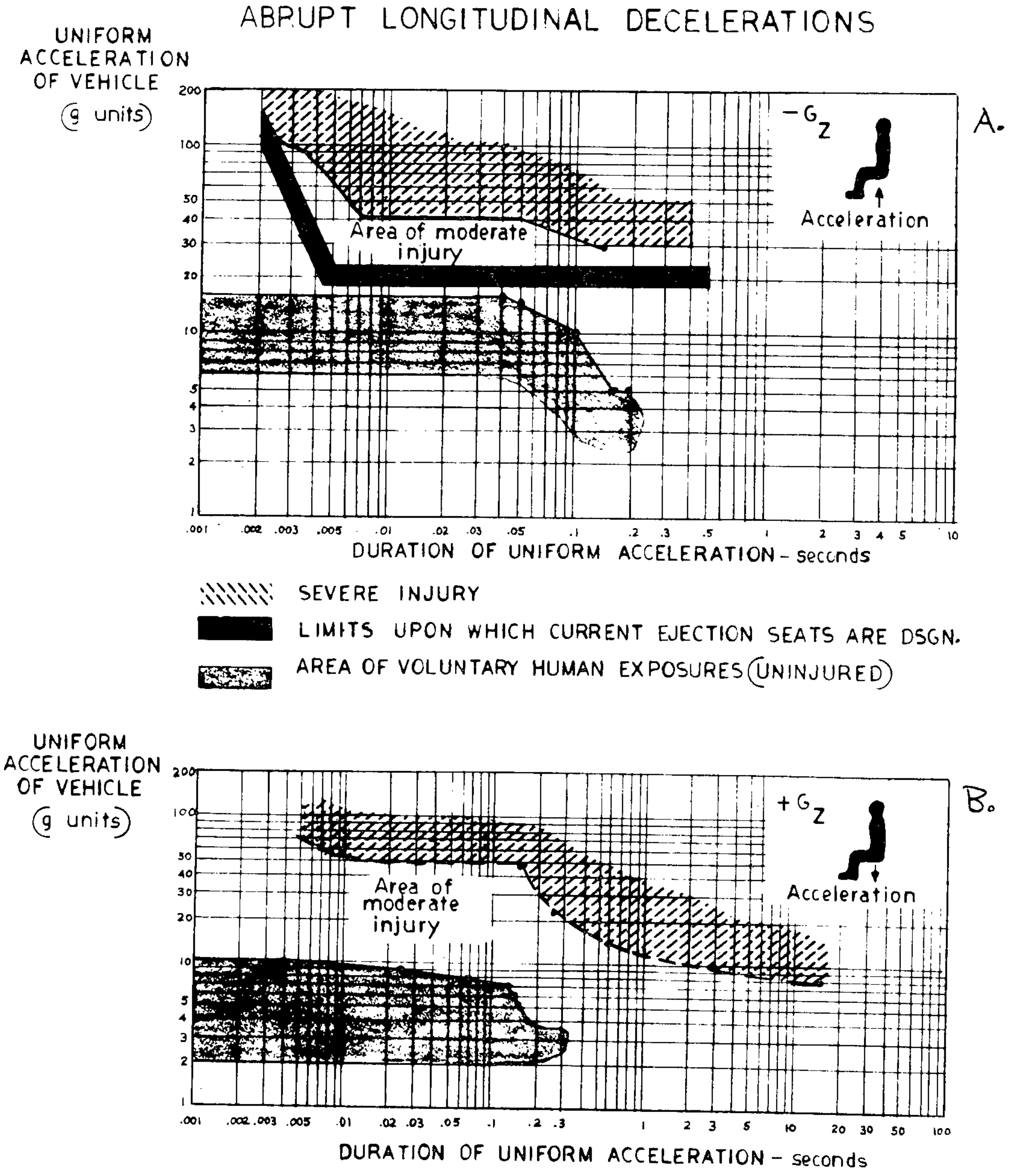
ACCELERATION TOLERANCE

REF. NASA SP-3006



REF. NASA SP-3006

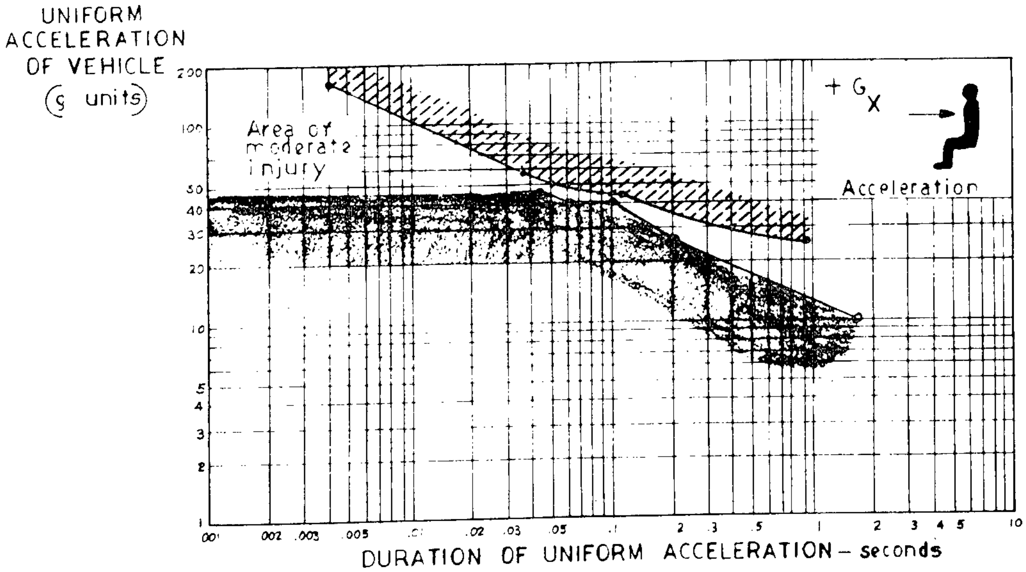
FIGURE A-1



REF. NASA SP-3006

FIGURE A-2

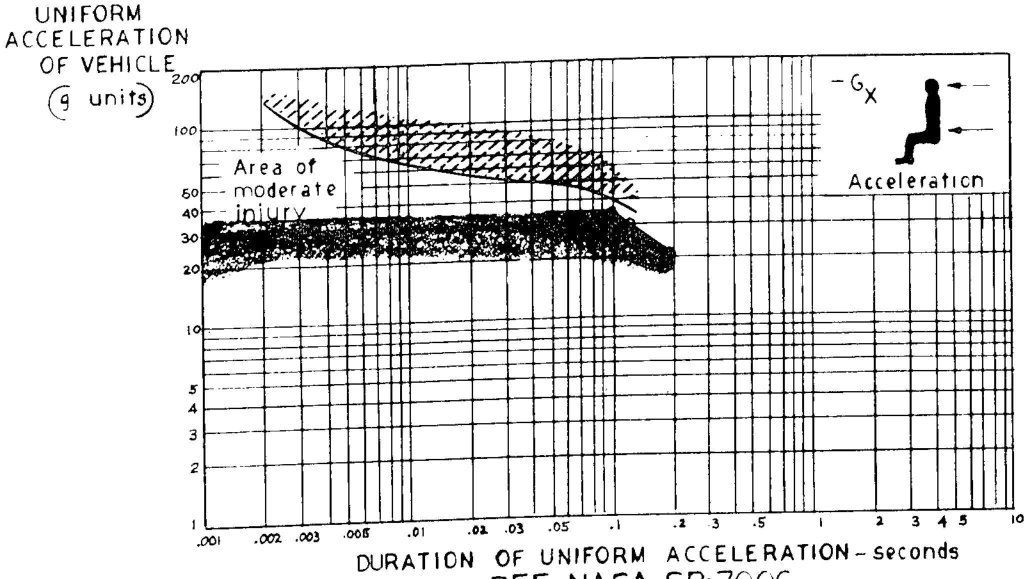
ABRUPT TRANSVERSE DECELERATIONS



A.

▨ SEVERE INJURY

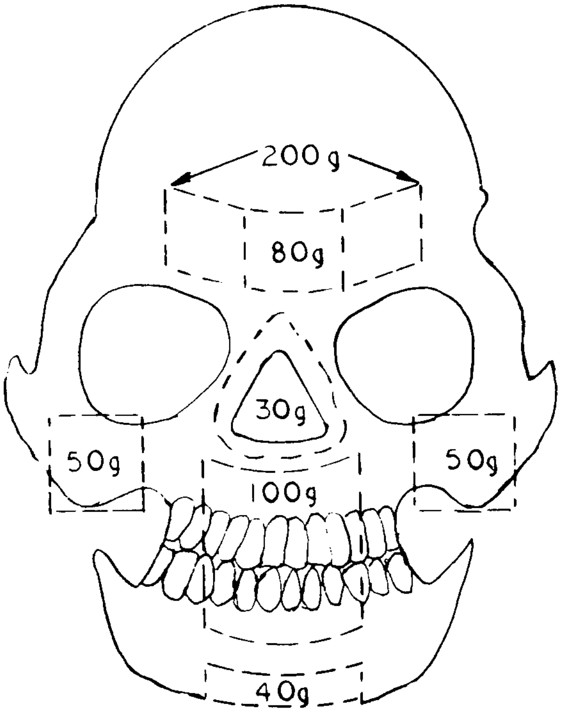
■ AREA OF UNINJURED



B.

REF. NASA SP-3006

FIGURE A-3



SUMMARY OF MAXIMUM TOLERABLE IMPACT FORCES ON A PADDED DEFORMABLE SURFACE

Ref. J. J. Swearingen AM-66-16
CIVIL AEROMEDICAL RESEARCH INSTITUTE
Office of Aviation Medicine
Federal Aviation Agency

FIGURE A-4

HUMAN TOLERANCE TO TEMPERATURE

REF. NASA SP-3006

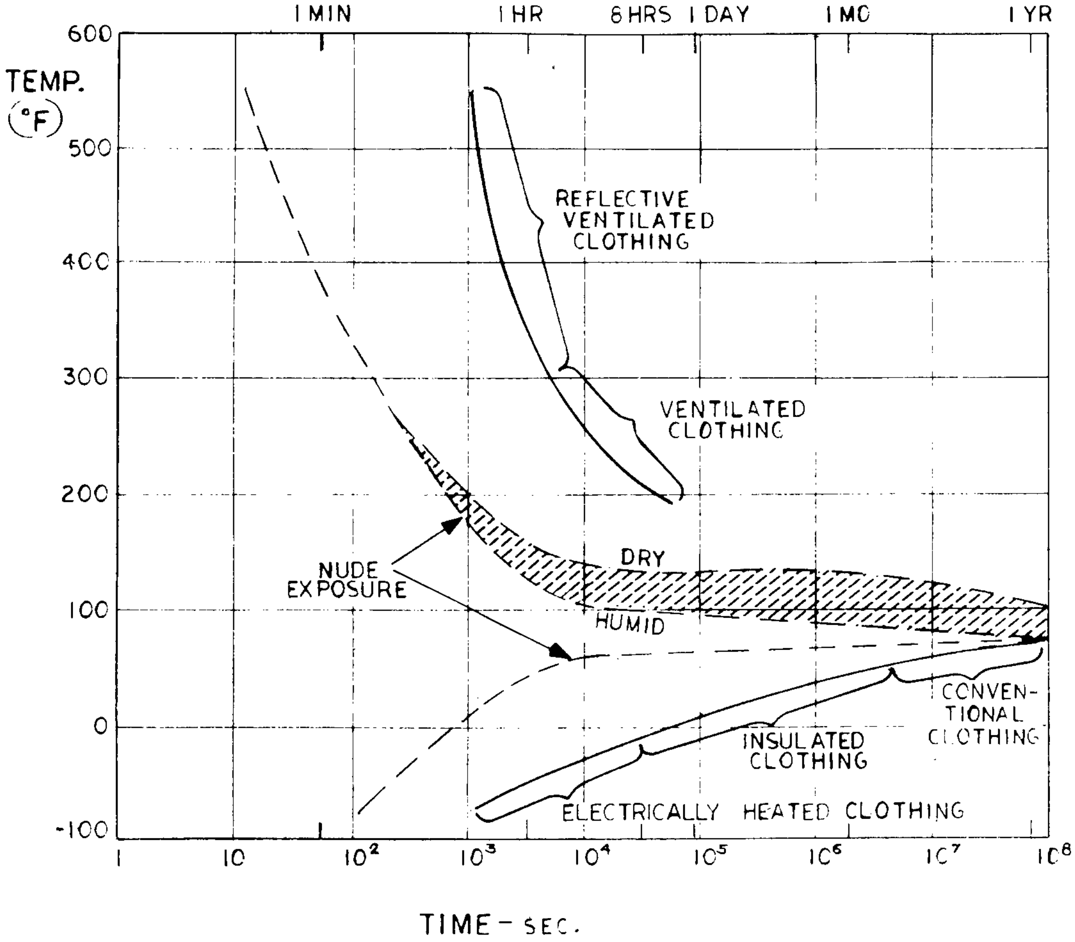
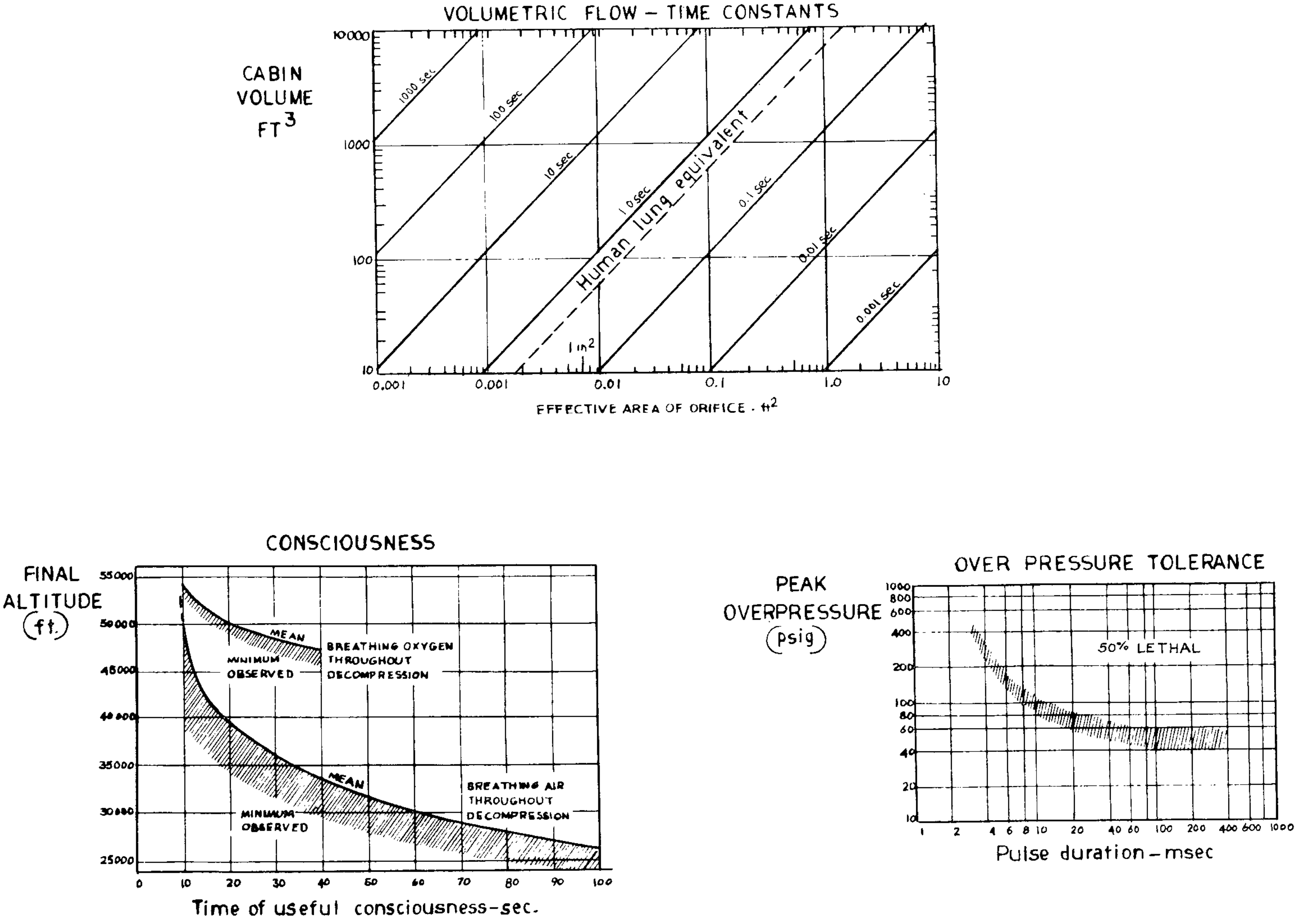


FIGURE A-5

DECOMPRESSION DATA



VOLUMETRIC FLOW – TIME CONSTANTS

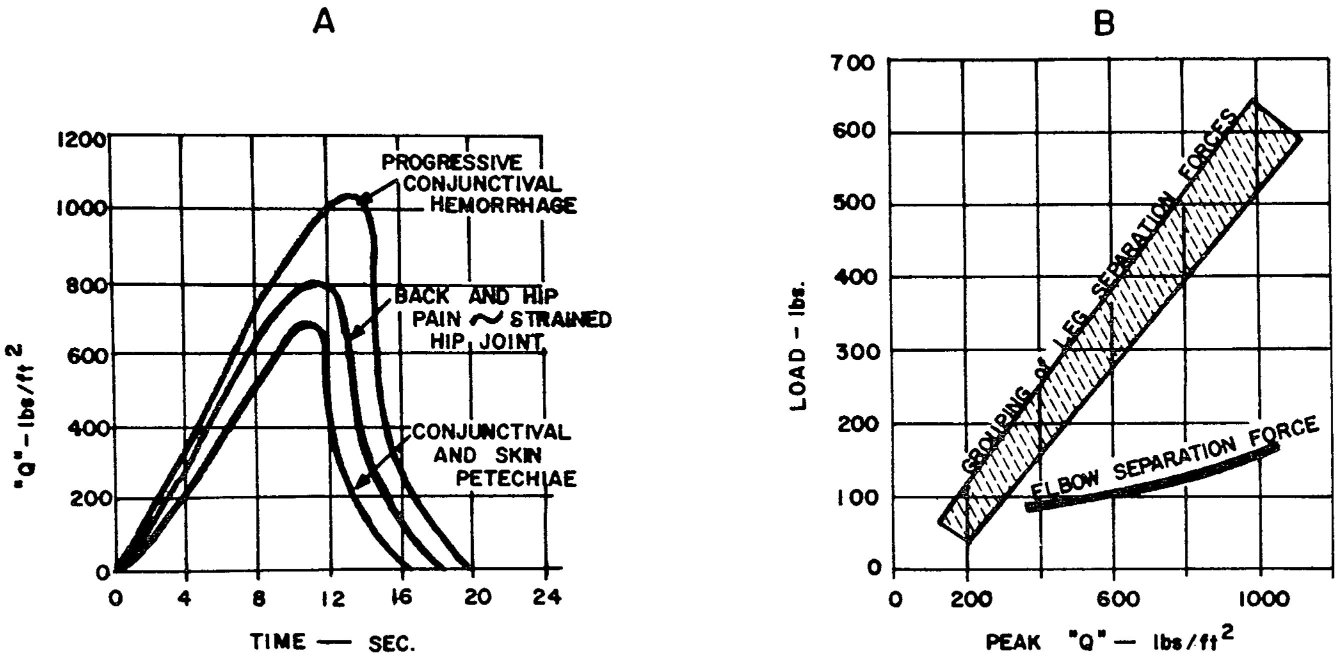
CONSCIOUSNESS

OVER PRESSURE TOLERANCE

REF. NASA SP-3006

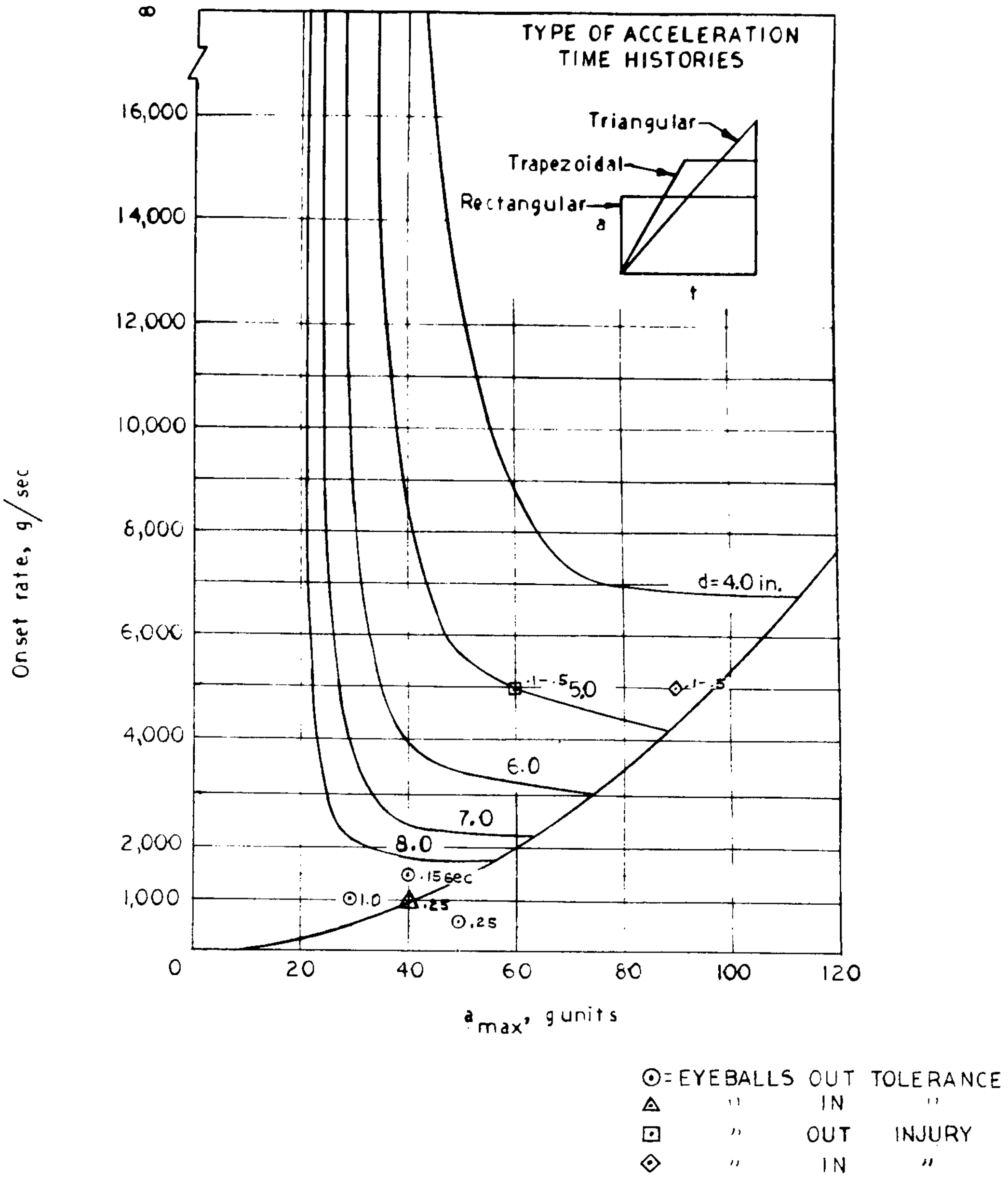
FIGURE A-6

MECHANICAL EFFECTS OF HIGH DYNAMIC PRESSURES



REF. NASA SP-3006

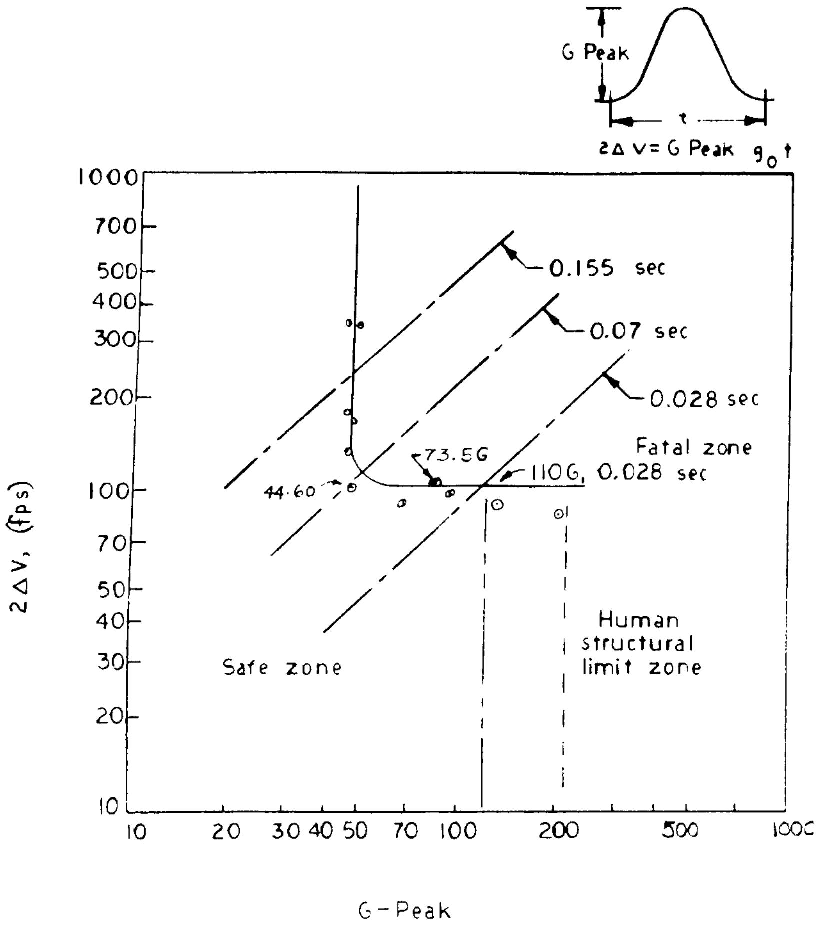
FIGURE A-7



Variation of maximum acceleration and onset rate for constant values of stopping distance for an impact velocity of 30 ft/sec.

REF. NASA TECH. NOTE D-158

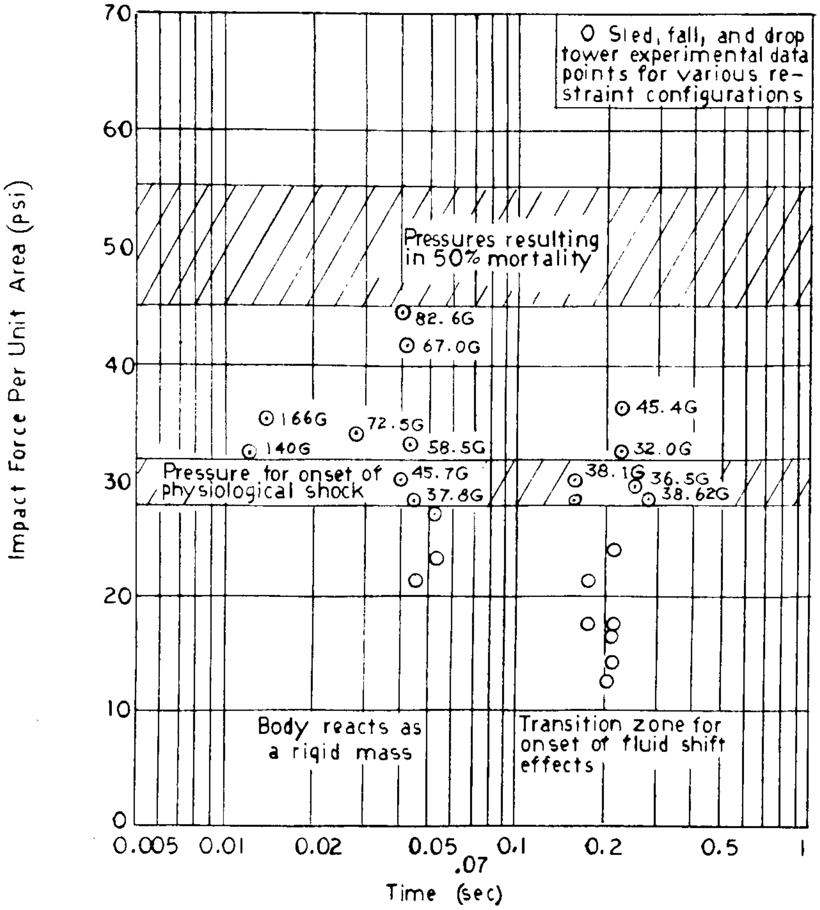
FIGURE A-8



-Human Transverse Impact Tolerance, 2ΔV Versus Peak G

REF. ASD-TDR-63-173

FIGURE A-9



Human Transverse Impact Tolerance as Defined by Unit Impact Pressure and Time

REF. ASD-TDR-63-173

FIGURE A-10

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By: Flight Safety Foundation; W.H. Reed, D. F. Carroll; Contract DA 44-177-AMC-888(T)
J.L. Reed, Project Engineer
Lt. Col. T. C. Woodbury Johnson, Group Leader
Larry M. Hewin, Technical Director

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