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US ARMY
AVIATION
SYSTEMS COMMAND

AIRCRAFT CRASH SURVIVAL DESIGN GUIDE

VOLUME I - DESIGN CRITERIA AND CHECKLISTS

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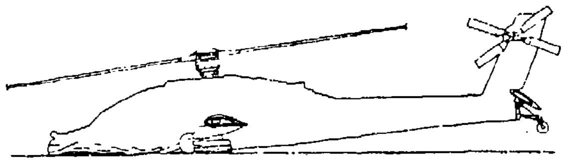

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FINAL REPORT

Prepared for

AVIATION APPLIED TECHNOLOGY DIRECTORATE
US ARMY AVIATION RESEARCH AND TECHNOLOGY ACTIVITY (AVSCOM)
FORT EUSTIS, VA 23604-5577

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AVIATION APPLIED TECHNOLOGY DIRECTORATE POSITION STATEMENT

This revised edition of the Aircraft Crash Survival Design Guide (ACSDG) was prepared to assist those design engineers responsible for the incorporation of crashworthiness into the design of helicopters, light fixed-wing aircraft, and tilt rotor aircraft. Also, this guide may be used in the evaluation of the level of crashworthiness design available in the various types of aircraft.

This report documents the components and principles of crashworthiness and suggests specific design criteria. In general, a systems approach is presented for providing a reasonable level of aircrew and aircraft protection in a crash, which is considered the preferred approach. The original Crash Survival Design Guide was published in 1967 as USAAVLABS TR 67-22 and subsequent revisions published as USAAVLABS TR 70-22, USAAMRDL TR 71-22, and USARTL-TR-79-22A thru E. This edition consists of a consolidation of up-to-date design criteria, concepts, and analytical techniques developed through research programs sponsored by this Directorate and others over the past 27 years.

This document has been coordinated with other Government agencies and helicopter airframe manufacturers active in aircraft crashworthiness research and development, and is considered to offer sound design criteria and approaches to design for crashworthiness.

The technical monitors for this program were Messrs. LeRoy Burrows, Harold Holland, and Kent Smith of the Safety and Survivability Technical Area, Aeronautical Systems Division, Aviation Applied Technology Directorate.

NOTE: All previous editions of the Aircraft Crash Survival Design Guide are obsolete and should be destroyed.

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13. ABSTRACT *(Maximum 200 words)*

This five-volume publication has been compiled to assist design engineers in understanding the design considerations associated with the development of crash-resistant U.S. Army aircraft. A collection of available information and data pertinent to aircraft crash resistance is presented, along with suggested design conditions and criteria. The five volumes of the Aircraft Crash Survival Design Guide cover the following topics: Volume I - Design Criteria and Checklists; Volume II - Aircraft Design Crash Impact Conditions and Human Tolerance; Volume III - Aircraft Structural Crash Resistance; Volume IV - Aircraft Seats, Restraints, Litters and Cockpit/Cabin Delethalization; and Volume V - Aircraft Postcrash Survival. This volume (Volume I) contains concise criteria drawn from Volumes II through V, supplemented by checklists intended to assist designers in implementing the criteria.

14. SUBJECT TERMS
Aircraft Design Guide, Human Tolerance, Restraint Systems, Test Dummies, Anthropometry, Postcrash Survival, Emergency Escape, Seats, Crash Resistance, Postcrash Fires, Fuel Systems, Litters, Protective Padding, Structural Crash Resistance (KR)

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PREFACE

This report was prepared for the Safety and Survivability Technical Area of the Aviation Applied Technology Directorate, U.S. Army Aviation Research and Technology Activity (AVSCOM), Fort Eustis, Virginia, by Simula Inc. under Contract DAAJ02-86-C-0028, initiated in September 1986. This guide is a revision of USARTL Technical Report 79-22, Aircraft Crash Survival Design Guide, published in 1980.

A major portion of the data contained herein was taken from U.S. Army-sponsored research in aircraft crash resistance conducted from 1960 to 1987. Acknowledgment is extended to the U.S. Air Force, the Federal Aviation Administration, NASA, and the U.S. Navy for their research in crash survival. Appreciation is extended to the following organizations for providing accident case histories leading to the establishment of the impact conditions in aircraft accidents:

- U.S. Army Safety Center, Fort Rucker, Alabama.
- U.S. Naval Safety Center, Norfolk, Virginia.
- U.S. Air Force Inspection and Safety Center, Norton Air Force Base, California.

Information was also provided by the Civil Aeronautics Board, which is no longer in existence.

Additional credit is due the many authors, individual companies, and organizations listed in the bibliographies for their contributions to the field. The contributions of the following authors to previous editions of the Aircraft Crash Survival Design Guide are most noteworthy:

D. F. Carroll, R. L. Cook, S. P. Desjardins, J. K. Drummond, J. L. Haley, Jr., A. D. Harper, H. G. C. Henneberger, N. B. Johnson, G. Kourouklis, Dr. D. H. Laananen, P. A. Rakszowski, W. H. Reed, M. J. Reilly, S. H. Robertson, J. Shefrin, L. M. Shaw, G. T. Singley, III, A. E. Tanner, Dr. J. W. Turnbow, and L. W. T. Weinberg.

This volume was prepared by Richard E. Zimmermann and Norman A. Merritt of Simula Inc. Technical review and comments were provided by S. P. Desjardins of Simula Inc.

Volume I is a compilation of criteria and checklists for the design of crash-resistant military aircraft. The criteria have been assembled in this one volume for the convenience of those involved in the design or evaluation of the overall aircraft and for use as a concise criteria reference. Additional background information is provided in Volumes II through V.

The design criteria contained in this volume are the result of studies made of crashes and experience gained during the design and manufacture of military aircraft.

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INTRODUCTION

For many years, emphasis in military aircraft accident investigation was placed on determining the cause of the accident. Very little effort was expended on the crash survival aspects of aviation safety. However, it became apparent through detailed studies of accident investigation reports that significant improvements in crash survival could be made if consideration were given in the initial aircraft design to the following factors that influence survivability:

1. Crash Resistance of Aircraft Structure - The ability of the aircraft structure to maintain living space for occupants throughout a crash.

2. Tiedown Strength - The strength of the linkage preventing occupant, cargo, or equipment from breaking free and becoming missiles during a crash sequence.

3. Occupant Acceleration During Crash Impact - The intensity and duration of accelerations experienced by occupants (with tiedown assumed intact) during a crash.

4. Occupant Crash Impact Hazards - Barriers, projections, and loose equipment in the immediate vicinity of the occupant that may cause contact injuries.

5. Postcrash Hazards - The threat to occupant survival posed by fire, drowning, entrapment, exposure, etc., following the impact sequence.

Early in 1960, the U.S. Army Transportation Research Command* initiated a long-range program to study all aspects of aircraft safety and survivabilty. Through a series of contracts with the Aviation Safety Engineering and Research (AvSER) Division of the Flight Safety Foundation, Inc., the problems associated with occupant survival in aircraft crashes were studied to determine specific relationships among crash forces, structural failures, crash fires, and injuries. A series of reports covering this effort was prepared and distributed by the U.S. Army, beginning in 1960. In October 1965, a special project initiated by the U.S. Army consolidated the design criteria presented in these reports into one technical document suitable for use as a designer's guide by military aircraft design engineers. The document was to be a summary of the current state of the art in crash survival design. The Crash Survival Design Guide, TR 67-22, published in 1967, realized this goal.

Since its initial publication, the Design Guide has been revised and expanded four times to incorporate the results of continuing research in crash resistance technology. The third edition, published in 1971, was the basis for the criteria contained in the original version of the Army's military standard MIL-STD-1290, "Light Fixed- and Rotary-Wing Aircraft Crash Resistance" (Reference 1). The fourth edition, published in 1980, entitled Aircraft Crash Survival Design Guide, expanded the document to five volumes, which have been updated by the current edition to include information and changes

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*Now the Aviation Applied Technology Directorate, U.S. Army Aviation Research and Technology Activity, U.S. Army Aviation Systems Command (AVSCOM).

developed from 1980 to 1987. This current edition, the fifth, contains the most comprehensive treatment of all aspects of aircraft crash survival now documented. It can be used as a general text to establish a basic understanding of crash impact conditions and the techniques that can be employed to improve chances for survival. It also contains design criteria and checklists on many aspects of crash survival and thus can be used as a source of design requirements.

It should be emphasized that the Design Guide is to be used as a guide, not as a specification. System specifications should reference applicable crash-resistant design specifications, such as MIL-STD-1290, MIL-S-58095, and MIL-S-85510, or should include specific criteria selected from the Design Guide or other sources.

The current edition of the Aircraft Crash Survival Design Guide is also published in five volumes. Volume titles and general subjects included in each volume are as follows:

Volume I - Design Criteria and Checklists

Pertinent criteria extracted from Volumes II through V, presented in the same order in which they appear in those volumes.

Volume II - Aircraft Design Crash Impact Conditions and Human Tolerance

Crash impact conditions, human tolerance to impact, military anthropometric data, occupant environment, test dummies, accident information retrieval.

Volume III - Aircraft Structural Crash Resistance

Crash load estimation, structural response, fuselage and landing gear requirements, rotor requirements, ancillary equipment, cargo restraints, structural modeling.

Volume IV - Aircraft Seats, Restraints, Litters, and Cockpit/Cabin Delethalization

Operational and crash impact conditions, energy absorption, seat design, litter requirements, restraint system design, occupant/restraint system/seat modeling, delethalization of cockpit and cabin interiors.

Volume V - Aircraft Postcrash Survival

Postcrash fire, ditching, emergency escape, crash locator beacons.

In this volume (Volume I), Chapter 1 introduces and explains the intended use of the material contained herein. Chapter 2 contains definitions of terms used in the Design Guide. Chapters 3, 4, 5, and 6 contain the criteria and checklists extracted from Volumes II, III, IV, and V, respectively. The reader of this volume is strongly urged to familiarize himself with the material in the other volumes, at least in his particular area of responsibility (for example, seats and restraints or fuel systems), in order to appreciate more fully the limitations of the criteria.

The criteria are supplemented by checklists that are intended for use by aircraft designers in the original design stages and in the design review. These checklists should help the designer apply the necessary criteria in a comprehensive and orderly manner during the development of crash-resistant designs and provide a rapid and positive means of determining that none of the criteria have been overlooked. The responses on the checklists also should aid the designer in determining the strengths and weaknesses of an existing or proposed design.

After the designer has finished reviewing a system design, each item on the applicable checklists should have a check mark in one of the spaces following the item. Those items marked "NO" should be examined to determine the reason for noncompliance with the design criteria. Unless the reason involves a conflicting, overriding requirement, the design should be revised to meet the crash-resistant criteria. Those items marked "N/A" should be carefully reviewed to be sure that the item is truly not applicable to the system under consideration.

The units of measurement shown in the Design Guide vary depending upon the units used in the referenced sources of information, but are mostly USA units. In some cases the corresponding metric units are shown in parentheses following the USA units. For the convenience of the reader a conversion table of some commonly used units follows:

USA Unit	Abbr. or Symbol	Metric Equivalent	Abbr. or Symbol
Weight			
Ounce	oz	28.350 grams	g
Pound	lb or #	0.454 kilogram	kg
Capacity (U.S. liquid)			
Fluidounce	fl oz	29.573 milliliters	ml
Pint	pt	0.473 liter	l
Quart	qt	0.946 liter	l
Gallon	gal	3.785 liters	l
Length			
Inch	in.	2.54 centimeters	cm
Foot	ft	30.48 centimeters	cm
Yard	yd	0.9144 meter	m
Mile	mi	1.609 kilometers	km
Area			
Square Inch	sq in. or $in.^2$	6.452 sq centimeter	sq cm or cm^2
Square Foot	sq ft or ft^2	0.093 square meter	sq m or m^2
Volume			
Cubic Inch	cu in. or $in.^3$	16.387 cubic centimeters	cu cm or cm^3
Cubic Foot	cu ft or ft^3	0.028 cubic meter	cu m or m^3
Force			
Pound	lb	4.4482×10^5 dynes	
		4.4482 newtons	N

1. BACKGROUND DISCUSSION

The overall objective of designing for crash resistance is to eliminate injuries and fatalities in relatively mild impacts and minimize them in all severe but survivable mishaps. A crash-resistant aircraft will also reduce aircraft crash impact damage. By minimizing personnel and material losses due to crash impact, crash resistance conserves resources, is a positive morale factor, and improves the effectiveness of the fleet both in peacetime and in war. Results from analyses and research have shown that the relatively small cost in dollars and weight of including crash resistance features is a wise investment (References 2 through 13). Consequently, new-generation Army rotary-wing aircraft are being procured to stringent, yet practical, requirements for crash resistance.

To provide as much occupant protection as possible, a systems approach to crash resistance must be followed. The systems approach to crash resistance means that the landing gear, aircraft structure, and occupant seats must all be designed to work together to absorb the aircraft kinetic energy and slow the occupants to rest without injurious loading, as shown in Figure 1 (Reference 14). In addition, the occupants must all be restrained and a protective structural shell maintained around the occupied areas during a crash to provide a livable volume. Weapon sights, cyclic controls, glare shields, instrument panels, armor panels, and aircraft structure must be delethalized if they lie within the strike envelope of the occupant. Postcrash hazards, such as fire, entrapment, drowning, emergency egress, and rescue must also be considered in an effective crash-resistant design.

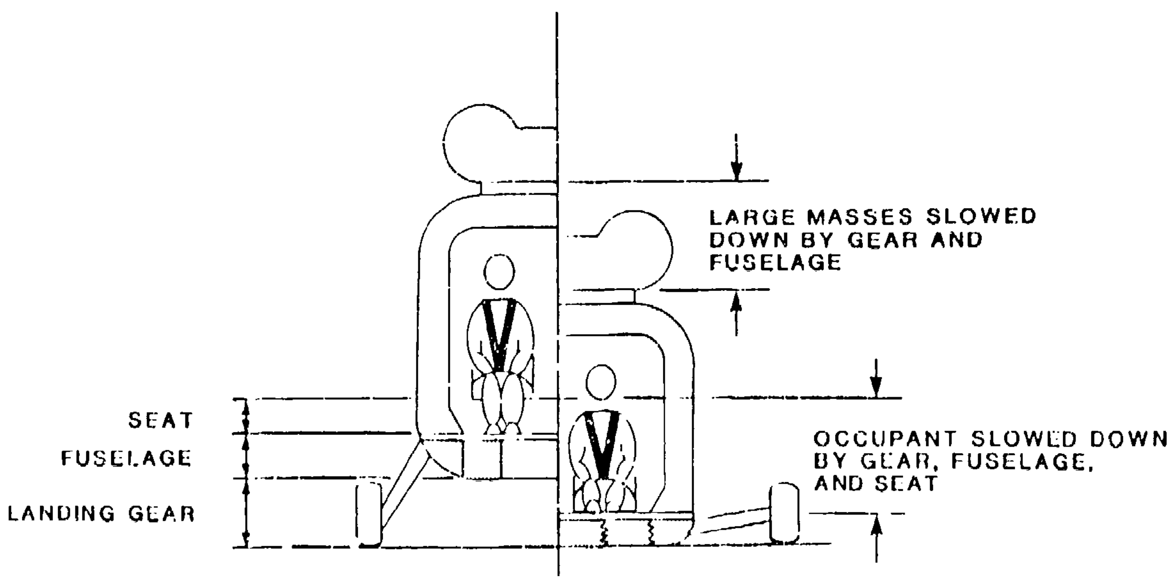


FIGURE 1. ENERGY MANAGEMENT SYSTEM. (FROM REFERENCE 14)

The composition of the surface being impacted must also be considered early in the design phase, when decisions concerning the relative energy-absorbing roles of the landing gear, structure, and seats are made. When impacting on hard surfaces, landing gear with high energy-absorbing capacity can protect the fuselage from major damage during low-velociy impacts and provide occupant protection during higher-velocity impacts. However, during impacts with soft surfaces, such as water or marshy ground or uneven surfaces caused by rocks, trees, etc., the force acting on the landing gear may not be great enough to activate its energy-absorption function, and it will not contribute at all to the occupant protective system. Aircraft with skids, instead of wheels, could provide better protection in such impacts, because the greater surface area of the skids would transmit a greater load and possibly activate the landing gear energy absorbers. The surface conditions can also affect the severity of the impact. Soft soil can deform and contribute energy absorption during a vertical impact. Soft soil can also cause plowing and rapid deceleration if there is a large horizontal velocity component. A vertical impact on water can be very severe, since the large aircraft fuselage area contacting the water would result in high deceleration rates and various crash load paths. A high-speed longitudinal impact into water can also cause high loads from water plowing as water enters through lower nose transparencies.

Thus it is usually not possible to design a system that relies only on one or two of the three energy absorption features available (landing gear, structure, and seats). Now that more helicopters use retracting landing gears, more emphasis on energy-absorbing fuselage understructure is required to control loads and permit the energy-absorbing seats to function. Even though it is difficult to design for, and predict the behavior of, energy-absorbing fuselage structure, it is as important as the other components in the system.

The introduction of composite primary structure into modern aircraft presents special problems for the designer dealing with crash resistance. The brittle failure modes of most composites makes the design of energy-absorbing crushable structures difficult, but not impossible. Fortunately, other composite materials are suitable for use in such fuselage structures. A more detailed discussion of designing with composites is presented in Volume III.

It would seem efficient to simply specify human tolerance requirements and an array of vehicle crash impact conditions and then develop the helicopter as a crash-resistant system with an efficient mixture of crash-resistant features for that particular helicopter. However, available structural and human tolerance analytical techniques needed to perform, evaluate, and validate such a maximum design freedom approach to achieving crash resistance are not sufficiently comprehensive to be relied upon completely. Furthermore, testing complete aircraft sufficiently early in the development cycle to permit evaluation of system concepts is not practical. The systems approach dictates that the designer consider probable crash conditions wherein one or more subsystems do not perform their desired functions, for example, an impact situation in which the landing gear does not absorb its share of the impact crash energy because of aircraft attitude at impact. Therefore, to achieve the overall goal, minimum levels of crash protection are recommended for the various individual subsystems with balance between the two extremes of: (1) defining necessary performance on a component level only, and (2) requiring that the aircraft system be designed only for impact conditions with no component design and test criteria.

Current aircraft crash resistance criteria require that a new aircraft be designed as a system to meet the vehicle impact design conditions recommended in Volume II; however, minimum criteria are also specified for a number of crash-critical components. For example, minimum crash energy-absorption requirements for seats and restraint systems and landing gear are specified. All strength requirements presented in this volume are based on the crash impact conditions described in Volume II. Testing requirements are based on ensuring compliance with strength and deformation requirements. Crash-resistance design criteria for U.S. Army light fixed- and rotary-wing aircraft are stated in MIL-STD-1290 (Reference 1). All pilot, copilot, observer, and student seats in these aircraft should conform to the requirements of MIL-S-58095 (Reference 15), while passenger seats should conform to MIL-S-85510 (Reference 16).

Although much higher levels of crash resistance can be achieved during the development of completely new aircraft designs, the crash resistance of existing aircraft can be significantly improved through retrofitting these aircraft with crash-resistant components adhering to the design principles of this design guide. This can even be achieved while expanding the combat effectiveness of the aircraft. Examples of this are the successful programs to retrofit all U.S. Army helicopters with crash-resistant self-sealing fuel systems (Reference 17) and the U.S. Navy program to retrofit the CH-46 SH-3, HH-3, and CH-53 helicopters (References 18, 19, and 20) with crash-resistant armored crewseats.

In an initial assessment, the definition of an adequate crash-resistant structure may appear to be relatively simple. In fact, many influencing parameters must be considered before an optimum design can be finalized. A complete systems approach (as summarized in Figure 2) should be employed to include all influencing parameters concerned with the design, manufacture, overall performance, and economic constraints on the aircraft in meeting mission requirements. Trade-offs among the parameters must be made in order to arrive at a final design that most closely meets the customer's specifications. Each type of aircraft may require a different emphasis in the parameter mix. Table 1 summarizes major crash resistance criteria that should be considered during the preliminary design phase.

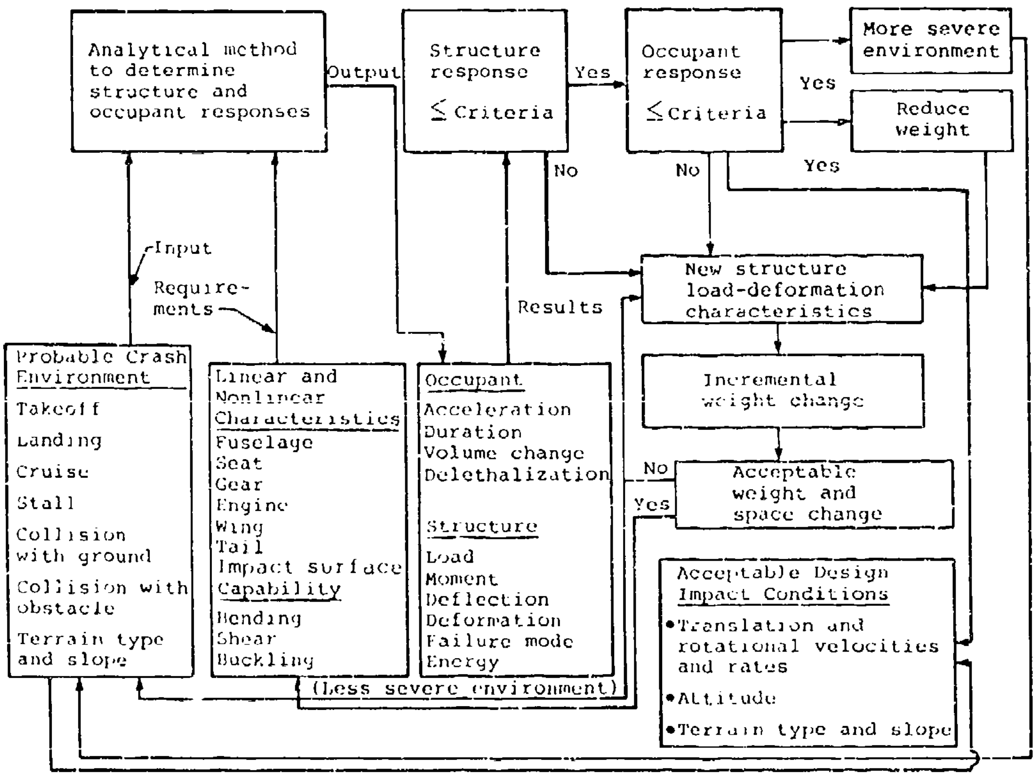


FIGURE 2. PROCEDURE FOR EVALUATION OF STRUCTURAL DESIGNS WITH RESPECT TO CRASH RESISTANCE.

TABLE 1. CRASH-RESISTANCE CRITERIA FOR THE PRELIMINARY DESIGN PROCESS

Crash Scenarios	Primary Structure	Energy Absorption	Postcrash Requirements
• MIL-STD-1290 defines predominant impact conditions • Single axis and combination of: - Vertical impact - Longitudinal impact - Lateral impact - Post impact Rollover Pitchover Nose plowing	• Support of large mass items • Support of systems • Occupant support and protection • Cargo containment and tiedown • Support of landing gear loads • Space consistent with occupant strike envelope • Emergency exit structure	• Landing gear • Controlled structural collapse • Crash-resistant energy-absorbing seats • Shedding of large mass items: - Engines - External stores - Tail boom (Shed items must not impact occupied areas) • Controlled displacement of: - Transmissions - Rotor heads • Impacted surface (soft ground etc.)	• Emergency egress - Occupant release from seats - Door/exit opening - Accessibility and illumination of exits • Minimization of postcrash fire hazards - Fuel containment - Oil and hydraulic fluid containment - Fuel modification - Ignition source control • Reduced material flammability, smoke and toxicity

2. DEFINITIONS

2.1 AIRCRAFT COORDINATE SYSTEMS AND ATTITUDE PARAMETERS

- Aircraft Coordinates

  Positive directions for velocity, acceleration, and force components and for pitch, roll, and yaw are illustrated in Figure 3. When referring to an aircraft in any flight attitude, it is standard practice to use a basic set of orthogonal axes as shown in Figure 3, with x, y, and z referring to the longitudinal, lateral, and vertical directions, respectively.

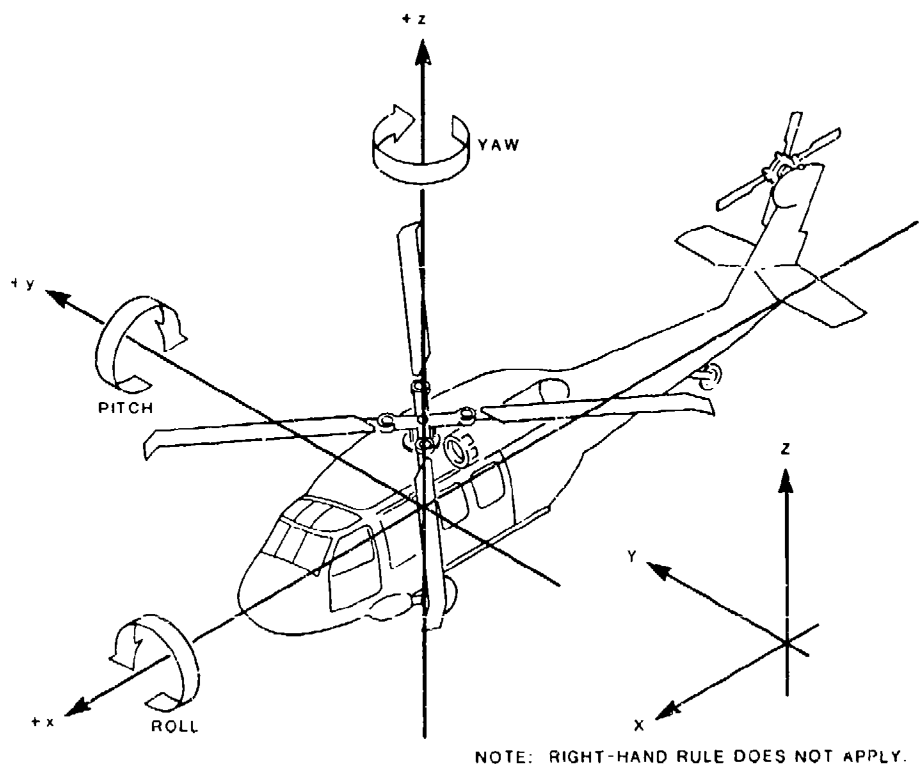


FIGURE 3. AIRCRAFT COORDINATES AND ATTITUDE DIRECTIONS.

However, care must be exercised when analyzing ground impact cases where structural failure occurs, aircraft geometry changes, and reaction loading at the ground plane takes place. In the simulation of such impacts, it is often necessary to use more than one set of reference axes, including the earth-fixed system shown in Figure 3 as X, Y, Z.

- <u>Attitude at Impact</u>

  The aircraft attitude, with respect to the aircraft coordinate system, in degrees at the moment of initial impact. The attitude at impact is stated in degrees of pitch, yaw, and roll (see Figure 3).

  Aircraft pitch is the angle between its longitudinal axis and a horizontal plane. Pitch is considered positive when the nose of the aircraft points above the horizon and negative when it points below the horizon. Yaw is measured between the aircraft's longitudinal axis and the flight path. Roll is the angle between an aircraft lateral (y) axis and the horizontal, measured in a plane normal to the aircraft's longitudinal axis.

- <u>Flight Path Angle</u>

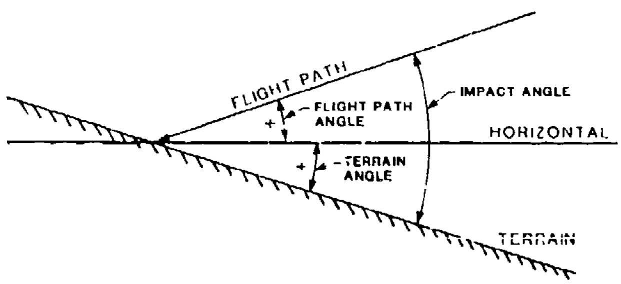
  The angle between the aircraft flight path and the horizontal at the moment of impact.

- <u>Terrain Angle</u>

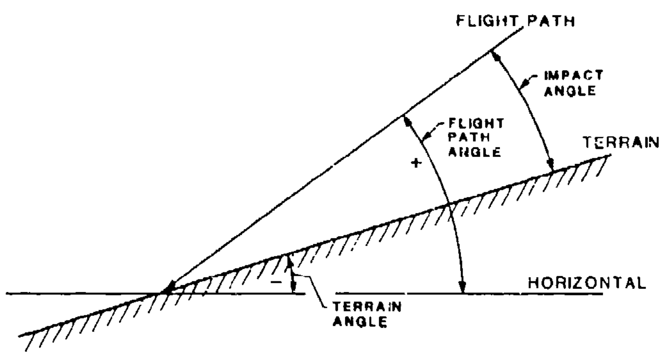
  The angle between the impact surface and the horizontal, measured in a vertical plane.

- <u>Impact Angle</u>

  The angle between the flight path and the terrain, measured in a vertical plane. The impact angle is the algebraic sum of the flight path angle plus the terrain angle.



UPHILL FLIGHT



DOWNHILL FLIGHT

2.2 ACCELERATION-RELATED TERMS

- Acceleration

  The rate of change of velocity. An acceleration is required to produce any velocity change, whether in magnitude or in direction. Acceleration may produce either an increase or a decrease in velocity. There are two basic types of acceleration: linear, which changes translational velocity, and angular (or rotational), which changes angular (or rotational) velocity. With respect to crash impact conditions, unless otherwise specified, all acceleration values are those at a point approximately at the center of the floor of the fuselage or at the center of gravity of the aircraft.

- Deceleration

  Acceleration in a direction to cause a decrease in velocity.

- Abrupt Accelerations

  Accelerations of short duration primarily associated with crash impacts, ejection seat shocks, capsule impacts, etc. One second is generally accepted as the dividing point between abrupt and prolonged accelerations. In abrupt accelerations the effects on the human body are limited to mechanical overloading (skeletal and soft tissue stresses), there being insufficient time for functional disturbances due to fluid shifts.

- The Term G

  The ratio of a particular acceleration (a) to the acceleration (g) due to gravitational attraction at sea level (32.2 ft/sec^2); G = a/g. In accordance with common practice, this report will refer to accelerations measured in G. To illustrate, it is customarily understood that 5 G represents an acceleration of 5 x 32.2, or 161 ft/sec^2.

- Rate of Onset

  Rate of application of G's, expressed in G's per second (rate of change of acceleration).

$$\text{Rate of Onset} = \frac{\Delta G}{\Delta t} \quad \text{(G's per second)}$$

2.3 VELOCITY-RELATED TERMS

- Velocity Change in Major Impact (Δv)

  The decrease in velocity of the airframe during the major impact, expressed in feet per second. The major impact is the one in which the highest forces are incurred, not necessarily the initial impact. For the acceleration pulse shown in Figure 4, the major impact should be considered ended at time t_2. Elastic recovery in

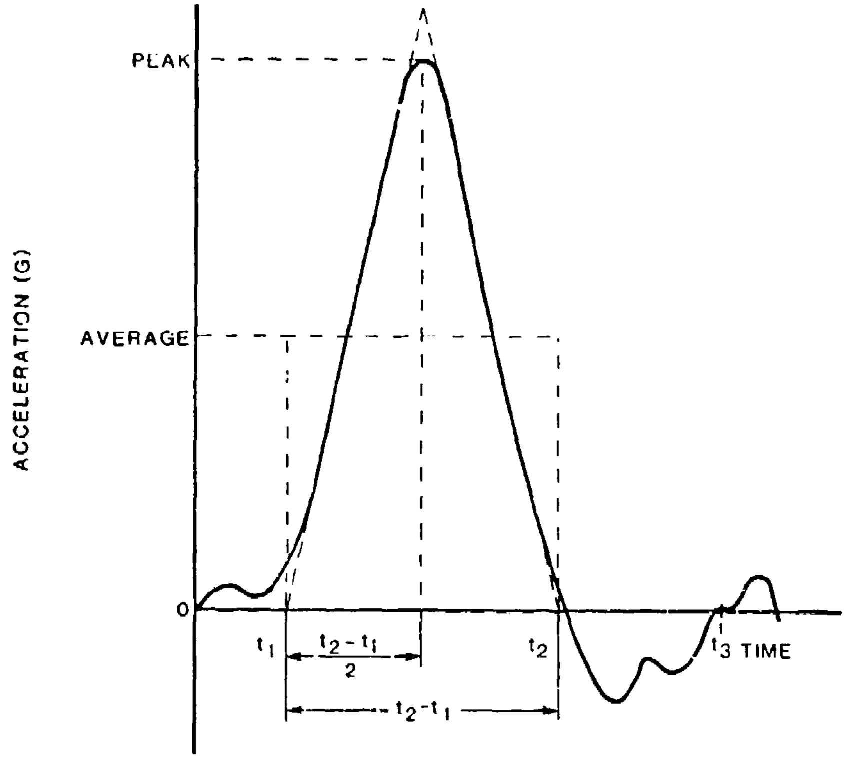


FIGURE 4. TYPICAL AIRCRAFT FLOOR ACCELERATION PULSE.

the structure will tend to reverse the direction of the aircraft velocity prior to t_2. Should the velocity actually reverse, its direction must be considered in computing the velocity change. For example, an aircraft impacting downward with a vertical velocity component of 30 ft/sec and rebounding with an upward component of 5 ft/sec should be considered to experience a velocity change

$$\Delta v = 30 - (-5) = 35 \text{ ft/sec}$$

during the major impact. The velocity change during impact is further explained in Section 7.1 of Volume III.

- <u>Longitudinal Velocity Change</u>

The decrease in velocity during the major impact measured along the longitudinal (roll) axis of the aircraft. The velocity may or may not reach zero during the major impact. For example, an aircraft impacting the ground at a forward velocity of 100 ft/sec and slowing to 35 ft/sec would experience a longitudinal velocity change of 65 ft/sec during this impact.

- Vertical Velocity Change

  The decrease in velocity during the major impact measured along the vertical (yaw) axis of an aircraft. The vertical velocity generally reaches zero during the major impact and may reverse if rebound occurs.

- Lateral Velocity Change

  The decrease in velocity during the major impact measured along the lateral (pitch) axis of the aircraft

2.4 FORCE TERMS

- Load Factor

  A crash force can be expressed as a multiple of the weight of an object being accelerated. A crash load factor, when multiplied by a weight, produces a force which can be used to establish ultimate static strength (see Static Strength). Load factor is expressed in units of G.

- Forward Load

  Loading in a direction toward the nose of the aircraft, parallel to the aircraft longitudinal (roll) axis.

- Aftward Load

  Loading in a direction toward the tail of the aircraft, parallel to the aircraft longitudinal (roll) axis.

- Downward Load

  Loading in a downward direction parallel to the vertical (yaw) axis of the aircraft.

- Upward Load

  Loading in an upward direction parallel to the vertical (yaw) axis of the aircraft.

- Lateral Load

  Loading in a direction parallel to the lateral (pitch) axis of the aircraft.

- Combined Load

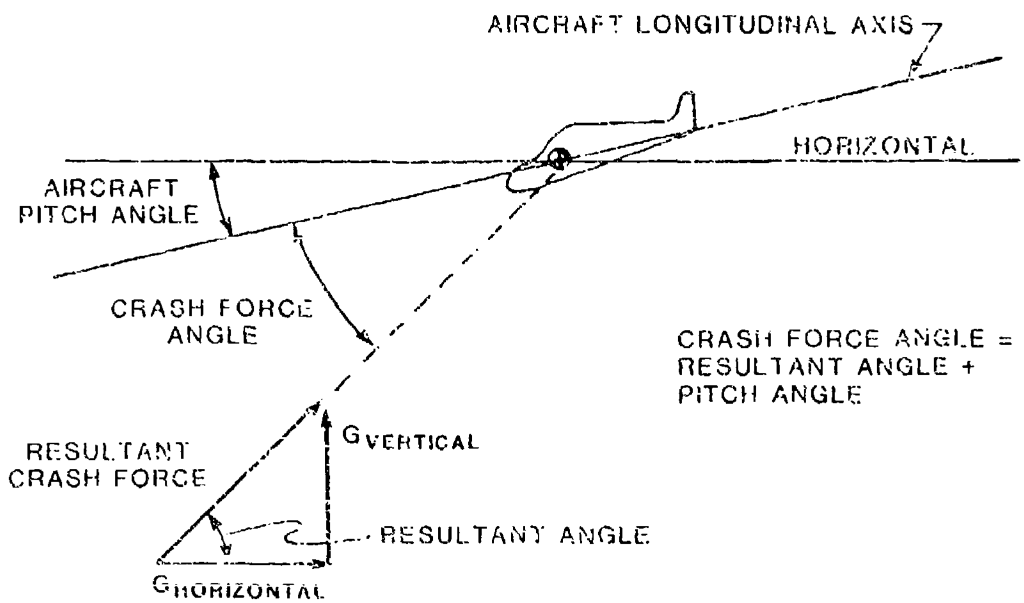
  Loading consisting of components in more than one of the directions described in Section 2.1.

- Crash Force Resultant

  The geometric sum of horizontal and vertical crash forces: horizontal and vertical velocity components at impact, and horizontal and vertical stopping distances. The crash force resultant is fully defined by determination of both its magnitude and its direction. The algebraic sign of the resultant crash force angle is positive when the line of action of the resultant is above the horizontal, and negative if the line of action is below the horizontal.

- Crash Force Angle

  The angle between the resultant crash force and the longitudinal axis of the aircraft. For impacts with little lateral component of force, the crash force angle is the algebraic sum of the crash force resultant angle plus the aircraft pitch angle.



2.5 DYNAMICS TERMS

- Rebound

  Rapid return toward the original position upon release or rapid reduction of the deforming load, usually associated with elastic deformation.

- Dynamic Overshoot

  The amplification of decelerative force on cargo or personnel above the floor input decelerative force (ratio of output to input). This amplification is a result of the dynamic response of the system.

- <u>Transmissibility</u>

  The amplification of a steady-state vibrational input amplitude (ratio of output to input). Transmissibilities maximize at resonant frequencies and may increase acceleration amplitude similar to dynamic overshoot.

2.6 CRASH SURVIVABILITY TERMS

- <u>Survivable Accident</u>

  An accident in which the forces transmitted to the occupant through the seat and restraint system do not exceed the limits of human tolerance to abrupt accelerations and in which the structure in the occupant's immediate environment remains substantially intact to the extent that a livable volume is provided for the occupants throughout the crash sequence.

- <u>Survival Envelope</u>

  The range of impact conditions, including magnitude and direction of pulses and duration of forces occurring in an aircraft accident, wherein the occupiable area of the aircraft remains substantially intact, both during and following the impact, and the forces transmitted to the occupants do not exceed the limits of human tolerance when current state-of-the-art restraint systems are used.

  It should be noted that, where the occupiable volume is altered appreciably through elastic deformation during the impact phase, survivable conditions may not have existed in an accident that, from postcrash inspection, outwardly appeared to be survivable.

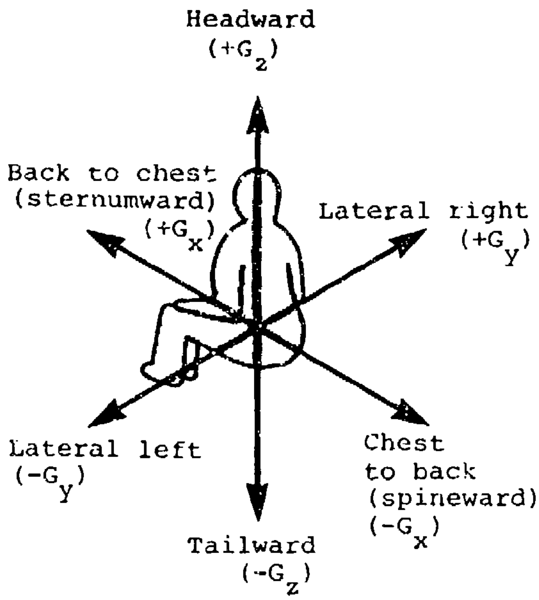
- <u>Strike Envelope</u>

  The extent of space surrounding a restrained occupant defined by the flailing of extended body parts during a crash impact of the aircraft. Parts of the body may strike objects located within this envelope.

2.7 OCCUPANT-RELATED TERMS

- <u>Human Body Coordinates</u>

  In order to minimize the confusion sometimes created by the terminology used to describe the directions of forces applied to the body, a group of NATO scientists compiled the accelerative terminology table of equivalents shown in Figure 5 (Reference 21). Terminology used throughout this guide is compatible with the NATO terms as illustrated.



Direction of accelerative force

Vertical

Headward	-	Eyeballs-down
Tailward	-	Eyeballs-up

Transverse

Lateral right	-	Eyeballs-left
Lateral left	-	Eyeballs-right
Back to chest	-	Eyeballs-in
Chest to back	-	Eyeballs-out

Note:

The accelerative force on the body acts in the same direction as the arrows.

FIGURE 5. TERMINOLOGY FOR DIRECTIONS OF FORCES ON THE BODY.

- Anthropomorphic Dummy

  A device designed and fabricated to represent not only the appearance of humans but also the mass distribution, joint locations, motions, geometrical similarities (such as flesh thickness and load/deflection properties), and relevant skeletal configurations (such as iliac crests, ischial tuberosities, rib cages, etc). Attempts are also made to simulate human response of major structural assemblages such as thorax, spinal column, neck, etc. The dummy is strapped into seats or litters and used to simulate a human occupant in dynamic tests.

- Human Tolerance

  For the purposes of this document, human tolerance is defined as a selected array of parameters that describe a condition of decelerative loading for which it is believed there is a reasonable probability for survival without major injury. As used in this volume, designing for the limits of human tolerance refers to providing design features that will maintain these conditions at or below their tolerable levels to enable the occupant to survive the given crash impact conditions.

Obviously, the tolerance of the human body to crash impact conditions is a function of many variables including the unique characteristics of the individual person as well as the loading variables. The loads applied to the body include decelerative loads imposed by seats and restraint systems as well as localized forces due to impact with surrounding structures. Tolerable magnitudes of the decelerative loads depend on the direction of the load, the orientation of the body, and the means of applying the load. For example, the critical nature of loads parallel to the occupant's spine manifests itself in any of a number of spinal fractures, but typically the fracture is an anterior wedge, or compressive failure of the front surface of a vertebra. Forces perpendicular to the occupant's spine can produce spinal fracture through shear failures or from hyperflexion resulting, for example, from jackknife bending over a lap-belt-only restraint. The lap belt might inflict injuries to the internal organs if it is not retained on the pelvic girdle but is allowed to exert its force above the iliac crests in the soft stomach region. Excessive rotational or linear acceleration of the head can produce concussion. Further, skull fracture can result from localized impact with surrounding structure. Therefore, tolerance is a function of the method of occupant restraint as well as the characteristics of the specific occupant. Refer to Volume II for a more detailed discussion of human tolerance.

- <u>Submarining</u>

  Rotation of the hips under and about the lap belt as a result of a forward inertial load exerted by deceleration of the thighs and lower legs, accompanied by lap belt slippage up and over the iliac crests. Lap belt slippage up and over the iliac crests can be a direct result of the upward pull of the shoulder harness straps at the middle of the lap belt.

- <u>Effective Weight</u>

  The portion of occupant weight supported by the seat with the occupant seated in a normal flight position. Since the weight of the feet, lower legs, and part of the thighs is carried directly by the floor through the feet, this is considered to be 80 percent of the occupant weight plus the weight of the helmet and any equipment worn on the torso. Clothing, except for boots, is included in the occupant weight.

- <u>Iliac Crest Bone</u>

  The upper, anterior portion of the pelvic (hip) bone. These "inverted saddle" bones are spaced laterally about 1 ft apart; the lower abdomen rests between these crest bones.

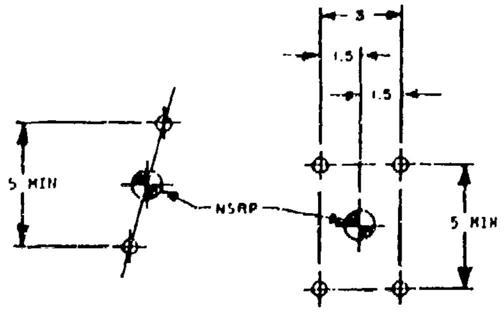
- <u>Lap Belt Tiedown Strap (also Negative-G Strap, Crotch Strap)</u>

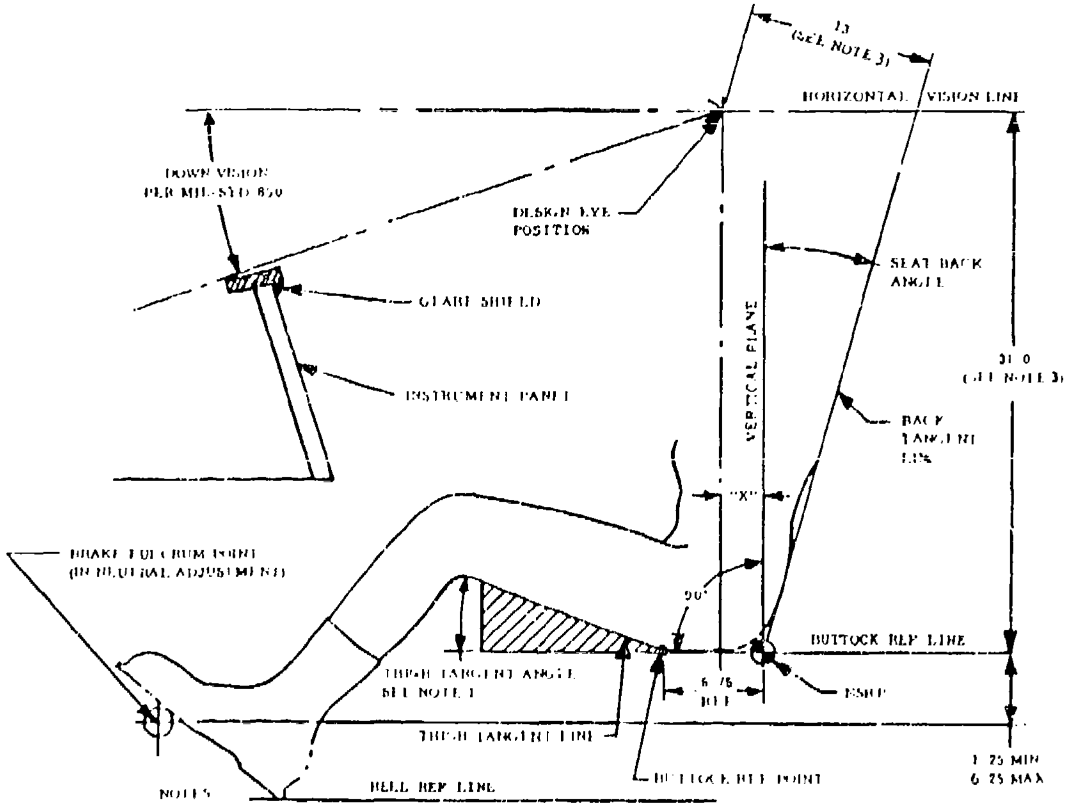
  Strap used to prevent the tensile force in shoulder straps from pulling the lap belt up when the restrained subject is exposed to $-G_x$ (eyeballs-out) acceleration.

2.8 SEATING GEOMETRY (See Figure 6)

DISTANCE FROM DESIGN EYE POSITION TO VERTICAL PLANE OF NEUTRAL SEAT REFERENCE POINT FOR VARIOUS SEAT BACK ANGLES

SEAT BACK ANGLE (DEGREES)	"X" (INCHES)
10	7.7
10½	7.4
11	7.1
11½	6.9
12	6.6
12½	6.3
13	6.1
13½	5.8
14	5.5
14½	5.3
15	5.0





NOTES

1. THIGH TANGENT ANGLE SHALL BE A MINIMUM OF 5° AND A MAXIMUM OF 20°. FOR HELICOPTERS, THE MINIMUM OF 10° SHALL APPLY.
2. THE DIMENSIONS SHOWN APPLY TO A PARTICULAR FLIGHT STATION AND POPULATION MEMBER.
3. DIMENSIONS BASED ON 13° SEAT BACK ANGLE. FOR FIXED WING AIRCRAFT, LESS THAN 13° SEAT BACK ANGLE IS UNDESIRABLE.

FIGURE 6. SEATING GEOMETRY. (REFERENCE 22)

- <u>Design Eye Position</u>

  A reference datum point based on the eye location that permits the specified vision envelope required by MIL-STD-850 (Reference 23), allows for slouch, and is the datum point from which the aircraft station geometry is constructed. The design eye position is a fixed point in the crew station, and remains constant for pilots of all stature via appropriate seat adjustment.

- <u>Horizontal Vision Line</u>

  A reference line passing through the design eye position parallel to the true horizontal in normal cruise position.

- <u>Back Tangent Line</u>

  A straight line in the midplane of the seat passing tangent to the curvatures of a seat occupant's back when leaning back and naturally compressing the back cushion. The seat back tangent line is positioned 13 in. behind the design eye position measured along a perpendicular to the seat back tangent line.

- <u>Buttock Reference Line</u>

  A line in the midplane of the seat parallel to the horizontal vision line and tangent to the lowermost natural protrusion of a selected size of occupant sitting on the seat cushion.

- <u>Neutral Seat Reference Point (NSRP)</u>

  The intersection of the back tangent line and the buttock reference line. The seat geometry and location are based on the NSRP. The NSRP is set with the seat in the nominal mid-position of the seat adjustment range. This seat position will place the 50th percentile (seated height) man with his eye in the design eye position.

- <u>Buttock Reference Point</u>

  A point 5.75 in. forward of the seat reference point on the buttock reference line. This point defines the vertical and longitudinal position of the approximate bottoms of the ischial tuberosities, thus representing the lowest points on the pelvic structure and the points that will support the most load during downward vertical loading.

- <u>Heel Rest Line</u>

  The reference line parallel to the horizontal vision line passing under the tangent to the lowest point on the heel in the normal operational position, not necessarily coincidental with the floor line.

2.9 STRUCTURAL TERMS

- Airframe Structural Crash Resistance

  The ability of an airframe structure to maintain a protective shell around occupants during a crash and to minimize accelerations applied to the occupiable portion of the aircraft during crash impacts.

- Structural Integrity

  The ability of a structure to sustain crash loads without collapse, failure, or deformation of sufficient magnitude to: (1) cause injury to personnel or (2) prevent the structure from performing as intended.

- Static Strength

  The maximum static load which can be sustained by a structure, often expressed as a load factor in terms of G (see Load Factor, Section 2.4). Also known as ultimate static load.

- Strain

  The ratio of change in length to the original length of a loaded component.

- Collapse

  Deformation or fracture of structure to the point of loss of useful load-carrying ability or useful volume.

- Failure

  Loss of load-carrying capability, usually referring to structural linkage rupture or collapse.

- Limit Load

  In a structure, limit load refers to the load the structure will carry before yielding. Similarly, in an energy-absorbing device, it represents the load at which the device deforms in performing its function.

- Load Limiter, Load Limiting Device, or Energy Absorber

  These are interchangeable names of devices used to limit the load in a structure to a preselected value. These devices absorb energy by providing a resistive force applied over a deformation distance without significant elastic rebound.

- Specific Energy Absorbed (SEA)

  The energy absorbed by a energy absorbing device or structure divided by its weight.

- Bottoming

  The exhaustion of available stroking distance accompanied by an increase in force, e.g., a seat stroking in the vertical direction exhausts the available distance and impacts the floor. With respect to energy-absorbing structure, bottoming is a condition in which the deforming structure or material becomes compacted and the load increases rapidly with very little increased deformation.

- Bulkhead

  A structural partition extending upwards from the floor and dividing the aircraft into separate compartments. Seats can be mounted to bulkheads instead of the floor.

- Basic Structural Design Gross Weight (BSDGW)

  The structural design gross weight is cited in the MIL-STD-1374 (Reference 24), Part I, "Group Weight Statement-Dimensional and Structural Data", and is further explained in the detail system specification for the aircraft.

2.10 FUEL, OIL, AND HYDRAULIC SYSTEM TERMS

- Crash Resistant Fuel Tank

  A tank which conforms to MIL-T-27422 (Reference 25).

- Crash-Resistant Fuel System

  A fuel system designed to conform to MIL-T-27422, MIL-STD-1290, ADS11B, and other related specifications and standards.

- Frangible Attachment

  An attachment possessing a part that is designed to fail at a predetermined location and/or load.

- Bladder Tank

  A flexible fuel tank, usually contained or supported by other more rigid structures.

- Fuel Pump

  A pump installed in the fuel system to move fuel. Usually located at one or more of the following places: the tank, the engine, or the interconnecting plumbing.

- Fuel Valve

  Any valve, other than a self-sealing breakaway valve, contained in the fuel supply system, such as fuel shutoff valves, check valves, etc.

- Self-Sealing Breakaway Valve

  A valve, for installation in fluid-carrying lines or hoses, that will separate at a predetermined load and seal at one or both halves to prevent dangerous flammable fluid spillage.

2.11 IGNITION SOURCE CONTROL TERMS

- Fire Curtain

  A baffle made of fire-resistant material that is used to prevent spilled flammable fluids and/or flames from reaching ignition sources or occupiable areas.

- Fire-Resistant Material

  Material able to resist flame penetration for 5 min when subjected to a 2000 °F flame and still be able to meet its intended function.

- Firewall

  A partition capable of withstanding a 2000 °F flame over an area of 5 sq in. for a period of 15 min without flame penetration.

- Flammable Fluid

  Any fluid that ignites readily in air, such as hydrocarbon fuels and lubricants.

- Flow Diverter

  A physical barrier that interrupts or diverts the flow of a liquid.

- Ignition Temperature

  The lowest temperature at which a flammable mixture will ignite when introduced into a specific set of circumstances.

- Inerting

  The rendering of an aircraft system or the atmosphere surrounding the system incapable of supporting combustion.

2.12 INTERIOR MATERIALS SELECTION TERMS

- Autoignition Temperature

  The lowest temperature at which a flammable substance will ignite without the application of an outside ignition source, such as flames or sparks.

- Flame-Resistant Material

  Material that is self-extinguishing after removal of a flame.

- Flashover

  The sudden spread of flame throughout an area due to ignition of combustible vapors that are heated to their flash point.

- Flash Point

  The lowest temperature at which vapors above a combustible substance ignite in air when exposed to flame.

- Intumescent Paint

  A paint that swells and chars when exposed to flames.

- Optical Density (D_S)

  The optical density is defined by the relationship

$$D_s = \log \frac{100}{T}$$

  where T is the percent of light transmission through a medium (e.g., air, smoke, etc.).

2.13 DITCHING AND EMERGENCY ESCAPE TERMS

- Brightness

  The luminous flux emitted per unit of emissive area as projected on a plane normal to the line of sight. Measured in foot-lamberts.

- Candela (cd)

  A unit of luminous intensity equal to 1/60 of the luminous intensity of one square centimeter of a blackbody surface at the solidification temperature of platinum. Also called candle or new candle.

- Class A Exit

  A door, hatch, canopy, or other exit closure intended primarily for normal entry and exit.

- Class B Exit

  A door, hatch, or other exit closure intended primarily for service or logistic purposes (e.g., cargo hatches and rear loading ramps or clamshell doors).

- Class C Exit

  A window, door, hatch, or other exit closure intended primarily for emergency evacuation.

- <u>Cockpit Enclosure</u>

  That portion of the airframe that encloses the pilot, copilot, or other flight crew members. An aircraft may have multiple cockpits, or the cockpit may be physically integrated with the troop/passenger section.

- <u>Ditching</u>

  The landing of an aircraft on water with the intention of abandoning it.

- <u>Emergency Lighting</u>

  Illumination required for emergency evacuation and rescue when normal illumination is not available.

- <u>Exit Closure</u>

  A window, door, hatch, canopy, or other device used to close, fill, or occupy an exit opening.

- <u>Exit Opening</u>

  An opening provided in aircraft structure to facilitate either normal or emergency exit and entry.

- <u>Exit Release Handle</u>

  The primary handle, lever, or latch used to open or jettison the exit closure from the fuselage to permit emergency evacuation.

- <u>Foot-candle (fc)</u>

  A unit of illuminance on a surface that is everywhere one foot from a uniform point source of light of one candela.

- <u>Foot-lambert (fL)</u>

  A unit of photometric brightness or luminous intensity per unit emissive area of a surface in a given direction. One foot-lambert is equal to $1/\pi$ candela per square foot.

- <u>Illumination</u>

  The luminous flux per unit area on an intercepting surface at any given point. Measured in foot-candles.

3. AIRCRAFT DESIGN CRASH IMPACT CONDITIONS AND HUMAN TOLERANCE

3.1 INTRODUCTION

Design criteria for aircraft crash impact conditions and the response of the human body to those conditions are presented in this chapter. Principles, data, and analysis methods that influence the survivability of aircraft occupants in crash impact conditions are summarized. The reader is referred to Volume II for a more complete discussion.

3.2 DESIGN CONDITIONS FOR IMPACT

3.2.1 Application

Although improvements in crash resistance can be achieved in existing aircraft by retrofit systems, such as energy-absorbing seats or crash-resistant fuel systems, the improvements are limited and may result in prohibitive weight and cost penalties if requirements are too severe. Retrofit decisions are made as the result of trade-offs between the benefits in survivability and the penalties of cost and weight. An aircraft should be designed as a system to provide the required occupant protection for the recommended velocity changes because deceleration is a design variable, a function of the structural stiffness of the fuselage. Consideration of crash resistance in design of the complete aircraft system eliminates many of the limitations inherent in retrofit and makes possible the design for more severe crash impact conditions without significant weight penalties.

3.2.2 Deceleration Pulse Shape

Experimental data obtained in full-scale crash tests of helicopters, light fixed-wing aircraft, and fixed-wing transports indicate that the deceleration pulse shape for major impact in accidents can be represented to a satisfactory degree for most engineering purposes by a triangle, as shown in Figure 4. Energy-absorbing landing gear on new aircraft will produce a lower-level deceleration plateau preceding the fuselage contact, thereby reducing the energy that must be absorbed by fuselage crushing. However, the shape of the deceleration pulse during fuselage contact with the ground will still approximate a triangle.

3.2.3 Impacted Surface

Statistically, the crash surface most frequently impacted is sod. It is recommended that sod with a California Bearing Ratio (CBR) of 2.5 be accepted as the standard for crash-resistance design. Trees are the second most frequently impacted obstacle; however, the secondary (in this case, major) impact would still be with sod.

3.2.4 Velocity Change

Velocity changes for crash survival design purposes are specified by MIL-STD-1290. Table 2 gives these velocity changes in feet per second. In addition to these conditions, the designer should consider longitudinal, lateral, and vertical impacts where the aircraft has pitch, yaw, and/or roll relative to the flight path. Attitude angles are presented in Volume II.

TABLE 2. CRASH IMPACT DESIGN CONDITIONS, WITH LANDING GEAR EXTENDED, MIL-STD-1290

Condition No.	Impact Direction (Aircraft Axes)	Object Impact	Velocity Change ΔV (ft/sec)
1	Longitudinal (cockpit)	Rigid	20
2	Longitudinal (cabin)	vertical barriers	40
3	Vertical*	Rigid	42
4	Lateral, Type I**	horizontal	25
5	Lateral, Type II***	surface	30
6	Combined high angle*	Rigid	
	Vertical	horizontal	42
	Longitudinal	surface	27
7	Combined low angle	Plowed	
	Vertical	Soil	14
	Longitudinal		100

*For the case of retracted landing gear the seat and airframe combination shall have a vertical crash impact design velocity change capability of at least 26 ft/sec.

**Type I - Light fixed-wing aircraft.

***Type II - Rotary-wing, including tilt-prop/rotor aircraft.

Note: See Volume II for vehicle attitude.

3.3 HUMAN TOLERANCE TO IMPACT

3.3.1 General

Results of research on tolerance of the human body to impact forces are presented in Volume II, Chapter 5. Although numerous experiments have been conducted and a wealth of information has been collected, very few criteria that may be useful in system design have been developed and validated. In this chapter, those criteria that are generally accepted for practical application in assessing the crash resistance of an aircraft system are presented. As discussed here, these criteria may be used to determine the acceptability of an aircraft or components, such as seats and restraint systems, based on the results of dynamic testing with anthropomorphic dummies or computer simulations, as discussed in Volume IV. Criteria are presented here only if validated quantitative values have been determined. Injuries to various body parts are discussed in Volume II.

3.3.2 Whole-Body Tolerance

Tolerance of the human body to abrupt acceleration has been shown to depend on the magnitude and duration of the applied force, as well as the direction and rate of onset. Data presented by Eiband (Reference 26) for occupants having upper torso restraint are summarized in Figures 7 and 8 for spineward ($-G_x$) acceleration and in Figures 9 and 10 for headward ($+G_z$) acceleration. Human tolerance to lateral (G_y) acceleration has not been extensively studied. However, based on the testing that has been conducted, a maximum lateral acceleration of 20 G at a duration of 0.1 sec is suggested for design.

An acceptable personnel restraint system for Army aircraft should include upper torso restraint, regardless of seat orientation. However, for reference and for comparison with the above values, a spineward ($-G_x$) human tolerance level of 20 G and a lateral (G_y) level of 10 G are recommended for lap-belt-only restraint. These levels are based on experiments with human subjects in which minor trauma were experienced.

Although Figures 7 through 10 indicate the regions of acceleration and rate of onset that may be considered acceptable for the aircraft interior, they do not permit complete evaluation of such protective systems as restraint systems, energy-absorbing seats, or protective padding. Injury criteria for critical body parts, such as the head and spinal column, must be employed in order to answer such questions as whether a seat has sufficient stroking distance, or whether a given shoulder belt webbing has acceptable stiffness.

3.3.3 Head Injury Criteria

Various criteria have been used as predictors of head injury. Concussive threshold values have been identified for four such criteria: peak G, peak transmitted force, Severity Index, and Head Injury Criterion. The Severity Index is defined as

$$SI = \int_{t_0}^{t_s} a^n dt \tag{1}$$

where SI = Severity Index

a = acceleration as function of time

n = weighting factor greater than 1

t = time

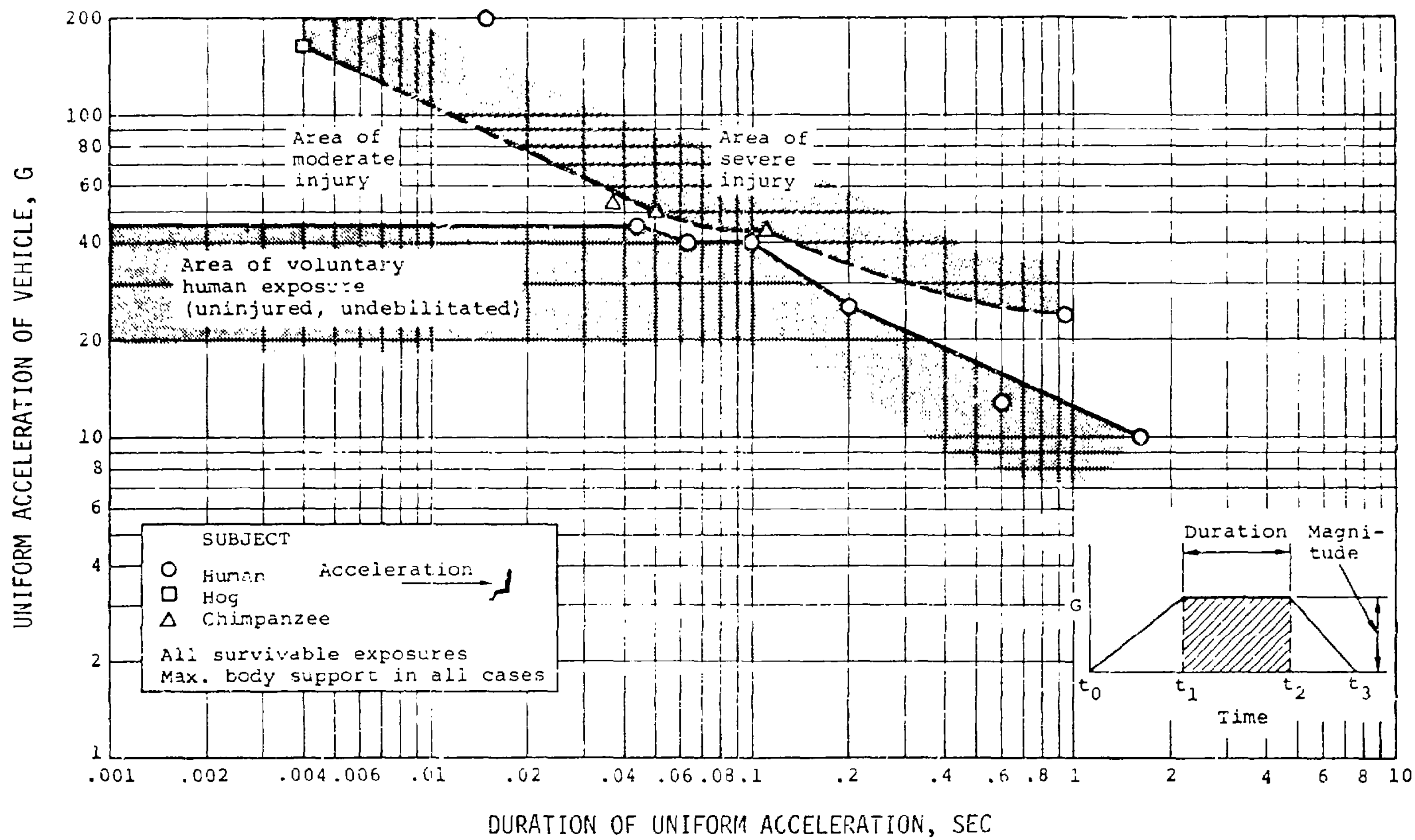


FIGURE 7. DURATION AND MAGNITUDE OF SPINEWARD ACCELERATION ENDURED BY VARIOUS SUBJECTS. (FROM REFERENCE 23)

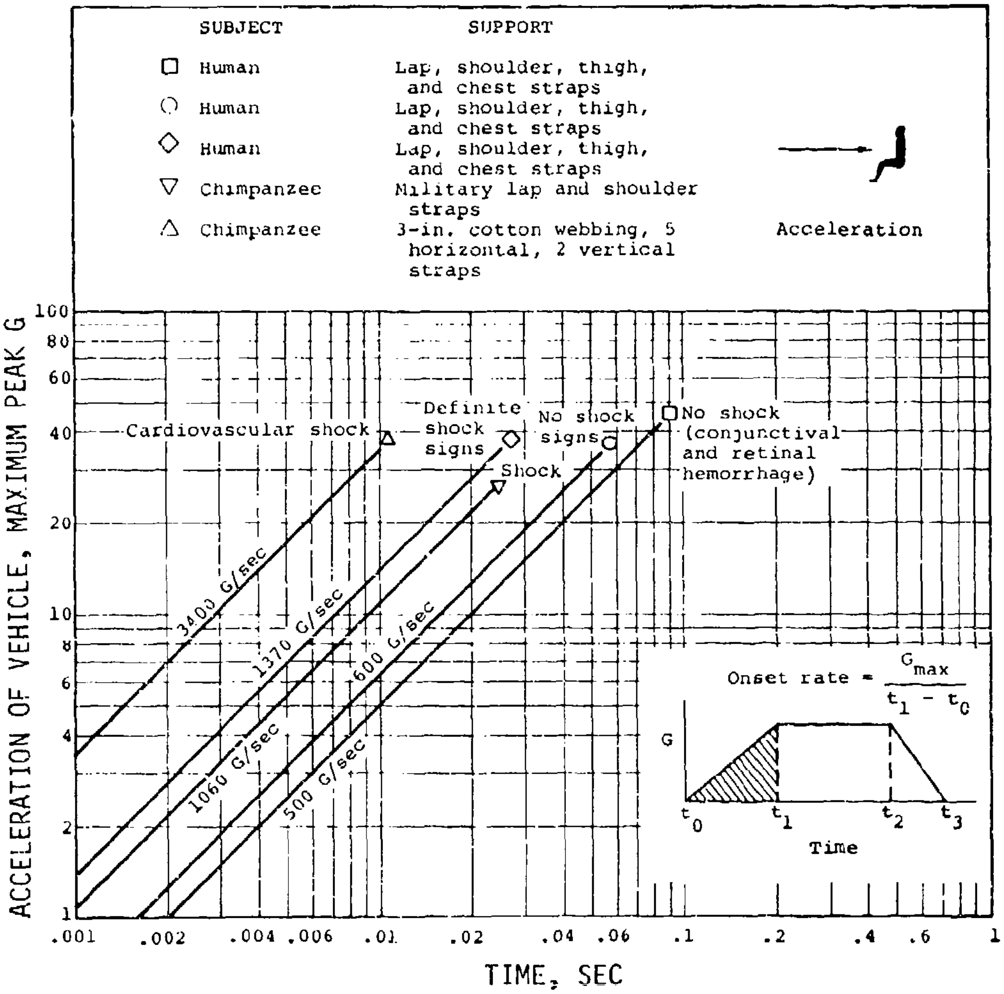


FIGURE 8. INITIAL RATE OF CHANGE OF SPINEWARD ACCELERATION ENDURED BY VARIOUS SUBJECTS. (FROM REFERENCE 26)

and the Head Injury Criterion (HIC) of Federal Motor Vehicle Safety Standard 208 is calculated according to

$$\text{HIC} = \max\left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right)^{2.5}(t_2 - t_1) \qquad (2)$$

where a is the resultant head acceleration, and t_1 and t_2 are any two points in time during the crash event.

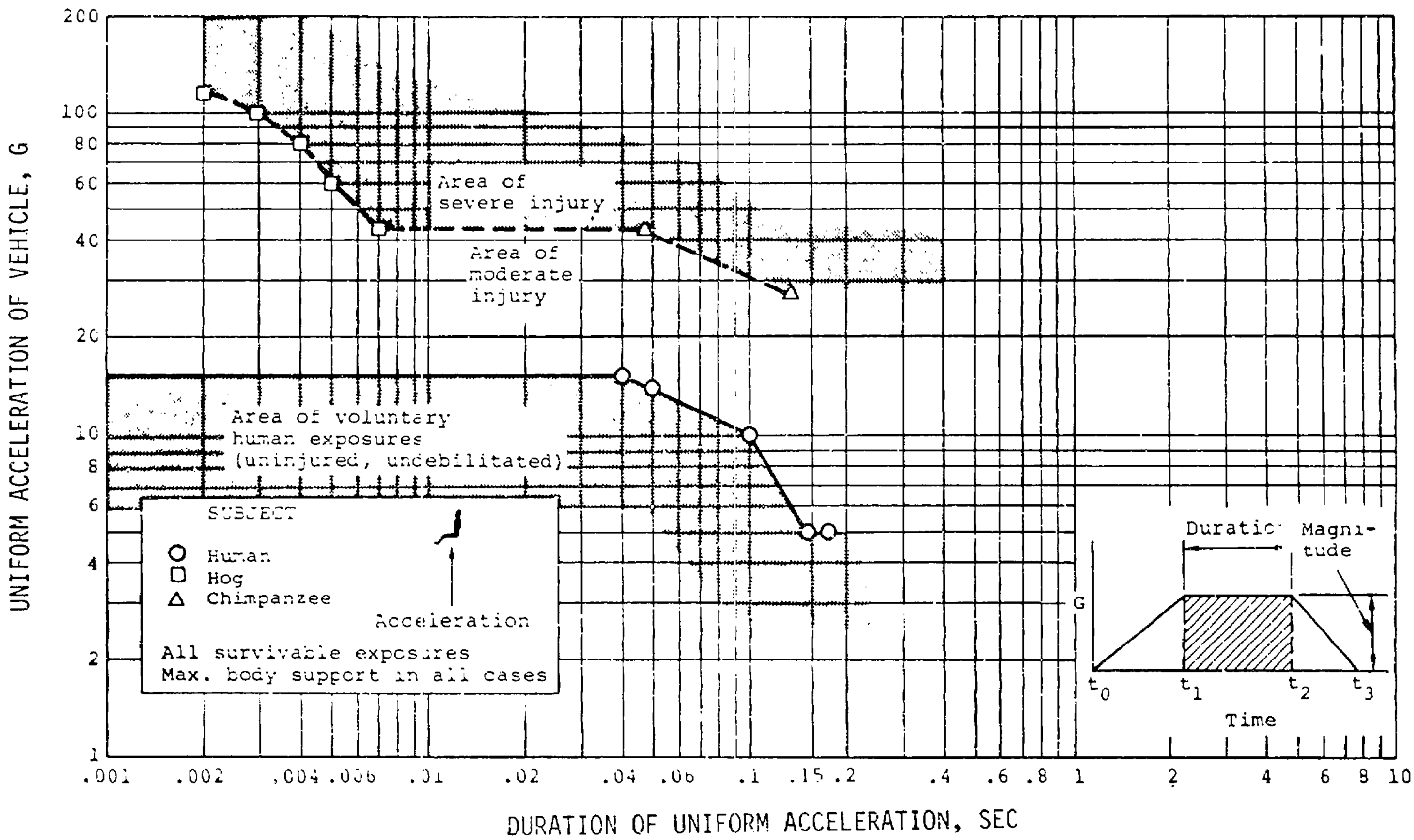


FIGURE 9. DURATION AND MAGNITUDE OF HEADWARD ACCELERATION ENDURED BY VARIOUS SUBJECTS. (FROM REFERENCE 26)

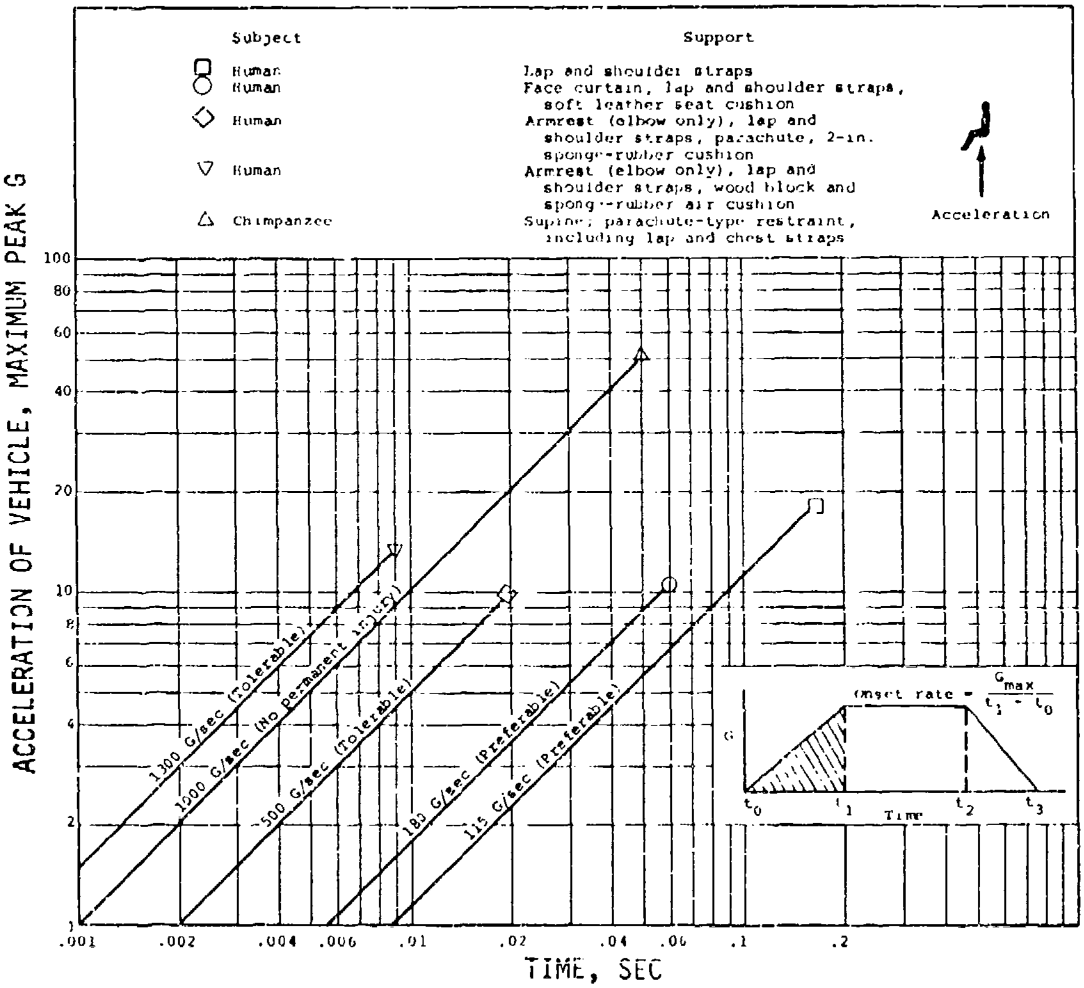


FIGURE 10. INITIAL RATE OF CHANGE OF HEADWARD ACCELERATION ENDURED BY VARIOUS SUBJECTS. (FROM REFERENCE 26)

Aircrewmen have experienced concussive head injury from helmeted head impacts that exceeded the following values for the four criteria: peak head accelerations that exceeded 150 G, peak force levels transmitted to the head that exceeded 1500 lb, Severity Index values that exceeded 600, and Head Injury Criterion values that exceeded 500. These values should be taken as the limits of human tolerance to concussion when using these criteria as predictors of head injury.

3.3.4 Spinal Injury Criteria

Although the Dynamic Response Index (DRI), as illustrated in Section 5.9.2 of Volume II, is the only model correlated extensively for ejection seat spinal injury prediction, it has serious shortcomings for use in accident analysis. It assumes the occupant to be well restrained and erect, so that the loading is primarily compressive, with insignificant bending. Although such conditions may be assumed for ejection seats, they are less probable for helicopter crashes in which an occupant may be leaning to either side for better visibility at the time of impact. Further, the DRI was correlated for ejection pulses of much longer duration than typical crash pulses.

A more detailed model of the spinal column would yield more realistic results, but injury criteria for the more complex responses have yet to be developed. Consequently, the DRI is not recommended as the criterion for use in designing crash-resistant seats. Rather, the data presented in Figure 8 are recommended for use until more comprehensive data and criteria are developed.

3.3.5 Leg Injury Criteria

Femoral fracture due to longitudinal impact on the knee has been studied extensively, probably because of the frequency of this type of injury in automobile accidents. A criterion that assesses the dependence of the permissible human knee load on the duration of the primary force exposure has been suggested in Reference 27. The permissible peak knee load suggested for design is given by

$$F = 5200 - 160\,t, \quad t < 20 \text{ msec}$$

$$F = 2000, \quad t \geq 20 \text{ msec} \tag{3}$$

where F is in pounds and t in msec.

3.3.6 Tolerance of Other Body Parts

Although some research has been conducted on the tolerance of other body parts, such as the neck, thorax, and abdomen, well-defined, valid criteria have not been established. The results of this research are discussed in Volume II, Chapter 5.

3.4 HUMAN BODY DIMENSIONS AND MASS DISTRIBUTIONS

3.4.1 General

Anthropometric measurements are external dimensions of the human body that can be used to define aircraft requirements such as seat height and width, eye height, or cabin height. A specialized type of anthropometric measurement is the "link length," or distance between joint centers, which can be used in locating control positions and is essential for the design of mathematical or physical simulators of the human body. Finally, the inertial properties of the body and parts of the body also are required in the design of human simulators.

3.4.2 Anthropometry

Two types of anthropometric measurements have been recorded, and the use of both types in vehicle design has been summarized in Reference 28.

In the first type, conventional dimensions of the body with subjects in rigid, standardized positions are easily obtained. Extensive collections of such data are used in clothing design and may determine certain vehicle design parameters including seat height and eye height. The anthropometric data of greatest potential usefulness, illustrated in Figure 11, for U.S. Army male aviators and soldiers of the 5th, 50th, and 95th percentiles are presented in Tables 3 and 4, respectively. Complete data can be found in References 29 and 30.

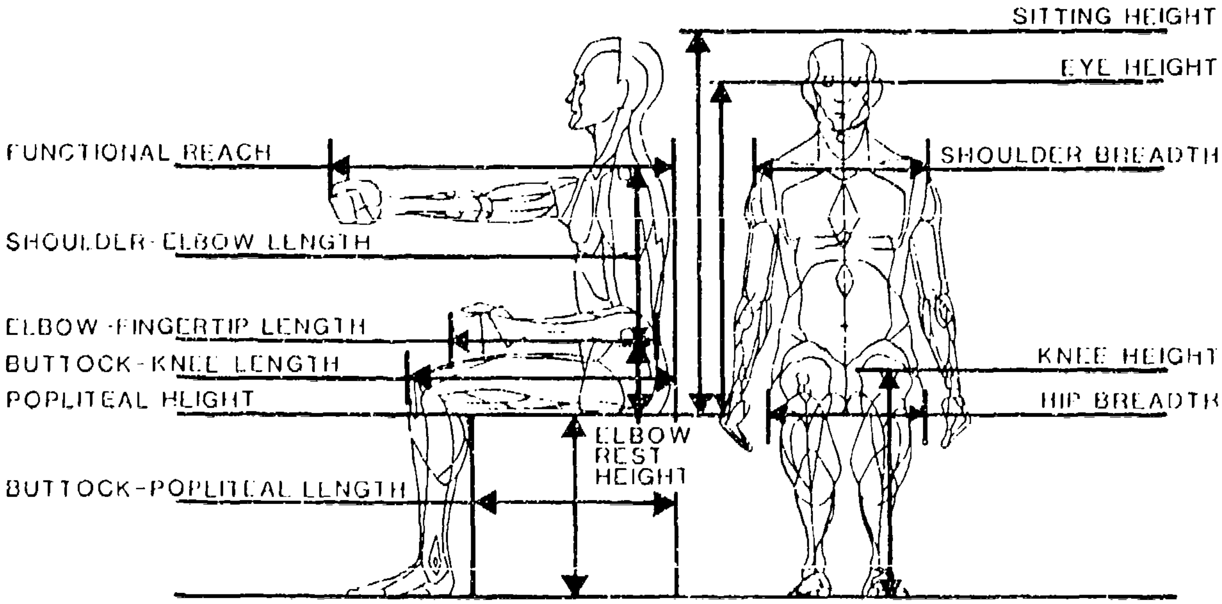


FIGURE 11. CONVENTIONAL SEATED ANTHROPOMETRIC DIMENSIONS.

The second type of anthropometric data, which may be referred to as workspace dimensions, is more difficult to obtain and can be applied only to the specific workspace studied. However, these workspace dimensions are essential in designing aircraft interiors for maximum occupant protection.

Workspace dimensions must involve a consideration of body joints, the distance between them, and their range of motion. Dempster reported on an extensive study of workspace requirements for seated operators, in which he determined "link lengths" between effective joint centers for major body parts (References 31 and 32). These link lengths have a number of crash resistance-related applications: (1) in developing or expanding the strike

TABLE 3. SUMMARY OF ANTHROPOMETRIC DATA FOR U.S. ARMY MALE AVIATORS (REFERENCE 26)

Measurement	Percentile (in.) 5th	50th	95th
Weight (lb)	133.0	171.0	212.0
Stature	64.6	68.7	72.8
Seated height	33.7	35.8	37.9
Shoulder breadth	17.0	18.7	20.3
Functional reach	28.8	31.1	34.2
Hip breadth, sitting	13.2	14.8	16.7
Eye height, sitting	29.0	31.0	33.1
Knee height, sitting	19.3	20.6	22.6
Elbow rest height, sitting	7.4	9.1	10.8
Popliteal height	15.1	16.6	18.3
Shoulder-elbow length	13.3	14.4	15.6
Elbow-fingertip length	17.6	19.0	20.3
Buttock-popliteal length	17.7	19.3	21.0
Buttock-knee length	22.0	23.7	25.4

TABLE 4. SUMMARY OF ANTHROPOMETRIC DATA FOR FOR MALE SOLDIERS (REFERENCE 27)

Measurement	Percentile (in.) 5th	50th	95th
Weight (lb)	125.0	156.0	202.0
Stature	64.5	68.7	73.1
Seated height	33.3	35.7	38.1
Shoulder breadth	16.3	17.6	19.6
Hip breadth, sitting	11.9	13.0	14.5
Eye height, sitting	28.6	31.0	33.3
Knee height, sitting	19.6	21.3	23.1
Popliteal height	16.0	17.5	19.2
Shoulder-elbow length	13.3	14.5	15.7
Elbow fingertip length	17.4	18.8	20.4
Buttock-popliteal length	18.0	19.6	21.3
Buttock-knee length	21.6	23.4	25.3

envelopes shown in Chapter 6 of Volume II, (2) in designing crash test dummies, and (3) in providing numbers for mathematical simulators. Skeletal joint locations and ranges of motion are presented in Section 7.2.3 of Volume II.

3.4.3 Inertial Properties

Anthropometric dummies and mathematical simulations require inertial properties of body segments, specifically moments of inertia, mass, and center-of-mass locations. Several studies of these properties have been made using live human subjects and cadavers, and such data as have been obtained should be integrated into the design of any anthropometric dummy or mathematical simulation. Results of several of these studies are summarized in Reference 33.

3.5 CRASH TEST DUMMIES

All of the recently developed dummies were designed for automotive testing and are based on the anthropometry of a 50th-percentile U.S. civilian male. In dynamic testing of an energy-absorbing seat, design for aircraft occupant weight can play a critical role. It would be desirable to evaluate a seat for a range of occupant sizes. A 95th-percentile dummy would verify the strength of the seat structure and restraint system as well as the adequacy of the energy-absorbing stroke. Testing with a 50th-percentile dummy would demonstrate the performance of the system for an occupant of average height and weight. A 5th-percentile dummy would probably experience accelerations of higher magnitude and would establish the severity of a given set of impact conditions for the smaller occupant. However, both the expense of dummy purchase and the cost of conducting dynamic tests may make such a test program impractical. An alternative procedure might be to establish the occupant protection capability of a seat design by analysis and to conduct a dynamic test with a 95th percentile dummy to verify system strength.

The design of different anthropomorphic dummies for military testing must be based on the military aviator population. Body dimensions, joint locations and mass distribution properties for small-, mid-, and large-size male aviators has been generated as a tri-service data base for three-dimensional, mathematical models and test dummies (Reference 34). These dimensions are available to designers for guidance in the design of dummies.

Another factor that must be considered in dummy selection for aircraft seat testing is that none of the dummies described for automotive testing have been designed for accurate response to vertical impact. The spinal column, which is a critical region of human tolerance to aircraft crash loading, has been designed to simulate response to $-G_x$ loading, rather than the more critical $+G_z$ loading. The articulated dummies developed for car crash testing are not suitable for vertical impact tests, because they do not usually represent spinal compressive stiffness and the large number of connected masses prevent the evaluation of seat forces from the deceleration measured in the dummy. Sarrailhe (Reference 35) proposes that the base of the test dummy be as narrow as the load-bearing part of a seated human to ensure that the seat and seat cushion receive representative loading. He states that the spinal stiffness of the dummy could affect the behavior of the seat.

In 1986 General Motors Corporation's Hybrid III test dummy was incorporated into the Department of Transportation's specifications for Part 572 test dummies (Reference 36). At present, manufacturers have the option of using either the original Part 572 dummy or the Hybrid III dummy for compliance testing; beginning September 1, 1991, the Hybrid III dummy will be used as the exclusive means of determining a vehicle's conformance with the performance requirements of Federal Motor Vehicle Safety Standard 208. Therefore, it appears that use of the Hybrid III dummy, modified to improve its simulation accuracy to impact loading in the $+G_z$ direction and sized to 5th-, 50th-, and 95th-percentile versions of the U.S. Army aviator, would provide the best available simulation and is, therefore, the recommended approach.

4. AIRFRAME STRUCTURAL CRASH RESISTANCE

4.1 INTRODUCTION

Salient features required in the definition of a crash-resistant structure are summarized in this chapter. The user is referred to Volume III for additional information concerning the criteria or their sources.

In a crash situation, the basic requirements for occupant survival of impact hazards are:

- The maintenance of a protective structural envelope.
- The attentuation of impact forces to maintain survivable acceleration conditions.

To achieve the desirable occupant survivable conditions, the following basic design requirements must be considered as an integrated problem, and a practical solution must be obtained. Such design requirements should be included in new aircraft, and existing designs should be improved by incorporating these features where possible.

- The basic structural envelope surrounding occupied areas must be designed to maximize its energy absorption capacity.
- The structure that makes initial contact with the ground must be designed to minimize the probability of earth gouging and scooping of soil. This will minimize the acceleration and force levels to which the structure is subjected.
- All items attached to the structure must, where possible, be retained in survivable crash conditions. These items include large masses, such as transmissions, engines, and rotor systems; internal cargo and on-board equipment racks; externally mounted components, such as fuel tanks, wings, and external stores; and the empennage and landing gear. In the past, shedding of large-mass items has been considered advantageous under crash impact conditions. This is true from the viewpoint of reducing the energy content of the aircraft and, hence, the loads acting on the structure in resisting aircraft postimpact motions. However, it is possible that penetration of occupied areas could occur, and during postimpact motions, the aircraft could traverse shed objects, causing high loading on the structure. It is, therefore, better to maintain a known mass if an optimum acceleration profile is desired for occupant survival. Thus mass retention and landing gear integrity are required for optimum crash resistance and occupant survivable conditions.
- In the case of helicopters, certain areas of the cockpit and cabin structure must be reinforced to withstand loads induced by blade strikes, impacts with external objects such as trees, and rollover. In addition, if overhead-mounted crash-resistant seats are used, the deflection of the overhead structure relative to the floor must be minimized.

- Unoccupied areas of structure, such as the underfloor, nose, and tail areas, must be designed to deform in a controlled manner to absorb as much energy as possible. Such deformation must be consistent with the safety requirements of other installed systems, such as fuel cells or seats, and should not intrude into adjacent occupied areas.

A crash can involve a wide range of dynamic conditions, from a simple unidirectional impact to a complex combination of rotational and multidirectional impact conditions. The current requirements for Army light fixed- and rotary-wing aircraft are summarized in Tables 5 and 6. Any light aircraft designed to similar criteria would exhibit improvements in crash resistance. A summary of desirable features for overall crash resistance is shown in Figure 12 for a single-rotor helicopter. Similar features should be implemented in all designs, whether fixed- or rotary-wing, to provide survivable conditions for all occupants.

When a more severe crash does occur, the service life of the aircraft is usually ended, and the only structural requirement is to provide occupant protection. In order to provide such protection, the design must permit large deflections of structural members and joints as well as loading in the plastic range of stress. Excessively strong airframe structure is no more acceptable than understrength structure for adequate crash resistance. Not only will unnecessary strength result in an unacceptable weight penalty but on impact high G levels that compromise occupant survivability may be generated.

TABLE 5. PERFORMANCE REQUIREMENTS UNDER CRASH IMPACT CONDITIONS PER TABLE 2

Condition No.	Impact Direction	Percentage Volume Reduction	Other Requirements
1	Longitudinal (Cockpit)	No serious hazard to pilot/copilot.	Does not impede postcrash egress. Engine transmission, rotor system remain intact and in place.
2	Longitudinal (Cabin)	15 maximum length reduction for passenger/troop compartment.	Inward buckling of side walls should not pose hazard to occupants or restrict their evacuation.
3	Vertical	15 maximum height reduction in cockpit and passenger/troop compartment.	G loads not injurious.
4 & 5	Lateral	15 maximum width reduction.	Lateral collapse of occupied areas not hazardous, no entrapment of limbs.
6	Combined High Angle	No serious hazard to occupant due to cockpit/cabin reduction.	
7	Combined Low Angle	No serious hazard to occupant.	

TABLE 6. OTHER STRUCTURAL PERFORMANCE REQUIREMENTS

Impact Direction	Impacted Surface	Velocity Differential (ft/sec)	Vehicle Attitude Limits	Percentage Volume Reduction	Other Requirements
Rollover	Earth	-	90° sideward or 180° inverted or any intermediate angle	Minimal (door hatches etc. assumed to be non-load carrying)	Forward fuselage buried to depth of 2 in. (inverted or on side). Load uniformly distributed over forward 25% of occupied fuselage length. Can sustain 4 G without injury to seated and restrained occupants. All loading directions between normal and parallel to skin to be considered.
Rollover (Post-impact)	Rigid		Two 360° Rolls (maximum)	15 maximum volume reduction (5 percent desired)	
Earth Plowing & Scooping	Earth	-	-	-	Preclude plowing when forward 25% of fuselage has uniformly applied vertical load of 10 G and rearward load of 4 G or the ditching loads of MIL-A-008865, whichever is the greatest.
Landing Gear	Rigid	20	$\pm 10^{\circ}$ Roll $+15^{\circ}$ to -5° Pitch	None. Plastic deformation of gear and mounting system allowable	Aircraft deceleration at normal G.W. for impact with no fuselage to ground contact. All other A/C structural parts, except blades, should be flightworthy following crash.
Landing Gear	Sod	100 long.[c]* 14 vertical	-5° Pitch $\pm 10^{\circ}$ Roll $\pm 20^{\circ}$ Yaw	15 maximum volume reduction (5 percent desired)	No rollover, or if rollover occurs, two 360° rolls without fuselage crushing.

* Velocity at impact, not differential.

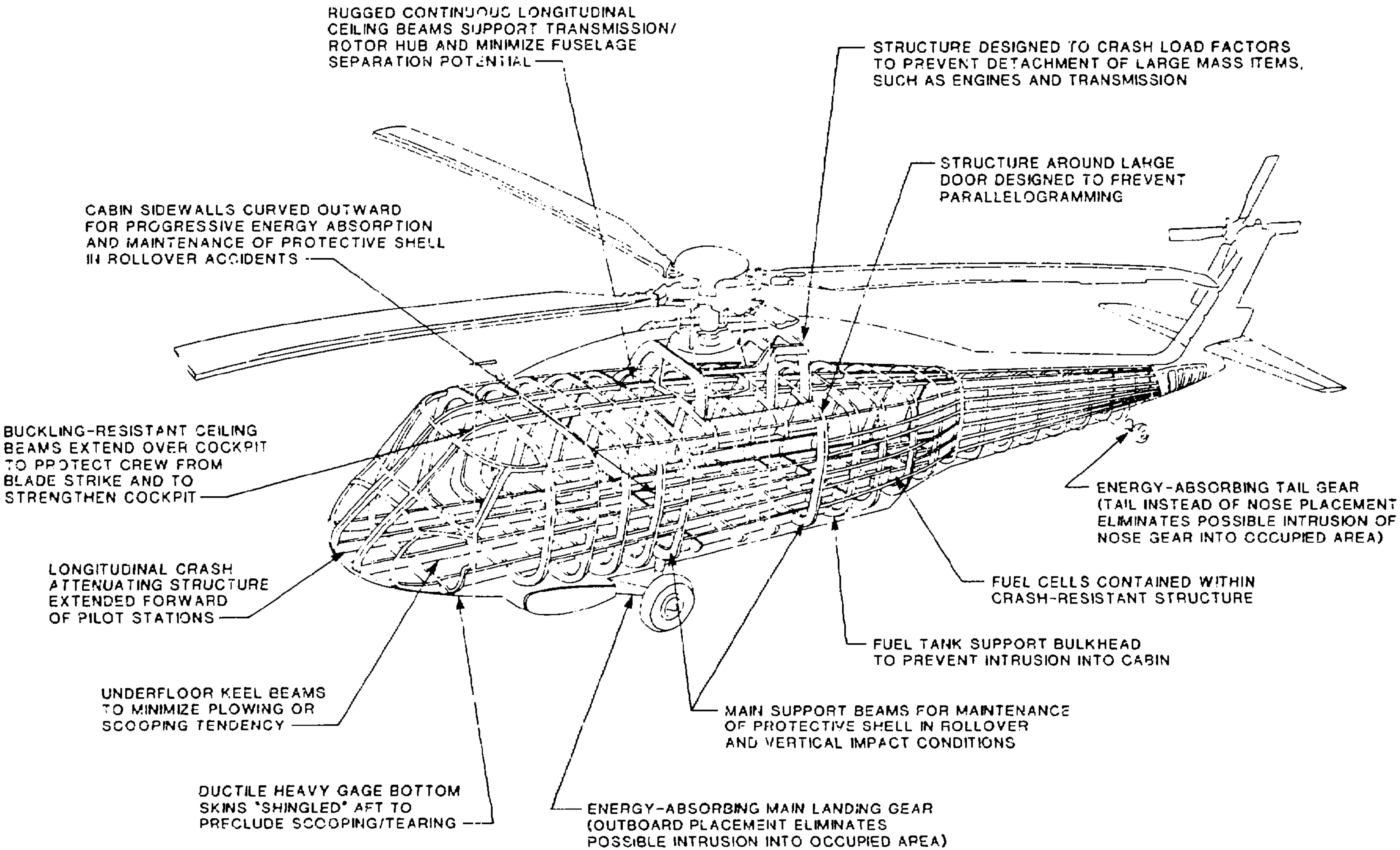


FIGURE 12. STRUCTURAL LAYOUT FOR OCCUPANT PROTECTION DURING CRASH IMPACT CONDITIONS.

4.2 AIRFRAME CRASH RESISTANCE

The aircraft structure should provide a protective shell for vehicle occupants in crashes; moreover, the structure should allow deformation in a controlled, predictable manner so that forces imposed upon the occupant will be minimized while still maintaining the protective shell. In structural areas where large structural deformations are anticipated, joints and attachments should be designed to withstand large angular deflections and/or large linear displacements without failure. All exterior surfaces and all structures which could be exposed to contact with the impact surface should be constructed of materials which characteristically resist sparking as a consequence of abrasion. Unless otherwise stated herein, the aircraft design gross weight (DGW) should be used for the vehicle weight in the analysis described below. Directions are assumed with respect to the aircraft (Figure 3) unless otherwise stated.

4.2.1 Longitudinal Impact

4.2.1.1 Impact Conditions. The basic airframe should be capable of impacting longitudinally into a rigid abutment or wall at a contact velocity of 20 ft/sec without crushing the pilot and copilot stations to an extent which would either preclude pilot and copilot evacuation of the aircraft or otherwise be hazardous to the life of the aircraft occupants. For such an impact, the engine(s), transmission, and rotor system for helicopters should remain intact and in place in the aircraft except for damage to the rotor blades. The basic airframe of passenger-carrying helicopters should be capable of impacting longitudinally into a rigid abutment or wall at a contact velocity of 40 ft/sec without reducing the length of the passenger/troop compartment by more than 15 percent. Any consequent inward buckling of walls, floor, and/or roof should not be hazardous to the occupants and/or restrict their evacuation. The aircraft should also be designed to withstand impact as in a low-angle missed approach. This impact in plowed soil (Figure 13) can result in a rollover and side impacts which may crush and/or separate the fuselage. The volume of the cockpit or the occupied passenger/troop compartment should not be reduced by more than 15 percent (5 percent desired).

Should the aircraft turn over, the fuselage container should maintain structural integrity for a minimum of two 360-degree rolls. The static loads to be considered for rollover analysis are described in Section 4.2.4.

4.2.1.2 Earth Scooping. Design features for reducing the earth scooping effects encountered in longitudinal impacts should include the following:

- Provide a large, relatively flat surface in those areas which could gouge or plow, thereby increasing the aircraft's tendency to slide over the impact terrain.
- Minimize inward buckling of the fuselage nose or engine nacelle to maintain skid surface integrity.
- Design the nose section to preclude any earth plowing and scooping tendency when the forward 25 percent of the fuselage has a uniformly applied local upward load of 10 G and an aft load of 4 G, as shown in Figure 14.

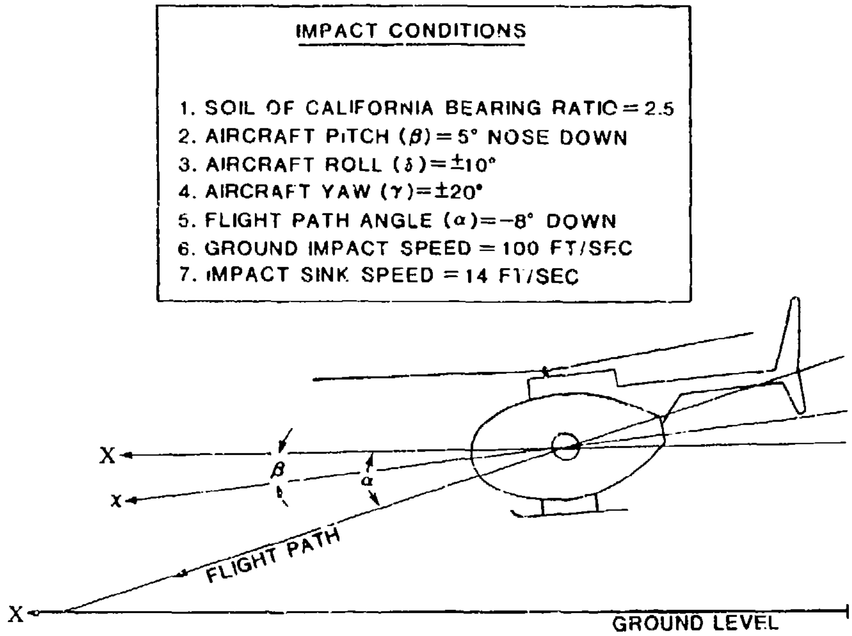


FIGURE 13. LOW-ANGLE IMPACT DESIGN CONDITIONS (SIMULATED APPROACH WITH ANTITORQUE LOSS UNDER POOR VISIBILITY).

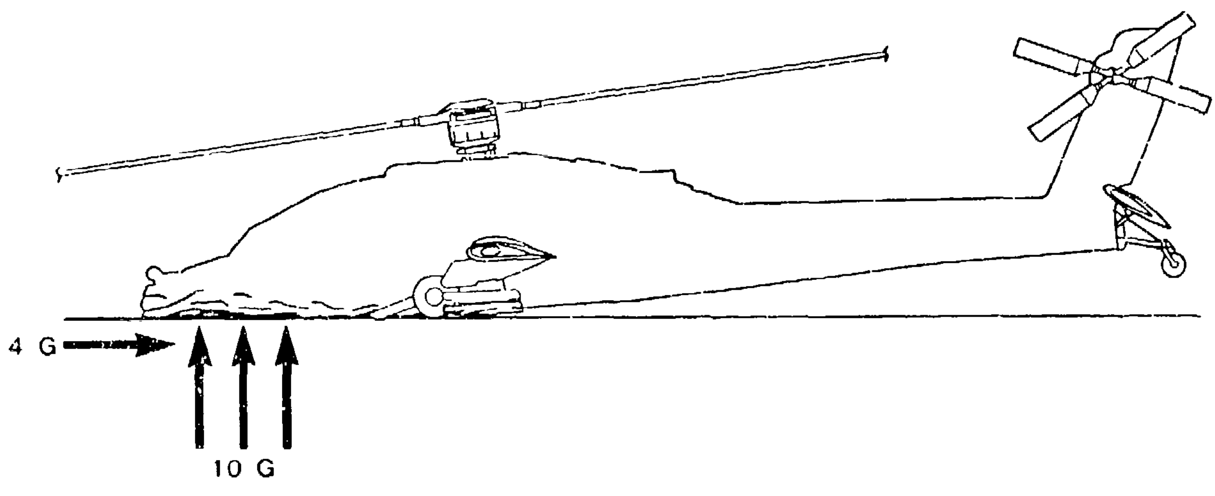


FIGURE 14. NOSE SECTION DESIGN CONDITIONS.

4.2.1.3 **Fuselage Deformation**. To minimize hazards to personnel created by buckling or other deformation of the structure, the aircraft should be designed to:

- Provide sufficient structural strength in the protective shell around the occupants to prevent bending or buckling failure of the fuselage, in accord with Table 5.
- Buckle the fuselage outward, if at all possible, rather than inward into living space, when its collapse strength has been exceeded.
- Have the cargo restraints be effective even when fuselage bending failure occurs.

4.2.1.4 **Floor and Bulkhead**. The floor structure should possess sufficient strength and ductility to carry, without failure, loads applied by the occupants and cargo restraint systems even when deformation and substructure crushing occur. Consideration should be made for the specific loads and moments applied by these items to the supporting structure in the warped conditions described in Chapter 5.

4.2.2 Vertical Impact

4.2.2.1 **Impact Conditions**. With the landing gear extended and the rotor/wing lift equal to DGW, the aircraft should withstand a 42-ft/sec vertical impact without reducing the height of the cockpit or cabin by more than 15 percent and/or causing the occupants to experience injurious accelerative loading. For this analysis, the aircraft attitude should be within +15/-5 degrees of pitch and ± 10 degrees of roll in accordance with MIL-STD-1290.

4.2.2.2 **Design Application**. Design applications for accomplishing the above goal should include the following:

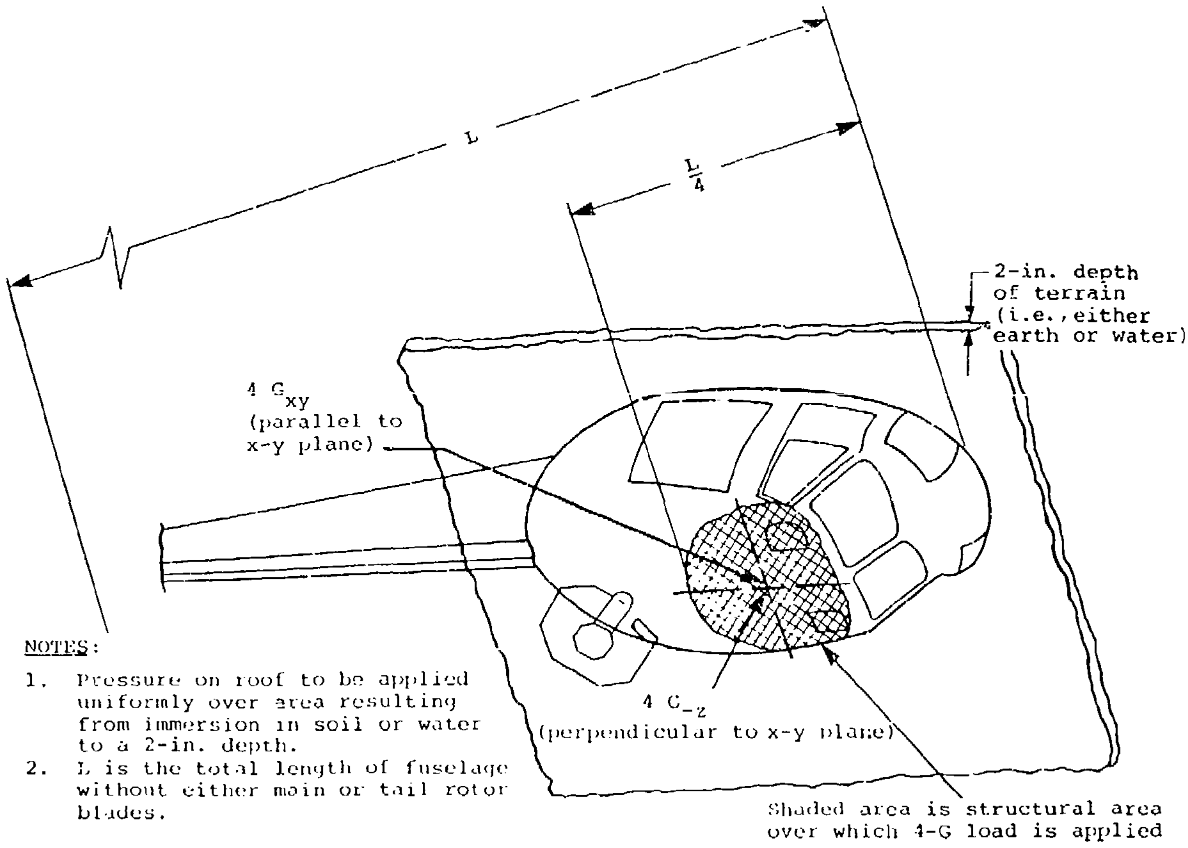
- Locate high-mass items so that they will not intrude into occupied areas during the crash.
- Provide sufficient vertical crushing strength to prevent more than 15 percent crush.
- Provide load-limiting structure beneath the floor.
- Provide load-limiting landing gear.
- Provide load-limiting seating for all occupants.

4.2.3 Lateral Impact

Light fixed- and rotary-wing aircraft should withstand a lateral impact of 25 and 30 ft/sec, respectively, into a rigid barrier without reducing the width of occupied areas by more than 15 percent. The design of the vehicle should minimize the chance of the occupant being trapped between the structure and an impacting surface following failure of doors, canopies, or hatches.

4.2.4 Rollover Impact

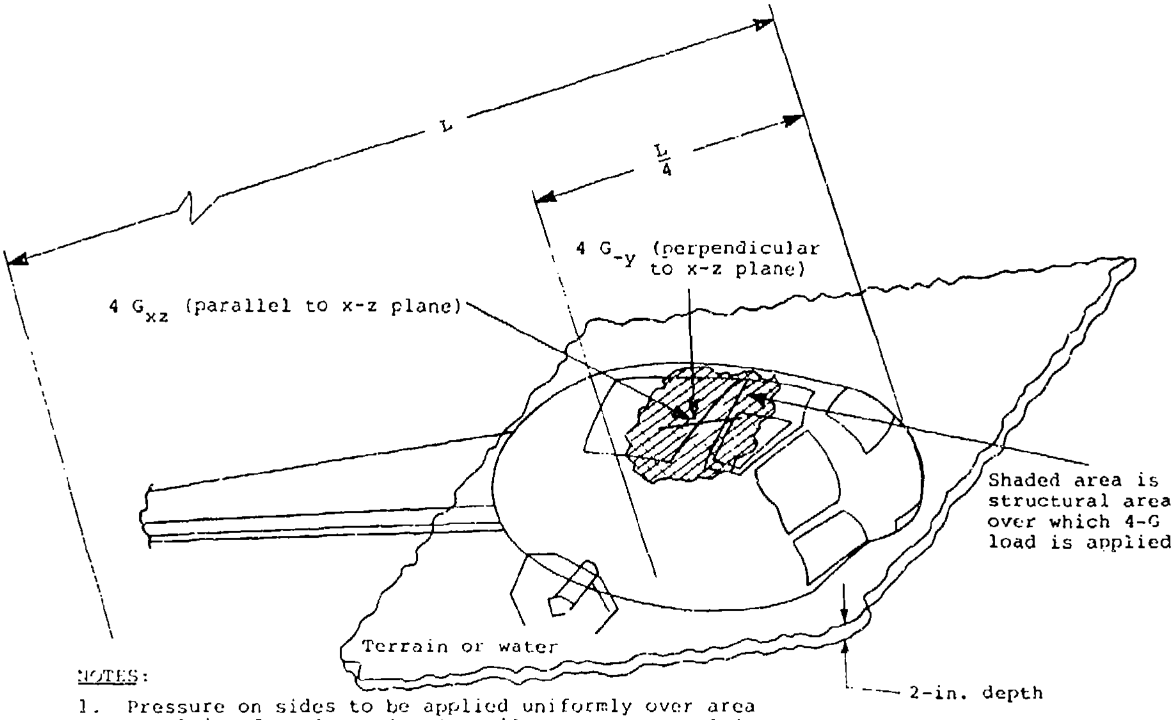
The aircraft should be designed to resist an earth impact loading as occurs when the aircraft impacts the ground and rolls to a 90-degree (sideward) or 180-degree (inverted) attitude. A rollover should not cause structural failure or major intrusion into occupied areas. It should be assumed that the forward fuselage roof is buried in soil to a depth of 2.0 in. for the inverted attitude and that the load is uniformly distributed over the forward 25 percent of the occupied fuselage length. It should also be assumed that the forward fuselage side is buried in soil to a depth of 2.0 in. for the sideward attitude and that the load is uniformly distributed over the forward 25 percent of the occupied fuselage length. The fuselage should be capable of sustaining a 4-G (i.e., 4.0 x aircraft DGW) load applied over the area(s) described for either the inverted or sideward attitudes shown in Figures 15 and 16, respectively, without structural failure or more than 15 percent loss of living space. For both cases in Figures 15 and 16, the 4-G distributed load should be analyzed for any angle of load application ranging from perpendicular to the fuselage skin (i.e., compressive loading) to parallel to the fuselage skin (i.e., shear loading). When designing for this condition, it should be assumed that all doors, hatches, transparencies, and similar openings cannot carry any loading and that rotor masts, wings, and tail boom are intact. These design conditions assume that the aircraft becomes inverted after impact. They are not intended to provide protection in an inverted impact.



NOTES:

1. Pressure on roof to be applied uniformly over area resulting from immersion in soil or water to a 2-in. depth.
2. L is the total length of fuselage without either main or tail rotor blades.

FIGURE 15. ROLLOVER, ROOF IMPACT DESIGN CONDITION.



NOTES:

1. Pressure on sides to be applied uniformly over area resulting from immersion in soil or water to a 2-in. depth.
2. L is the total length of fuselage without either main or tail rotor blades.

FIGURE 16. ROLLOVER, SIDE IMPACT DESIGN CONDITION.

4.2.5 Wings and Empennage

As discussed in Section 4.1, the wings and empennage structure should remain attached during a moderate crash. However, for fixed-wing aircraft, wing design should possess frangible characteristics to allow wings to break free from the fuselage under high longitudinal inertia loads. This would limit distributed impact loads caused by striking a barrier such as an earth mound. Empennage structure should also be designed to collapse or break away during a severe longitudinal crash impact. The structures should be designed to ensure that failure occurs outside the occupant-protecting section of the fuselage.

For rotary-wing aircraft, wings used to support external stores prevent rollover in many accidents and should not be frangible, but should allow the stores to separate under high-G loads while maintaining the structural integrity of the wing. However, the wing should break off before the fuselage structure itself collapses.

The adjusted position of control surfaces such as flaps should not block doors or other escape routes from the aircraft.

4.2.6 Engine/Transmission Mounts

For light fixed-wing aircraft, engine mounts should be designed to keep the engine attached to the basic supporting structure under the crash conditions cited in Table 2, even though considerable distortion of the mounts and support structure occurs. The basic structure supporting the engine should fail or separate before engine mount failure occurs.

On helicopters, the transmission, rotor mast, rotor hub, and rotor blades should not displace in a manner hazardous to the occupants during the following impact conditions:

- Rollover about the vehicle's roll or pitch axis on sod.

- Advancing and retreating blade obstacle strikes that occur within the outer 10 percent of blade span, assuming the obstacle to be an 8-in.-diameter rigid cylinder.

Unless otherwise specified, all engines, transmissions, rotor masts, armament systems, external stores, and rotor hubs that could be hazardous to the occupants should be designed to withstand the following ultimate load factors (G) in the directions that cause those hazards and remain restrained:

- Applied Separately

Longitudinal	±20
Vertical	+20/-10
Lateral	±18

- Applied Simultaneously

	Design Conditions		
	1	2	3
Longitudinal	±20	±10	±10
Vertical	+10/-5	+20/-10	+10/-5
Lateral	±9	±9	±18

4.2.7 Landing Gear

The landing gear should be capable of ground taxi, towing, ground handling, takeoff and landing roll, and landings including autorotative landings at design sink speeds in accordance with AMCP 706-201 (Reference 37). Unless otherwise specified, strength and rigidity requirements should be provided in accordance with MIL-S-8698 (Reference 38). An analytical casting factor of 1.25 should be applied for the design of all castings which will not be static tested to failure, or which are not procured to MIL-A-21180 (Reference 39). The yield factor of safety should be 1.0.

4.2.7.1 Landing Gear Location. The landing gear subsystem location should minimize the possibility that a part of the gear or support structure will be driven into an occupiable section of the aircraft, or into a region containing a flammable fluid tank or line, in any accident falling within the crash conditions of Table 6. If this cannot be accomplished by location, the gear should be designed to break away under longitudinal impact conditions, with points of failure located so that damage to critical areas is minimized.

Failure of the landing gear should not result in a failure of any personnel seat/restraint system or seat/restraint system tiedown. Also, failure of the landing gear should not result in blockage of a door or other escape route or prevent the opening of any door or other escape route.

4.2.7.2 **Vertical Crash Force Attenuation.** The landing gear should be of the load-limiting type and should be capable of decelerating the aircraft at DGW from a vertical impact velocity of 20 ft/sec onto a level, rigid surface without allowing contact of the fuselage proper with the ground. Plastic deformation and damage of the gear and mounting system are acceptable in meeting this requirement. The aircraft should be capable of meeting this requirement in accidents with simultaneous fuselage angular alignment of ±10 degrees of roll and +15 to -5 degrees of pitch. For the case of retracted landing gear, the seat and airframe combination should have a vertical crash impact design velocity change capability of at least 26 ft/sec. The landing gear should provide energy absorption at sink rates up to 42 ft/sec onto an impact surface within ±10 degrees roll and +15 to -5 degrees pitch.

4.3 ANCILLARY EQUIPMENT RETENTION

Ancillary equipment is all removable equipment carried inside the aircraft that could constitute a hazard if unrestrained during a crash. Typical items are:

- Emergency Equipment

  Oxygen bottles
  Fire extinguishers
  First-aid kits
  Portable searchlights
  Crash axes

- Aircraft Subcomponents

  Panel-type consoltes containining control circuitry
  Radio and electronic equipment
  Auxiliary power units
  Batteries
  Special Equipment

- Survival Equipment

  Survival kits
  Life rafts
  Life jackets
  Locator beacons
  Special clothing
  Food and water

- Miscellaneous Equipment

  Navigation kits
  Briefcases
  Log books
  Flashlights
  Luggage
  Toolboxes.

All ancillary equipment frequently carried aboard an aircraft should be provided with integrated restraint devices to ensure retention of the equipment during any survivable crash of the severity cited in Table 2. Stowage space should be provided for nonrestrained items that are not regularly carried. This space should be located so that the items stored in it cannot become hazards in a survivable crash. Stowage under energy-absorbing seats is not acceptable.

4.3.1 Strength

Restraint devices and supporting structure for ancillary equipment should be designed for static loads of 50 G downward, 10 G upward, 35 G forward, 15 G aftward, and 25 G sideward. Load-limiting devices are recommended for restraint of heavier equipment. However, load-limiter stroking should not allow equipment to enter an occupant strike envelope.

4.3.2 Emergency and Survival Equipment Stowage Location

Equipment should be: (1) located close to the primary crew chief station, if applicable; (2) stowed in easy view of crew and passengers; and (3) easily and reliably accessible in an emergency. Equipment should not be placed in areas where cargo shifting or fuselage distortion will prevent or impair access to it. Extreme temperatures, abrasion, and uncleanliness should be minimized.

4.3.3 Release of Emergency and Survival Equipment

Retention devices used to restrain emergency and survival equipment should be capable of quick release without the use of tools by one person using one hand. Release should be effected by a single motion actuating one device and should not require more than 5 sec from time of contact with the actuating device to the time when the equipment either falls free or is lifted free. If equipment is stowed in an enclosure, no more than 5 sec should be required for opening the enclosure and removing the equipment. Aircraft attitude should not adversely affect release device operation. It should be possible to see the latch position (open or closed) of the release device. The release device actuating handle should be of a color that contrasts with the surrounding area and be easily discernible in poor light or smoky conditions.

4.4 INTERFACE OF OCCUPANT AND CARGO RETENTION SYSTEMS WITH AIRFRAME

Both seats and cargo tiedowns require structural attachments capable of withstanding the applied loads without failure or excessive deformation. Although additional seat design and installation requirements are discussed in Chapter 5 of this volume, there are several important points to be considered where structural interface occurs. For example, the basic floor structure should evenly distribute loading to the underfloor frames and longitudinal members. All seat and cargo attachment fittings should be attached through the floor to primary underfloor structure, i.e., either the heavy, full-depth longitudinal beams, or substantial underfloor frame elements. The elements should be compatible with the types and magnitudes of crash loading applied by the seat or cargo attachments. This includes reaching the loads and moments applied by the seats or cargo with deformed floor and bulkhead structure.

The tiedown points must be designed for the worst case combination of cargo weight, center-of-gravity height above the floor, and G conditions during the crash.

If energy absorbers are used for the seat or cargo attachments, the attachments and their fasteners should be designed to the limiting load condition, considering the effects of angular displacement relative to the floor. To ensure structural integrity, all seat attachments must be designed to withstand or attenuate computed maximum loads with consideration for bottoming, or exhausting of available stroke. In the case of tiedown rings, which usually are rated to a certain load capability such as 5000 lb, the attachments and structures must be capable of withstanding the worst case, angled load without yielding. Although cargo tiedown energy absorbers may be used, if a choice exists between energy-absorbing and nonenergy-absorbing tiedowns, the design criteria must be for the worst case, which will likely be the nonabsorbing equipment.

Structure surrounding an energy-absorbing seat must be designed to allow clearance for seat operation. Elastic deformation should be added to the envelope of seat stroke in determining the required clearance. If a well is provided in the aircraft floor to allow additional stroking distance, at least a 2-in. clearance should be maintained between the outer edges of the bucket and the innermost hardware extension on the sides or front of the well, including the tracks.

4.5 OCCUPANT RETENTION

Seating and litter systems should ensure that occupants are retained in their precrash positions within the aircraft. Seating and litter systems design should be coordinated and interfaced with the design of the other surrounding aircraft areas to achieve a completely integrated and efficient crash-resistant aircraft system design. Seat and litter design should provide the greatest practical amount of support and contact area for the occupants in the directions of the most severe and likely impacts. Seats should provide an integral means of crash force attenuation. Occupant comfort should not be compromised to the extent that flight safety and/or crew efficiency is adversely affected. Volume IV contains a detailed discussion of occupant retention.

4.6 CARGO RETENTION

Cargo restraint should:

- Be as light as possible.
- Require minimum storage space.
- Be easy to install and remove.
- Be easily and reliably adjustable for different sizes and shapes of cargo.
- Provide sufficient restraint of cargo in all directions to prevent injury to personnel in a survivable crash.

If the structure of the fuselage and floor is not strong enough to withstand the longitudinal loads, load limiters should be used. Cargo restraints should be capable of maintaining their integrity under longitudinal loads of 16 G peak with a longitudinal velocity change of 43 ft/sec. Complete load and displacement requirements are presented in Table 7, and the requirements for the longitudinal and lateral directions are illustrated in Figures 17 and 18. If load-limiters are used, low-elongation restraining lines should be used to ensure the most efficient energy absorption.

Nets used to restrain small bulk cargo should be constructed of material with low-elongation characteristics in order to reduce dynamic overshoot to a minimum. Restraining lines without load limiters used for large cargo, as defined in Table 8, for longitudinal restraint should be so arranged that maximum load in all lines is reached simultaneously. Restraining lines having different elongation characteristics should not be used on the same piece of cargo.

TABLE 7. CARGO RESTRAINT LOADS AND DIPSLACEMENT REQUIREMENTS

Item No.	Load Direction (With Respect to Floor)	Restraint Load	Controlled Displacement
1	Forward	See Figure 17	See Figure 17
2	Aftward	5 G	No Requirement
3	Lateral	See Figure 18	See Figure 18
4	Downward	16 G	No Requirement
5	Upward	5 G	No Requirement
6	Forward and Combined	See Figure 17	See Figure 17
	Lateral	4 G	No Requirement

4.7 SPECIAL TILT-ROTOR CONSIDERATIONS

Crash resistance design considerations for tilt-rotor aircraft share many common items with conventional helicopter and fixed-wing aircraft. These include the items listed in Table 1.

On conventional helicopters, the main rotor pylons and engines generally are located near the occupied areas, and adequate tiedown strength is required to prevent potentially hazardous displacement of the large mass items into the occupied areas. On tilt/rotor aircraft the pylons are located at the wing tips, well away from the occupied areas. By allowing the wings to fail in a controlled manner the aircraft mass is greatly reduced, and less material is required in the fuselage structure to absorb the reduced aircraft kinetic energy.

The aircraft design approach to control the wing, pylon, and rotor failure modes is illustrated in Figure 19. By proper choice of the prop-rotor direction of rotation, the pylon and rotor are directed away from the occupied areas in the event of a rotor ground strike. If a rotor ground strike occurs, the composite blades typically exhibit benign failures and stay together because of the tensile strength of the fibers, even though severely damaged. Although large blade sections are not expected to separate, debris from the ground and rotor blade fragments may impact the fuselage sidewalls in the vicinity of the tip path plane. The seating arrangements and the design of the structure in those areas adjacent to the tip path plane should consider this possibility.

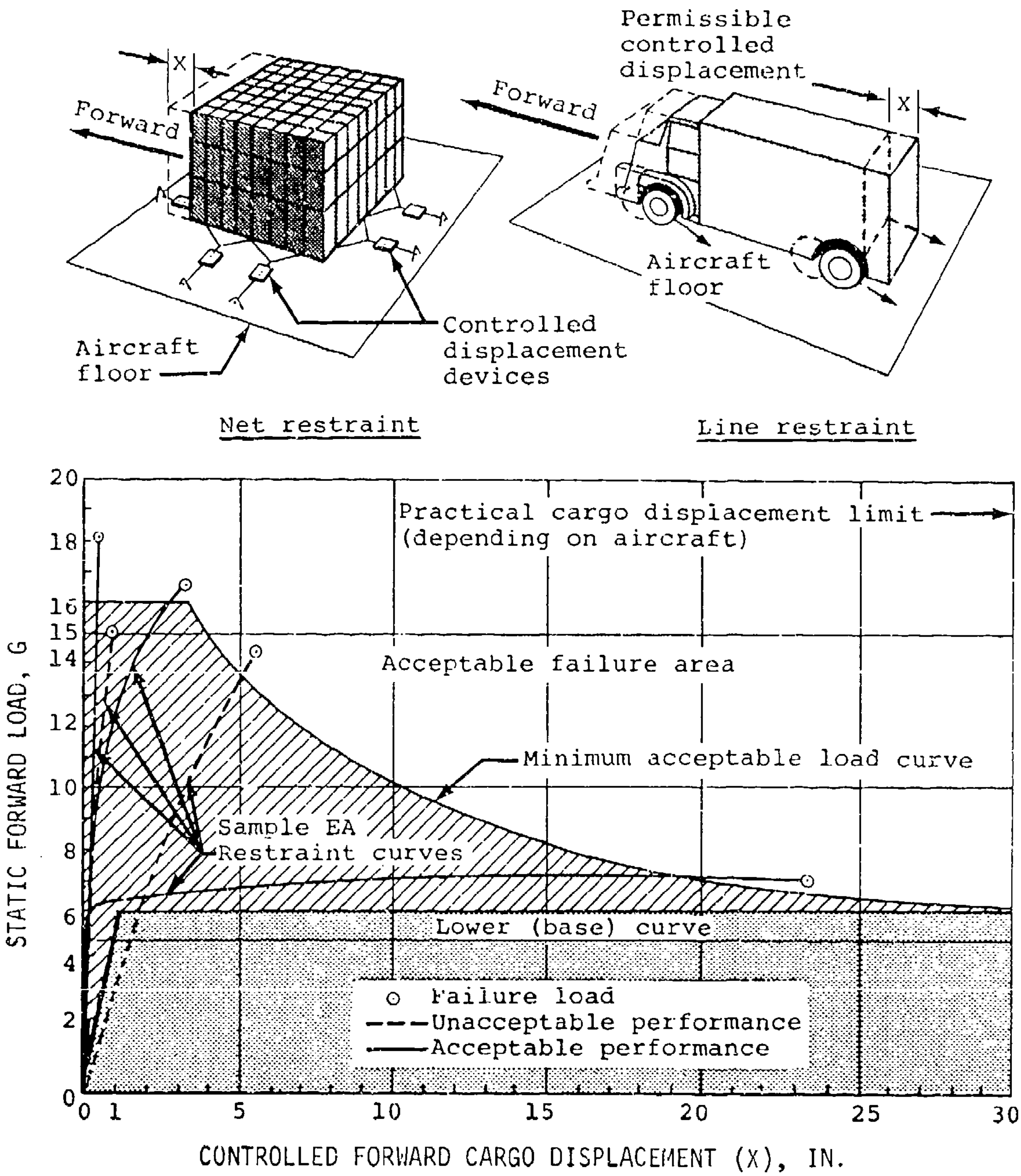


FIGURE 17. LOAD-DISPLACEMENT REQUIREMENTS FOR ENERGY-ABSORBING CARGO RESTRAINT SYSTEMS (FORWARD LOADING OF ROTARY- AND FIXED-WING AIRCRAFT).

To maintain the fuselage occupied compartment area, the fuselage is designed stronger than the wings. Similarly, the wings are designed stronger than the pylon. Consequently, the pylon and wing will fail prior to the fuselage, preventing collapse of the occupant compartment (Reference 40).

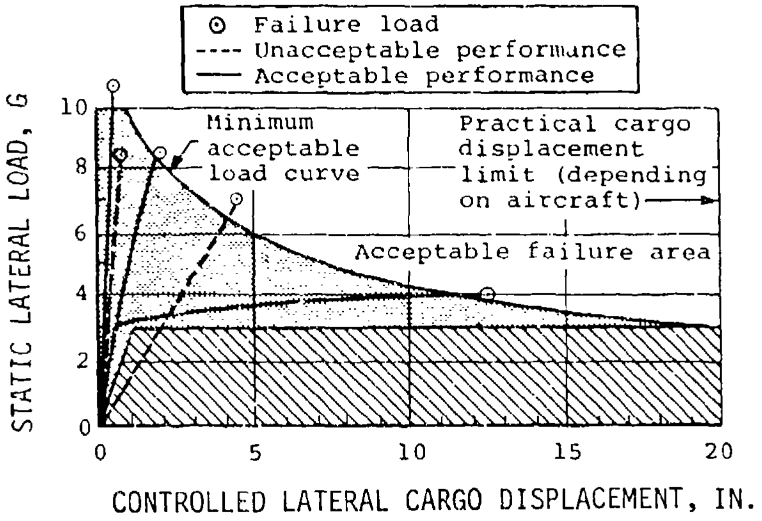
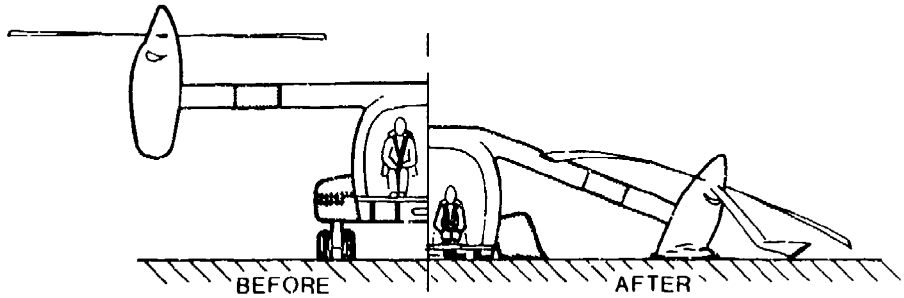


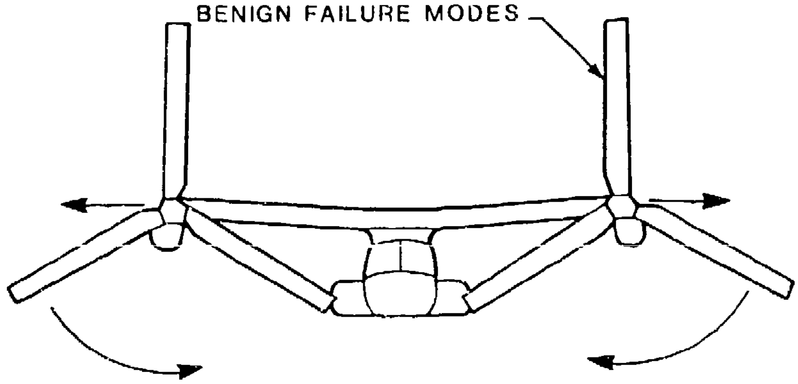
FIGURE 18. CARGO LATERAL LOAD-DISPLACEMENT REQUIREMENTS.

TABLE 8. AIRCRAFT CARGO CATEGORIES

Small Bulk Cargo (Net Restraint)	Large Rigid Cargo (Line Restraint)
This class includes all boxes or unpacked cargo of approximately 3 ft^3 or less in size.	This class inclues all rigid cargo of 3 ft^3 or more in size.
Examples:	Examples:
1. Ammunition boxes	1. Wheeled or tracked vehicles
2. Foodstuffs	2. Aircraft engines
3. Medical supplies	3. Fuel barrels
4. Clerical supplies	4. Artillery pieces
5. Vehicle maintenance components	5. Special weapons (priority cargo)



CONTROLLED WING FAILURE ALLOWS MASS RELIEF. PREVENTS FUSELAGE COLLAPSE.



DIRECTION OF ROTATION CAUSES PYLONS/ROTORS TO BE DRIVEN AWAY FROM FUSELAGE SHOULD BLADE STRIKE OCCUR.

FIGURE 19. WING/ROTOR/PYLON CRASH FAILURE MODES.

4.8 TESTING

4.8.1 Aircraft System Testing

Instrumented, full-scale crash test(s) should be conducted: (1) to verify analyses performed, (2) to substantiate the capability of the aircraft system to meet crash-resistance specifications, and (3) to gather further engineering data on the impact response of aircraft structures. A more detailed discussion of full-scale aircraft system testing is presented in Volume III.

4.8.2 Landing Gear Crash Testing

Instrumented drop tests should be conducted: (1) to verify landing gear crash force attenuation and crash loading strength characteristics analytically predicted and (2) to substantiate the capability of the aircraft landing gear to meet the criteria of Section 4.2.7. Drop testing of wheel and skid landing gear should be conducted in accordance with paragraph 9-2.3 of AMCP 706-203 (Reference 41). The 20-ft/sec sink speed drop test should be conducted with the landing gear oriented in a 5-degree nose down and 10-degree roll attitude and drop tested onto a level, rigid surface with a sink speed of 20 ft/sec at ground contact. Landing gear should also be drop tested in a 0-degree roll, pitch, and yaw attitude onto a level, rigid surface with a sink speed of 42 ft/sec at ground contact to demonstrate crash impact energy-absorption capability. Rotor/wing lift for all drop tests should be equal to DGW. Tests with a pair of gear mounted on an "iron bird" fixture simulate the aircraft crash conditions more accurately than do tests on a single gear.

4.8.3 Cargo Restraint

Design loads are specified in Section 4.6. Static tests to these loads are recommended. All deformation measurements are to be made at the floor level. Sufficient dynamic tests should be made to assure that design predictions can be accurately based on static test results.

4.8.4 Seat and Restraint System

Since proper performance of these items is critical for occupant survival, extensive qualification testing is required by MIL-S-58095. Testing requirements for seats and occupant retention systems are also described in Volume IV.

4.8.5 Fuel System

Testing requirements for fuel systems are described in Volume V.

4.8.6 Ancillary Equipment Retention

Design loads are specified in Section 4.3. Static tests to these loads are recommended. If applicable dynamic overshoot is likely, dynamic tests should be conducted.

4.9 DESIGN CHECKLISTS

4.9.1 Landing Gear Design Checklist

	Yes	No	N/A
1. Will the gear withstand an impact velocity of up to 42 ft/sec without catastrophic failure?	___	___	___
2. Will the gear prevent the fuselage from contacting the ground in a 20-ft/sec impact?	___	___	___
3. Will the gear survive a 10-ft/sec impact without structural damage?	___	___	___
4. Will the gear remain attached to the fuselage after impact?	___	___	___

	Yes	No	N/A
5. Is the gear located to prevent penetration of occupied areas during the energy-absorbing stroke or in the event of gear failure?	___	___	___
6. Has the gear been designed to absorb the maximum energy consistent with available stroke?	___	___	___
7. Is the gear located to prevent rupture of fuel cells?	___	___	___
8. Is every blow-off valve located where fluid will be confined or ejected outside the aircraft?	___	___	___
9. Has the gear been designed to avoid interference with the stroke of energy-absorbing seats?	___	___	___
10. Has the gear been designed to continue to absorb energy after initation of underfloor crushing?	___	___	___

4.9.2 Airframe Design Checklist

4.9.2.1 Fuselage

1. Are forward bulkheads canted aftwards below the floor to prevent earth scooping?	___	___	___
2. Are the forward lower skin panels made of tough, yet ductile, material to minimize tearing?	___	___	___
3. Are the forward lower skin panels shingled aftward to prevent scooping?	___	___	___
4. Will the nose structure support an upward load of 10 G and an aftward load of 4 G applied over the forward 25 percent of the fuselage without failure that would increase earth scooping tendencies?	___	___	___
5. Is the underfloor structure designed for energy-absorbing crush under upward loading while remaining intact under longitudinal impact conditions?	___	___	___
6. Is structure designed to transfer loads due to overhead masses to floor level without hazardous crushing of the occupied volume?	___	___	___

4.9.2.2 Wings and Empennage

1. Will the loss of wings occur in a manner that does not endanger the occupants and that does not destroy the usable volume?	___	___	___

	Yes	No	N/A

4.9.2.3 **Rollover Structure**

1. Will the forward fuselage roof support a 4-G load? ___ ___ ___

2. Are the side frame members designed for high load capacity to prevent collapse during a rollover-type impact? ___ ___ ___

4.9.2.4 **Blade Impact Protection**

1. Are overhead longitudinal members extended continuously over cockpit areas? ___ ___ ___

2. Are upper surfaces smooth and is lateral structure angled to deflect passing blades rather than allow penetration? ___ ___ ___

4.9.2.5 **Heavy Mass Support**

1. Are the supports for massive overhead components designed to withstand the following loads:

   ±18 G lateral? ___ ___ ___

   ±20 G longitudinal? ___ ___ ___

   +20/-10 G vertical? ___ ___ ___

2. Will the supports for massive overhead components withstand the following combinations of loads:

   ±20 G long., +10/-5 G vert., ±9 G lat.? ___ ___ ___

   ±10 G long., +20/-10 G vert., ±9 G lat.? ___ ___ ___

   ±10 G long., +10/-5 G vert., ±18 G lat.? ___ ___ ___

3. Do the engine mounts and fittings, integral to the engine as well as the aircraft structure, have sufficient strength to remain intact until after failure of major structural supporting members? ___ ___ ___

	Yes	No	N/A
4.9.2.6 Fuel Tank Installation			
1. Are fuel tanks located above floor level and away from possible impact surfaces?	___	___	___
2. Are fuel tanks located as far from occupiable areas as reasonably possible?	___	___	___
3. Is fuel containment assured for all anticipated survivable impacts?	___	___	___
4. Is the structure that supports fuel tanks smooth and clean of projections to provide uniform support and avoid puncture?	___	___	___
5. Are frangible and self-sealing couplings used in fuel lines where relative displacements of structure may occur?	___	___	___
6. Are fuel tanks located outside the likely landing gear motion envelope?	___	___	___
7. Have checklists of Chapter 6 been referred to for fuel system design?	___	___	___
4.9.2.7 Seat and Cargo Installation			
1. Is structure around seats designed to avoid interference with seat stroking and has sufficient clearance been allowed to enable efficient seat design (see Volume III)?	___	___	___
2. Are seat and cargo attachment fittings secured through the floor to primary structural members?	___	___	___
3. Are tiedown points designed for the worst case combination of cargo weight, center-of-gravity height above the floor, and directions of loading and structural deflection?	___	___	___
4. Have checklists of Chapter 5 been referred to for seat system design?	___	___	___
4.9.2.8 Emergency Egress			
1. Has the structure surrounding emergency exits been designed for minimum distortion?	___	___	___
2. Have the egress checklists of Chapter 6 been referred to for emergency egress requirements?	___	___	___

5. AIRCRAFT SEATS, RESTRAINTS, LITTERS, AND COCKPIT/CABIN DELETHALIZATION

5.1 INTRODUCTION

This chapter summarizes the criteria for including crash resistance into the design of aircraft subsystems that interface directly with the occupants. These subsystems include restraint systems, seats, litters, cockpit controls, and padding materials. The user is referred to Volume IV for additional information concerning the criteria and their sources.

It is important to remember the basic operational difference between passenger seats and crewseats. The primary function of passenger seats and litters is to provide a place for aircraft occupants to sit or lie during their transport, while the crewseats must provide the comfort, adjustments, and features that aid crew members in accomplishing their operational responsibilities. These functional requirements obviously are of highest priority; however, crash resistance and the ability of the subsystems to help protect the occupant during crashes are also of extreme importance and can be accomplished without significant degradation of comfort and operational aspects.

5.2 PRIMARY DESIGN CONSIDERATIONS

5.2.1 General

Occupant protection and survival in aircraft accidents should be a primary consideration in the design, development, and testing of aircraft seats and litters. All operational requirements as specified in other design guides should also be met. Adequate occupant protection requires that both seats and litters be retained generally in their original positions within the aircraft throughout any survivable accident. In addition, the seat should provide an integral means of crash load attenuation, and the occupant's strike envelope should be delethalized.

Several environmental and operational factors other than those associated with crash resistance affect the design of an adequate seating system. They are very important in overall design and are discussed in Section 3.2 of Volume IV.

5.2.2 Design Conditions

The design impact conditions for light fixed- and rotary-wing aircraft are presented in Volume II and are repeated in Chapter 3, Table 2, of Volume I. All seats, restraint systems, and litters should be designed to provide the desired performance in the design crash impact conditions. It must be remembered that, to produce a truly crash-resistant design, systems analyses must consider likely combinations of loadings, including potential losses of energy-absorbing structure, such as landing gear.

5.2.3 Structural Distortion

Structural distortion of the airframe and its resulting loading of the seat must be considered in the design. A major consideration in providing crash-resistant seating systems is the possibility of a local distortion in that part of the aircraft to which the seat is attached.

In ceiling-mounted seats the efficiency of use of the available stroke distance must be considered. Energy-absorbing stroke should be provided to maximize usage of the available space, but the effective stroke of a seat considered to be rigidly attached (no energy absorbers between the seat and ceiling) to the ceiling must be considered. The ceiling may deflect downward at loads too low to make efficient use of the available stroke, a particular concern for retrofit applications to older aircraft. A systems analysis should be used to evaluate the advisability of using ceiling-mounted seats in this situation and, if so, establish the correct combination of variables.

A considerable amount of the downward motion of an aircraft ceiling may be elastic. It would be advantageous to eliminate from the occupant and ceiling-supported seat the rebound due to recovery of this elastic distortion. Consideration should be given to a device that allows vertical downward motion of the seat but restrains it from following the roof during its elastic rebound.

Adequate support of the ceiling for the applied loads with low deflections eliminates the problems mentioned above, and efficient use of ceiling-mounted seats can be achieved in aircraft with such features.

Considerations for seats mounted on the floor, bulkhead or sidewall, including requirements necessary for the attachments to survive fuselage warpage, are presented in Section 5.4.5, Joint Deformation.

5.3 DESIGN PRINCIPLES FOR SEATS AND LITTERS

5.3.1 Seating System Orientation

There are several types of Army aircraft seating systems: pilot, copilot, crew chief, gunner, observer, student, medical attendant, troop, and passenger. Cockpit seats are typically forward-facing; cabin seats may face in any direction. Many are single-place seats, but in some aircraft two-, three-, and four-occupant cabin seats are provided. A single occupant seat is the preferred configuration in order to avoid situations in which the energy-absorbing systems of multi-unit seats are rendered ineffective due to partial occupancy (insufficient weight to activate the energy-absorbing mechanisms at loads within human tolerance limits). Seats should be interchangeable.

The rearward-facing seat is optimal for providing maximum support and contact area in longitudinal impacts. The only critical impact sequence for the rearward-facing seat is one that involves a severe lateral component that allows sideward movement of the occupant prior to application of the longitudinal or vertical pulse. However, lateral torso movement can be minimized by use of a torso restraint system of much lighter weight than that required for other seat orientations. The rearward-facing cabin seat is preferred.

Those crew members required to face forward in the conduct of their duties can be afforded adequate protection by the use of a restraint system consisting of shoulder straps, a lap belt, and a lap belt tiedown strap as discussed in Section 5.7. Lap-belt-only restraint is undesirable, as noted in the human tolerance section of Volume II. If all forward-facing passengers are provided with adequate upper- and lower-torso restraint, forward-facing seats are acceptable as a second choice to rearward-facing seats. If a single, diagonal upper-torso restraint is used, it should be placed over the outboard shoulder of the occupant to provide restraint against lateral protrusion of the occupant outside the aircraft or impact with the sidewall.

Previously, many side-facing seats were provided with lap belt restraint only. Even with the addition of a shoulder harness or diagonal chest strap, the tolerance to abrupt longitudinal acceleration is less than that for any other orientation. The use of side-facing seats is least desirable for crash safety; when no reasonable alternative exists, adequate torso restraint should be provided. When a single, diagonal, upper-torso restraint is used, it should be over the forward-facing shoulder (relative to the aircraft).

5.3.2 Litter Orientation

Litters should be installed laterally when practical, to provide more positive restraint for expected combined crash forces. A lateral litter orientation also will prevent detachment of the litter from its supports, which may occur as explained in Reference 42. The litter should withstand all of the conditions previously described for seats.

5.3.3 Materials

Designers should select materials that offer the best strength-to-weight ratios while still maintaining sufficient ductility to prevent brittle failures.

The degree of ductility needed in a seat's basic structural elements is highly dependent upon whether the seat structure is designed to absorb energy by the use of a separate load-limiting device or whether large plastic deflections of the basic structure are required. As a general rule, a value of 10-percent elongation is a rough dividing line between ductile and nonductile materials. The 10-percent value is recommended as a minimum for use on all critical structural members of nonload-limited seats because the exact peak load is unpredictable due to pulse shape, dynamic response of the system, and velocity change. A minimum elongation of 5 percent in the principal loading direction is suggested for use on critical members of load-limited seats, because the loads and strains are more predictable. Also, castings are not recommended for use in primary structural load paths.

The effects of stress corrosion must be considered, as well as hydrogen embrittlement, due to heat treating or various processing steps such as pickling. In short, adherence to all the normal engineering design principles is recommended.

Flammability and toxicity retardation requirements are discussed in Chapter 6. Upholstery padding and other materials used in seats should meet the specified requirements.

5.4 STRUCTURAL CONNECTIONS

5.4.1 Bolted Connections

For the manufacture of basic aircraft structure, most aircraft companies recommend 15- and 25-percent margins of safety for shear and tensile bolts, respectively. The margin of safety for shear and tensile bolts located in load-limited portions of the seat, where loads can be predicted accurately, can be reduced to 10 and 15 percent, respectively. Also, good aircraft engineering practice dictates that bolts less than 0.25 in. in diameter should not be used in tensile applications because of the ease with which these smaller bolts can be overtorqued. Because of the obvious advantages of structure being able to distort while maintaining load-carrying ability, fasteners of maximum ductility for the application should always be selected. Where possible, fasteners such as bolts and pins should have a minimum elongation of 10 percent. A bolt loaded in shear should have a shank of sufficient length to prevent application of the shear load on the threaded portion of the bolt. For the best failure mode, bolts, pins, and joints should be designed to fail in bearing.

5.4.2 Riveted Connections

Guidelines for riveted joints are presented in MIL-HDBK-5, and it is recommended that these guidelines be followed (Reference 43).

5.4.3 Welded Connections

Welded joints can be completely acceptable and even superior to bolted or riveted joints. However, strict inspection procedures should be used to ensure that welded joints are of good quality. The cross-sectional area of the basic material in the vicinity of a welded joint should be 10 percent greater than the area needed to sustain the design load. Welding processes are discussed in Military Specifications MIL-W-8604, -6873, -45205, and -8611; these specifications should be used as guides to ensure quality welding.

5.4.4 Seat Attachment

Acceptable means of attaching seats to the cabin interior are listed below. (Refer to Section 3.3.3 of Volume IV for a discussion of ceiling-mounted seats.)

1. Suspended from the ceiling with energy absorbers and wall or bulkhead stabilized.

2. Suspended from the ceiling with energy absorbers and floor stabilized.

3. Wall or bulkhead mounted with energy absorbers.

4. Floor mounted with energy absorbers.

5. Ceiling and floor mounted (vertical energy absorbers above and below seat).

Suspension or mounting provisions for all seats should not interfere with rapid ingress or egress. Braces, legs, cables, straps, and other structures should be designed to prevent snagging or tripping. Loops should not be formed when the restraint system is in the unbuckled position. Cabin seats must often be designed so that they may be quickly removed or folded and secured. Tools should not be required for this operation. The time required by one person to disconnect each single occupant seat should not exceed

20 sec. The time required by one person to disconnect multi-occupant seats should not exceed 20 sec multiplied by the number of occupants. All foldable seats should be capable of being folded, stowed, and secured or unstowed quickly and easily by one person in a period not to exceed 20 sec multiplied by the number of occupants.

5.4.5 Joint Deformation

To prevent seat connection failures induced by fuselage distortion, structural joints should be capable of large angular displacements in all directions without failure. A floor-mounted seat designed properly for structurally integral load limiting would also satisfactorily accommodate floor buckling and warping under crash conditions. Figure 20 illustrates recommended limits of floor warping or buckling that should be withstood by all floor-mounted seat designs. The mounts should be capable of withstanding a ±10-degree warp of the floor, as well as a ±10-degree rotation about a roll axis of a single track. The angles are based on distortions that have been noted in potentially survivable accidents.

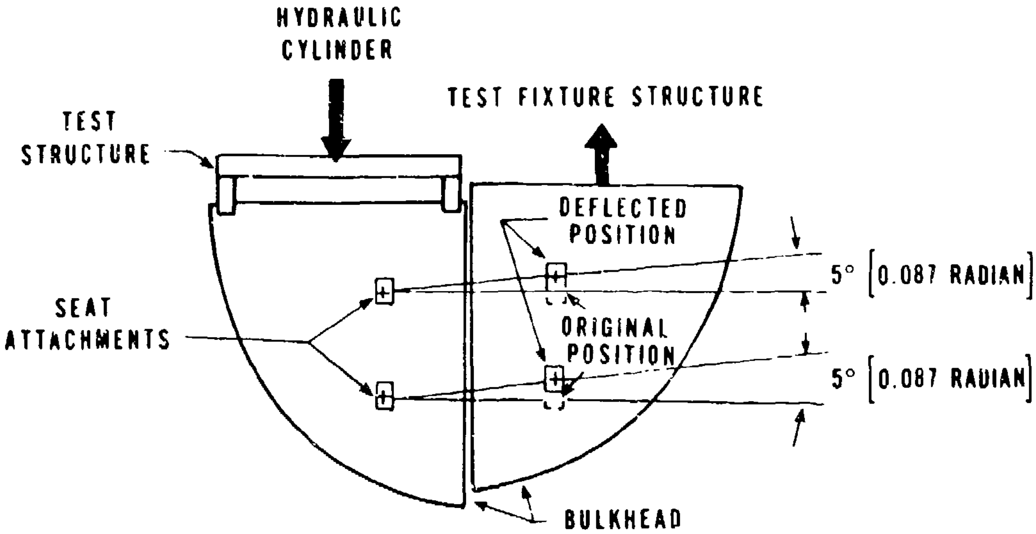
The same general principles that apply for floor-mounted seats also apply for bulkhead-mounted seats, except that the deflection and degree of warping of the bulkhead appear to be less than those of the floor. A possible bulkhead distortion configuration is shown in Figure 21. The recommended angular deflection requirement for bulkhead-mounted seats is a 5-degree rotation in the plane of the bulkhead. To accommodate local deformation, each attachment of the seat to the bulkhead should be released to permit ±10-degree rotations in any direction.

Combined sidewall-mounted and floor-mounted seats require the same considerations as bulkhead-mounted seats. The sidewalls of aircraft tend to bow outboard during impacts with high vertical loading. Therefore, it is advisable that these seats be designed to accept relatively large distortions without failure. Seats mounted to both the floor and the sidewall will require special design considerations. One way to provide the flexibility needed is to include releases such as pin joints, oriented to allow rotation around an aircraft roll axis. An example is shown in Figure 22. The attachments should be designed to permit the angle θ to reach 25 degrees at the maximum dynamic deflection. Seats that are mounted totally on the sidewall should be less of a problem.

The underfloor, bulkhead, or sidewall structure must be designed to be compatible with the seat. For example, the design of structural releases between the seat and the track may enable the seat to maintain its attachment during large floor deformations but may add to the torsional loading on the underfloor beams. If a large downward load is applied to the floor structure through a joint that does not carry moment (released), then the underfloor beams must resist any moment that may be developed without assistance from the seat structure.

5.4.6 Material

5.4.6.1 **General**. An elastic stress analysis, as used in the design of airframes and aircraft components subjected to normal flight loads, is inadequate for the study of all the structure in a crash situation. For normal flight loads, keeping the stresses well below the material yield stress to



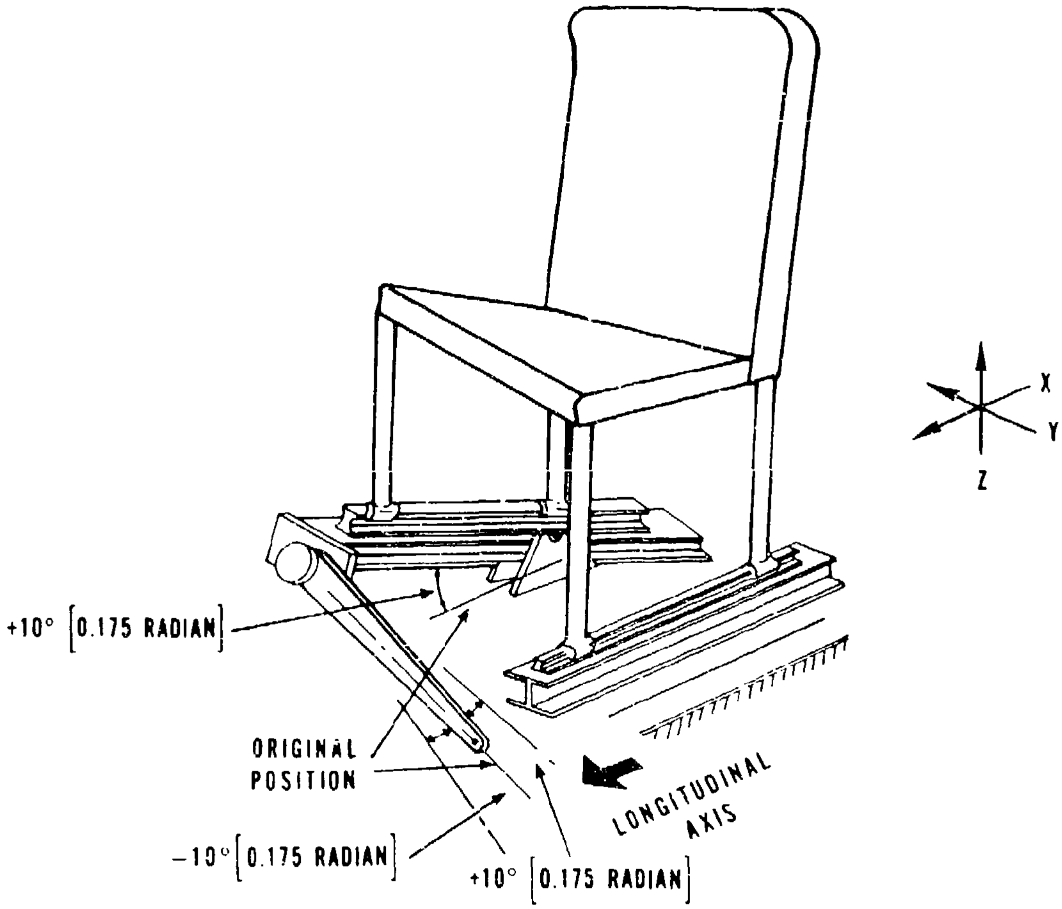


FIGURE 20. FLOOR OR BULKHEAD WARPAGE REQUIREMENT FOR STATIC LOADING OF SEAT. (REFERENCE 15)

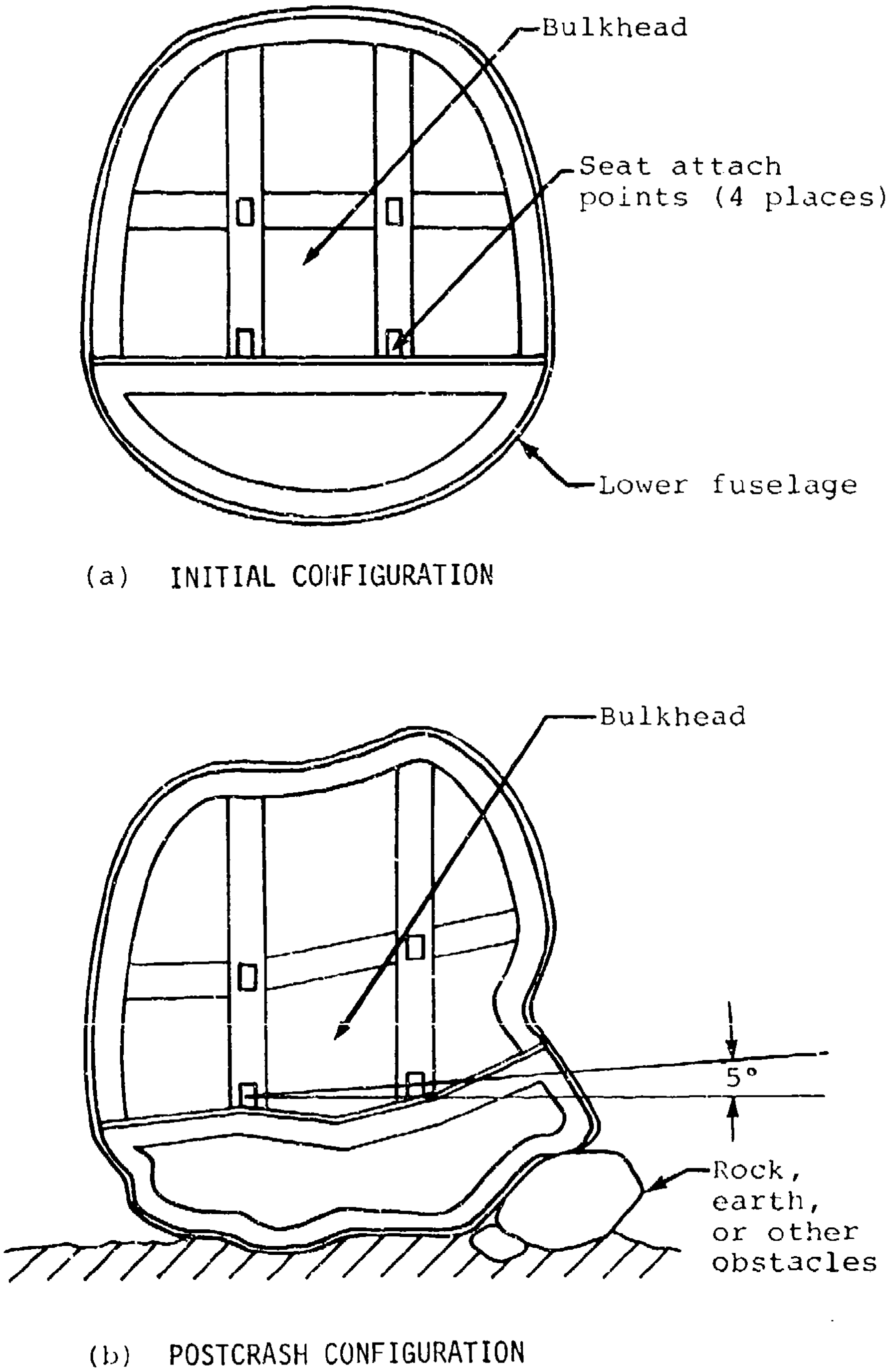


FIGURE 21. BULKHEAD IN-PLANE WARPAGE.

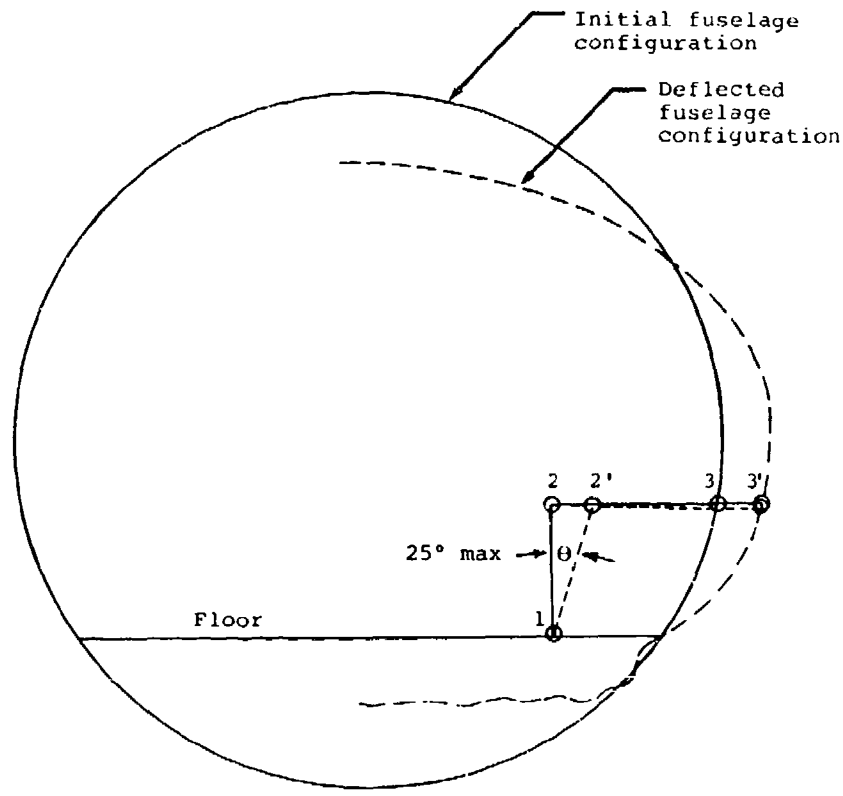


FIGURE 22. PIN JOINT RELEASES ORIENTED TO ALLOW ROTATION AROUND AN AIRCRAFT ROLL AXIS.

avoid permanent deformation is necessary because of fatigue problems and other considerations. In a crash situation, however, where only one application of the maximum load is expected, fatigue is not a factor, and the final appearance of a structural component or its subsequent operational use need not be considered. Consequently, the load-carrying capacity of components deformed beyond the elastic limit should be considered in determining the ultimate seat strength. For certain items in the load path it is advisable to use the rupture strength as listed for many materials in MIL-HDBK-5 (Reference 43). The concepts of limit analysis or, in some circumstances, large deformation analysis may be employed to make the best use of materials in certain components.

5.4.6.2 Limit Analysis Concepts. Where ductile materials are used, strain concentrations do not produce rupture prior to significant plastic deformation. If the geometric configuration of the structure permits only small elastic deflections, a "rigid-plastic" mathematical model may be used. This permits the use of a limit analysis, which assumes no deformation of structure until sufficient plastic hinges, plastic extensors, etc., exist to permit a geometrically admissible collapse mode.

Limit analysis is concerned with finding the critical load sufficient to cause plastic collapse with the physical requirements of static equilibrium, yield condition for the materials, and consistent geometry considerations.

Two useful principles are mentioned here: the upper and lower bound theorems. The upper bound theorem for the limit load (collapse load for a "rigid-plastic" structure) states that the load associated with the energy dissipated in plastic deformation will form an upper bound for the limit load. The lower bound theorem states that the load associated with a statically admissible stress distribution, which at no point exceeds the yield conditions, forms a lower bound for the limit load. Use of the upper and lower bound theorems to bracket the limit load for a given structure makes it possible to obtain a realistic evaluation of the structure's load-carrying capacity.

5.4.6.3 Large Deformation Analysis. If a structure contains elements that will permit large, stable elastic deformations when under load, the equilibrium of the deformed state must be considered in evaluating ultimate strength. For example, if a suitable attachment is made to a thin, flat sheet rigidly fixed at the edges so as to load the sheet normal to the surface, a diaphragming action will occur. The equilibrium and stress-strain (elastic-plastic) relations for the deformed state would determine the load-carrying capacity. An example of this situation is a seat pan in which membrane rather than flexural stresses are important.

5.4.6.4 Strain Concentrations. Handbook stress concentration factors will provide sufficiently accurate data to allow the designer to modify the structure in the vicinity of stress concentrations. When large deformations at high load-carrying capacity are desired, as in energy-absorbing seats, these areas frequently become strain concentration points, and rupture occurs due to excessive strain in areas with little deformation and energy input. Large amounts of energy can be absorbed in the structure only if large volumes of material are strained uniformly.

5.4.7 Restraint System Anchorage

The seat designer should consider the effect of the anchorage of the restraint system on the characteristics of the seat design. If possible, the restraint system should be anchored to the seat rather than to basic aircraft structure.

If the harness is anchored to basic aircraft structure, a desirable reduction of loads on the seat frame results; however, the restraint system must be designed to permit the energy-absorbing deformation of the seat during an impact. For example, if a load-limited seat strokes vertically and the seat belt is anchored to the floor, loosening of the belt permits the occupant to either submarine or move laterally under the belt. When the harness is anchored to the seat structure, the problem of maintaining a tight harness is reduced.

5.5 ENERGY-ABSORBING DEVICES

The seat structure, in order to perform its intended retention function, should possess either (1) the capability of sustaining, without collapsing, the maximum inertial forces imposed by the deceleration of the occupant and the seat or (2) sufficient energy-absorption capacity to reduce the occupant's relative velocity to zero before structural failure occurs.* The first alternative may result in an excessive strength requirement because the input pulse shape and the restraint system and cushion elasticity can result in a large dynamic overshoot. Computer simulation and experimental investigation have shown that overshoot factors range from 1.2 to 2.0. This would necessitate a seat design strength requirement of 24 G to 40 G to accommodate an input floor pulse of 20 G.

The second alternative of using collapse behavior (load limiting) appears to offer the more practical approach to most seat design situations. With this option, the seat structure would begin plastic deformation when the acceleration of the occupant and seat mass reaches a level corresponding to the critical structural load; the seat should absorb enough energy without failure to stop the motion of the occupant relative to the aircraft. This energy should be absorbed at force levels within human tolerance limits to provide the intended protective function. The energy can be absorbed either by plastic deformation of basic aircraft structure or by the introduction of mechanical load-limiting devices. Energy-absorbing motion of the seat can be provided in all three directions as well as for all combinations of directions; however, it is absolutely necessary for the vertical direction. A properly restrained occupant can withstand the loads associated with the design crash impact conditions in the longitudinal (x) and lateral (y) directions but cannot sustain the loads in the vertical (z) direction without injury. Therefore, the requirement for load reduction through use of energy-absorption devices is mandatory for the vertical direction.

Energy-absorbing mechanisms in aircraft structures which transmit crash forces to the occupant should stroke at loads tolerable to humans and should provide stroke distances consistent with these loads and with the energy to be absorbed. Desirable features of energy absorbers are as follows:

- The device should require a constant, predictable stroking force.
- The rapid loading rate expected in crashes should not cause unexpected changes in the force-versus-deformation characteristic of the device.
- The device should resist loads in the opposite direction to the stroking (rebound) or be able to stroke in either direction.
- The assembly in which the device is used should have the ability to sustain tension and compression. (This might be provided by one or more energy absorbers, or by the basic structure itself.)
- The device should be as light and small as possible.
- The specific energy absorption (SEA) should be high.
- The device should be economical.

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*The term "failure" implies a rupture of restraint linkage, while the term "collapse" pertains to a state of active deformation with restraint integrity maintained.

- The device should be capable of being relied upon to perform satisfactorily throughout the life of the aircraft (a minimum of 10 years or 8000 flight hours) without requiring maintenance.

- The device should be easily replaceable.

- The device should not be affected by vibration, dust, dirt, heat, cold, or other environmental effects. It should be protected from corrosion.

- The device(s) should decelerate the occupant in the most efficient manner possible while maintaining the loading conditions within the limits of human tolerance. A multiple-limit-load device, adjustable for occupant weight, is desirable.

5.6 SEAT CUSHIONS

5.6.1 General

The seat bottom and back cushions with which the occupant is in constant contact should be designed for comfort and durability. Sufficient cushion thickness of the appropriate material stiffness should be provided to preclude body contact with the seat structure when subjected to either the specified operational or crash loads. Seat bottoms made of fabric diaphragms should have adequate clearance to prevent contact between the occupant and the seat structure and should be provided with means of tightening to compensate for sagging during use.

For seat cushions, the problem is one of developing a compromise design that will provide both acceptable comfort and safety. The optimum aircraft seat cushion should:

- Be lightweight.

- Possess flotation capabilities.

- Be nonflammable.

- Be nontoxic; not give off fumes when burned, charred, or melted.

- Be tough and wear resistant.

- Be easily changeable.

- Provide comfort by distributing the load and reducing or eliminating load concentrations.

- Provide thermal comfort through ventilation.

- Provide little or no rebound under crash loading.

- Minimize motion during crash loading.

5.6.2 Requirements

For seats of light movable weight (less than 30 lb), cushions should be comfortable with a maximum uncompressed thickness of 1-1/2 in., unless it can be shown through analysis or through dynamic tests that the cushion design and material properties produce a beneficial (reduced force transmissibility) result.

For seats of greater movable weight, such as integrally armored seats, every effort should be made to design a cushion that minimizes relative motion between the occupant and the seat and that acts as a shock damper between the occupant and the heavy seat mass. Again, dynamic analysis and/or testing should be conducted to demonstrate that the cushion design produces a desirable system result over the operational and crash impact conditions of interest. In both lightweight and heavyweight seats the cushion should be as thin as possible (without being uncomfortable) in order to minimize submarining.

5.6.3 Energy-Absorbing Cushions

The use of load-limiting cushions in lieu of load-limiting seats is undesirable. The only justifiable use of energy-absorbing cushions instead of load-limited seats might be in retrofit circumstances where, because of limitations in existing aircraft, another alternative does not exist.

5.6.4 Net-Type Cushions

This type of cushion serves the same purpose as the filled cushion; however, a net material is stretched over a contoured seat frame, and the body is supported by diaphragm action in the net rather than by deformation of a compressible material. The net-type cushion might more properly be called a net support. If a net support is used in the seat, its rebound characteristics should be capable of limiting the return movement from the point of maximum deformation to 1-1/2 in. Net supports should not increase the probability of occupant submarining or dynamic overshoot.

5.6.5 Seat Back Cushions

The back cushion should be of a lightweight foam material or net. The foam can be a standard furniture type that meets the other requirements listed in Section 5.6.2. Lumbar supports, particularly those that are adjustable by the occupant, are desirable for comfort and because a firm lumbar support that holds the lumbar spine forward increases the tolerance to $+G_z$ loading.

5.6.6 Headrests

A headrest should be provided for occupant head/neck whiplash protection. Headrest cushions are used only to cushion head impact and prevent whiplash injury due to backward flexure of the neck. The cushioning effect can be provided by a thin pad and a deformable headrest or a thicker cushion on a more rigid headrest. For a rigid headrest, the provisions of Section 5.13.10 should be applied, and at least 1.5 in. of cushion is desirable. If the space limitations of the application prohibit this thickness, the cushion should be at least 1 in. thick for compliance with MIL-S-58095.

5.7 DESIGN PRINCIPLES FOR PERSONNEL RESTRAINT SYSTEMS

5.7.1 General

Restraint harnesses for personnel should provide the restraint necessary to prevent injuries to all aircraft occupants in crash conditions approaching the upper limits of survivability. Appropriate strength analysis and tests as described in Section 5.9 should be conducted to ensure that a restraint system is acceptable. Qualities that a harness should possess are listed below:

- It should be comfortable and light in weight.
- It should be easy for the occupant to put on and take off even in the dark.
- It should contain a single-point release system, easy to operate with one (either) hand since a debilitated person might have difficulty in releasing more than one buckle with a specific hand. Also, it should be protected from inadvertent release, e.g., caused by the buckle being struck by the cyclic control or by inertial loading.
- It should provide personnel with freedom of movement to operate the aircraft controls. This requirement necessitates the use of an inertia reel in conjunction with the shoulder harness.
- It should provide sufficient restraint in all directions to prevent injury due to decelerative forces in a survivable crash.
- The webbing should provide a maximum area, consistent with weight and comfort, for force distribution in the upper torso and pelvic regions and should be of low elongation under load to minimize dynamic overshoot.

5.7.2 Types of Systems

5.7.2.1 Aircrew Systems. The existing military lap belt and shoulder harness configuration with a center tiedown strap as shown in Figure 23 should be used by U. S. Army pilots. The configuration shown in Figure 24 is preferred because it provides improved lateral restraint due to the addition of the reflected shoulder straps. This system resulted from the investigation reported in Reference 44. Details of the hardware in these systems are presented in Section 7.5 of Volume IV.

5.7.2.2 Troop Systems. Considerations in the selection of a troop or passenger seat restraint system are different from those for an aircrew system. First of all, the seat may face forward, sideward, or aftward. Secondly, the restraint system must be capable of being attached and removed quickly in an operational environment by troops encumbered by varying types and quantities of equipment. Also, whereas a pilot probably uses the restraint system in his aircraft so frequently that its use becomes a matter of habit, troops and passengers are often unfamiliar with the system. The effects of this lack of familiarity would probably become more pronounced in a combat situation when

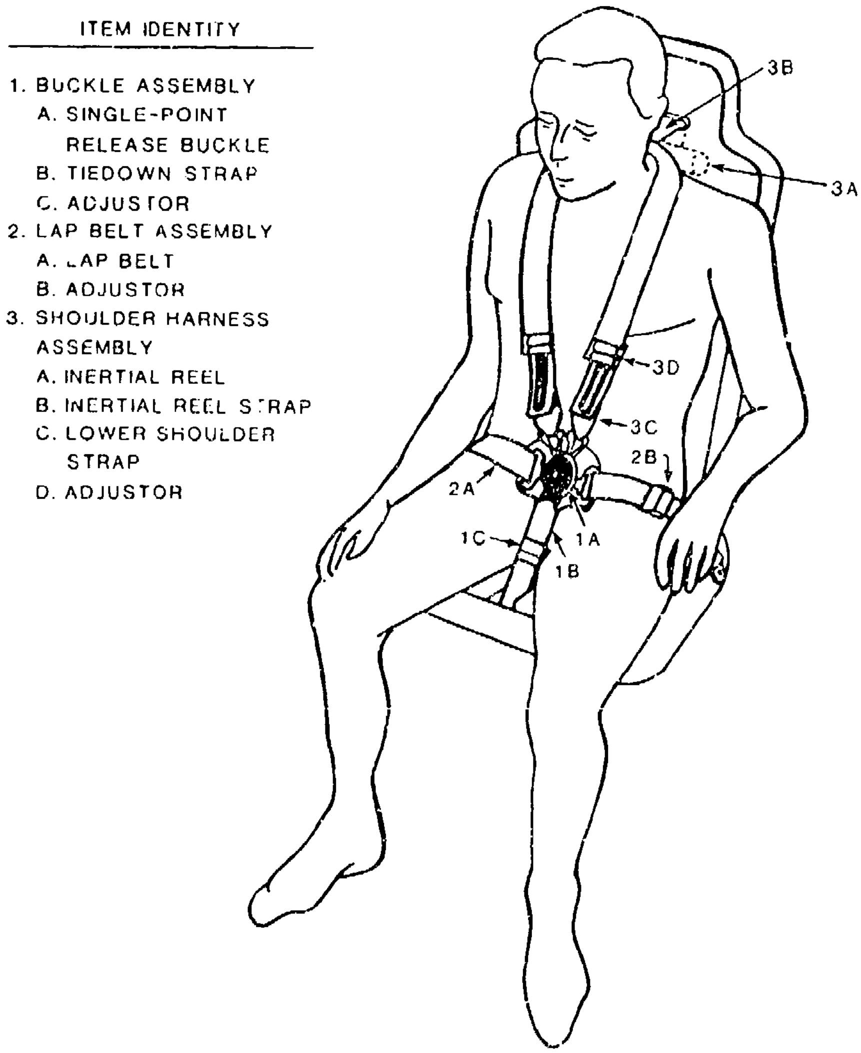


FIGURE 23. BASIC AIRCREW RESTRAINT SYSTEM. (REFERENCE 15)

the risk involved in not using the restraint system becomes even higher. Therefore, hardware should be uncomplicated and, if possible, resemble the familiar, such as automobile restraints.

Two systems that resulted from the investigation reported in Reference 45 are shown in Figure 25. The Type II troop restraint system is preferred and consists of a two strap shoulder harness and a lap belt assembly. The two shoulder straps are attached to two single inertia reels. They extend forward and down over the occupant's upper torso and are connected into the single point release, lift lever buckle. The lap belt assembly includes left and right-hand belts, with adjusters, that are connected together at the lap belt buckle. The Type I troop restraint system is acceptable and

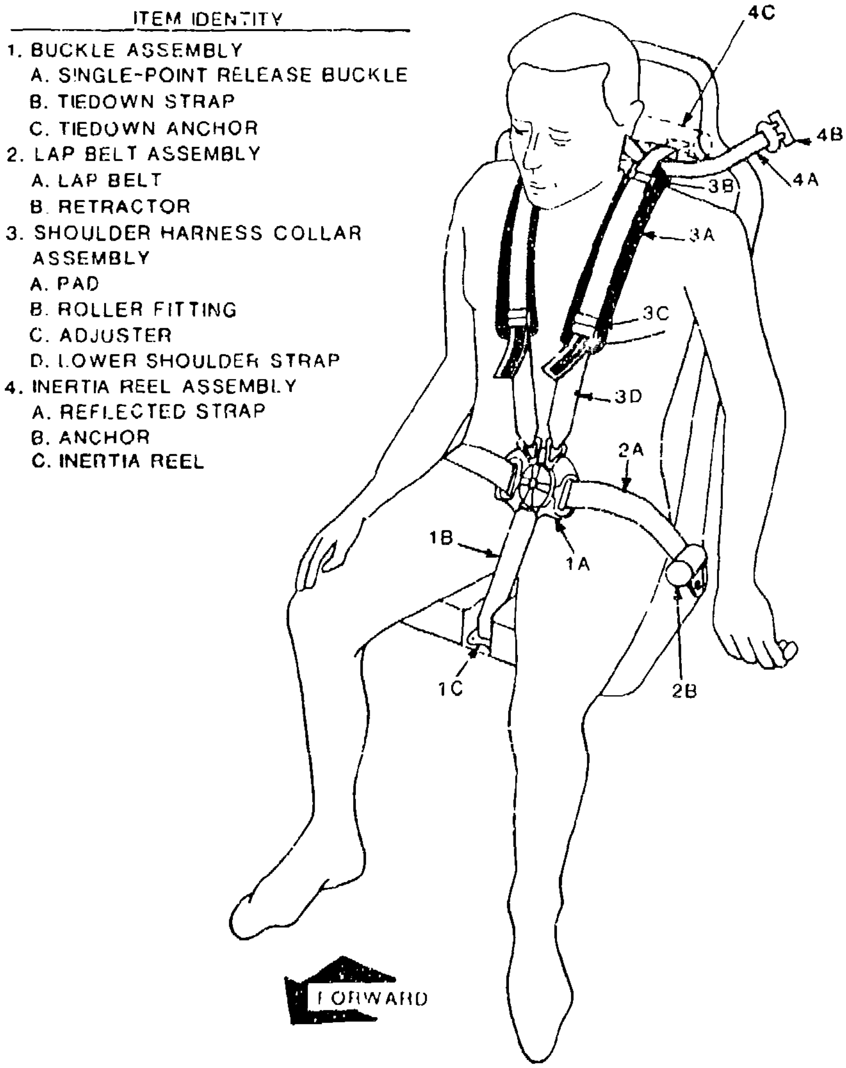


FIGURE 24. AIRCREW RESTRAINT SYSTEM, INCLUDING REFLECTED SHOULDER STRAPS.

differs from the Type II restraint by having a single shoulder strap that passes diagonally across the occupant's upper torso. For side-facing seat, it should pass over the shoulder closest to the nose of the aircraft. If the Type I system is used in either a forward or aft facing seat, the diagonal shoulder strap should pass over the outboard shoulder to restrain the occupant from protruding outside the aircraft during lateral loading.

6.7.2.3 Crew Chief and Door/Window Gunner Systems. Restraint systems for crew chiefs and door/window gunners are similar to troop systems; however, they must allow the crewmember to move out of the seat to perform duties such as maneuvering the gun or observing tail rotor clearance while landing in unprepared areas. The system should restrain the occupant to the

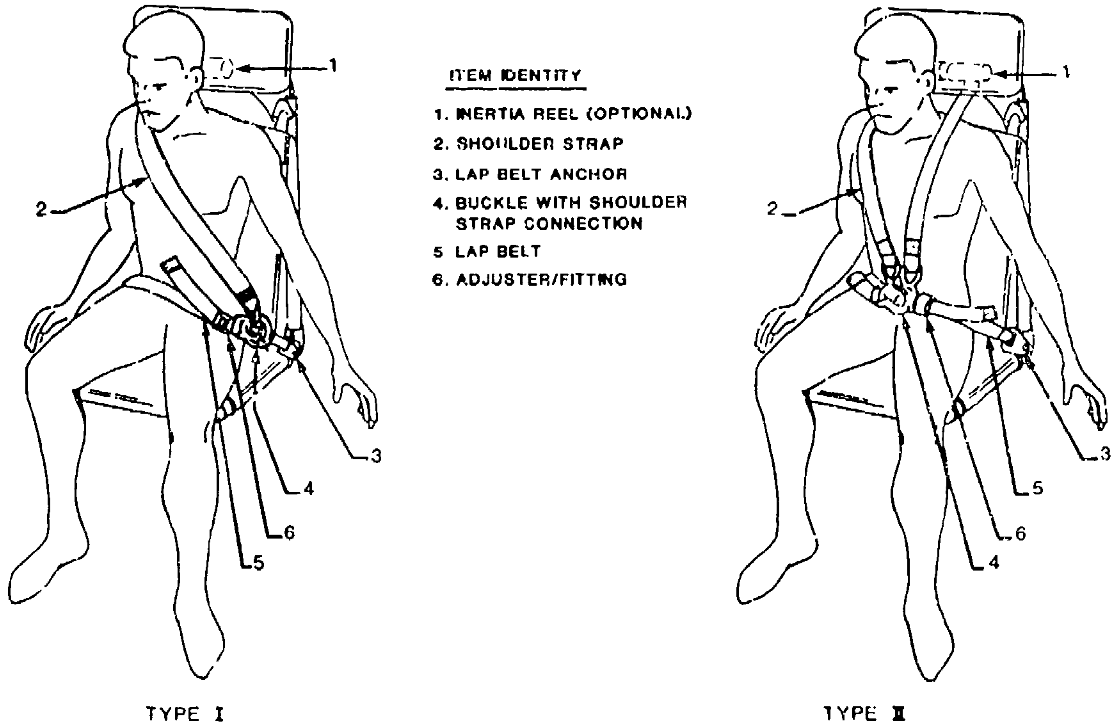


FIGURE 25. AIRCRAFT TROOP/PASSENGER RESTRAINT SYSTEMS.

seat the instant he returns to the seat and provide adequate restraint during a crash. The system should maintain the lap belt buckle in the proper relationship to the gunner, preventing the shoulder straps from pulling it up or the lap belt from pulling it sideways. Such a system has been described in Reference 46 and is shown in Figure 26. It consists of a lap belt with inertia reels on each side of the seat and two shoulder straps connected in an inverted Y arrangement to a single inertia reel strap. The lap belt with thigh strap attachment is easy to put on and prevents the lap belt from riding up during operation of the gun. The lap belt is plugged into the two seat pan inertia reels when the crewmember is to be seated or is standing in front of the seat. The shoulder harness and lap belt with thigh straps may serve as a "monkey harness" when the crewmember disconnects the two lap belt plug in fittings from the inertia reels. The resultant configuration permits the crewmember more extensive travel within the cabin while still being connected to the shoulder harness inertia reel, thereby restraining the crew member from falling out of the aircraft.

5.7.2.4 Inflatable Systems. An automatically inflatable body and head restraint system (IBAHRS) for helicopter crewmen has been jointly developed and tested by the Naval Air Development Center and the Aviation Applied Technology Directorate. As illustrated in Figure 27, this system provides increased crash protection because it provides automatic pretensioning that forces the occupant back in his seat, thereby reducing dynamic overshoot and reducing strap loading on the wearer when the inflated restraint is compressed during

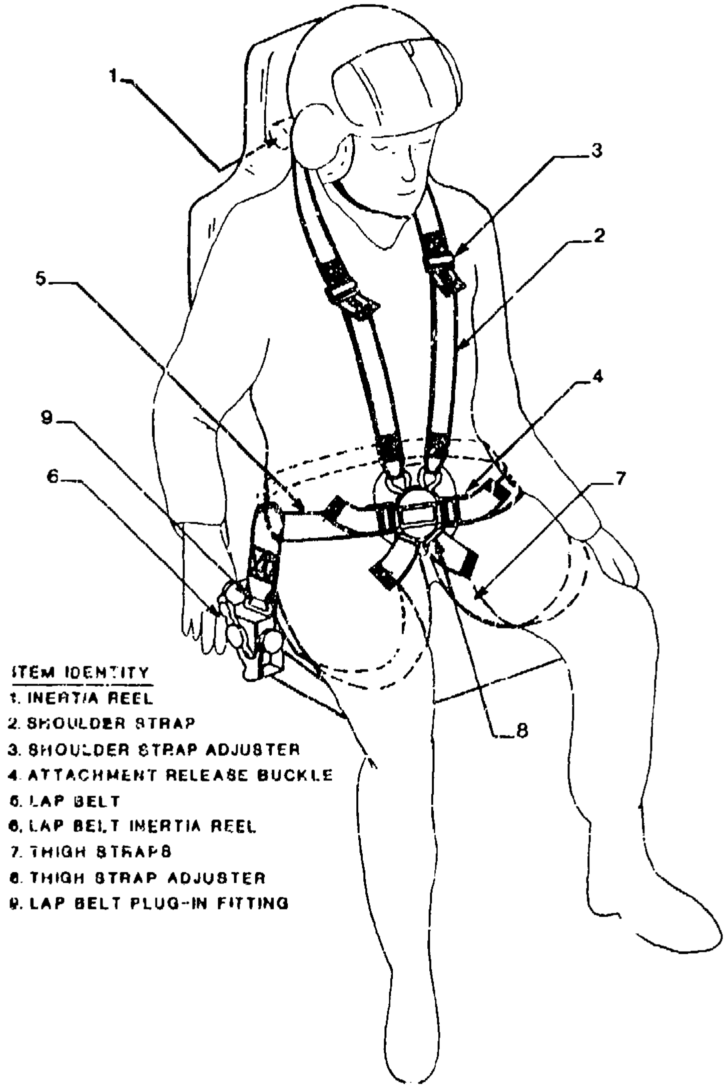


FIGURE 26. GUNNER RESTRAINT SYSTEM. (REDRAWN FROM REFERENCE 46)

the crash. The concentration of strap loads on the body is reduced because of the increased bearing surface provided by the inflated restraint, and both head rotation and the possibility of whiplash induced trauma are also reduced.

Although more complex and costly than conventional restraint systems, such a system may be justified because of its potential for improved occupant protection. Development of the system and results of testing are documented in References 47 and 48.

6.7.3 General Design Criteria

6.7.3.1 Comfort. For obvious reasons, comfort must not be compromised by crash survival requirements. The main comfort consideration for restraint harnesses is the absence of rigid hardware located over bony portions of the

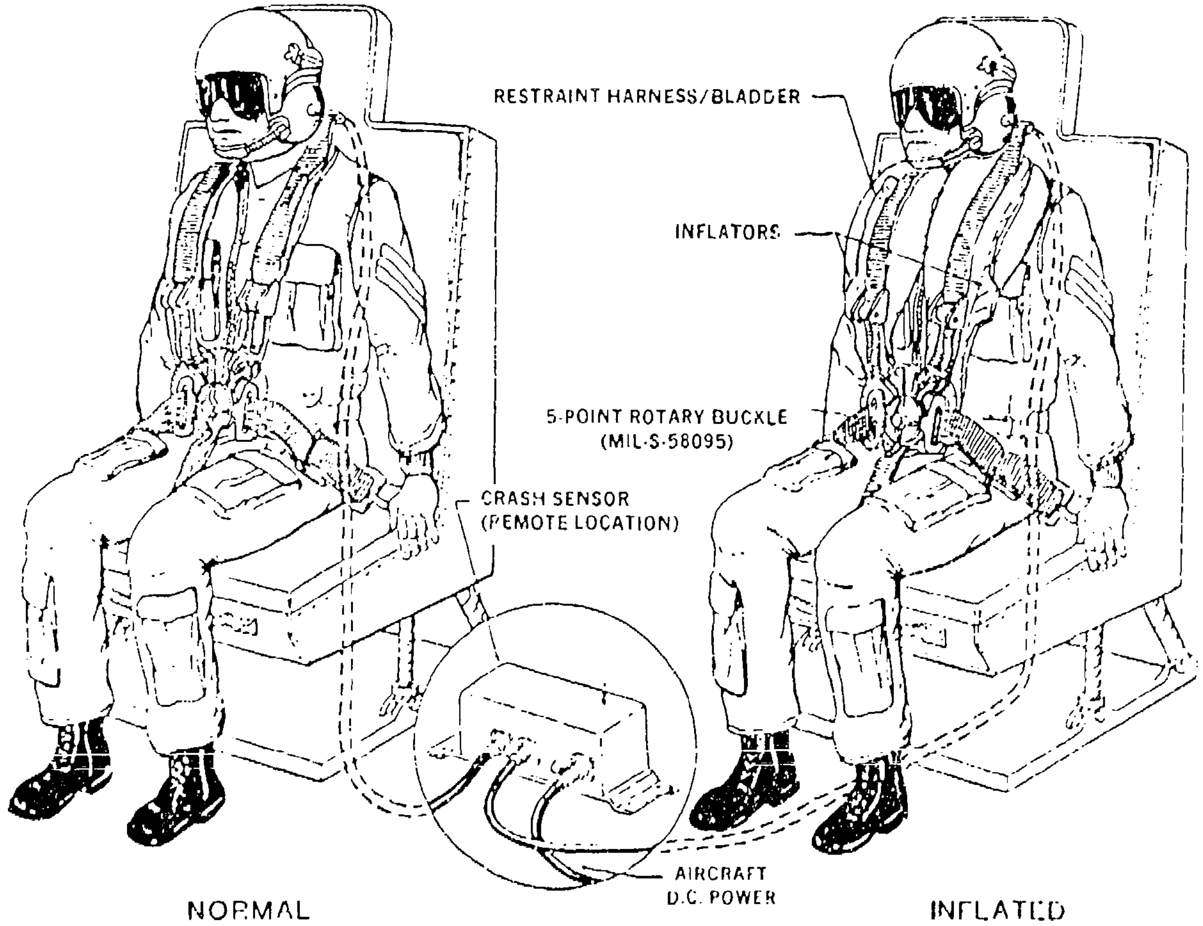


FIGURE 27. INFLATABLE BODY AND HEAD RESTRAINT.
(REFERENCE 47)

torso. Also, hardware assemblages that are too wide or large, or are not configured efficiently to fit the desired location on the body, could be uncomfortable. Webbing that is too wide or too stiff could also cause discomfort through creasing of the webbing or perspiration due to reduced ventilation.

5.7.3.2 Emergency Release Requirements. A shoulder harness/lap belt combination should have a single point of release that can be operated by either hand so that debilitated occupants can quickly free themselves from their restraint because of the dangers of postcrash fire or sinking. However, vibration, decelerative loading, or contact with the occupant or aircraft controls should not inadvertently open the buckle, and the intentional release of the restraint harness with only one finger should require at least 5 lb (22.25 newtons) of force. Further, the release should be possible with the occupant hanging inverted in the restraint system after experiencing a severe survivable crash. The force required to release the system with a 250 lb (114 kg) occupant inverted in a crash should not exceed 50 lb (222.5 newtons).

In restraint systems other than the Type I of Figure 25, if a lift latch or similar type buckle is used, the restraint system design should ensure that the latch lifts from left to right on all installations. This will reduce the possibility of reverse installations and the resulting confusion.

The release buckle should either have the capability to withstand the bending moments associated with deflections and motions during loading, or it should contain features that allow the fittings to align themselves with the loads, thereby reducing or eliminating the moments. If belt loading direction is such as to cause the strap to bunch up in the end of a slot, failure can occur through initiation of edge tear. The fitting and motion angles illustrated in Figure 28 are recommended.

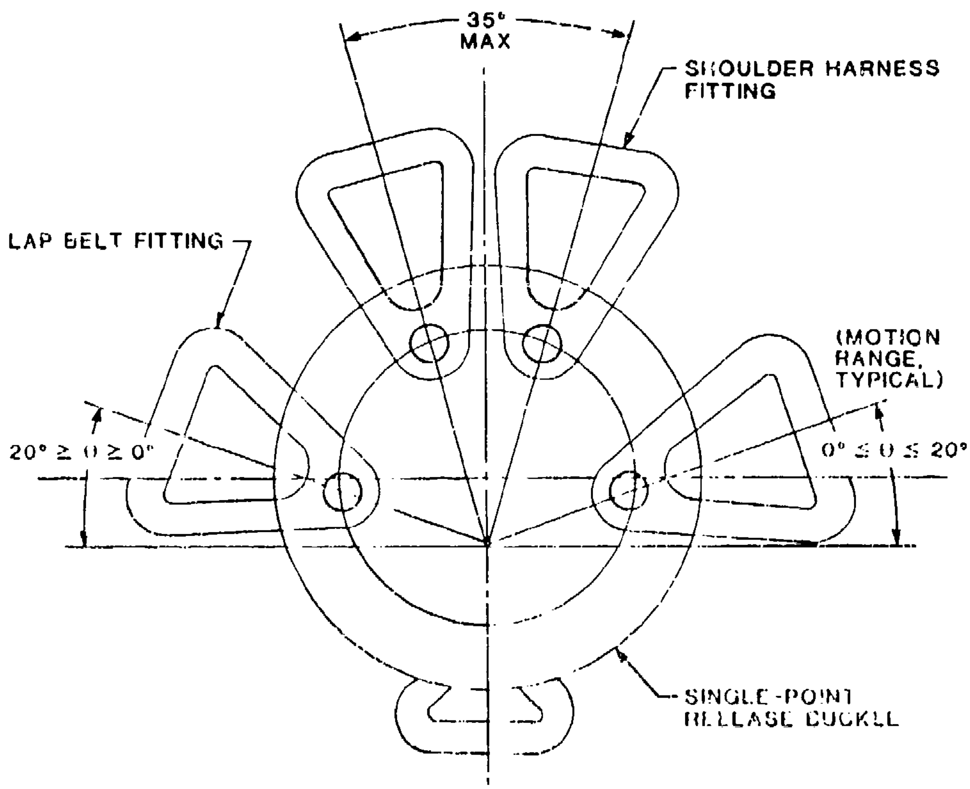


FIGURE 28. BUCKLE FITTING ATTACHMENT AND MOTION ANGLES.

If the integrity of the attachment of the fitting within the buckle can be compromised by rotation, then rotation should be completely eliminated. Eliminating fitting rotation in the flat plane of the buckle during loading may prove to be difficult in lightweight systems. Experience has shown that it is better to design the attachment of the fitting within the buckle to be insensitive to rotation than to rely on restraining the fitting against rotation. For example, a round pin in a round hole would be preferable to a flat-faced dog which must seat on a flat face of a slot. In the latter case, a small amount of rotation can cause point loading of a corner of the dog against one end of the slot. The point loading can easily increase the stress applied at the contact point to its ultimate bearing strength, which results in deformation and the formation of a sloped surface which can act to cam open the attachment mechanism.

Further, the release mechanism (buckle) should be protected against accidental opening. Neither decelerative loading of components nor contact with aircraft controls, such as helicopter cyclic sticks, should open the device. Required cockpit dimensions should be reviewed. It appears that the occupant can be placed too close to the cyclic control in helicopters and that a fully retracted cyclic head can contact the buckle. The buckle release mechanism should be protected against inadvertent release either during operation or in a crash. It should be emphasized that, if contact between the cyclic control and the buckle is possible in an operational mode, a considerable overlap can exist during crash loading when the restraint system may be deformed forward several inches.

5.7.3.3 Lap Belt Anchorage. The actual anchorage point for the lap belt may be located either on the seat bucket or on the basic aircraft structure, although it is usually desirable to locate it on the seat. If the anchorage is located on the basic aircraft structure, consideration should be given to the movement of the seat when load-limiting means are used so that the lap belt restraint remains effective regardless of seat position. Longitudinal load limiting of the seat serves little purpose if the lap belt is attached to the basic structure; therefore, the belt should be attached to the seat bucket itself.

The lap belt should be anchored to provide optimum restraint for the lower torso when subjected to eyeballs-out ($-G_x$) forces. One of the anchorage variables which has an influence on restraint optimization is the location of the lap belt anchorage in the fore-and-aft direction. The important characteristic is the angle in a vertical fore-and-aft plane between a projection of the lap belt centerline and the buttock reference line, or plane. This angle defines the geometrical relationship between the longitudinal and vertical components of the belt load. A small angle provides an efficient path for supporting longitudinal loads while a large angle provides an efficient system for supporting vertical loads. Thus, for supporting large forward-directed loads, a small angle would be desirable, but for reacting the large vertical loads imposed on the lap belt by the loaded shoulder harness a large angle is required. The compromise for location of the anchorage must consider all the variables including the tendency for the occupant to submarine under the lap belt.

A properly designed restraint system should not allow submarining to occur, but an efficient angle should be maintained to limit the forward motion of the occupant.

Comfort is another concern in lap belt anchor location. A pilot must raise and lower his thighs during operation of rudder or antitorque pedals. If the lap belt anchor is too far forward, the lap belt will pass over the pilot's thighs forward of the crease between the thighs and the pelvis and thus interfere with vertical leg motion. It is important, therefore, to position the lap belt anchorage so that it provides optimum restraint while not interfering with the pilot's operational tasks. A more forward location of the anchor point does not reduce the comfort of passengers, since they do not perform such tasks.

In order to satisfy comfort and crash safety requirements, the vertical angle between the lap belt centerline and the buttock reference line as installed on the 50th-percentile occupant should not be less than 45 degrees and should not exceed 55 degrees, as shown in Figure 29. Further, it is desirable to locate the anchor point at or below the buttock reference line to maximize comfort and performance. If the anchor point must be located above the buttock reference line, as on most armored seats, the anchor point should be positioned to ensure that the belt angle lies within the desired 45- to 55-degree range. For a system having a lap belt tiedown strap to counteract the upward force of the shoulder harness (e.g., in pilot seats), the lap belt anchors should be positioned so that the centerline of the lap belt passes through the seat reference point. If the restraint system does not have a tiedown strap (e.g., in passenger seats), the lap belt anchor should be positioned so that the belt centerline passes through the buttock reference line 1.5 to 2.0 in. forward of the seat reference point. This position provides sufficient vertical load to counteract the upward force of the shoulder straps.

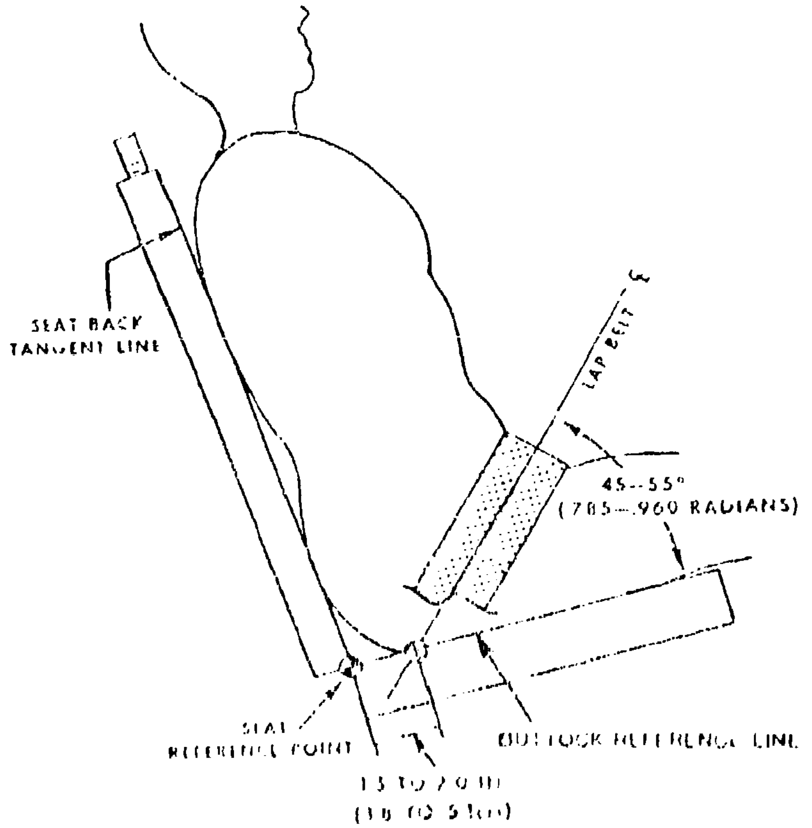


FIGURE 29. LAP BELT ANCHORAGE GEOMETRY. (REFERENCE 15)

For anchors that do not fall on the buttock reference line, the angle between the lap belt centerline and the buttock reference line should be 45 degrees for systems with tiedown straps and 55 degrees for those without.

For seats that limit lateral motion of the occupant with structure, such as in armored seats, the anchorage point and hardware should possess sufficient flexibility and strength to sustain design belt loads when the belt is deflected laterally toward the center of the seat through an angle of up to 60 degrees from a vertical position. The side motion of fittings on other seats should also be capable of supporting design loads with the lap belt deflected laterally away from the center of the seat through an angle up to 45 degrees from the vertical. These recommendations are made to ensure that lateral loading on the torso will not result in lap belt anchorage failure.

5.7.3.4 <u>Shoulder Harness Anchorage</u>. The shoulder harness or inertia reel anchorage can be located either on the seat back structure or on the basic aircraft structure, although it is usually more desirable to locate it on the seat. In placing the inertia reel, strap routing and possible reel interference with structure during seat adjustment or energy-absorbing stroke of the seat must be considered. Locating the anchorage on the basic aircraft structure may be the only practical approach for improving crash resistance in light aircraft, particularly in retrofit applications. It will relieve a large portion of the overturning moment applied to the seat under longitudinal loading. However, due consideration must be given to the effect of seat bucket movement in load-limited seats. Vertical movement of the seat can be accommodated by placing the inertia reel a sufficient distance aft of the seat back shoulder strap guide so that seat vertical movement will change the horizontal position and the angle of the straps very little.

Shoulder straps should pass over the shoulders in a plane perpendicular to the back tangent line or at any upward (from shoulders to pull-off point) angle not to exceed 30 degrees, as illustrated in the upper-left sketch in Figure 30. A shoulder harness pull-off point should be at least 26.5 in. above the buttock reference line; however, this dimension should not be increased, because then the harness would not provide adequate restraint for the shorter occupant.

The shoulder harness anchorage or guide at the top of the seat back should permit no more than 0.5 in. lateral movement (slot no more than 0.5 in. wider than strap) to ensure that the seat occupant is properly restrained laterally. The guide should provide smooth transitions to the slot. The transition contour should be of a radius no less than 0.25 in. and should extend completely around the periphery of the slot to minimize edge wear on the strap and reduce the possibility of webbing failure due to contact with sharp edges under high loading. Also, the guide that the strap loads should be sufficiently stiff to limit deflection under load. Excessive deflection can produce edge loading and cause premature failure of the webbing.

5.7.3.5 <u>Lap Belt Tiedown Strap Anchorage</u>. A lap belt tiedown strap is recommended for forward facing crewmembers. The tiedown strap anchorage point should be located on the seat pan centerline at a point 14 to 15 in. forward of the seat back. For shorter seat pans, the anchor must be placed as far forward as possible.

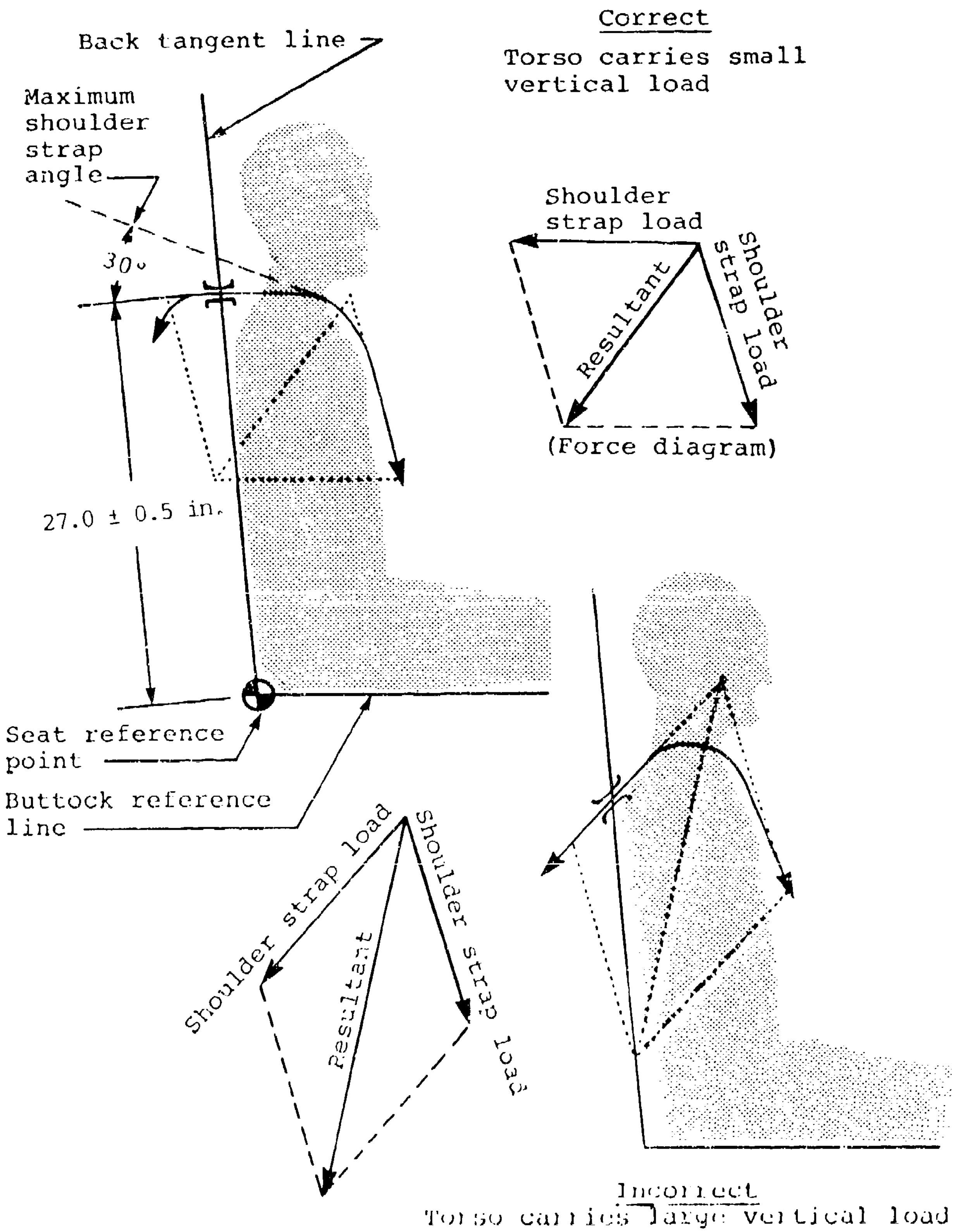


FIGURE 30. SHOULDER HARNESS ANCHORAGE GEOMETRY.

5.7.3.6 Adjustment Hardware. Adjusters should carry the full design load of their restraint system subassembly without slipping, crushing, or cutting the webbing. In extremely highly loaded applications, this may require that the strap be double-reeved in a manner that allows the adjuster to carry only one half of the strap assembly load. The force required to adjust the length of webbing should not exceed 30 lb in accordance with existing military requirements for harnesses. Insofar as possible, all adjustments should be easily made with one (either) hand. Adjustment motions should be toward the single-point release buckle to tighten and away from the buckle to slacken the belts.

5.7.3.7 Location of Adjustment and Release Hardware. Adjusters should not be located directly over hard points of the skeletal structure, such as the iliac crests of the pelvis or the collarbones. The lap belt adjuster should be located either at the center of the belt near the release buckle or at the side of the hips below the iliac crests, preferably the latter. The shoulder strap adjusters should be located as low on the chest as possible.

5.7.3.8 Webbing Width and Thickness Requirements. Webbing requirements are discussed in detail in Section 5.7.4.

5.7.3.9 Hardware Materials. All materials used for the attachment of webbing (release buckles, anchorages, and length adjusters) should be ductile enough to deform locally, particularly at stress concentration points. A minimum elongation value of 10 percent (as determined by standard tensile test specimens) is recommended for all metal harness-fitting materials. There are obviously some components that, for operational purposes, rely on hardness. These components should be designed to perform their necessary function but be made from materials as nearly as possible immune to brittle failures.

5.7.3.10 Structural Connections

5.7.3.10.1 Bolted Connections. The safety margins for shear and tensile bolts in restraint systems should be 5 and 10 percent, respectively. Also, bolts less than 0.25 in. in diameter should not be used in tensile applications. Wherever possible the bolts should be designed for shear rather than tension. Because of the vibration environment in which seats operate, all fasteners that affect the structural integrity should be self-locking or lock-wired.

5.7.3.10.2 Riveted Connections. The guidelines presented in MIL-HDBK-5 (Reference 43) are recommended for restraint system hardware design.

5.7.3.10.3 Welded Connections. Acceptable welding processes are discussed in Military Specifications MIL-W 8604, -6873, -45205, and -8611; however, strict inspection procedures should be used to ensure that all welded joints are of adequate quality. (Other provisions presented in Section 5.4.3 also apply.)

5.7.3.10.4 Plastic Strength Analysis. Plastic analysis methods should be used for strength determination wherever applicable in order to obtain maximum strength hardware at the lowest possible weight.

5.7.4 Webbing and Attachments

5.7.4.1 **Properties**. The main advantage of a single-strength harness (only one restraint harness in the inventory) would be the assurance that harnesses could be interchanged between load-limited seats and nonload-limited seats without fear that an understrength harness might be installed on a nonload-limited seat. On this premise, the design strength of all forward-facing and side-facing restraint harnesses should be equal. The design loads for the various harness components attached to the seat are listed in Table 9. The elongation of all webbing used in the harness must be minimized to decrease overshoot. Table 9 shows that the shoulder harness elongation is restricted to 8 percent, while the lap belt is restricted to 7 percent when stretched to a load of 4000 lb. Restraint systems for the new generation of Army helicopters use a low-elongation polyester webbing, other characteristics of which are also listed in Table 9.

TABLE 9. OCCUPANT RESTRAINT HARNESS REQUIREMENTS (MIL-S-58095A(AV))

	Harness Webbing			Harness Assembly	
Component	Nominal Width (in.)	Thickness (in.)	Minimum Tensile Breaking Strength (lb)	Maximum Elongation (%)	Minimum Ultimate Strength (lb)
Inertia reel lead-in	1.75	0.055-0.075	8,000	8 @ 4,000 lb	5,000
Shoulder harness	2.00	0.045-0.065	6,000	8 @ 4,000 lb	5,000
Lap belt	2.00 - 2.25	0.045-0.065	6,000	7 @ 4,000 lb	4,000
Lap belt tiedown	1.75 - 2.00	0.045-0.065	6,000	10 @ 3,000 lb	3,000

NOTES:

(1) To determine elongation and minimum ultimate strength, the shoulder harness assembly and the inertia reel shall be tested together in straight tension with the inertia reel in a locked position and attached to a suitable stationary fixture. The two shoulder harness end fittings shall be plugged into the buckle and the buckle attached to a movable fixture. The webbing shall be adjusted to fit a 95th percentile occupant. The test shall proceed as described in Section 4.7.7.3 of MIL-S-58095A(AV), and the elongation shall be determined for the free webbing length exclusive of the spooling webbing on the reel.

(2) As a separate test of minimum ultimate strength, only the inertia reel lead-in strap and the shoulder straps shall be tested together, and the inertia reel webbing and its stitching to the two shoulder straps shall demonstrate a minimum strength of 5,000 lb while loading both shoulder straps and 3000 lb when loading one strap.

(3) The inertia reel shall be tested to demonstrate an ultimate strength of 5000 lb when following the procedures of Section 4.3.3.1 of MIL-R-8236.

5.7.4.2 <u>Width and Thickness Requirements</u>. Minimum webbing width requirements are specified in Table 10. All webbing used for restraint harnesses must be thick enough to ensure that the webbing does not fold or crease to form a "rope" or present a thin sharp edge under high loading that will cause damage to soft tissue. A minimum thickness of 0.045 in. is considered acceptable for the shoulder harness and lap belt straps, while 0.055 in. minimum is specified for the inertia reel lead-in strap.

TABLE 10. MINIMUM WEBBING WIDTH REQUIREMENTS

Webbing Identify	Minimum Width (in.)
Lap belt	2.00*
Shoulder strap	2.00
Tiedown strap	1.75

*A greater width (up to 4 in.) or pad is desirable in the center abdominal area.

5.7.4.3 <u>Webbing Attachment Methods</u>

5.7.4.3.1 Stitched Joints. The strength and reliability of stitched seams must be ensured by using the best known cord sizes and stitch patterns for a specified webbing type. The stitch patterns and cord sizes used in existing high-strength military restraint webbings appear to provide satisfactory performance. The basic stitch pattern used in these harnesses is a "W-W" configuration for single-lapped joints. The 27-lb strength No. 3 nylon thread at 6 to 9 stitches per inch is recommended, as illustrated in Figure 31, for use on MIL-W-25361 webbings. The use of the 27-lb cord and an 80-percent efficiency results in a minimum strength of 130 lb/in. (6 stitches x 27 lb/stitch x 0.80 efficiency) for a single-lapped joint or 260 lb/in. for a looped joint. Thus, the total stitch length needed can be determined by the total required load.

It has been shown recently that the heavier thread is not compatible with the new low elongation polyester webbing (Reference 49). For these webbings, a smaller diameter cord offers the advantages of reduced webbing fiber damage and the ability to be used with automatic sewing machines and is therefore acceptable.

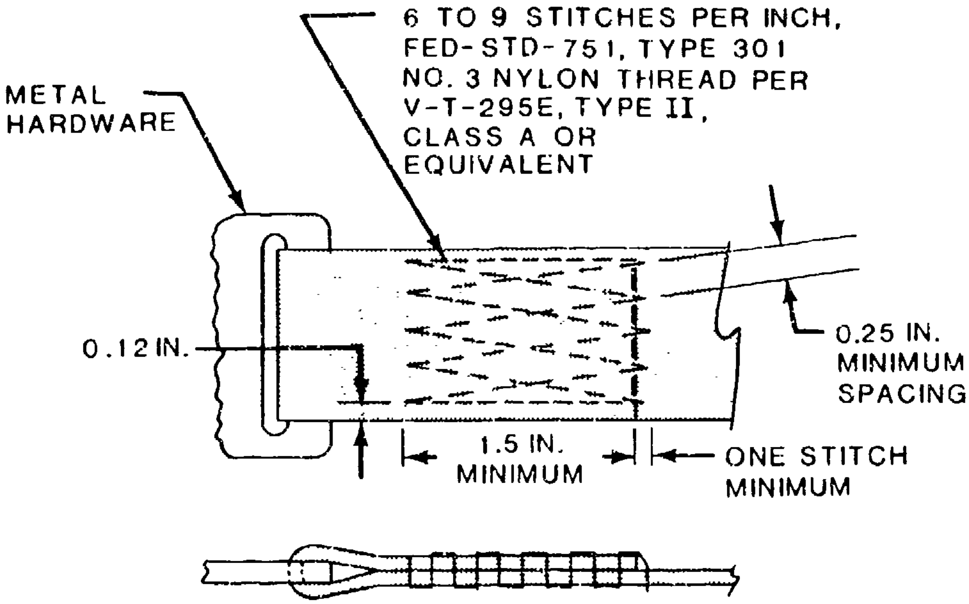


FIGURE 31. STITCH PATTERN AND CORD SIZE.

The use of a 30-percent increase in the total stitch length required is recommended to offset the normal aging strength decrease as well as the possible abrasion strength decrease. Covering the stitched joints with cloth to provide wear protection for the cords is also recommended.

The size of the overlapped and stitched area should be minimized to reduce weight, reduce the stiffened section of the webbing, and provide more room between fittings for adjustment.

5.7.4.3.2 Webbing Wrap Radius. The wrap radius is the radius of the fitting over which the webbing is wrapped at buckles, anchorages, and adjusters, as illustrated in Figure 32. The 0.062-in. minimum radius should be carried around the ends of the slot as shown in Figure 32 to preclude edge cutting of webbing if the webbing should be loaded against the slot end.

5.7.4.3.3 Hardware-to-Webbing Folds. A possible method of reducing fitting width at anchorage, buckle, or adjuster fittings is to fold the webbing as shown in Figure 33. This reduces the weight and size of attachment fittings; however, it can also cause premature webbing failure because of the force applied by the top layer of webbing compressing the lower against the fitting slot edge. If this technique is to be used, tests to demonstrate integrity are recommended. Also, for configurations that require two load paths, such as lap belts, where an adjuster cannot hold the required 4000-lb load, the webbing is looped through a full-width slot which halves the load in each strap. An adjuster is then included in one strap. Adjustment requires that the webbing be freely drawn through the fitting, a requirement that folded webbing cannot meet.

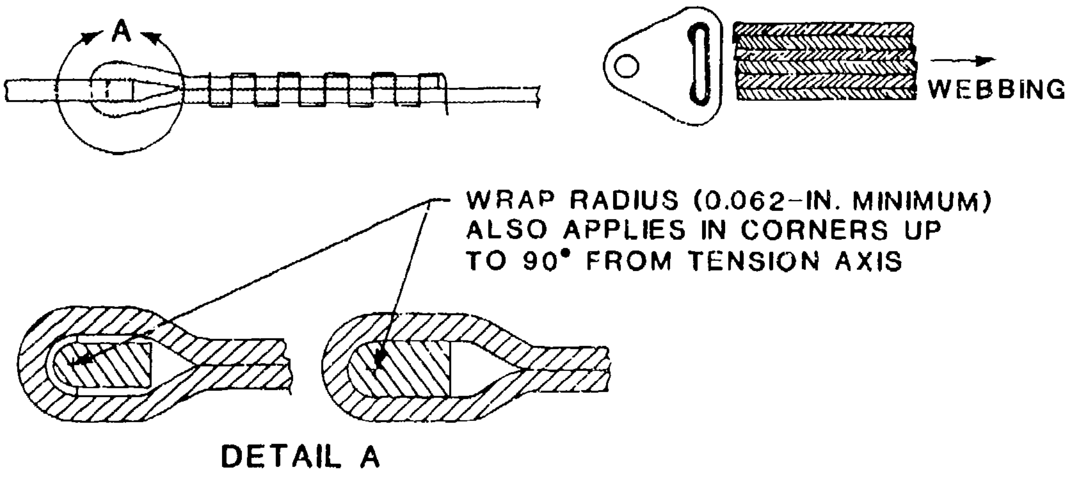


FIGURE 32. WRAP RADIUS FOR WEBBING JOINTS.

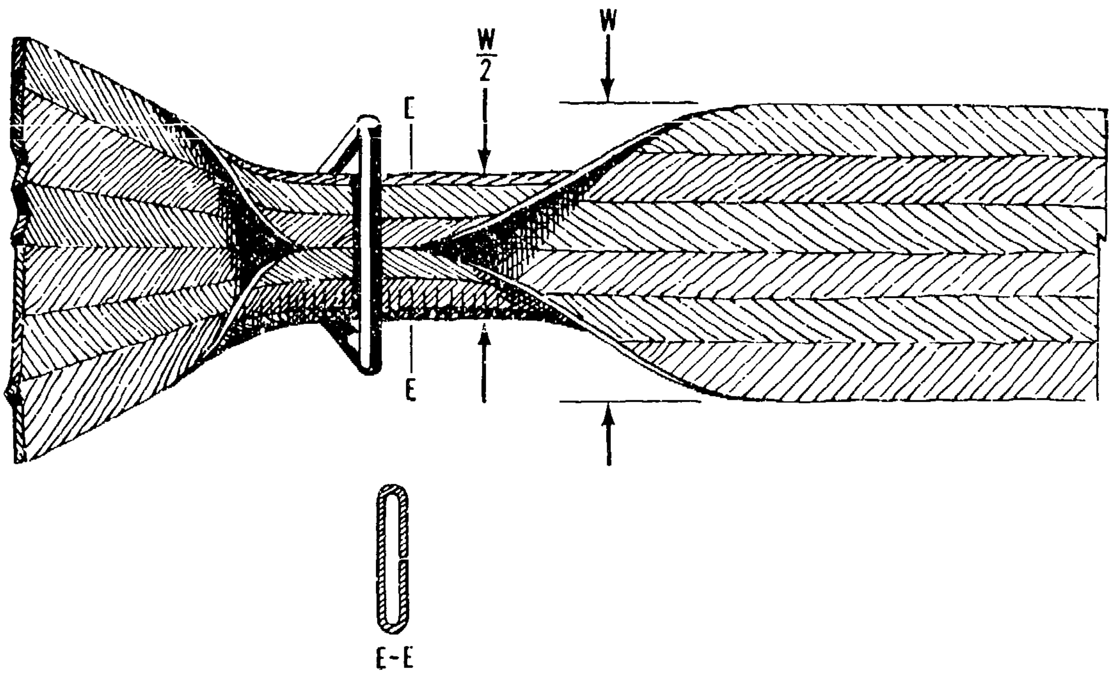


FIGURE 33. WEBBING FOLD AT METAL HARDWARE ATTACHMENT.

5.7.4.3.4 **Surface Roughness of Fittings.** A surface roughness of no more than RMS-32 is recommended to prevent fraying of the webbing due to the frequency of movement over the metal.

5.7.4.4 **Energy-Absorbing Webbing.** Energy-absorbing restraint system webbing has been considered for limiting loads on the occupant. However, primarily because of the increased potential for secondary impacts of occupants, energy-absorbing webbing is not recommended for use in seating systems. The limited space available in aircraft requires that the strike envelope be minimized. Therefore, the use of the lowest elongation available is specified.

5.7.5 Inertia Reels, Control, and Installation

The inertia reel should give the crewmember full freedom of movement during normal operating conditions while automatically locking the shoulder harness during an abrupt deceleration. The design requirements specified in MIL-R-8236 (Reference 50) are compatible with the restraint harness requirements listed in Table 9, and it is recommended that the use of this specification be continued.

In addition to the MIL-R-8236-type reel, which has the function of preventing further strap extension, there are power-haulback reels that rapidly retract slack to apply a tensile load to the belt. Generally, these systems, some of which use a basic MIL-R-8236 inertia reel, are powered by a gas generator and must be manually actuated prior to impact. Automatic actuation by an acceleration sensor is not recommended, because human tolerance considerations limit the haul-back velocity. By the time the crash could be sensed, there would not be time to complete the haulback within tolerable accelerative limits.

It is recommended that the rate-of-extension type reel be used on all aircraft types to assure locking regardless of load direction.

The inertia reel may be anchored to the seat back structure or to the basic aircraft structure with the same reservations previously mentioned in Section 5.7.3.4. The shoulder straps must be maintained within the acceptable angle range as presented in Figure 30. If an anchorage to basic structure is used, consideration must be given to the possible seat bucket motion so that the shoulder strap remains effective during the energy-absorbing stroke. The reel should be mounted and the webbing routed so that the webbing does not bear on the reel housing.

5.8 SEAT STRENGTH AND DEFORMATION DESIGN REQUIREMENTS

5.8.1 Recommended Occupant Weights for Seat Design

The 95th- and 5th-percentile occupant weights are recommended for the upper and lower limits of occupant weights to be considered in seat design.

5.8.1.1 Crewseats. For some applications the design weight should be based on the typical weight of the seat occupant, not the extremes. This means that the aviator weight recommended for crewseat design should not include combat gear. Typical male and female weights are presented in Table 11.

5.8.1.2 Troop and Gunner Seats. The same percentile range of occupant sizes should be considered for troop and gunner seat designs. A greater variation of clothing and equipment is used by troops than by aviators; troop seats should be designed to accommodate them. The 95th-percentile occupant should be considered heavily clothed and equipped, while the 5th percentile occupant should be considered lightly clothed and equipped. The typical weights of male and female seated troops in aircraft are as shown in Table 12.

TABLE 11. TYPICAL AVIATOR WEIGHTS

Item	95th-Percentile Weight (lb)		50th-Percentile Weight (lb)		5th-Percentile Weight (lb)	
	Male	Female	Male	Female	Male	Female
Aviator	211.7	164.3	170.5	131.4	133.4	102.8
Clothing	3.1		3.1		3.1	
Helmet	3.4		3.4		3.4	
Boots	4.1		4.1		4.1	
Total weight	222.3	174.9	181.1	142.0	144.0	113.4
Vertical effective weight	175.2	137.2	142.3	111.0	112.6	88.1

TABLE 12. TROOP AND GUNNER WEIGHTS

Item	95th-Percentile Weight (lb)		50th-Percentile Weight (lb)		5th-Percentile Weight (lb)	
	Male	Female	Male	Female	Male	Female
Troop/Gunner	201.9	164.3	156.3	131.4	126.3	102.8
Clothing (less boots)	3.0		3.0		3.0	
Boots	4.0		4.0		4.0	
Equipment	33.3		33.3		33.3	
Total weight	242.2	204.6	196.6	171.7	166.6	143.1
Vertical effective weight clothed	163.9	133.6	127.4	107.5	103.4	84.6
Vertical effective weight equipped	197.2	167.1	160.7	140.8	136.7	117.9

5.8.2 Strength and Deformation

5.8.2.1 Forward Loads. For a load-limited system, a minimum displacement must be achieved if the system is to remain in place during a given decelerative pulse. Actually, all systems are load limited, although not necessarily through original intent. The inherent load-deflection curve for any system imposes a definite limit on the system's ability to resist impulsive loading. The objective of intentionally load-limited seat systems is to make the best use of the space available for relative displacement of the seat and occupant with respect to the airframe, while maintaining loads on the occupant consistent with the type of restraint system used and the occupant's capacity to survive the loads imposed.

Design curves for the forward direction are presented in Figure 34, where it is estimated that the requirements are not conservative for the input pulses selected for design purposes. These are a 30-G peak triangular pulse of 50-ft/sec velocity change in the cockpit and a 24-G peak with 50-ft/sec velocity change in the cabin area.

The static loads that the seat must withstand are obtained by multiplying the load factors (G) shown in Figure 34 by the sum of the total weight of the 95th-percentile crewmember or passenger plus the weight of the seat and any armor or equipment attached to or carried in the seat. For crewseats, the weight of combat gear is not included (see Section 5.8.1.1).

Longitudinal displacement of approximately 6 in. for cockpit seats and 12 in. for cabin seats measured at the seat reference point (the seat reference point may be projected to the outside of the seat pan for measurement convenience) is the practical limit for seats in existing Army aircraft. Since there is typically more room available in cabins than in cockpits, the advantages of longer energy-absorbing strokes can usually be achieved. Longer strokes permit the absorption of equivalent energy at lower loads and thus can serve to reduce seat weight and increase the level of protection offered over a wider occupant weight range.

In viewing Figure 34, it can be seen that for cabin seats 12 in. of stroke enables the minimum limit load to be reduced to 15 G, whereas for cockpit seats a 20-G minimum limit load is required with only 6 in. of stroke. The 15-G and 20-G minimum limit loads fix the G levels of the base curves for the cabin and cockpit seat, respectively. The available stroke will be unique for each specific aircraft, and the energy-absorbing mechanisms in the seats should be compatible with the available stroke distances. If forward or sideward motion threatens to limit the effectiveness of the vertical energy attenuating system or increase the possibility of severe injury caused by secondary impact of the occupant with items in the aircraft, then energy-absorbing stroke in directions other than vertical should not be used. The 6 in. and 12 in. allowed by the curves of Figure 34 should be viewed as maximum distances which are subject to limitations of available space in each specific aircraft and location in the aircraft.

The initial slope of the cockpit seat base curve to 1.0 in. of deflection allows for elastic deformation consistent with a relatively rigid crewseat while the lighter weight and more flexible troop/gunner seat requires a lesser slope. The 30-G and 35-G upper cutoffs reflect consideration of human tolerance limits, load variations between cockpit and cabin locations, and practical limitations of seat weight and excessive airframe loading.

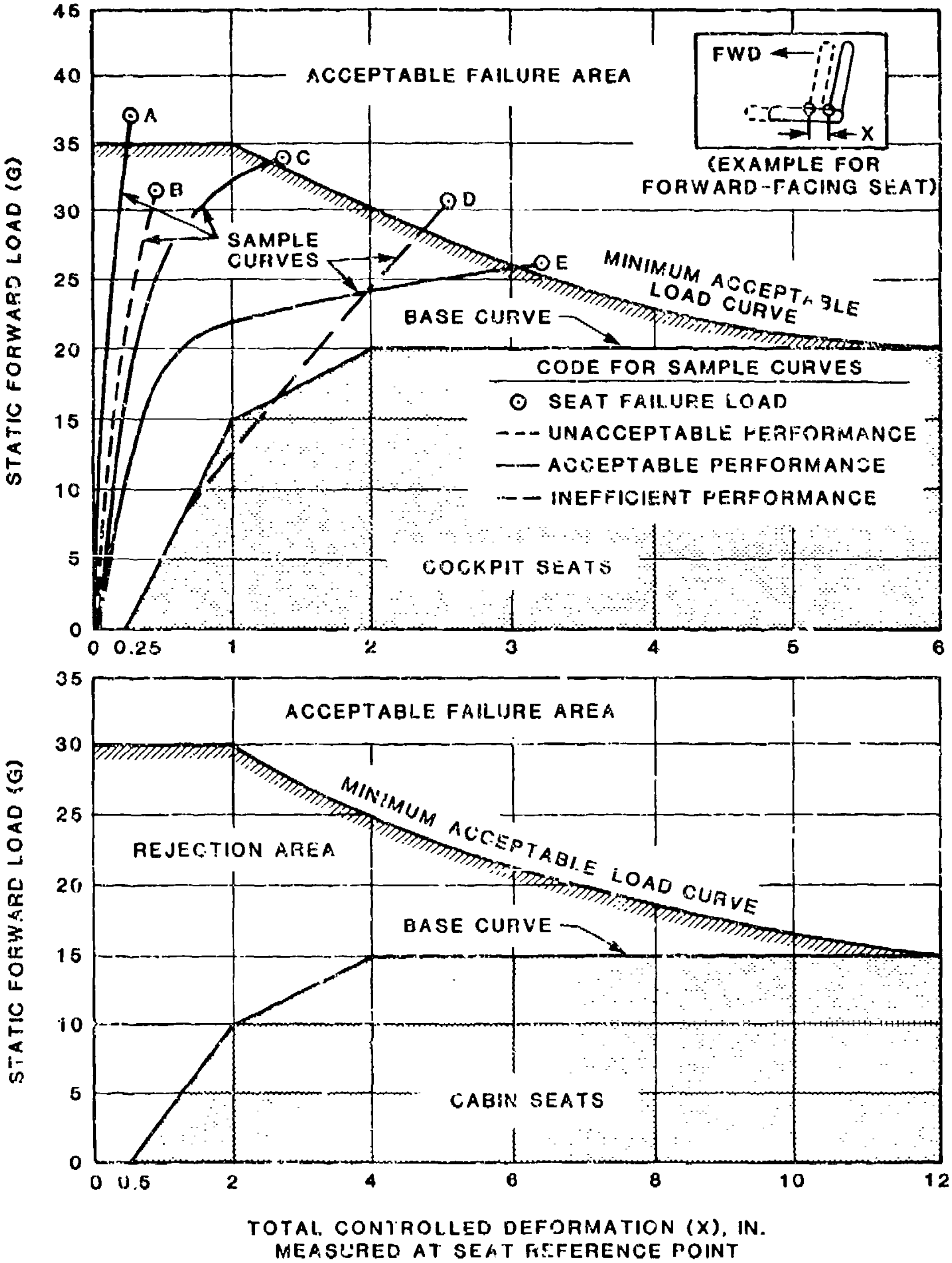


FIGURE 34. SEAT FORWARD LOAD AND DEFLECTION REQUIREMENTS FOR ALL TYPES OF ARMY AIRCRAFT (FORWARD DESIGN PULSE).

5.8.2.2 Use of Design Curves. To be acceptable, a seat design must have a characteristic load-deflection curve that rises to the left and above the base curves of Figure 34 and extends into the region beyond the upper curve. This requirement also applies to the lateral strength and deformation requirements discussed in Section 5.8.2.6. In Figure 34, curves A, C, and E are acceptable curves, but curve B is unacceptable because it does not reach the required ultimate strength. Curve D reveals inefficient use of seat deflection by intruding into the base area. The seat is deflecting at too low a load, thus absorbing less energy than desirable.

5.8.2.3 **Aftward Loads.** Large aftward loads seldom occur in fixed-wing aircraft accidents but may occur in rotary-wing accidents. A capability to withstand 12 G is recommended for aftward loads for all seats. This value will usually be automatically met by all seats meeting the forward load requirements. Occupant weight should be the total weight of the 95th-percentile crewmember or trooper as presented in Section 5.8.1.

5.8.2.4 **Downward Loads.** Human tolerance to vertical impact limits the acceptable forces in the vertical direction for all aircraft seats. The maximum allowable headward acceleration (parallel to the back tangent line) for seated occupants is on the order of 23 G for durations up to approximately 0.025 sec. Therefore, the 48-G design pulse imposes the requirement for energy absorption in the vertical direction by some form of load limiting.

The effective weight in the vertical direction of a seat occupant is approximately 80 percent of the occupant's total weight because the lower extremities are partially supported by the floor. The effective occupant weight may be determined by summing the following:

- Eighty percent of the occupant's body weight.
- Eighty percent of the weight of the occupant's clothing (less boots).
- One hundred percent of the weight of any equipment carried on the body above knee level. Combat gear is not usually included in the effective weight of the pilot or copilot (see Section 5.8.1.1). However, armored seats are often designed for a 95th-percentile male occupant wearing a chest protector.

The dynamic limit load for the load-limiting system should be established by use of a load factor (G_L) of 14.5. The dynamic limit load is determined by multiplying the summation of the effective weight of the seat occupant and the weight of the movable or stroking portion of the seat by 14.5. The resulting dynamic limit load includes the total force resisting the vertical movement of the seat in a crash; the dynamic limit load of the energy-absorption system, simple friction, and friction due to binding, etc. This requirement may be difficult to satisfy with a sliding guidance system because the frictional load varies with contact load which, in turn, varies with the impact load vector direction. Special treatment of sliding surfaces can reduce this problem. Relatively friction-free rolling and sliding mechanisms have both been used successfully. A rolling mechanism eliminates the friction problem but can introduce a looseness during normal use. This can be overcome by spring loading the roller joint.

The 14.5-G design criterion, taken from Reference 51, considers the dynamic response of the seat and occupant. The factor of 14.5 was established to limit the decelerative loading on the seat/occupant system to less than 23 G for durations in excess of 0.025 sec (the tolerable level for humans as interpreted from the Eiband data) in crashes that do not exhaust the stroke of the seat.

Crewseats should be designed to stroke a minimum distance of 12 in. when the seat is in the lowest position of the adjustment range. This distance is needed to absorb the residual energy associated with the vertical design pulse. Further, the load-limiting system should be designed to stroke through the full distance available, including the vertical adjustment distance. Since a vertical adjustment of $\pm 2\frac{1}{2}$ in. from neutral is typically required by crewseat specifications, proper design can provide up to 17 in. of stroke, depending on seat adjustment position. For inclusion of the 5th-percentile female occupant, additional vertical adjustment would be required.

If it is absolutely impossible to obtain a minimum of 12 in. of stroke, a systems analysis should be used; the goal of the analysis is to show that occupant protection is equivalent to the system in which the 12-in. stroke is available.

For retrofit applications, the maximum protection possible should be obtained in any component being modified, i.e., seats, gear, etc. Separate test criteria have been established for seats not having the required 12 in. of stroke and are presented in Section 5.10.2.2.

Since energy-absorbing systems should be designed for dynamic loading, to obtain the static test loads, dynamic limit loads should be reduced by the amount due to rate sensitivity of the particular device used. Further, in the design of the system the desired total resistive load on the seat should be obtained by summing the resistive load provided by the energy-absorbing system and the resistive load resulting from friction and/or other mechanisms unique to the particular system. Thus, the resistive load of the energy-absorbing subsystem must be less than the load required to decelerate the seat by the amount of the other stroke-resisting variables.

If the energy-absorbing system is to provide only one force setting, the effective weight of the 50th-percentile occupant from Tables 11 and 12 should be used for sizing it in order to ensure a tolerable stroke for the majority of the occupants, not exceeding the stroke limitations of the seat. These weights are 142.3 and 160.7 lb for pilot/copilot and troop and gunner seats, respectively.

In order to use the stroke distance available at maximum efficiency, regardless of occupant weight, a variable-force load-limiting mechanism is desirable. With an infinitely variable force system, the deceleration levels can be maintained within acceptable limits (if the stroke is not exhausted) for the full range of occupant weights. Some benefit may also be obtained from a device that can provide two or more limit loads that can be selected by the seat occupant. The selection would be made on the basis of seat occupant weight. In operation then, the occupant would be required to select a limit load by movement of a lever or dial upon entering the seat.

It is recommended that at least a dual-level load limiter (preferably three or more levels) be used to provide maximum protection over the complete occupant weight range.

The interaction between the occupant and the movable seat masses increases with seat mass. Therefore, the movable seat mass should be minimized.

Troop seats should be designed for the maximum stroke feasible to maximize protection over the large weight range represented by the fully equipped and lightly equipped occupant. It is recommended that the full 17-in. seat pan height normally considered desirable from the human engineering standpoint be used for energy-absorbing stroke. It is further recommended, as a minimum, that the limit load of the system be sized using the 14.5-G load factor and the effective weight of the 50th-percentile heavily equipped occupant (160.7 lb). Variable-level load limiters sized as discussed previously are also desirable for troop seats only if automatically adjusted, since improper adjustment of such devices can increase the hazard to the occupant.

5.8.2.5 <u>Upward Loads</u>. A capability to withstand a minimum upward load of 8 G is recommended for all aircraft seats. Occupant weight should be that of the 95th-percentile crewmember or trooper as presented in Section 5.8.1.

5.8.2.6 <u>Lateral Loads and Deformation Requirements</u>. The lateral load and deformation requirements for forward- and aft-facing seats are presented in Figure 35. Two curves are presented. One is for utility and observation helicopters, and the other is for light fixed-wing aircraft and attack and cargo helicopters. The deflections at the seat reference point should be measured. Occupant weight should be as specified in Section 5.8.1 and should be that of the 95th-percentile aircrew member or trooper.

Lateral loading in the forward direction (aircraft reference system) on side-facing seats should be the same as for forward loading (Figure 34), except that load limiting should be employed.

For crewseats, the lateral deflection should be minimized; however, it is doubtful if any great stiffness can be achieved in lightweight hardware. It is believed adequate, as a design goal, to attempt to limit the initial deflection to 1 in. with a 2-in. requirement. Because of the possible loading rate sensitivity of the seat materials, it is felt to be acceptable to allow analysis of test data to demonstrate compliance. This analysis might include adjustments of static test data by use of measured or known deflection and load data from dynamic tests. Further, in cases where wells are provided under the seats to increase the available stroke distance, the deformation should be elastic. This will allow the seat to realign itself with the well prior to entry after reduction of the lateral and longitudinal loads in those cases where the loads are relieved soon enough.

5.8.3 <u>Other Seats</u>

The requirements presented for crewseats and troop and gunner seats also apply to passenger seats and any other seat installed in the aircraft for any purpose. Unique seats installed for special uses are not to be exempt.

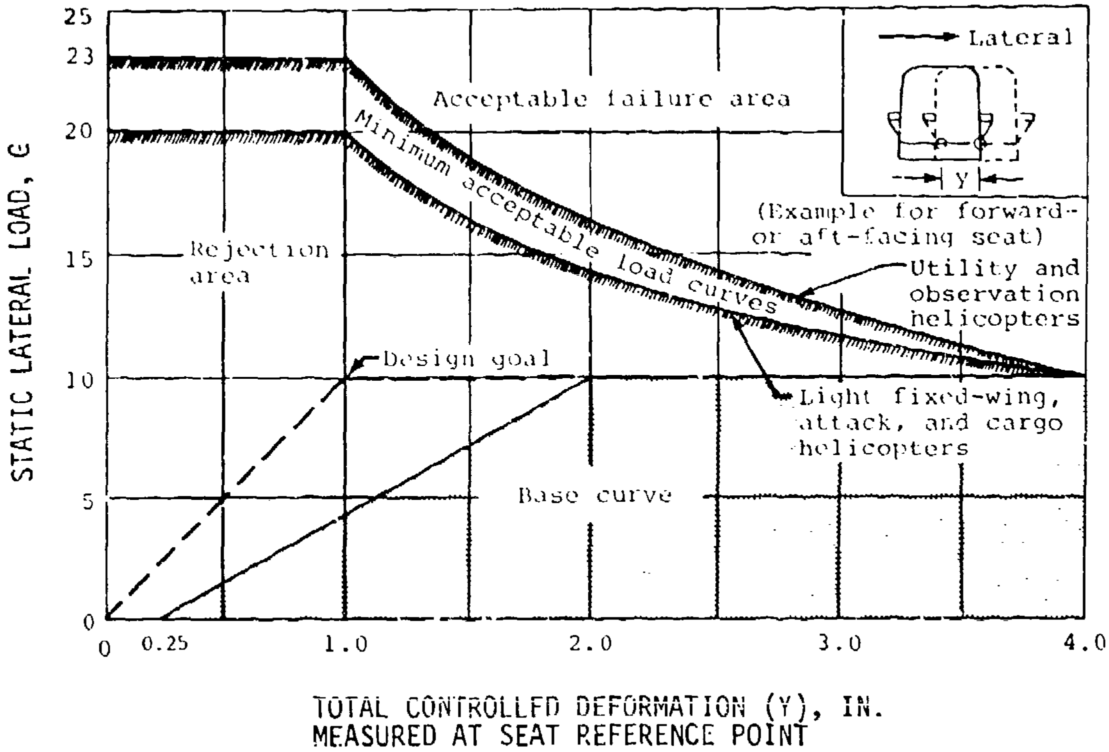


FIGURE 35. LATERAL SEAT LOAD AND DEFORMATION REQUIREMENTS FOR ALL TYPES OF ARMY AIRCRAFT.

5.9 PERSONNEL RESTRAINT HARNESS TESTING

The restraint harnesses are to be statically and dynamically tested along with the seat and/or structure to which they are attached. However, the lap belt, shoulder straps, and tiedown straps, including all hardware in the load path, should be statically tested separately to ensure that all components possess adequate strength and to determine elongation. The strength and elongation test requirements of restraint system subassmblies are specified in Table 9.

Specific component tests, including operational tests, are detailed in a draft military specification (Reference 52). However, all components and subassemblies should be statically load tested. Each subassembly should be tested to its full design load to demonstrate its adequacy. Elongation characteristics should be measured to document these data for comparison with requirements and use in systems analyses.

5.10 STRUCTURAL SYSTEM TEST REQUIREMENTS

Both static and dynamic tests are recommended, and it is also recommended that all seat and litter systems be tested as complete units. This is not to imply that component tests are not useful; on the contrary, they can be extremely useful and should be employed wherever possible to verify required strengths.

Upon acceptance of prototype systems tested under both static and dynamic conditions, no further tests should be required except for quality assurance. Major structural design changes in the basic seat system will require static retesting of the new system to ensure that no loss in strength has been caused by the design changes. If the changes could affect the energy-absorbing, or stroking, performance of the seat, additional dynamic tests should also be conducted. Major structural design changes are those changes involving principal load-carrying members such as floor, bulkhead, or ceiling tiedown fittings, structural links or assemblies, seat legs, or energy-absorbing systems. Minor changes, such as in ancillary fittings, can be accepted without a structural test. However, a significant weight increase such as the addition of personnel or seat armor, would require additional testing. In summary, changes that increase loading, decrease strength, produce significant changes in load distribution, or affect the stroking mechanism will require retesting.

All testing is to be conducted with the seat cushions in place and, for seats with adjustments, the seats should be in the full-aft position unless another position is shown to be more critical. The seat vertical position should be consistent with normal operation (i.e., the 95th-percentile occupant with the seat in the full-down adjustment or the 50th-percentile occupant in the neutral position or as most probably used in flight). All tests should be conducted under simultaneous conditions of floor bucklir and warping or bulkhead warping, as illustrated in Figure 20. The combination of warping conditions should be that which represents the most critical cas. for seat performance, such as that most likely to impede seat stroking. For xample, considering the combined-load static test (No. 6 in Table 13) of a seat such as that shown in Figure 20, if the lateral load component were applied to the right, the right-hand track should be warped upward at the forward end (+10 degrees) to evaluate the possibility of interference with vertical stroke. Also, the seat should be mounted for testing on actual aircraft hardware, i.e., tracks or bulkhead fittings.

5.10.1 <u>Static Test Requirements</u>

5.10.1.1 <u>General</u>. Table 13 presents the static test requirements for complete crewseat units per MIL-S-58095. All static tests should be conducted under simultaneous conditions of floor or bulkhead buckling and warping as described above. For static testing of troop/passenger seats the requirements of MIL-S-85510 should be met. The criteria are different, because the crash environment is usually less severe in the cabin than in the cockpit.

5.10.1.2 <u>Unidirectional Tests</u>. Where separate strength and deformation requirements have been specified in Table 13 for longitudinal, vertical, and lateral loading of seats, the loads should be applied separately. Seats must demonstrate no loss in structural integrity during these tests and should demonstrate acceptable energy-absorbing capacity.

5.10.1.3 <u>Combined Loads</u>. Seats must demonstrate no significant loss of structural integrity under conditions of combined loading as shown in Table 13 and should demonstrate ability to stroke in the vertical direction with the transverse loads applied.

TABLE 13. SEAT DESIGN AND STATIC TEST REQUIREMENTS

Test Ref. No.	Loading Direction with Repect to Fuselage Floor	Body Weight Minimum Load Factor[a] (G)	Used in Load Determination lb (kg)	Seat Weight Used in Load Determination	Deflection Limited[d] in (cm)
		Undirectional Loads			
1	Forward	35	250 (114)	Full	2 (5.1)
2	Aftward	12	250 (114)	Full	2 (5.1)
3	Lateral[c]	20	250 (114)	Full	4 (10.2)
4	Downward (Bottomed)	25	200[f] (91)	Full	No. Reqmt.
5	Upward	8	250 (114)	Full	2 (5.1)
		Combined Loads			
6	Combined				
	Forward	25	250 (114)	Full	
	Lateral[c]	9	250 (114)	Full	
	Downward[b] (Stroking)	e	140 (64)	Stroking Part	Full Stroke

NOTES:

(a) The aircraft floor or bulkhead shall be deformed prior to the conduct of static tests and kept deformed throughout load application.
(b) Forward and lateral loads shall be applied prior to downward load application.
(c) The lateral loads shall be applied in the most critical direction.
(d) Under load at neutral seat reference point.
(e) Static load factor as necessary to meet dynamic test criteria, Figure 37.
(f) Effective weight of a 250 lb (114 kg) occupant.

5.10.1.4 **Load Application Method.** The test loads should be applied through a body block (see Section 5.10.1.5) restrained in the seat with the restraint system. The loads are to be applied at the expected center-of-gravity location of the occupant or occupants of each seat, as illustrated in Figure 36.

The loads calculated by multiplying the weight of the occupant and equipment plus the weight of the seat by the required load factor should be applied continuously, or in not more than 2-G increments while the load-deformation performance of the seat is recorded. Maximum loads need not be held for more than 1 sec. The maximum load reached, regardless of duration, is to be used to assess compliance.

On integrally armored crewseats, care should be taken to assure that the loads are applied proportionally to the proper assembly or test item to simulate the loads that would typically be carried by the restraint harness and the seat support structure. In other words, the portion of the load that

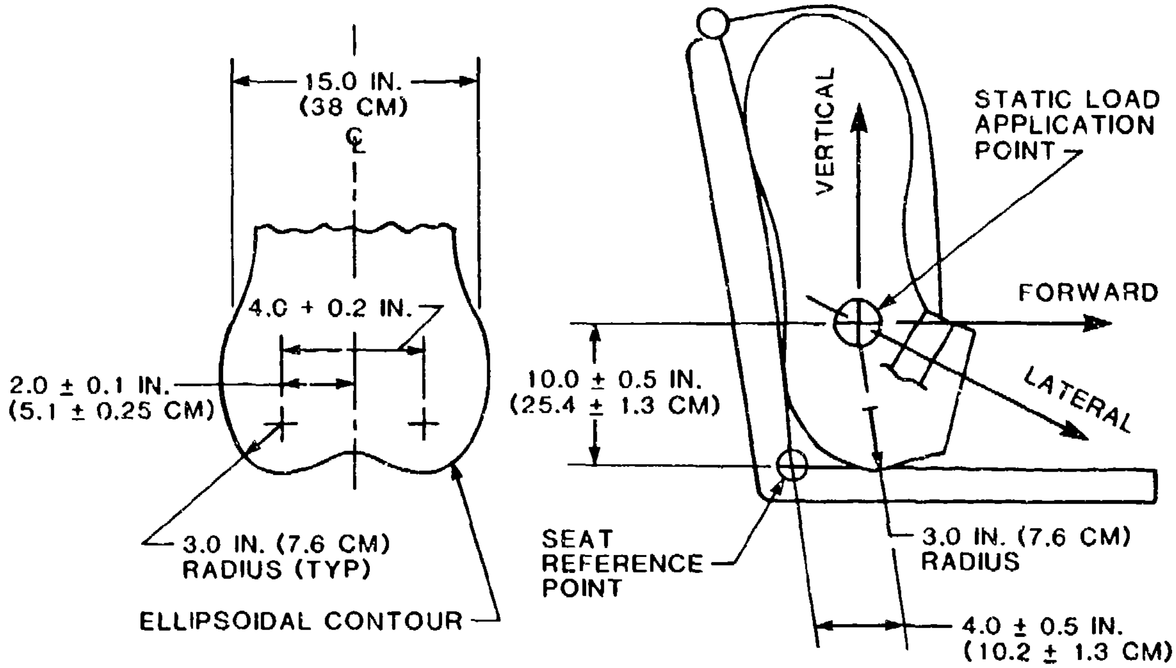


FIGURE 36. STATIC LOAD APPLICATION POINT AND CRITICAL BODY BLOCK PELVIS GEOMETRY.

could be expected to be restrained by the restraint harness should be applied to the body block as described above. The portion of the load representing inertial loading of the movable assembly should be applied separately at the center of gravity of the appropriate substructure through another provision. For example, a lever to proportion the load between the body block and movable section of the seat and a sling to apply the appropriate portion of the load to the bucket can be used. For seats with a relatively heavy frame, the inertial load of the frame can be applied separately at its appropriate center of gravity. This technique, although adding complexity to the test setup, assures that all components in the seat and restraint system assembly have been tested to their approximate static design loads and that, as far as a static test simulation can be extended, performance and structural adequacy have been demonstrated. For lightweight seats (less than approximately 45 lb for total seat and restraint system), the total load can be applied to the body block.

As an alternative, static loads may be applied with a centrifuge. In this case, a dummy, rather than a body block, will be used to simulate occupant loads.

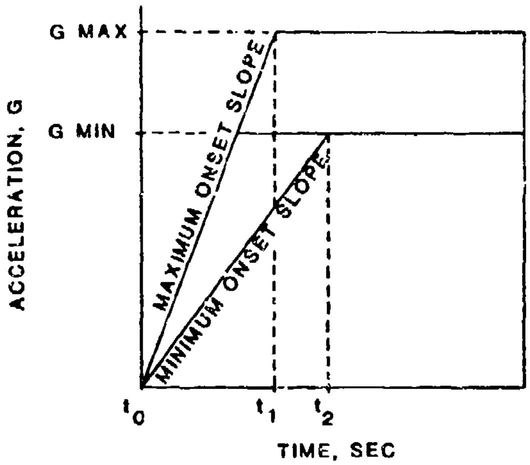
5.10.1.5 Static Load Body Block Or Dummy. The static test loads should be applied through a body block contoured to approximate a 95th-percentile occupant seated in a normal flying attitude. The body block should contain shoulders, neck, and upper legs, and provide for passage of a lap belt tiedown strap between the legs. The upper legs should be contoured to simulate the flattened and spread configuration of seated thighs and to allow the proper location of the buckle. Critical pelvis dimensions are shown in Figure 36. Buttock contours must be provided to permit proper fit in a contoured seat pan. The leg stubs should be configured to permit proper seat pan loading as the body block rotates forward under longitudinal loading; i.e., the leg stubs should be only long enough to provide a surface to react the downward lap belt load component. The side view of the buttocks should include an up-curved surface forward of the ischial tuberosities to allow the forward rotation of the body block and loading of the shoulder hardness while maintaining the primary contact between the ischial tuberosities and the seat pan through the cushions.

5.10.1.6 Deflection Measurements. Deflection should be measured as close to the seat reference point as possible to prevent seat structure rotational deformation from influencing the test results. To simplify these measurements, the seat reference point can be projected to the outside of the seat pan or bucket.

Normally the restraint system will be attached to the seat. However, if a unique situation should develop in which the only option for increasing crash resistance is to attach the system (lap belt and shoulder harness) to the basic aircraft structure rather than to the seat, certain factors should be considered. First, the forward and lateral deflection requirements of Figures 34 and 35 need not be considered, because the restraint harness limits torso and seat deflection. Second, the vertical deflection of the seat pan still must be considered since the downward movement of the seat pan could cause excessive slack in the restraint harness, or the harness could limit the stroke of the seat, depending on where the restraint system is anchored. Neither of these conditions is acceptable in the design.

5.10.1.7 Load Determination. The total load required for all test directions except downward is determined by multiplying the required load factor from Table 13 by the total of a body weight of 250 lb plus the weight of each seat. The total load required for the unidirectional downward (bottomed) test is determined by multiplying the required load factor by the total of an effective body weight of 200 lb plus the weight of each seat. For the combined-load test the downward (stroking) load required is determined by multiplying the static load factor necessary to meet the dynamic test criteria in Figure 37 by the total of a body weight of 140 lb (average occupant weight less portion supported by legs rather than seat) plus the weight of the stroking part of the seat. For centrifuge tests, the dummy weight should be 250 lb for all tests except the downward tests where it should be 170 lb, and the centripetal acceleration should apply the load factors of Table 13 for at least 1 sec.

5.10.1.8 Multiple Seats. Multiple-occupancy seats should be fully occupied when tested. If it is determined that the most adverse loading condition occurs in other than full-occupancy situations, additional tests should be run for those conditions.



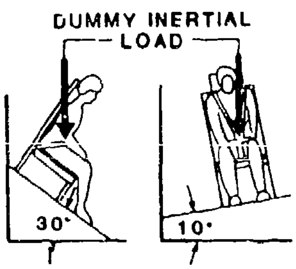
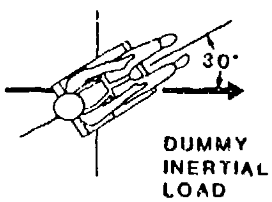
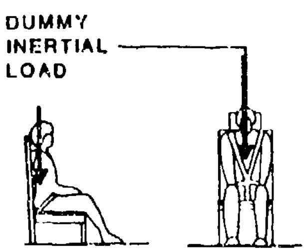
TEST	CONFIGURATION	PARAMETER	COCKPIT SEATS LIMITS	CABIN SEATS LIMITS
1		t_1 SEC	0.043	0.059
		t_2 SEC	0.061	0.087
		G MIN	46	32
		G MAX	51	37
		ΔV MIN, FT/SEC	50	50
2		t_1 SEC	0.066	0.081
		t_2 SEC	0.100	0.127
		G MIN	28	22
		G MAX	33	27
		ΔV MIN, FT/SEC	50	50
3&4		t_1 SEC	0.036	
		t_2 SEC	0.051	
		G MIN	46	
		G MAX	51	
		ΔV MIN, FT/SEC	42	

FIGURE 37. DYNAMIC TEST REQUIREMENTS FOR QUALIFICATION.

5.10.2 Dynamic Test Requirements

5.10.2.1 Dynamic Test Requirements for Seats Having at Least 12 in. of Vertical Stroke.

5.10.2.1.1 Crewseats Designed for a Fixed Load. All prototype crewseats shall meet the requirements of MIL-S-58095. These seats shall be dynamically tested to the conditions specified in Tests 1 and 2 of Figure 37. These test conditions were determined from the design velocity changes presented in Volume II of the Design Guide. Test 1 is required to ensure that the vertical load-limiting provisions will perform satisfactorily under simultaneous forward and lateral loading conditions. Test 2 is required to ensure that the seat can resist the loads produced by the design pulse when applied simultaneously in the forward and lateral directions. The actual aircraft seat attachment hardware shall be used for mounting the seat in the test fixture. All tests shall be performed with the inertia reel seat in the "autolock" mode. The seat shall retain the dummy within the confines of the restraint harness and shall evidence no loss of structural integrity. Any failure of a restraint system component or of a primary load-carrying structural member of the seat shall be unacceptable. A primary load-carrying structural member is defined as a nonredundant member whose failure would allow uncontrolled motion of the seat and/or potentially injurious impact of the occupant with cockpit components. Permanent deformations of the structure which do not present a hazard to the occupant are acceptable. Webbing slippage at adjusters in excess of 1 in. (25.4 mm) is unacceptable. The initial seat height adjustment shall be set in the mid-position for Test 1 and in the fullup position for Test 2. A clothed Hybrid III or VIP-95 95th-percentile dummy weighing 230 lb (105 kg) shall be used for Tests 1 and 2. For all tests, the dummy's feet should be secured in a representative anti-torque pedal position.

5.10.2.1.2 Crewseats Designed with an Adjustable Load Attenuation System. These seats should be dynamically tested to the conditions specified in all four tests of Figure 37. Test procedure, conditions, and results should be the same as noted above, except as specified in this paragraph. The initial seat height adjustment should be set in the mid-position for all tests except Test 2, which should be in the full up position. A clothed Hybrid III or VIP-95 95th-percentile dummy weighing 230 lb (105 kg) should be used for all tests except Test 3. Test 3 should use a 50th-percentile dummy of Hybrid III or CFR Title 49, Chapter 5, Part 572, lightly clothed with both arms removed at the shoulder joints to simulate a 5th-percentile dummy weight. The adjustable attenuation system should be placed in a load setting corresponding to a 5th-percentile occupant weight for Test 3, and a 95th-percentile occupant weight for Tests 1, 2, and 4. For Tests 3 and 4, an accelerometer should be rigidly attached to the lower seat pan centerline surface at a point 5.5 in. (14 cm) forward of the seat reference point to measure accelerations parallel to the seat back tangent line. The acceleration measured during Tests 3 and 4, should not exceed 23 G for more than 0.025 sec., when measured in accordance with a SAE J211, Class 60 instrumentation system. This time duration should be additive, in a cumulative manner, for all acceleration excursions exceeding 23 G. The minimum acceptable seat stroking distance for Tests 3 and 4 should be 9.5 in. (24.1 mm).

5.10.2.1.3 Cabin Seats All prototype troop/passenger seats should meet the requirements of MIL-S-85510 (Reference 53), which requires dynamic testing to the conditions specified in Tests 1 and 2 of Figure 37, using a clad 50th percentile dummy (Reference 36) in Test 1 and a clad 95th-percentile dummy in Test 2. Dynamic testing of multiple-occupant seats should be performed with the maximum number of occupants specified for the test seat. Additional tests should be run if it is determined that the most adverse loading condition occurs in other than full-occupancy situations or that occupant size is a factor. For both tests of Figure 37, adjustable seats should be adjusted to the full-aft and up position of the adjustment range. Plastic deformation of the seat is permissible; however, structural integrity must be maintained in all tests. For Test 1, the seat should limit the acceleration as measured in the pelvis of the dummy to values which ensure that the 50th-percentile clothed seat-system occupant (see Section 5.8.1) will not experience vertical, $+G_z$, accelerations in excess of human tolerance as defined in Sections 5.3 and 5.9 of Volume II (see Figure 9 herein). The roll direction (10 degrees right or left) for Test 1 should be selected to produce the more critical loading for the specific seat design.

When determining compliance of the achieved test pulse with the dynamic test requirements of Figure 37:

1. Determine the maximum acceleration and construct the onset slope for the test pulse by the method explained in Section 5.10.3.

2. Compare the achieved onset and peak acceleration of the test pulse with those allowed and presented in Figure 37. The achieved onset slope should lie between the minimum and maximum onset slopes using the values of t_1 and t_2 listed in Figure 37 for the specific test conditions. The maximum acceleration should also fall between the upper and lower limits allowed.

3. Integrate the actual acceleration-time curve of the test pulse and establish the achieved velocity change. The velocity change achieved should be equal to or greater than that tabulated for the specific test conditions.

5.10.2.2 <u>Special Dynamic Test Requirements for Seats Having Less Than 12 in. of Vertical Stroke</u>. In the event that the application of a systems approach permits the seat to have less than 12-in. minimum vertical stroke or retrofit restraints preclude available room, additional requirements are made of the dynamic testing. First, it would be desirable to perform a full-scale crash test with the test specimen, including all assemblies involved in the energy-absorbing process. This would include a section of the fuselage, landing gear, and the seat or seats. This approach is totally acceptable for demonstrating the dynamic response and acceptability of the system.

Since cost associated with the type of system testing described above is usually prohibitive, a different approach is acceptable. This approach includes dynamically testing the seat only, as is done for systems with at least 12 in. of stroke, but modifying the input pulse to represent the energy-absorbing processes of the gear and fuselage. An example of such a modified test pulse is presented in Figure 38. The initial plateau (t_1 to t_0') represents the acceleration-time history created by stroking of the landing gear. The sharp increase in acceleration at t_0' relates to fuselage impact, and the pulse beyond t_0' represents the crushing of the stiffer fuselage

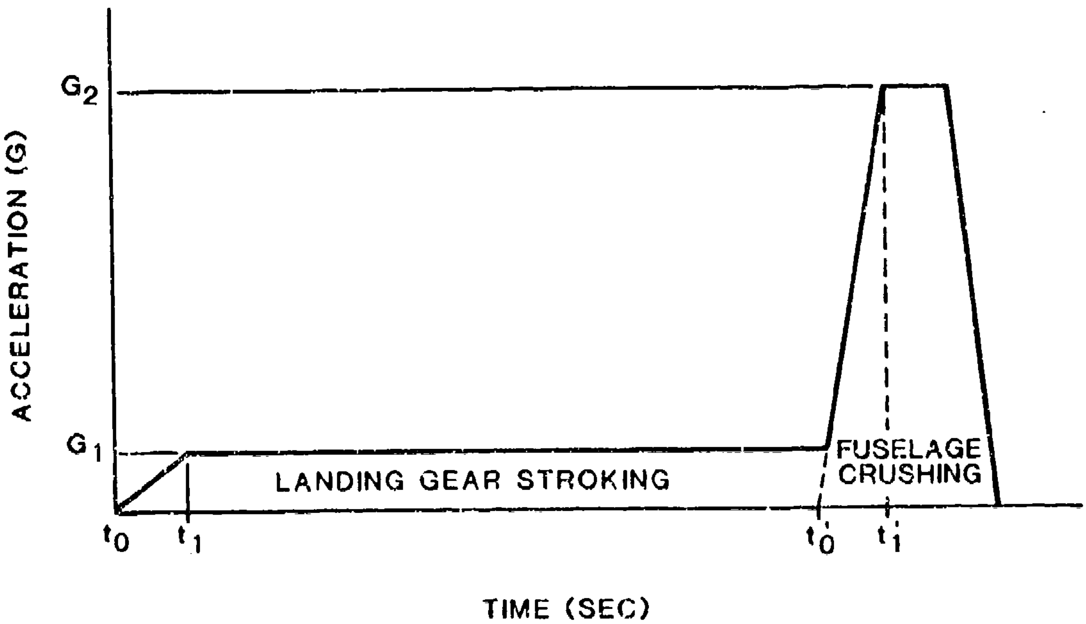


FIGURE 38. EXAMPLE OF INPUT PULSE FOR SEATS HAVING LESS THAN 12 IN. OF STROKE.

section. The velocity change under the pulse should be the same as identified for the particular crash force direction for other established tests (50 ft/sec for Test No. 1 or No. 2 of Figure 37).

It will be difficult to determine accurate dynamic crush characteristics of the various portions of the system to enable establishment of a representative, and thus acceptable, test pulse. The best analytical techniques, supported by test data, should be used for determining the properties of the fuselage. Since drop tests of landing gear are required, a much more accurate approach exists for obtaining the landing gear influence on the pulse. Seat testing should await completion of landing gear tests so that the results can be used to establish the initial plateau (or other shape) between t_1 and t_0' of the input pulse.

Typically the landing gear will stroke at loads below those required to stroke the seat; therefore, much of the kinetic energy of the occupant and seat will be absorbed prior to fuselage impact. If the systems analysis is accurate, the energy-absorbing capacity of the seat will be sufficient to absorb the residual energy at limit loads tolerable to the occupant.

Since each system may display different characteristics, it is not appropriate to present in this document specific quantitative limits for use in evaluating the acceptability of the test pulse. However, the same general approach and tolerances already presented for the standard pulse apply and should be used. The technique described in Section 5.10.2.1 for establishing compliance with the required test pulse applies directly to the portion of the special test pulse following t_0.

5.10.3 Data Acquisition and Reduction

Data acquisition and reduction should comply with the requirements of SAE J211 (Reference 54) for measurements on anthropomorphic dummies and structures.

Dynamic test data must usually be smoothed by filtering out high-frequency data and/or noise to be useful. This is especially true if it is to be sampled and digitized. It is good practice to use filtering procedures common to other test laboratories, as this eases valid comparison of results. The suggested criteria for data filtering are found in Figure 1 and Table 1 of SAE J211. These are reproduced in Table 14 for convenience. Data should be visually examined in the unfiltered state to assure that saturation or other distortion did not occur.

TABLE 14. DATA CHANNELS

Test Measurement	Channel Class	Response Range[(2)] H_z
Dummy		
Head acceleration	1000	0.1 - 1000
Chest acceleration	180	0.1 - 180
Femur force	600	0.1 - 600
Restraint system loads	60	0.1 - 60
Sled or vehicle acceleration	60[(1)]	0.1 - 60

(1) Except for component analysis use Channel Class 600 and for integration for velocity use Channel Class 180.

(2) Flat response ± 1/2 dB at low end to + 1/2 -1 dB at high end. Filter rolloff characteristics above high end are defined in SAE J211.

Instruments for dynamic measurements must have the proper frequency response range to prevent distortion of the data. In addition to adequate high-frequency response, response to 0 H_z is needed to prevent distortion of low-frequency data which is also typically found in crash data. Therefore, piezoresistive or wire strain gage devices are preferred over piezoelectric devices. Instruments should also be calibrated over the frequency range of interest. A centrifuge calibration of an accelerometer, for example, really calibrates the device under static G loading conditions. That calibration may not accurately represent the performance of the device under dynamic conditions. A dynamic calibration over the entire frequency range of interest is preferred.

Data should be presented in both analog and tabular form in compliance with the sign convention shown in Figure 5. Impact velocity should be determined and recorded for the test platform or vehicle. In the analysis of the data, velocity change should be computed through either electronic means or graphically with a planimeter by integrating the area under the measured acceleration-time trace.

The method recommended for use in establishing the acceptability of the pulse (see Section 5.10.2) and to determine other parameters associated with the data is similar to that presented in MIL-S-9479(USAF) (Reference 55). Parameters such as rise time, onset slope, and acceleration plateau duration may be obtained using the following graphic approximation technique shown in Figure 39:

- Locate the calibration baseline.
- Determine the maximum (G_p) acceleration magnitude.
- Construct a reference line parallel to the calibration baseline at a magnitude equal to 10 percent of the peak acceleration (G_p). The first and last intersections of this line with the acceleration-time plot defines points 1 and 2.
- Construct a second reference line parallel to the calibration baseline at a magnitude equal to 90 percent of the peak acceleration. The first and last intersections of this line with the acceleration-time plot define points 3 and 4.
- Some practical judgment may be required for selection of the first and last intersections depending on the degree of noise apparent in the data. Significant tendencies are important, not noise.
- Construct the onset line defined by a straight line through points 1 and 3.
- If desired, construct the offset line defined by a straight line through points 2 and 4.
- If desired, construct a line parallel to the calibration baseline, through the peak acceleration. The time interval defined by the intersections of this line with the constructed onset and offset lines (points 5 and 6) is the plateau duration (vt).
- Locate the intersection of the constructed onset line with the calibration baseline (point 7). The time interval defined by points 7 and 5 is the rise time ($t_r - t_0$). Referring to Figure 37, the rise time should be greater than t_1 but less than t_2 when determining compliance with dynamic test requirements. Point 7 in Figure 39 is the initial time t_0 in Figure 37.

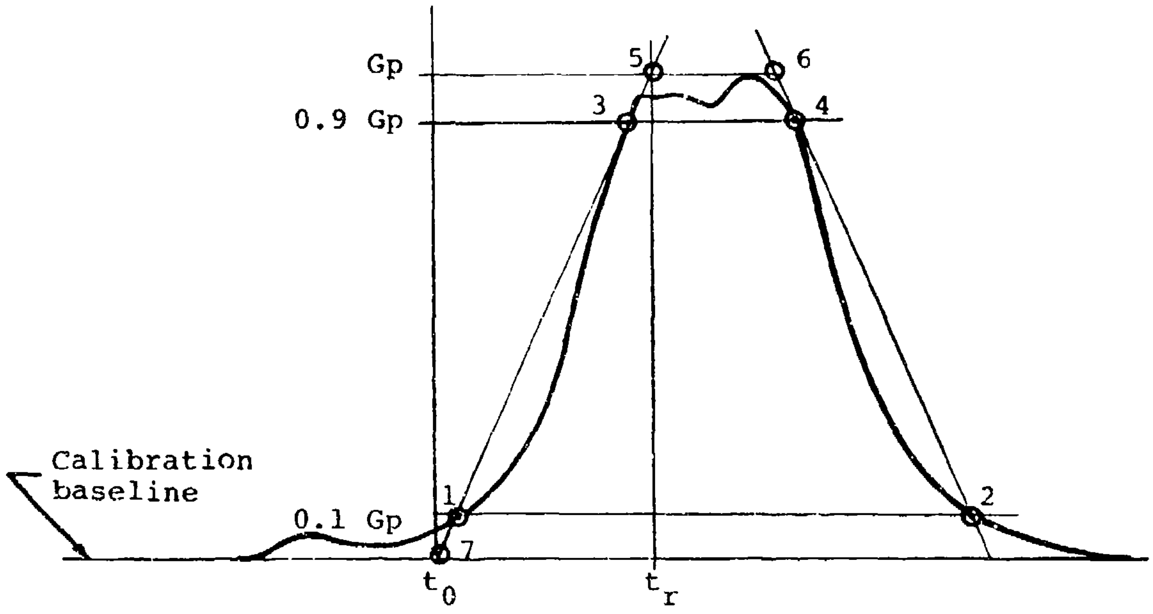


FIGURE 39. GRAPHIC APPROXIMATION EXAMPLE. (REFERENCE 55)

5.10.4 Seat Component Attachment

Since components that break free during a crash can become lethal missiles, it is recommended that attachment strengths be consistent with those specified for ancillary equipment mounted to the seat (see Volume III). Therefore, static attachment strengths for components, e.g., armored panels, should be as follows:

Downward:	50 G	Aftward:	15 G
Upward:	10 G	Lateral:	25 G
Forward:	35 G		

5.11 RETROFIT FOR SEATING SYSTEMS

5.11.1 General

If a retrofit effort is to install crash-resistant seats in an existing airframe, complex interface problems may result. This is because the seat attachment points on the airframe were not designed for the loads which will be imposed by a crash-resistant seat. The first, and preferred, approach is to calculate the loads required to support a crash-resistant seat and then determine how the floor or bulkhead should be modified to support those loads. Seat design will then proceed as discussed in previous sections. If the impact velocities of the retrofitted aircraft are significantly different from the recommended standards presented herein, then more representative velocities should be used to design the retrofitted seats.

5.11.2 Forward-Load-Limiting Seats

If, for any reason, the aircraft attachments cannot be modified to support the loads applied by a crash-resistant seat, then another approach is possible. That is to design features into the seat which will permit it to limit loads applied to the aircraft. It can be accomplished through controlled deformation of the seat structure. The technique has been used for crewseats for both the SH-3 and CH-53 helicopters. For each of these aircraft, crewseats were designed which limited loads in the forward and lateral directions as well as the downward direction. The forward and lateral load limiting protects the attachment structure and has nothing to do with human tolerance. The downward load limiting is determined by human tolerance considerations, as discussed in previous sections.

Figure 40 shows a sketch of the CH-53 crew seat. The rear struts are energy-absorbing devices which will elongate at a fixed constant load. This permits the center of gravity of the seat occupant system to move forward relative to the floor attachment and limits the attachment forces. The back view of the seat in Figure 40 shows the high elongation diagonal braces which allow the seat and occupant cg to move sideways at a controlled load. These braces simply employ the plastic stretching of metal. The seat designed for the SH-3 uses the same techniques. These seat systems are further described in References 19 and 20.

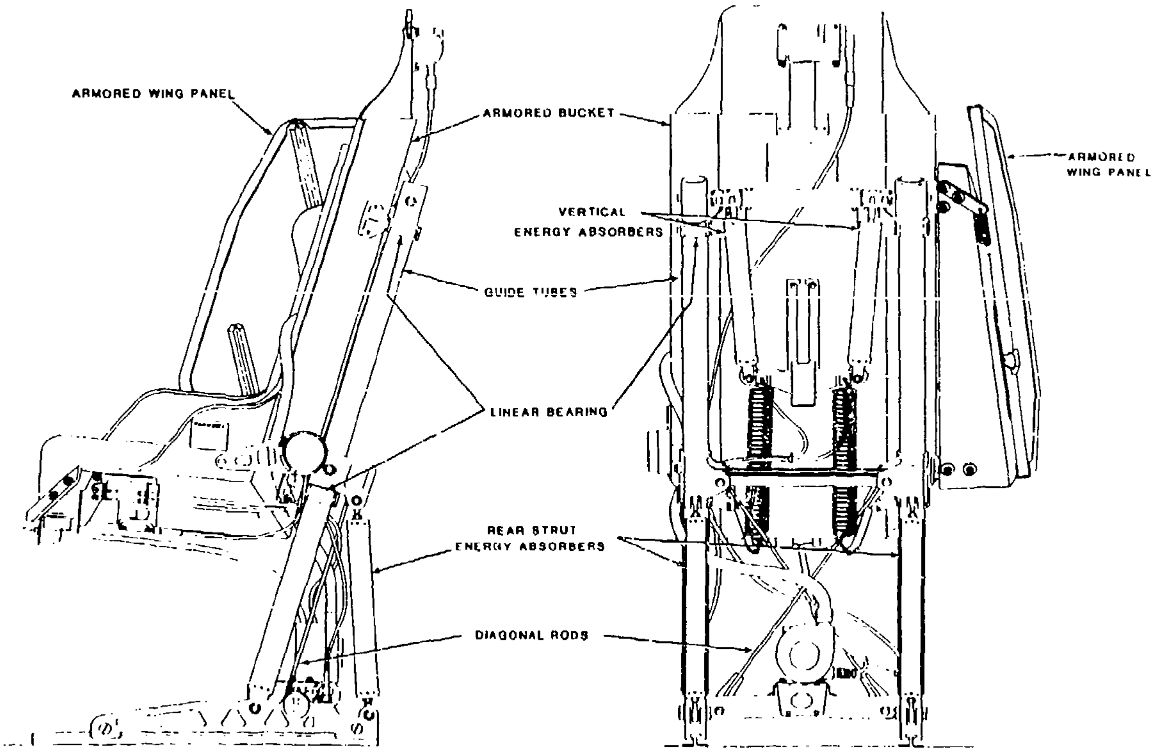


FIGURE 40. CH-53 CREW SEAT.

5.12 LITTER STRENGTH AND DEFORMATION REQUIREMENTS

5.12.1 General

The ultimate vertical strength of existing litters with a 200-lb occupant and a total system weight of 250 lb (see Section 5.12.2) is about 13 G. Since the desired decelerative loads to be imposed on these litters exceed 13 G, special techniques must be used to limit the deflection and to support some of the occupant load.

Lateral orientation in the aircraft is preferred because of the characteristics of existing restraint systems used on litters which provide more support when loaded laterally than when loaded longitudinally.

5.12.2 Recommended Occupant Weights for Litter Design

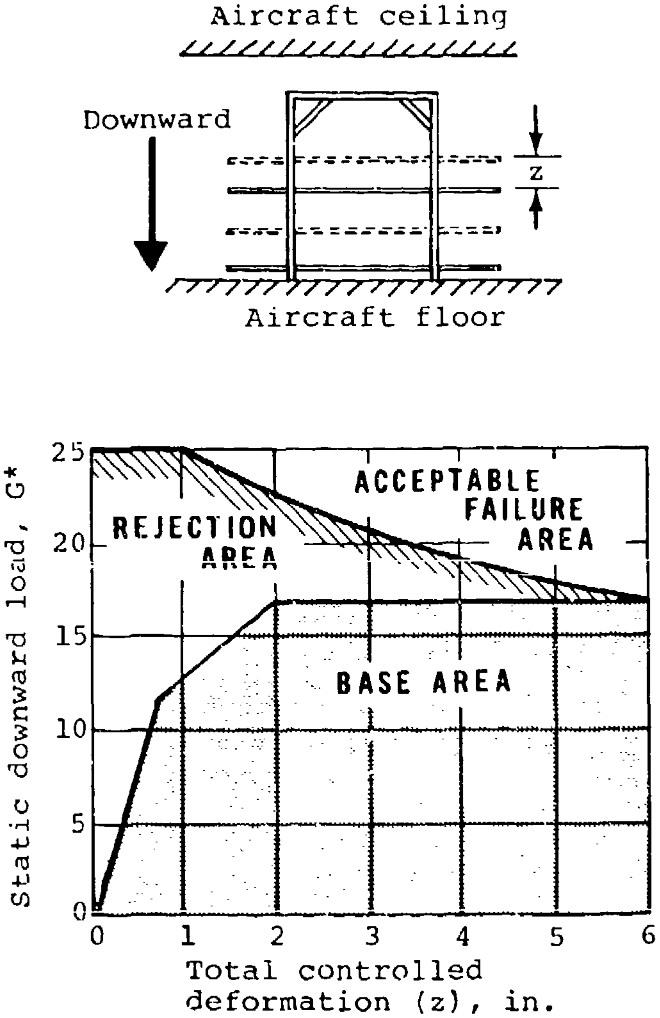
The litter strength and deformation requirements defined below are based on a 200-lb, 95th-percentile litter occupant with 20 lb of clothing and personal gear, a 10-lb splint or cast, and 20 lb of litter and support bracket weight for a total weight of 250 lb (the weight of a litter and patient as specified in MIL-A-8865 (ASG), Reference 56).

5.12.3 Vertical Loads

5.12.3.1 Downward Loads. In the case of litter systems, human tolerance is not the limiting case in the vertical direction. The loads would be applied in a transverse direction to the body of a litter occupant. However, design to the 45-G human tolerance level is impractical due to the strength requirements for litters and for the basic structure to support the litter systems.

Litters are either hung from the ceiling or supported at the floor. In either case, the input deceleration pulses are the same as for floor- or bulkhead-mounted seats. Litters should not be suspended from the overhead structure unless it is capable of sustaining, with minimum deformation, the downward loads from the tiers of litters. Therefore, in the design of an efficient system, intentional load limiting should be related to the floor pulse.

The vertical strength and deformation requirements for a litter system are detailed in Figure 41. This curve is read in the identical manner as the seat load-deflection curve shown in Figure 34. The load factors in units of G are based on the summation of the weights of the occupant plus clothing, personal gear, splint or cast, and the weight of the litter and attachment brackets for a total of 250 lb as described in Section 5.12.2. The curve of Figure 41 is based on the assumption that 3 or 4 in. of vertical deflection will occur at the midpoint of the litter. In the unlikely event that a rigid litter is used, an additional 2 in. of deflection should be added to the curve. The deflection curve is limited to 6 in., because a large deflection occurring on one corner of the litter due to an asymmetric loading could cause ejection of the litter occupant. A larger energy-absorbing stroke can be used effectively if a mechanism is included in the system to control the amount of tilt allowed. For example, a system mechanism could be designed that forced all four corners of the litter to stroke the same distance (within elastic limits) thus achieving this goal.



*G value based on 250-lb per litter position.

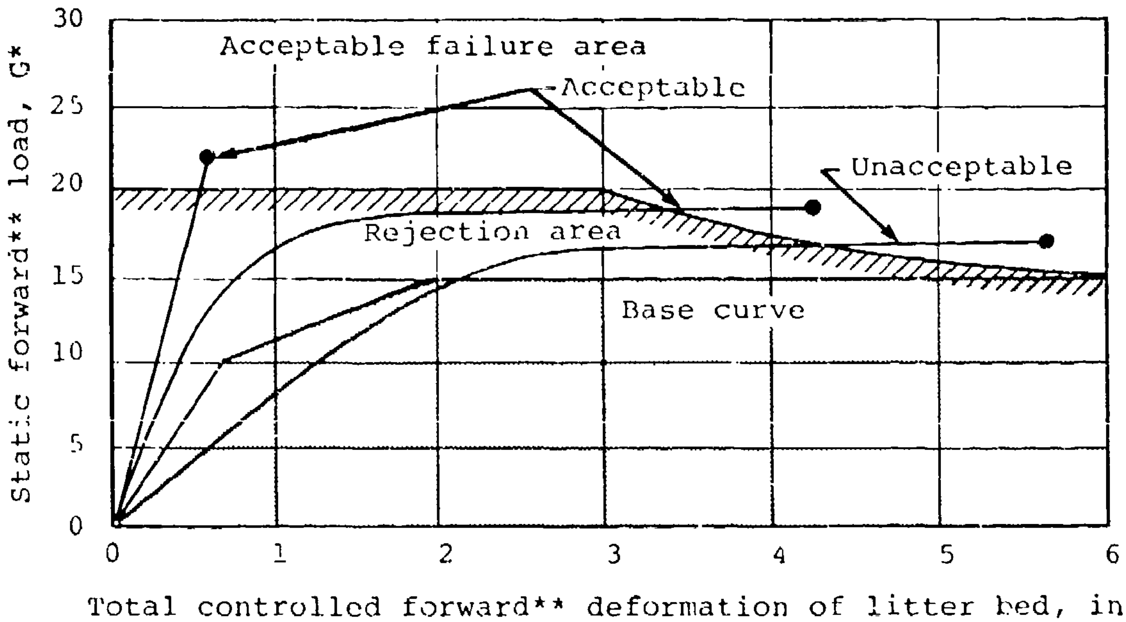
FIGURE 41. LITTER DOWNWARD LOAD AND DEFLECTION REQUIREMENTS.

The additional problem associated with inadequate litter strength must be dealt with in the design of litter systems. The curve of Figure 41 assumes a litter capable of at least 17 G with a maximum of 25 G. If the existing litter is used, then a pan, net, or other device should be included under the litter to catch and support the litter occupant if the litter fails. Actually, the device should limit the deflection to a value less than that required to fail the litter and should stroke with the litter. If all of these provisions are included, i.e., a rigid new litter or old litter with supporting pan underneath, together with the tilt-limiting mechanims, then the stroke can be extended to 12 in. at a 17-G limit-load factor. The load-deformation curve of Figure 41 would be extended at 17 G to 12 in. of stroke.

5.12.3.2 Upward Loads. All litter systems should be capable of withstanding a minimum upward load of 8 G.

5.12.4 Lateral and Longitudinal Loads

Litter systems for all military aircraft should be designed to withstand the load and deformation requirements indicated in Figure 42 in all radials of the lateral/longitudinal plane. The litter lateral loads are made equal to the longitudinal loads because the litters may be oriented in either direction depending upon the aircraft.



*G value based on 250-lb per litter position.

**Forward is the direction towards the nose of the aircraft regardless of litter orientation in the aircraft.

FIGURE 42. LITTER FORWARD OR LATERAL LOAD AND DEFLECTION REQUIREMENTS FOR ALL TYPES OF ARMY AIRCRAFT.

The 20-G acceptable load level indicated in Figure 42 is predicated on the tolerance to acceleration of an individual restrained by straps on existing "table top" litters. If litters and allied restraint harnesses are designed for improved crash resistance, the 20-G load should be increased to 25 G.

Acceptable or nonacceptable load-deformation characteristics are read from Figure 42 in the identical manner as the readings from Figures 34 and 35 for seats. The deformation is measured with respect to the aircraft floor along the longitudinal axis toward the nose of the aircraft, regardless of litter orientation.

5.12.5 Litter Restraint Harness Testing

The restraint used in existing military litters consists of two straps wrapped around the litter. These straps should withstand a straight tensile minimum load of 2000 lb (4000-lb loop strength). The maximum elongation should not be more than 3.0 in. under the straight pull (end-to-end) test on a minimum strap length of 48 in. Elongation is restricted for litter belts in order to minimize dynamic overshoot.

5.12.6 Litter System Test Requirements

5.12.6.1 Static Test Requirements

5.12.6.1.1 General. Table 15 presents the static test requirements for complete litter systems. Since previous studies have shown that existing litters will not withstand the loads as specified in this chapter, the assumption must be made that a litter of sufficient strength will be developed prior to implementing these recommendations. If a pan or net to catch the litter occupant is included in the system, it should also be included in the static testing to demonstrate its adequacy.

TABLE 15. LITTER SYSTEM STATIC TEST REQUIREMENTS

Test Ref. No.	Loading Direction With Respect to Fuselage Floor	Load Required	Deformation Requirements
1	Forward	See Figure 42	See Figure 42
2	Lateral	See Figure 42	See Figure 42
3	Downward	See Figure 41	See Figure 41
4	Upward	8 G	No requirement
5	Combined loading		
	Downward plus	See Figure 41	See Figure 41
	transverse load along any radial in the x, y plane of the aircraft	See Figure 42	See Figure 42

5.12.6.1.2 Unidirectional Tests. The test loads for forward, lateral, and downward loading of litter systems as presented in Table 15 should be applied separately.

5.12.6.1.3 Combined Loads. Litter systems must demonstrate no loss of system integrity under conditions of combined loads as specified in Table 15.

5.12.6.1.4 Point of Load Application. The loads should be applied through a body block that simulates a supine occupant.

5.12.6.1.4.1 Forward (Longitudinal) - Lateral Tests. For systems using the existing litter, a rigid simulated litter may be substituted for the actual litter. This will enable application of equal loads at all attachment points between the litter and the suspension system and allow testing of the suspension system. The rigid litter substitution does not apply if the litter system has adequate strength to take the loads.

5.12.6.1.4.2 Downward and Upward Tests. Downward and upward loads may be applied to each vertical suspension point separately. If the suspension system has the tilt-limiting features, and the litter strength is adequate, then the load should be applied at the center of gravity of the body block.

5.12.6.1.5 Deflection Measurements. Downward, forward (longitudinal), and lateral deflections should be measured at the bracket attaching the litter to the suspension system.

5.12.6.1.6 Load Determination. The test load should be determined by multiplying the required load factor (G) as specified in Table 15 by 250 lb.

5.12.6.2 <u>Litter System Dynamic Test Requirements</u>. A single test to evaluate the vertical load-limiting system is required. Litter systems with 95th-percentile anthropomorphic dummies and 30 lb of additional weight (250-lb total) in each litter should be subjected to a triangular acceleration pulse of 48-G peak and 0.054-sec duration (42-ft/sec velocity change).

The same test pulse tolerances, data, handling, and processing requirements as presented for the seats in Section 5.10.2 apply. At least three accelerometers should be placed in the dummy; one in the head, one in the chest, and one in the pelvic region. The instruments should be positioned to sense accelerations in the vertical directions (x-axis of the supine occupant, z-direction relative to the aircraft). The input acceleration-time pulse also should be measured. It is advisable to use redundant accelerometers to sense the input pulse to assure acquisition of the needed impact environment data.

5.13 DELETHALIZATION OF COCKPIT AND CABIN INTERIORS

5.13.1 General

The kinematics of body action associated with aircraft crash impacts are quite violent, even in accidents of moderate severity. The occupant's immediate environment should be designed so that, when the body parts do flail and contact rigid or semi-rigid structures, injury potential is minimized.

Several approaches are available to alleviate potential secondary impact problems. The most direct approach, which should be taken if practical, is to relocate the hazardous structure or object out of the occupant's reach. Such action is normally subject to trade-offs between safety and operational or human engineering considerations. If relocation is not a viable alternative, the hazard might be reduced by mounting the offending structure on frangible or energy-absorbing supports and applying a padding material to distribute the contact force over a larger area on the body member.

5.13.2 Occupant Strike Envelopes

5.13.2.1 Full Restraint. Body extremity strike envelopes are presented in Figures 43 through 45 for a 95th-percentile Army aviator wearing a restraint system that meets the requirements of MIL-S-58095 (Reference 15). The restraint system consists of a lap belt, lap belt tiedown strap, and two shoulder straps. The forward motion shown in Figures 43 and 44 was obtained from a test utilizing a 95th-percentile anthropomorphic dummy subjected to a spineward ($-G_x$) acceleration of 30 G. The lateral motion is based on an extrapolation of data from the same 30-G test. In positions where an occupant is expected to wear a helmet, the helmet dimensions must be added to the envelope of head motion.

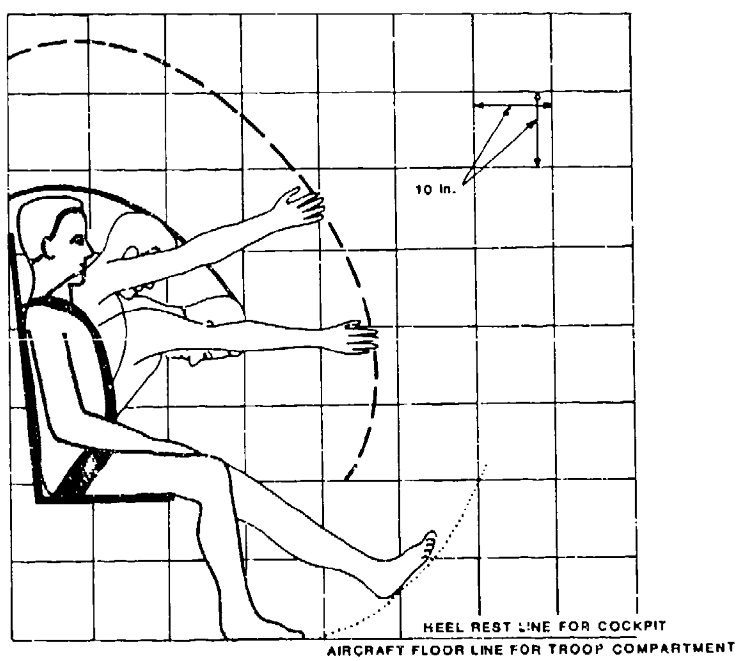


FIGURE 43. FULL-RESTRAINT EXTREMITY STRIKE ENVELOPE - SIDE VIEW.

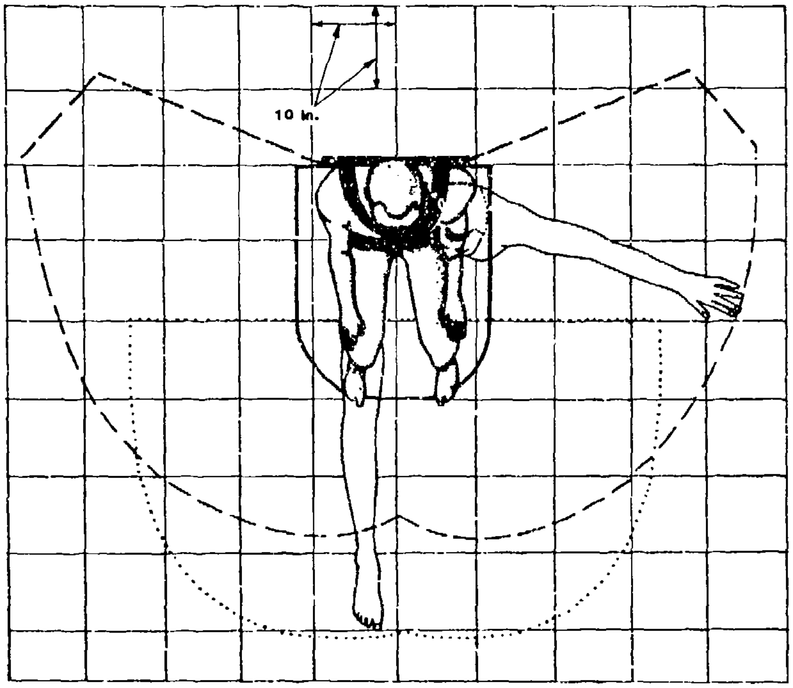


FIGURE 44. FULL-RESTRAINT EXTREMITY STRIKE ENVELOPE - TOP VIEW.

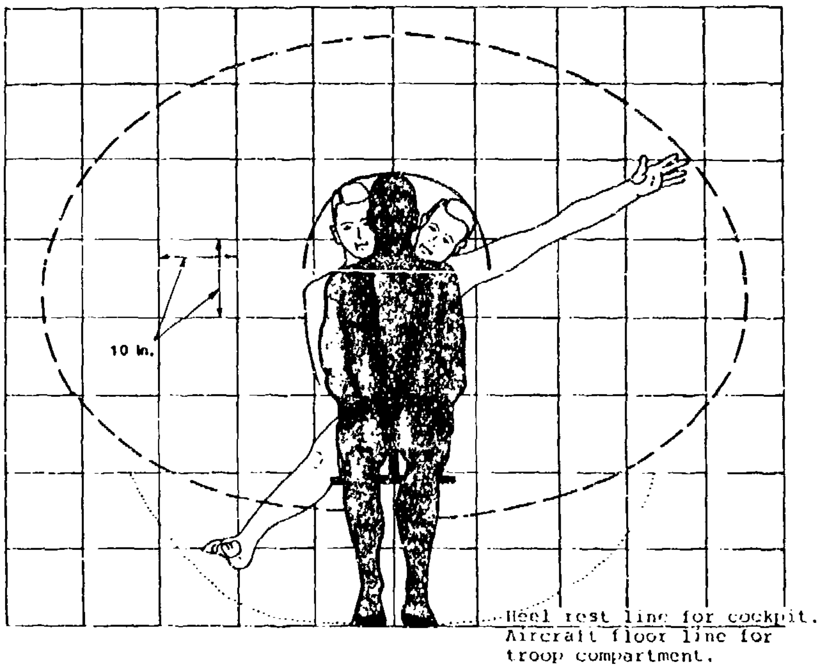


FIGURE 45. FULL-RESTRAINT EXTREMITY STRIKE ENVELOPE - FRONT VIEW.

5.13.2.2 <u>Lap-Belt-Only Restraint</u>. Although upper torso restraint is required in new Army aircraft, strike envelopes for a 95th-percentile aviator wearing a lap-belt-only restraint are presented in Figures 46 through 48 for possible use. They are based on 4-G accelerations and 4 in. of torso movement away from the seat laterally and forward. In positions where an occupant is expected to wear a helmet, the helmet dimensions must be added to the envelope of head motion.

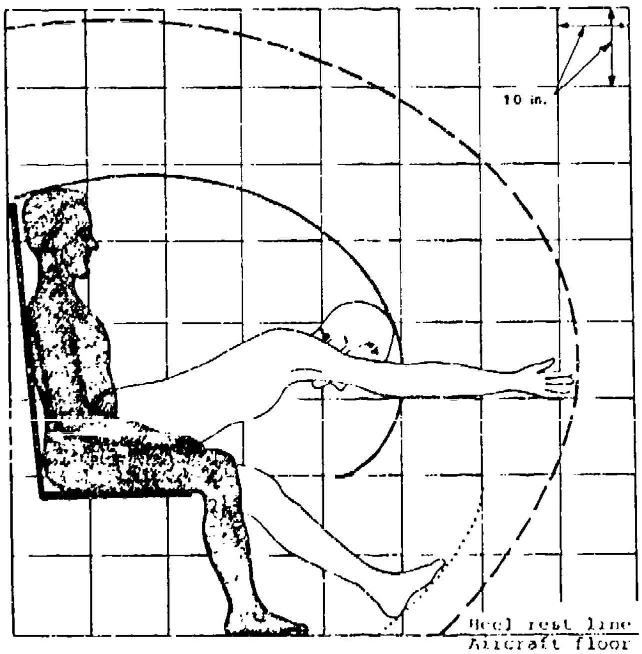


FIGURE 46. LAP-BELT-ONLY EXTREMITY STRIKE ENVELOPE - SIDE VIEW.

5.13.2.3 <u>Seat Orientation</u>. The strike envelopes of Figures 43 through 48 apply to all seat orientations.

5.13.3 <u>Head Strike Envelope in Stroking Seats</u>

The head strike envelope for a stroking energy-absorbing seat is obviously exaggerated relative to the above diagrams. Reference 57 describes some simulations which were performed to evaluate the head strike envelope in this situation. Additional information may be found in Volume IV.

5.13.4 <u>Environmental Hazards</u>

5.13.4.1 <u>Primary Hazards</u>. The primary environmental hazards are those rigid or semirigid structural members within the extremity envelope of the head and chest. Since the upper torso, and particularly the head, is the most vulnerable part of the body, maximum protection must be provided within its strike envelope.

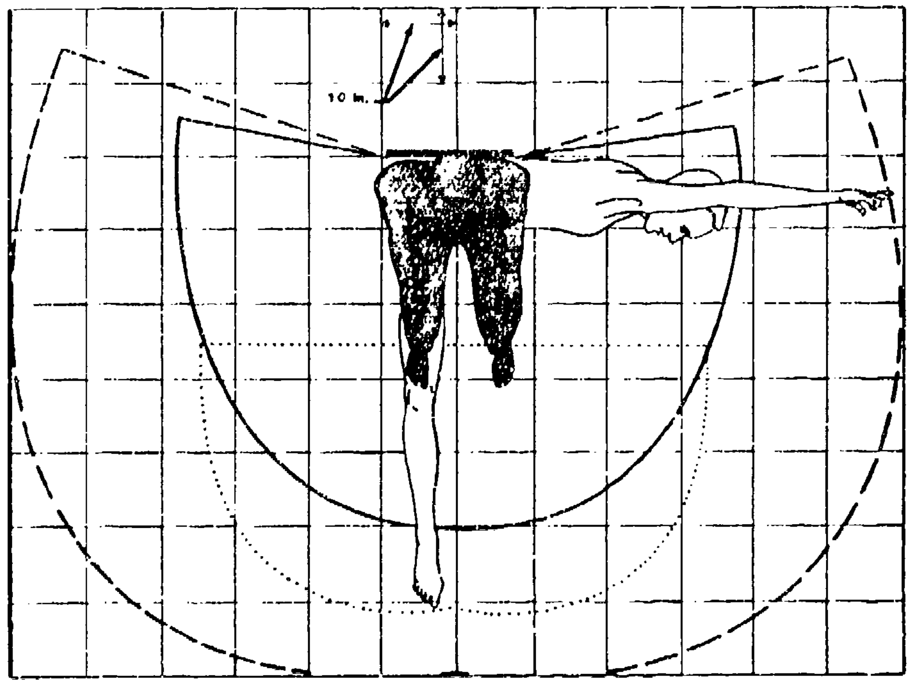


FIGURE 47. LAP-BELT-ONLY EXTREMITY STRIKE ENVELOPE - TOP VIEW.

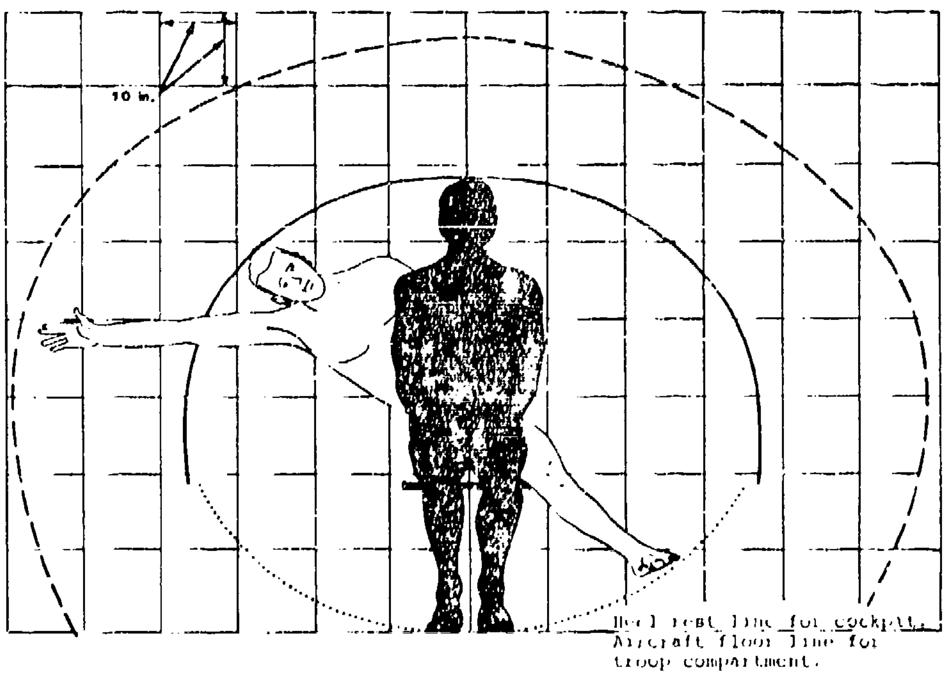


FIGURE 48. LAP-BELT-ONLY EXTREMITY STRIKE ENVELOPE - FRONT VIEW.

5.13.4.2 Secondary Hazards. Secondary environmental hazards are those that could result in trapping or injuring the lower extremities to the extent that one's ability to rapidly escape would be compromised. Areas within the lower extremity strike envelope must also include ample protective design.

5.13.4.3 Tertiary Hazards. Tertiary environmental hazards are those rigid and semirigid structural members that could cause injury to flailing upper limbs to an extent that could reduce an occupant's ability to operate escape hatches or perform other essential tasks.

5.13.5 Head Impact Hazards

5.13.5.1 Geometry of Probable Head Impact Surfaces. Typical contact hazards in the cockpit area include window and door frames, consoles, controls and control columns, seat backs, electrical junction boxes, glare shields, and instrument panels. Contact hazards commonly found in aircraft cabin areas include window and door frames, seats, and fuselage structure. Use of suitable energy absorbing padding materials, frangible breakaway panels, smooth contoured surfaces, or ductile materials in the typical hazard areas mentioned is recommended to reduce the injury potential of occupied areas.

5.13.5.2 Tolerance to Head Impact. Protection of the head in the form of protective helmets and energy-absorbing structure and padding in the occupant's immediate environment is essential.

Tolerance levels for head impact are discussed in detail in Volume II, and the reader should refer there for an understanding of the problem. However, for the case of forehead impact on a flat surface, which is pertinent to the discussion of this section, the most widely accepted collection of tolerance data is represented in the tolerance curve of Figure 49 (Reference 58).

5.13.5.3 Test Procedures. The simplest test procedure for evaluating the effectiveness of protective structure and padding in preventing serious head injury makes use of an instrumented headform. The headform, equipped with an accelerometer, can be propelled by a ram, dropped, or swung on a pendulum to impact the surface to be evaluated. This procedure is described in SAE J921 (Reference 59). The measured acceleration pulse can be averaged for comparison with the Wayne State Tolerance Curve, or integrated to compute a Severity Index, as discussed in Section 5.4.1 of Volume II.

Another approach is to use simulations or tests of the entire occupant seat system. Section 11.4.5 of Volume IV presents information on this approach.

5.13.6 Instrument Panel Structure Proximity

In most aircraft cockpits, the instrument panel and its supporting structure are placed directly above the pilot's lower legs. The danger of impact from this proximity dictates that designers consider using suitable energy-absorbing padding materials, frangible breakaway panels, or ductile panel materials for structure within the lower leg strike envelope.

As discussed in Section 11.5.1 of Volume IV, the use of a fiberglass instrument glare shield may be used as an alternative to padding or to provide additional protection from protruding instruments.

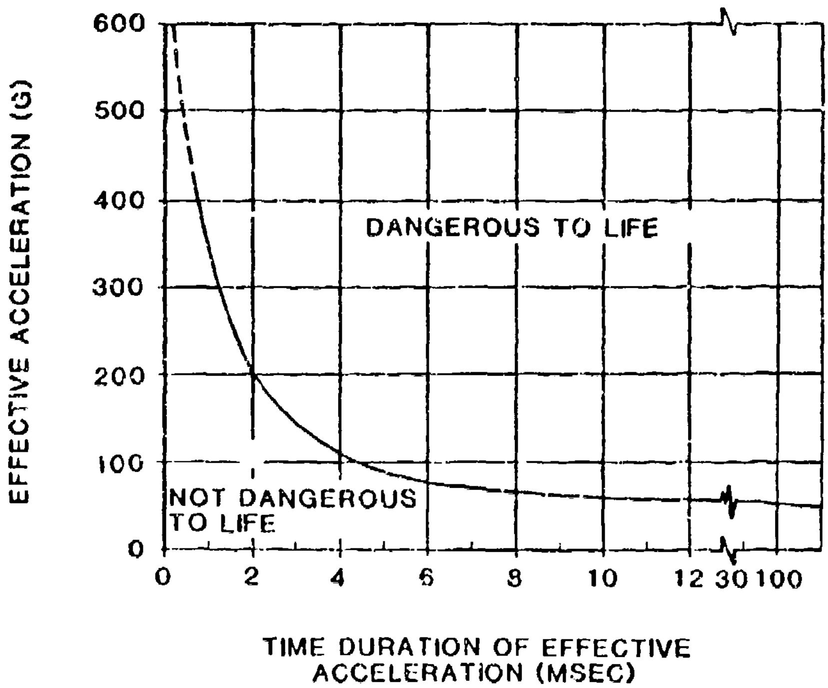


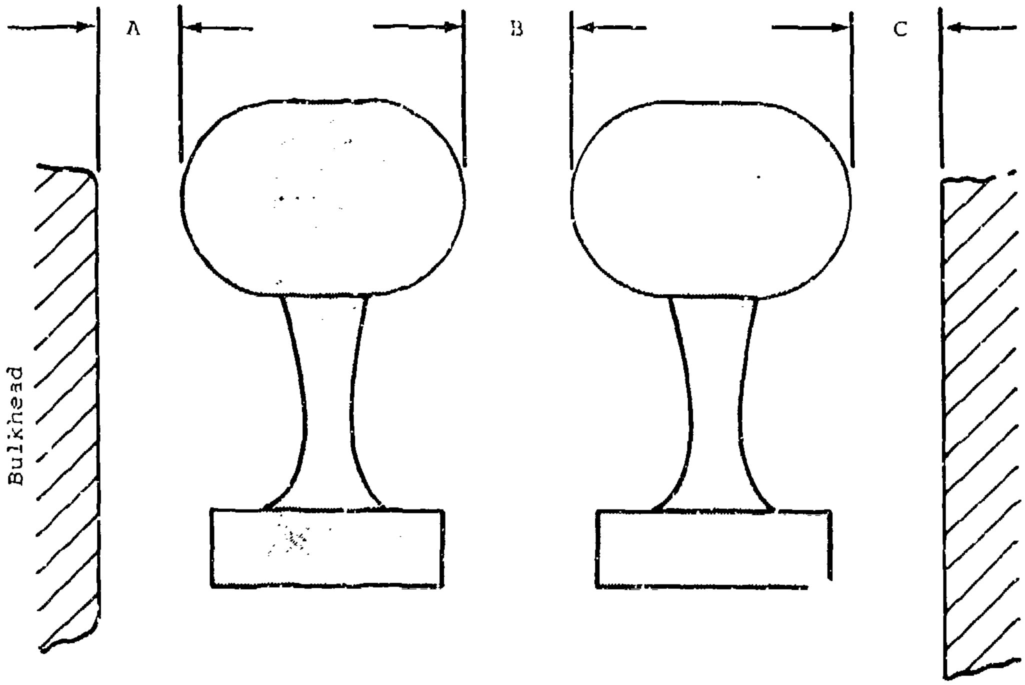
FIGURE 49. WAYNE STATE TOLERANCE CURVE FOR THE HUMAN BRAIN IN FOREHEAD IMPACTS AGAINST PLANE, UNYIELDING SURFACES. (REFERENCE 58)

5.13.7 Rudder Pedal Configuration

Rudder pedals should be capable of supporting both the ball of the foot and the heel, and provide a surrounding structure of sufficient strength to prevent crushing and trapping of the lower limbs. The geometry required by MIL-STD-1290 (Reference 1) to prevent entrapment of feet is illustrated in Figure 50.

5.13.8 Controls and Control Columns

Control columns located in front of flight crew stations can present a serious hazard to crewmembers if they fail at any appreciable distance above the aircraft floor. The failure should occur in the form of a clean break, leaving no jagged or torn edges. Control columns that pass longitudinally through the instrument panel are not recommended since these tend to impale the crewmembers in severe longitudinal impacts. However, where they are used they should be equipped with a frangible or energy-absorbing section similar to automotive steering columns.



Dimensions A, B, and C must be either
less than 2 in. or more than 6 in.

FIGURE 50. ANTITORQUE, OR RUDDER, PEDAL GEOMETRY TO PREVENT ENTRAPMENT OF FEET.

The cyclic control stick is an example of a lethal object which may be involved in head impacts. This hazard may be increased if stroking energy-absorbing seats are installed, because, as the seat strokes, the crewmember's head comes closer to the stick. Section 11.7 of Volume IV discusses means of delethalizing the stick.

5.13.9 Sighting and Visionic Systems

Delethalization of the copilot/gunner (CPG) station of an attack or scout helicopter equipped with a weapon sighting optical relay tube (ORT) can present a difficult design problem. The cockpit should be designed to minimize the probability of the CPG head/neck striking the ORT and minimize injury if the CPG should strike the ORT, for both the "head-up" and "head-down" CPG positions. Some of the options available to the designer given this task are:

- ORT Eyepiece Relocation - Consideration should be given to reducing occupant strike hazards by moving the ORT farther away from the CPG.

- <u>Restraint System</u> - The restraint system of Figure 24 would offer improved upper torso restraint, particularly when combined with the power-haulback inertia reel.

- <u>Inflatable Restraint</u> - Consideration should be given to the inflatable restraint system (IBAHRS) discussed in Section 5.7.2.4. This type of restraint harness can prevent injury to the CPG in both the erect and head-down position by reducing slack, supporting the head, and increasing the surface area of the body over which the harness reacts.

- <u>Frangible/Breakaway Features</u> - ORT or ORT components designed to be frangible should break away at a total force not to exceed 300 lb. For the frangible ORT, this force should be applied along any direction of loading within the plane normal to the axis of the ORT, as well as along the axis of the ORT. Breakaway point(s) of the ORT should be outside the head strike envelope.

- <u>Collapsible Features</u> - If the ORT is designed to collapse in order to avoid injuring the CPG, the collapse load along the axis of the ORT should not exceed 300 lb. Figure 51 illustrates one crushable sight eyepiece concept (from Reference 60). Two advantages of the crushable sight eyepiece are that it is always available and, it should function regardless of head location. A helmet crash-absorber pad would attenuate crash loads to the helmet when available crushing is expended.

- <u>Power-Haulback Inertia Reel (PHBIR)</u> - On the basis of Air Force testing accomplished for the development of PHBIR, the retraction time is 0.3 to 0.4 sec, which is too slow for effectiveness in most crashes. If this time were reduced, the retraction velocity of the torso would have to be increased considerably over the current limit of 9 ft/sec. A retraction velocity greater than this is not recommended due to the lack of human tolerance data on this type of loading. In a crash with a single pulse of 30-G peak and 50-ft/sec velocity change, the retraction velocity should be approximately 25 ft/sec; therefore, the known tolerance limits would be exceeded at the higher velocity. In summary, the PHBIR, as currently qualified under both Air Force and Navy military specifications, requires excessive time to position the torso by crash sensing. To be fully effective, the system should move the torso into position in approximately 0.06 sec, but the resulting acceleration would exceed known human tolerance limits. The primary crash-resistance advantage of the PHBIR would be as a manually activated tightening device for the head-up CPG position; the PHBIR offers only limited advantage for the headdown CPG position.

5.13.10 <u>Energy-Absorbing Requirements for Cockpit and Cabin Interiors</u>

5.13.10.1 **<u>General</u>**. To minimize occupant injury, the acceleration experienced during secondary impacts of the occupant with surrounding structures must be reduced to a tolerable level. The areas of contact to be considered for energy absorption include instrument panels, glare shields, other interior surfaces within the occupant's strike envelope, and seat cushions. A padding material should not only reduce the decelerative force exerted on an

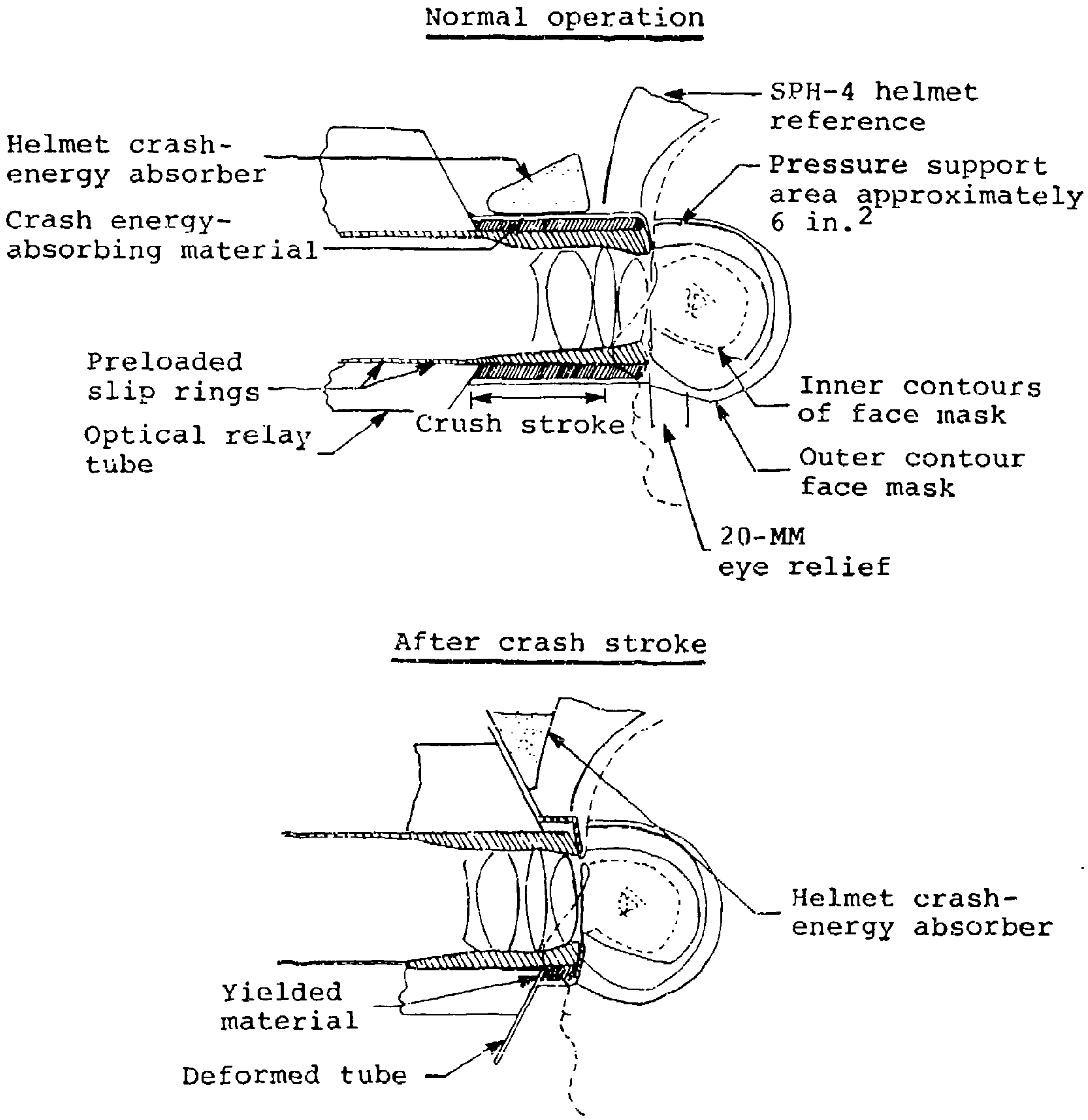


FIGURE 51. CRUSHABLE EYEPIECE CONCEPT. (REFERENCE 60)

impacting body segment but should distribute the load in order to produce a more uniform pressure of safe magnitude.

In order to prevent head injury, materials must be carefully selected to absorb and attenuate the energy of impact. The material must reduce the level of acceleration, the rate of onset, and the amount of energy transmitted to the head.

5.13.10.2 Padding Material Properties. The selection of a foam material for vehicle energy-absorbing applications involves an evaluation of its processability; its mechanical, thermal, and chemical properties; as well as its cost. Along with the primary foam materials, the characteristics of adhesives and surface coatings must be considered, particularly with respect to emission of smoke and toxic vapors. The characteristics of suitable materials for such use are listed below:

- Adaptability and ease of processing
- High energy dissipation
- Effective load distribution
- Low rebound
- Temperature insensitivity
- Resistance to chemicals, oil, ultraviolet radiation, and sunlight
- Nontoxic fume generation
- Favorable flammability rating
- Minimal smoke generation
- Durability and long life
- Cost competitive
- Aesthetically acceptable.

5.13.10.3 <u>Standard Test Methods</u>. ASTM standard test procedures are widely used by manufacturers to specify various properties of a particular type of material. Table 16 summarizes ASTM test methods and specifications for flexible cellular plastics that provide a basis for comparison of materials. Here it may be noted that most ASTM tests involve simple tests, whereas the operational environment involves dynamic loading and more complex conditions.

In particular, ASTM D 1564-71 describes "Standard Methods of Testing Flexible Cellular Materials-Slab Urethane Foam" (Reference 61). Among other tests, there are compression-set and load-deflection tests.

The above tests provide results that specify the material, but do not necessarily portray its performance under actual impact situations. A simple dynamic drop test, such as ASTM D1596-64 (1976), "Standard Test Method for Shock-Absorbing Characteristics of Package Cushioning Materials" (Reference 62), more closely simulates actual impact conditions.

Other standard test procedures include SAE J815, "Load Deflection Testing of Urethane Foams for Automotive Seating" (Reference 63), which points out the factors of interest in testing materials for vehicle seat cushions: the thickness of the padding under the average passenger load, a measurement that indicates the initial softness, and a measurement that indicates resiliency.

Also, SAE J388, "Dynamic Flex Fatigue Test for Slab Urethane Foam" (Reference 64), describes procedures for evaluating the loss of thickness and the amount of structural breakdown of slab urethane foam seating materials.

SAE J921, "Motor Vehicle Instrument Panel Laboratory Impact Test Procedure - Head Area," describes a test procedure for evaluating the head impact characteristics of such areas as instrument panels (Reference 59).

5.13.10.4 <u>Acceptable Stress-Strain Characteristics</u>. Energy-absorbing materials with stress-strain curves that fall between the limits shown in Figure 52 will offer reasonable survival potential for head impacts at velocities of up to 22 ft/sec where a padding thickness of 2.0 in. is used.

TABLE 16. SUMMARY OF ASTM TEST METHODS AND SPECIFICATIONS FOR FLEXIBLE CELLULAR PLASTICS (REFERENCE 61)

D1564-71*	Testing Flexible Cellular Materials - Slab Urethane Foam
D1667-76*	Specification for Flexible Cellular Materials - Vinyl Chloride Polymers and Copolymers (Closed-Cell Sponge)
D1565-76*	Specifications for Flexible Cellular Materials - Vinyl Chloride Polymers and Copolymers (Open-Cell Foam)
D1055-69* (1975)	Specification for Flexible Cellular Materials - Latex Foam
D1056-73*	Specification for Flexible Cellular Materials - Sponge or Expanded Rubber
D3575-77	Testing Flexible Cellular Materials Made from Olefin Plastics
D1596-64* (1976)	Test for Shock-Absorbing Characteristics of Package Cushioning Materials
D2221-68* (1973)	Test for Creep Properties of Package Cushioning Materials
D1372-64* (1976)	Testing Package Cushioning Materials
D696-70*	Test for Coefficient of Linear Thermal Expansion of Plastics
E143-61* (1972)	Test for Shear Modulus at Room Temperature
D412-75*	Tests for Rubber Properties in Tension
D1433-76*	Test for Rate of Burning and/or Extent and Time of Burning of Flexible Thin Plastic Sheeting Supported on a 45-degree Incline
D1692-76	Test for Rate of Burning and/or Extent and Time of Burning of Cellular Plastics Using a Specimen Supported by a Horizontal Screen

*Indicates that the standard has been approved as American National Standard by the American National Standards Institute.

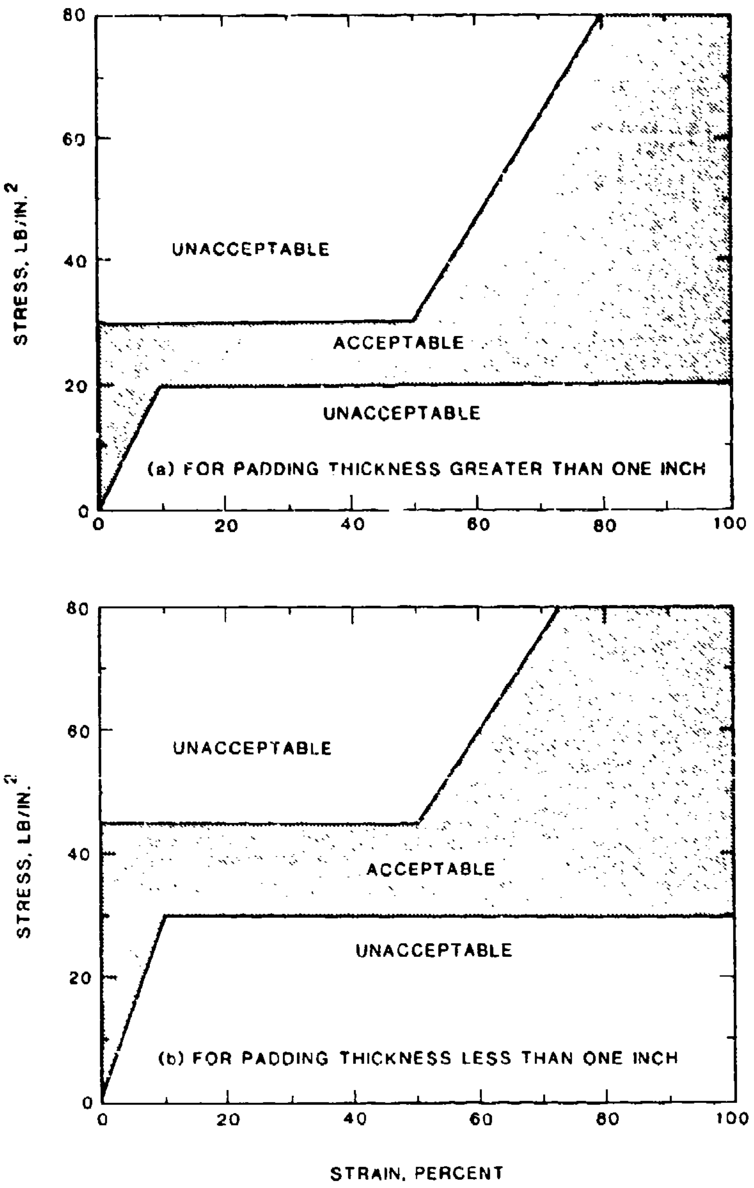


FIGURE 52. RECOMMENDED STRESSS-STRAIN PROPERTIES FOR PADDING MATERIAL FOR HEAD CONTACT WITH CUSHION THICKNESS OF AT LEAST 1.5 IN.

The impact surface is assumed to be flat; the data from which Figure 52 was developed were obtained for simulated head impacts on flat surfaces with energy levels up to 84 ft-lb, i.e., 11.2-lb head weight x 7.5-ft drop height. The acceleration of the head should not exceed 120 G at an impact velocity of 20 ft/sec (or greater) while a higher level of acceleration can be sustained at lower velocities (shorter pulse duration). This accounts for the different stress-versus-strain values shown in Figure 52, i.e., a higher G or crush stress is acceptable at the lower design velocity expected for the thin padding.

The criteria of Figure 52 are to be satisfied by the padding material over the entire anticipated operating temperature range if the potential for survival is to be maintained. However, practical considerations and risk analysis may reduce the temperature range requirements. Temperature sensitivity must be considered as a padding material selection criterion. Other padding material evaluation methods are discussed in Section 11.9.4 of Volume IV.

Stress-strain curves for several polyurethane-foamed plastics are shown in Figure 53. The curves show that a density of 3 lb/ft^3 or less will satisfy the criteria of Figure 52 (superimposed as a crosshatched area) over at least part of the operational temperature range.

5.13.10.5 Application of Padding Material. In the absence of data for extremity impacts, it is assumed that padding material that is suitable for head impact protection will be suitable also for protecting extremities. Extremity impacts are not likely to have the potentially severe effects of head impacts. It is suggested that areas within the extremity strike envelope having radii of 2 in. or less be padded and that such padding have a minimum thickness of 0.75 in.

Caution must be exercised in padding sharp edges and corners. Padding installed in a manner that allows it to be broken away from the corner or cut through by sharp edges offers no protection. It is recommended that edges and corners to be padded have a minimum radius of 0.5 in. prior to padding. A definite volume of the padding must be crushed to absorb the initial kinetic energy of the head and protective helmet.

5.13.10.6 Ductile Materials. In cases where the use of padding material is impractical or the thickness allowed is inadequate to provide the necessary protection, ductile energy-absorbing materials or frangible breakaway panels should be used where possible. Window and door frames, control columns, electrical junction boxes, etc., should be designed with large radii (1 in. or more) rather than with sharp edges and corners.

Swearingen concluded in Reference 65 that at impact velocities of 30 ft/sec against rigid structure padded with materials even 6 in. thick, unconsciousness, concussion, and/or fatal head injuries will be produced. Where possible, a combination of deformable structure and padding material should be considered to absorb the impact energy and to adequately distribute the forces over the face. Surfaces to which this combination should be applied are instrument panels, seat backs, bulkheads, and any other structure that the head may impact during the crash sequence.

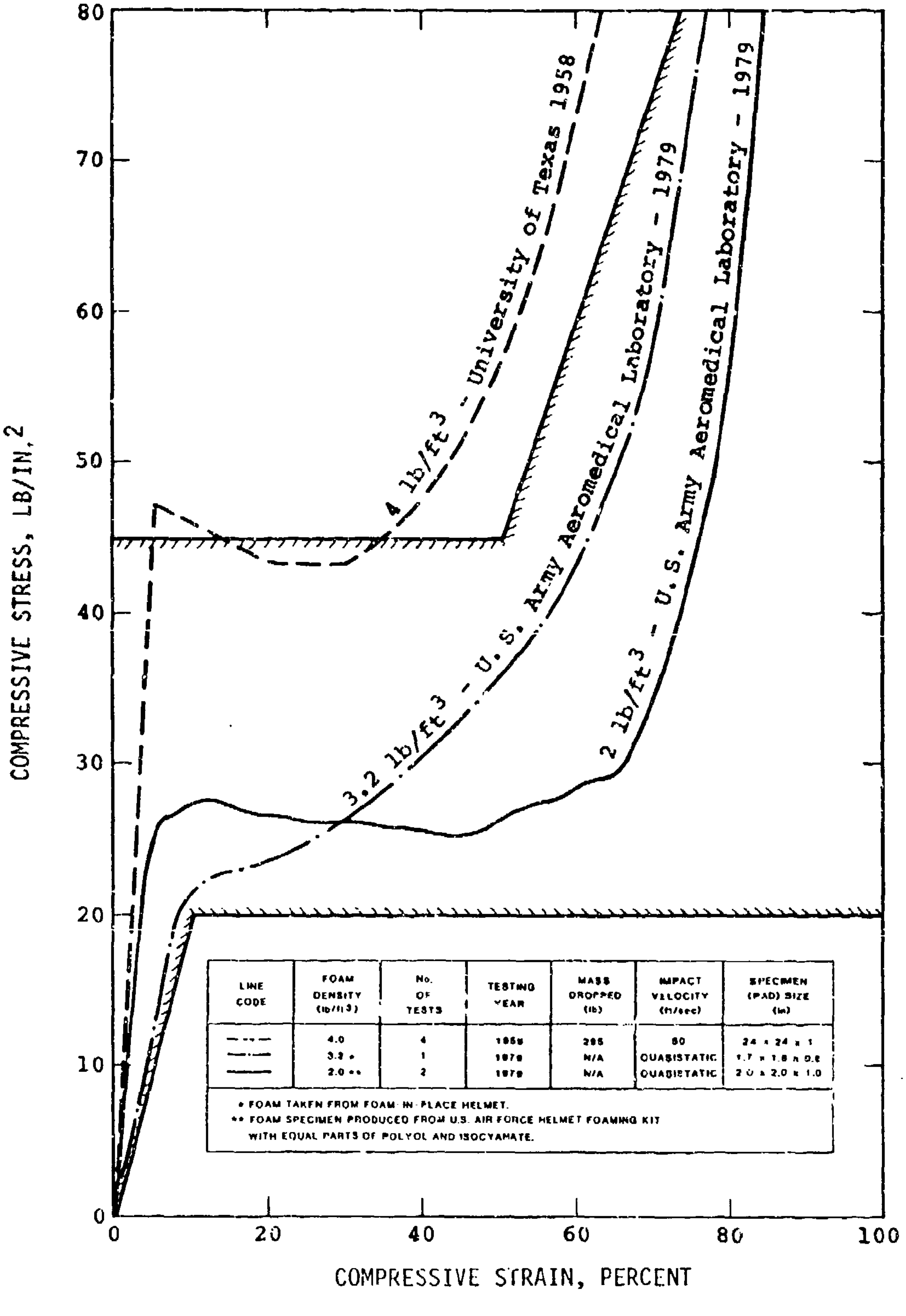


FIGURE 53. EFFECT OF DENSITY ON STRESS-STRAIN CURVES FOR POLYURETHANE-FOAMED PLASTIC.

5.14 DESIGN CHECKLISTS

5.14.1 General Design Checklist

	Yes	No	N/A
1. For load-limited seats, do all materials in critical structural members possess a minimum elongation of 5 percent in the principal load direction?	___	___	___
2. For nonload-limited seats, do materials in critical structural members possess a minimum of 10 percent elongation?	___	___	___
3. Is there adherence to the flammability and toxicity requirements of Chapter 6?	___	___	___
4. In load-limited portions of the seat, where loads can be predicted accurately, are minimum margins of safety for shear and tensile bolts 5 and 10 percent, respectively?	___	___	___
5. In nonload-limited portions of the seat, are minimum margins of safety for shear and tensile bolts 15 and 25 percent, respectively?	___	___	___
6. In the vicinity of welded joints, have cross-sectional areas been increased by 10 percent to account for uncertainties, stress concentrations, etc.?	___	___	___
7. Have seat attachments been designed so that neither buckling nor warping of the floor or bulkhead will interfere with seat operation or seat integrity in a crash?	___	___	___
8. Has the restraint system anchorage been designed so that the restraint system will function effectively as the seat strokes?	___	___	___
9. Is the use of castings avoided in the primary seat structure?	___	___	___
10. If castings are used, are they sufficiently ductile, or does the design allow for realistic seat deformation during crash load application without failure of the castings?	___	___	___
11. Do nonmetallic materials comply with FAR 25?	___	___	___
12. Can troop seats be removed in 20 sec per occupant position?	___	___	___

	Yes	No	N/A

5.14.2 Seat Strength and Deformation Checklist

1. Does the seat meet the longitudinal load-deformation requirements of Figure 34? ___ ___ ___
2. Will the seat withstand a 12-G aftward load? ___ ___ ___
3. Is the vertical energy-absorption system designed for a load factor of 14.5 G based on the effective weight of the 50th-percentile aviator or trooper? ___ ___ ___
4. Does the crew seat possess a minimum vertical stroke distance of 12 in. (from the lowest vertical adjustment position)? ___ ___ ___
5. Has the use of a variable-force energy absorber been considered? ___ ___ ___
6. Does the troop seat possess a minimum of 17 in. of vertical stroke? ___ ___ ___
7. Does the seat have a capability of withstanding an upward load of 8 G? ___ ___ ___
8. Does the seat meet the lateral load-deformation requirements of Figure 35? ___ ___ ___
9. Are the static attachment strengths for components mounted on the seat, such as armored panels, based on the following load factors:
   - Downward: 50 G
   - Upward: 10 G
   - Forward: 35 G
   - Aftward: 15 G
   - Lateral: 25 G

   ___ ___ ___

5.14.3 Seat Cushions Checklist

1. Are seat cushions of the type that minimize dynamic overshoot in vertical deceleration? ___ ___ ___
2. Is the thickness of the compressed seat cushion between 0.5 and 0.75 in., or has it been demonstrated that the cushion design and material properties produce a beneficial result? ___ ___ ___

	Yes	No	N/A
5.14.4 Litter Strength and Deformation Requirements Checklist			
1. Does the litter system possess the vertical strength-deformation capability of Figure 41, based on an occupant weight of 250 lb?	___	___	___
2. Does the litter system possess the capability of withstanding an upward load of 8 G?	___	___	___
3. Does the litter system meet the lateral load-deformation requirements of Figure 42?	___	___	___
4. Can the litters be loaded laterally into the aircraft?	___	___	___
5. Can the complete set of litters be loaded and unloaded to flight readiness in 10 sec or less in an emergency situation?	___	___	___
6. Does the litter system eliminate need for special mounting hardware that remains attached to the aircraft?	___	___	___
7. Can the standard cargo tiedown system be used as the primary litter system attachment to the aircraft structure?	___	___	___
8. Will the litter installation accept the current standard military litter?	___	___	___
9. Does the installation support the litter in such a manner as to develop the maximum load-carrying capability of the standard litter?	___	___	___
10. Would the litter installation be adaptable to a new and improved military litter design?	___	___	___
11. Does the litter installation, when removed from the aircraft, leave the aircraft free of all protuberances, brackets, and other objectionable operational hazards?	___	___	___
5.14.5 Restraint System Design Checklist			
1. Are the lap belt anchor points located so that a maximum angle of 55 degrees and a minimum angle of 45 degrees exists between the lap belt and the buttock reference line, as illustrated in Figure 29?	___	___	___
2. Is the point where the shoulder harness is attached to or passes through the seat back between 26.5 and 27.5 in. above the seat reference point?	___	___	___

	Yes	No	N/A
3. Does the shoulder harness anchorage or guide on the seat back permit no more than 0.5-in. lateral clearance?	___	___	___
4. Does the shoulder harness guide on the seat back have a 0.25-in. minimum radius as illustrated in Figure 32?	___	___	___
5. Is the lap belt tiedown strap (crotch strap) attached to the seat pan centerline at a point 14 to 15 in. forward of the seat back?	___	___	___
6. Are the forces required for adjustment of all webbing item lengths no greater than 30 lb?	___	___	___
7. Are the lap belt adjusters located so as to not exert pressure on the iliac crests?	___	___	___
8. Are the shoulder strap adjusters located low enough on the chest to avoid concentrated pressure on the collar bones?	___	___	___
9. Do the restraint harness subassemblies meet the minimum load and maximum elongation requirements of Table 8?	___	___	___
10. Have the stitched joints in the restraint harness been designed according to the criteria discussed in Section 5.7.4.3 and do the joints have a 30-percent margin?	___	___	___
11. Is a minimum webbing thickness of 0.045 in. used on all restraint harness components?	___	___	___
12. Do the restraint harness components meet the following minimum width requirements: • Lap Belt - 2.00 in. • Shoulder strap - 2.00 in. • Tiedown Strap - 1.75 in.	___	___	___
13. Do all webbing fittings, over which webbing is wrapped, possess the 0.062-in. minimum radius illustrated in Figure 32?	___	___	___
14. Does the restraint harness have a single-point release system that can be released after being exposed to design crash loads by exerting a 30-lb force with one finger or a 50-lb force with one finger when supporting the entire weight of the occupant?	___	___	___

	Yes	No	N/A
15. Is the single-point release protected from inadvertent release?	___	___	___

5.14.6 Protective Padding Checklist

	Yes	No	N/A
1. Are all areas within the extremity strike envelope, having radii of 2 in. or less, padded with a minimum thickness of 0.75 in.?	___	___	___
2. Do padded corners of edges have a minimum unpadded radius of 0.5 in.?	___	___	___
3. Are ductile energy-absorbing supports used where possible under padding, particularly where head impact is likely?	___	___	___

5.14.7 Cockpit Controls and Equipment Checklist

	Yes	No	N/A
1. Are rudder pedals separated from each other and from adjacent structure by less than 2 in. or more than 6 in., as illustrated in Figure 50?	___	___	___
2. Are controls and control columns designed so that fracture due to an occupant's striking the column will occur at a point no more than 4 in. above the pivot point, and so that the failure will be clean without jagged or torn edges, or are they equipped with an energy-absorbing section?	___	___	___

6. AIRCRAFT POSTCRASH SURVIVAL

6.1 INTRODUCTION

This chapter presents the criteria that are to be applied in designing post-crash survival into an aircraft. Although initial crash-resistance considerations, such as maintaining structural integrity around the occupant and reducing the crash forces transmitted to the occupant, are of primary importance in survival, hazardous postcrash conditions must be prevented or reduced if the occupant is ultimately to survive. The threat of postcrash fire must be minimized, and adequate escape and rescue provisions must be incorporated into the aircraft.

This section includes criteria for designing fuel, oil, and hydraulic systems to minimize the occurrence of postcrash fires; for selecting less flammable interior materials; for selecting provisions that increase survival chances during aircraft ditchings; and for designing emergency escape provisions and crash locator beacons. The user is referred to Volume V for more complete information and reference sources.

6.2 FUEL SYSTEM DESIGN CRITERIA

The following criteria are applicable to all auxiliary fuel systems, such as ferry systems and extended range systems, as well as to the primary aircraft fuel system.

6.2.1 General

The fuel system must be designed to minimize fuel spillage during and after all survivable crash impacts. It must also be designed to prevent spillage of fuel through the vents during a rollover or in any other adverse attitude. Spillage that cannot be avoided, such as that occurring during the functioning of self-sealing breakaway couplings, must be precluded from ignition by controlling ignition sources (see Section 5.5 of Volume V).

6.2.2 Fuel Tanks

6.2.2.1 Fuel Tank Location. The location of fuel tanks in an aircraft is of considerable importance in minimizing the postcrash fire hazard. The location must be considered with respect to occupants, ignition sources, and probable impact areas. The fuel tanks should be located as far as possible from probable impact areas and from areas where structural deformation might cause crushing or penetration of the tank. If possible, fuel tanks should not be installed:

- Immediately adjacent to occupiable areas.
- Immediately adjacent to engine compartments.
- Immediately adjacent to electrical compartments.
- Under heavy masses, such as transmissions and engines.
- Near the bottom of the fuselage.

- Over landing gears.

- In leading edges or anticipated failure areas of wings.

6.2.2.2 Fuel Tank Construction. Fuel tanks should have smooth, regular shapes with the sump area contoured gradually into the tank bottom. All concave corners should have a minimum radius of 3 in., and all convex corners a minimum radius of 1 in.

All fuel tanks must be fabricated from crash-resistant material which meets or exceeds the requirements of MIL-T-27422 (Reference 66). All fuel tank fittings must have a tank pullout strength that meets or exceeds that specified in MIL-T-27422.

A self-sealing, breakaway, tank-to-tank coupling should be used wherever two tanks are connected directly with no intervening fuel line.

6.2.3 Fuel Lines

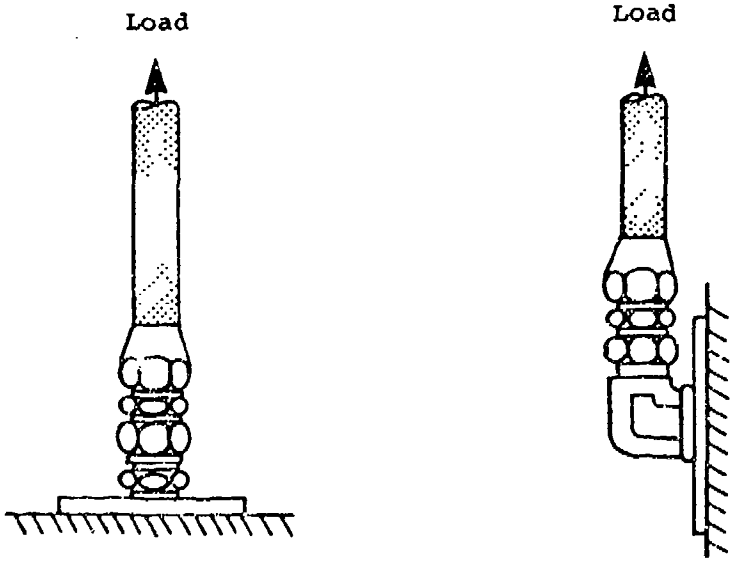
Fuel lines should be constructed and routed so as to withstand all survivable crash impacts. This may be done by allowing the lines to elongate or shift with deforming aircraft structure rather than being forced to carry high tensile loads.

6.2.3.1 Fuel Line Construction. All fuel lines that could be readily damaged in an accident of severity up to that indicated in Table 2 should consist of flexible rubber hose with a steel-braided outer sheath, where possible. The hoses should be capable of elongating 20 percent without the hose assembly spilling any fuel. If "stretchable" (20-percent minimum elongation) hoses are not used, all hoses should be 20 to 30 percent longer than necessary to provide added length for structural displacement.

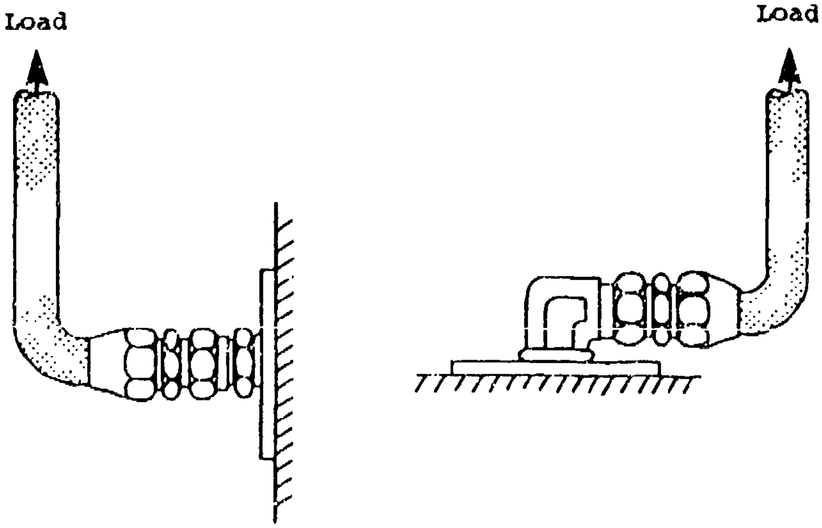
When the hose assemblies are subjected to pure tension loads or to loads applied at a 90-degree angle to the longitudinal axis of the end fitting, as shown in Figure 54, hoses must not pull out of their end fittings, neither should the end fittings break, at less than the minimum loads shown in Table 17. Loads must be applied at a constant rate not exceeding 20 in./min.

The number of fuel line couplings should be held to a minimum. Wherever possible, a single, one-piece hose should be run through a bulkhead opening rather than be attached to the bulkhead with rigid fittings. The opening should be 1 in. larger in diameter than the hose diameter, with the hose stabilized by a frangible panel or structure. A grommet should be installed in the opening to preclude wear on the hose. Self-sealing breakaway couplings must be used whenever a line goes through a firewall so that the line will seal if the engine is displaced during crash impact. Breakaway couplings will not be required if the engine is tied down to a strength level of 20 G_z, 20 G_x, and 18 G_y, and if the engine is located so that crushing of the lines and fittings is not likely in any survivable accident.

All fuel line-to-fuel tank connections should consist of self-sealing breakaway couplings. These couplings must be recessed into the tank so that the tank half does not protrude outside the tank wall more than 1/2 in. after coupling separation. The shape of the tank coupling half should be basically smooth to avoid snagging on adjacent structures or cutting the tank wall. An



Tension tests

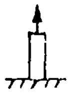
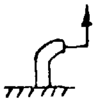
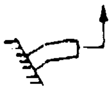


90-degree tests

FIGURE 54. HOSE ASSEMBLY TEST MODES.

acceptable substitute for a breakaway valve is a hose constructed of material identical to that of the tank with an end fitting strength equal to 80 percent of the tank tear-out strength (MIL-T-27422, Paragraph 4.6.5).

TABLE 17. REQUIRED MINIMUM INDIVIDUAL LOADS FOR STANDARD HOSE AND HOSE-END FITTING COMBINATIONS

Hose End Fitting Type	Fitting Size*	Minimum Tensile Load (lb)	Minimum Bending Load (lb)
STRAIGHT	-4	575	450
Tension =	-6	600	450
	-8	900	700
	-10	1250	950
	-12	1900	1050
	-16	1950	1450
Bending =	-20	2300	1600
	-24	2350	2750
	-32	3500	4000
90° ELBOW	-4**	575	800
Tension =	-6**	600	850
	-8**	900	1250
	-10	1250	575
	-12	1900	675
	-16	1950	1200
	-20	2300	1250
Bending =	-24	2350	2025
	-32	3500	3500
45° ELBOW	-4**	575	
Tension =	-6**	600	425
	-8**	900	425
	-10	1250	425
	-12	1900	600
	-16	1950	1000
	-20	2300	1600
Bending =	-24	2350	2400
	-32	3500	3700

*Fitting size given in 1/16 in. units, i.e., -4 = 4/16 or 1/4 in.
**Elbow material is steel.

6.2.3.2 **Fuel Line Location**. Fuel lines should be located as far as possible from probable impact areas and areas where structural deformation can cause crushing, penetration, or excessive tensile loading of the lines. When fuel lines must be routed through areas of probable large displacement, such as wing-to-fuselage attachment points, self-sealing breakaway couplings must be incorporated into the lines to allow for complete line separation with a minimum of fuel spillage.

Fuel lines should not be routed in the following areas:

- Near the bottom of the fuselage.
- Over landing gears.
- Under, in front of, or at the sides of heavy masses, such as engines and transmissions.
- In the leading edges of wings.
- In anticipated areas of rotor blade impact.
- Adjacent to electrical wiring.

Fuel lines should not be routed through electrical compartments or occupiable areas unless they are shrouded or otherwise designed to prevent spillage.

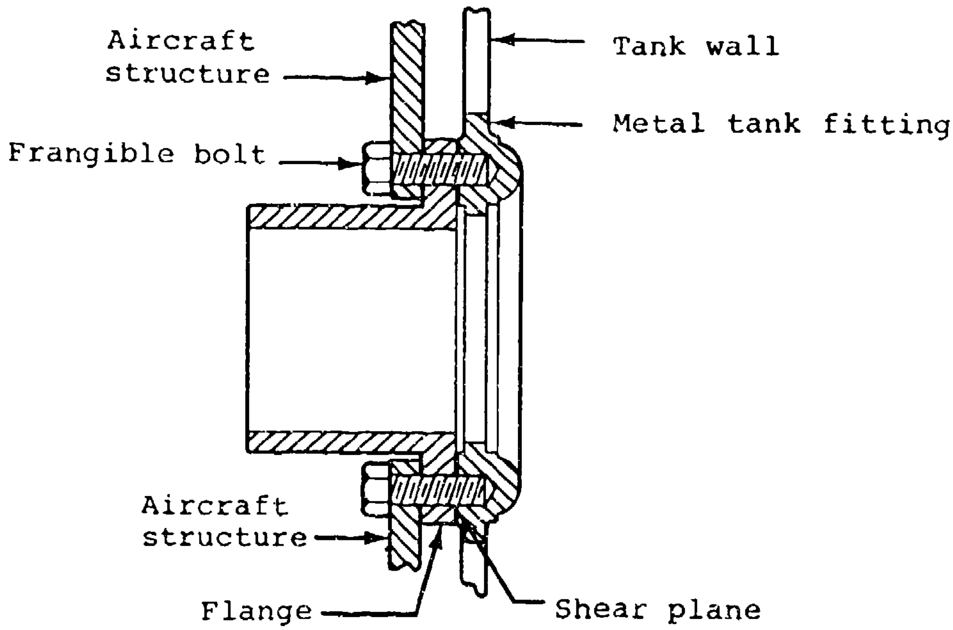
In order to protect the lines from impact damage, fuel lines should be routed along heavier basic structural members wherever possible. All fuel lines must be adequately supported by frangible clamps attached to other structure. Fuel lines should be grouped together and exit a fuel tank in one centralized location. This location should be in the area of the tank that is least vulnerable to anticipated crash loads and structural deformations. However, ballistic vulnerability considerations may modify this requirement.

The number of fuel lines in the engine compartment should be minimized. When more than one line enters an engine compartment, the lines should be grouped together and pass through the firewall in a protected location unless the structur l integrity of the firewall would be compromised.

6.2.4 Frangible Attachments

Frangible structures or frangible bolts should be used at all attachment points between fuel tanks and aircraft structure to prevent fuel tank components from being torn out of the tank wall during impact. Frangible attachments should be used at other points in the flammable fluid systems where aircraft structural deformation could lead to flammable fluid leakage.

The load required to separate a frangible attachment from its support structure must be between 25 and 50 percent of the minimum load required to fail the weakest component in the attached system, as illustrated in Figure 55. (The failure load of the attached system components may be determined either by analytical computations or by testing methods based upon the failure modes most likely to occur during crash impact.) To prevent inadvertent separation, failure loads should be at least five times normal operational and service loads at the frangible attachment location.



ITEM	LOWEST FAILURE LOAD (LB)*	FAILURE MODE
Aircraft structure	4000	Shear
Tank fitting	3000	Pull out of tank
Flange	5000	Shear
Frangible bolt	Not more than $\frac{3000}{2} = 1500$ Not less than $\frac{3000}{4} = 750$	Break (tension-shear)

*Loads may or may not be representative; values are for explanatory purposes only.

FIGURE 55. SAMPLE FRANGIBLE ATTACHMENT SEPARATION LOAD CALCULATION.

A frangible attachment should separate whenever the required load (as defined above) is applied in the modes most likely to occur during crash impact. These modes--whether tension, shear, compression, or combinations thereof, such as bending (tension-shear)--should be determined for each attachment by analyzing the surrounding aircraft structure and probable impact forces and directions.

All frangible devices should be statically tested in the three most likely anticipated modes of separation. Test loads must be applied at a constant rate, not exceeding 20 in./min, until failure occurs. In addition, all frangible attachments should be proof tested under dynamic loading conditions in the three most likely anticipated modes of operation. The test load should be applied in less than 0.005 sec, and the velocity change experienced by the loading jig should be 36 ± 3 ft/sec.

6.2.5 Self-Sealing Breakaway Valves

Self-sealing breakaway valves should be installed at all fuel-tank-to-fuel-line connections, tank-to-tank interconnects, and at other points in the fuel system where aircraft structural deformation could lead to system failure. The valves should allow only a minimal amount of spillage upon separation and should permit no external leakage when partially separated.

The load required to separate a breakaway valve should be between 25 and 50 percent of the minimum load required to fail the weakest component in the attached system, as illustrated in Figure 56. To prevent inadvertent actuation during flight and maintenance operations, the separation load must be greater than five times normal operational and service loads at the coupling location. To avoid complete or partial breakaway coupling separation during maintenance operations, the separation load should never be less than 300 lb, regardless of the fuel line size.

A breakaway valve should separate and seal whenever the required load (as defined above) is applied in the modes most likely to occur during crash impact. These modes, whether tension, shear, compression, or combinations thereof, should be determined for each coupling by analyzing the surrounding aircraft structure and probable impact forces and directions.

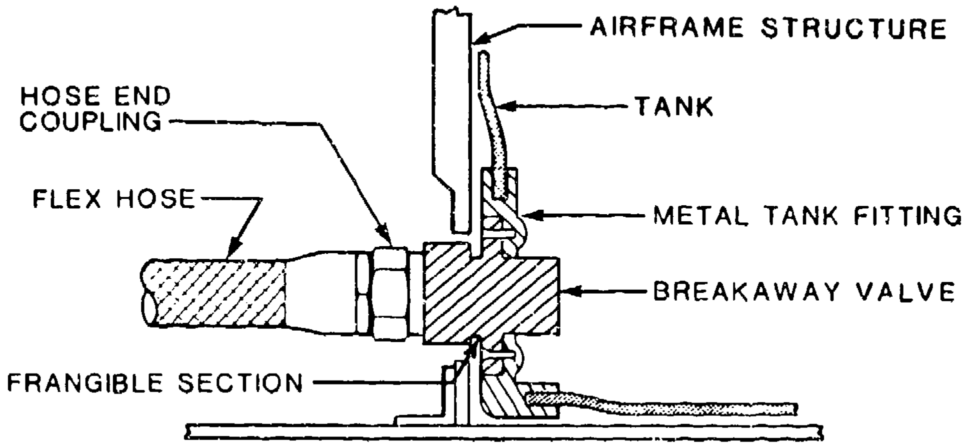
All breakaway valves should be subjected to static tensile and shear loads to establish the load required for separation, nature of separation, leakage during valve actuation, general valve functioning, and leakage following valve actuation. The rate of load application should not be greater than 20 in./min. Tests to be used where applicable are shown in Figure 57.

In addition, all breakaway valves must be proof tested under dynamic loading conditions. The valves must be tested in the three most likely anticipated modes of separation. The test configurations should be similar to those shown in Figure 57. The load should be applied in less than 0.005 sec, and the velocity change experienced by the loading jig should be 36 ± 3 ft/sec.

All breakaway valves should incorporate positive provisions for ascertaining that the valve is locked together during normal installation and service. In addition, all breakaway valves must incorporate provisions in their design to prevent uncoupling due to operational shocks, vibrations, accelerations, etc.

6.2.6 Fuel Drains

All fuel tank drains should be recessed into the tank so that no part of the drain protrudes outside the tank wall. All attachments of fuel drains to aircraft structure should be made with frangible fasteners.



Item	Lowest Failure Load (lb)*	Failure Mode
Flex hose	3000	Tensile breakage
Flex hose	1500	Pull out of end fitting
Tank fitting	7500	Pull out of tank
Hose end coupling	1650	Break (bending)
Breakaway valve	2500	Pull out of tank fitting
Breakaway valve	Not more than $\frac{1500}{2} = 750$ Not less than $\frac{1500}{4} = 375$	Break at frangible section

*Loads may or may not be representative; values are for explanatory purposes only.

FIGURE 56. TYPICAL METHOD OF BREAKAWAY LOAD CALCULATION FOR FUEL-TANK-TO-LINE BREAKAWAY VALVE.

The number of fuel line drains should be held to a minimum by designing the fuel system to avoid low points in the lines. If drain lines are necessary, they must be made of low-strength materials.

Drain valves for tanks and lines should be designed to be positive locking in the closed position. Fuel drain actuation must not require the operator to lie down under the aircraft. Drains should be located where discharged fuel will not cause an added fire hazard.

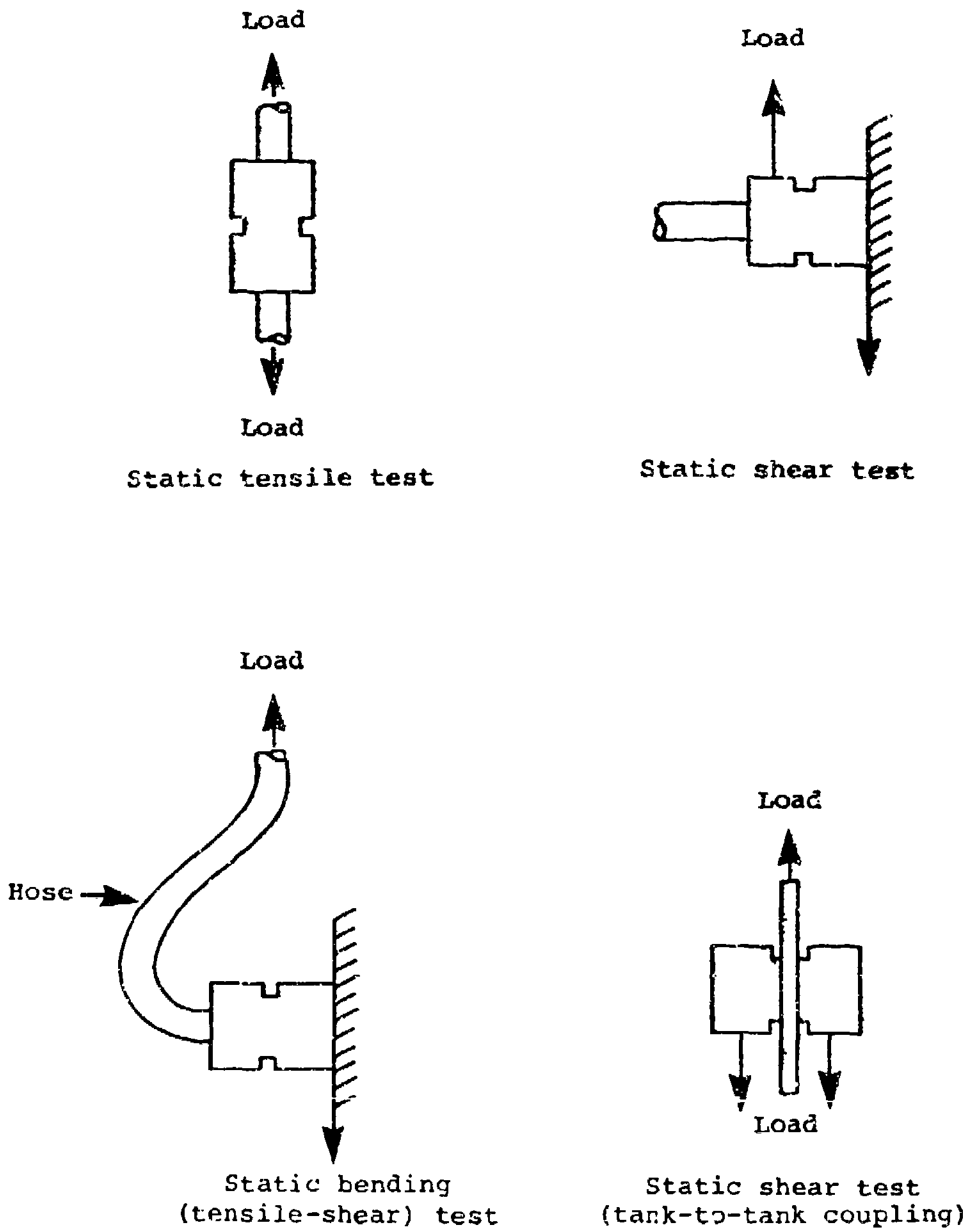


FIGURE 57. STATIC TENSILE AND SHEAR TEST MODES FOR SELF-SEALING BREAKAWAY VALVES.

6.2.7 Filler Units

The filler unit must be fastened to the structure with a frangible attachment, and filler caps must be recessed into the tank wall to ensure that the cap remains with the tank if the tank moves relative to the aircraft structure.

Long filler necks should be avoided if possible. If they must be used, they should be fabricated from frangible materials and designed so that the filler cap remains with the tank and does not snag on the aircraft structure during impact.

Tank fillers must not be located adjacent to engine intakes or exhausts where flammable vapors could be ingested and ignited.

6.2.8 Fuel Boost Pumps

Boost pumps should be selected according to the following order of preference:

1. Suction system, engine-mounted pump.
2. Air-driven, tank-mounted or in-line pump.
3. In-line electric pump.
4. Electrically operated tank-mounted pump.

Pumps mounted within the fuel tanks should be rigidly bolted to the fuel tank only. If the pump must be supported or attached to the aircraft structure, a frangible attachment should be used.

The state of the art in fuel system design has shown that electrically driven boost pumps can be eliminated. Air-driven boost pumps and engine-mounted suction-type boost pumps now in operation are much less hazardous alternative solutions.

If electric boost pumps are used, the electrical wires must contain 6 in. of extra length at the pump connection to accommodate crash-induced structural deformation. The wires also must be shrouded to prevent their being cut during crash impact. Nonsparking breakaway wire disconnects may be used in lieu of the extra wire length.

6.2.9 Fuel Filters and Strainers

Fuel filters and strainers should not be located within the engine compartment or adjacent to engine intakes or exhausts, if at all possible.

Filters and strainers should retain the smallest possible quantity of fuel.

Filters and strainers must have a structural attachment capable of withstanding a 30-G load applied in any direction.

Self-sealing breakaway valves should be used to attach fuel lines to fuel filters and strainers in those locations where structural displacement is likely to cause a separation of those components. Care should be taken to assure that the valve, not the strainer or filter, is the weak link in the system.

6.2.10 Fuel Valves

The number of fuel valves should be kept to a minimum.

Large valves (e.g., fuel shutoff valves) should have a structural attachment capable of withstanding a 30-G load applied in any direction. Self-sealing breakaway couplings should be used at the valve-fuel line connections. Small valves (e.g., check valves) must be fastened to the aircraft structure with frangible attachments.

If electrically operated valves are used, they should be mounted on bulkheads so that the electrical wires are on one side of the bulkhead and the valves and lines are on the other side.

Section 4.3.3.9 of Volume V discusses the use of spillage control valves designed to stop the flow of fuel to the engine area when the engine is not running, as in a crash.

6.2.11 Fuel Quantity Indicators

Fuel counters and float-type quantity indicators are preferred over rigid capacitance probes to preclude puncture of the fuel tank during impact. If a capacitance probe must be used, it should be fabricated from material processing as low a flexural rigidity as is consistent with operational requirements. A slightly rounded shoe should be incorporated at the probe bottom end to avoid any tank-cutting tendency. Consideration should be given to the use of frangible low-flexural rigidity curved probes to reduce the danger of puncturing the tank during crash impact. The probe may also be mounted frangibly or at an angle.

If tank-mounted quantity indicators must be attached to the aircraft structure, frangible attachments should be used.

6.2.12 Vents

Vent systems should be designed to prevent fuel flow through the vent lines regardless of aircraft attitude or vent line failure. For this reason, high strength fittings should be used between the metal insert in the tank and the vent line. If the vent outlet must be supported, it should be supported by frangible attachments. The vent line should be made of wire-covered flexible hose and should be routed so that it cannot be snagged in displacing structure during a crash. Self-sealing breakaway valves should be used at the tank-to-line attachment if there is danger of the tank being torn free of the supporting structure.

Vent lines should be routed inside the fuel tank in such a manner that if rollover occurs spillage cannot continue. This can be accomplished with siphon breaks and/or U-shaped traps in the line routing.

Antispillage vent valves inside the fuel tank are particularly advantageous during rollover accidents and can be used in lieu of flexible lines, breakaway valves, and all other alternate considerations. These valves must be designed and tested to demonstrate that:

- The vent will remain fully open during all normal flight environmental conditions.
- The vent valves will close in extreme attitudes such as would occur in a rollover.
- The vent valves will possess adequate venting capability under critical icing conditions in flight.

If the fuel system is to be pressure refueled, a bypass system for tank overpressurization must be used. However, care must be taken to ensure that spillage resulting from overpressurization due to tank compression during a crash is released away from aircraft occupants and ignition sources.

6.3 OIL AND HYDRAULIC SYSTEM DESIGN CRITERIA

6.3.1 General

Even though oil and hydraulic fluids are carried in relatively small quantities, they are easily ignited and can serve, in turn, as ready ignition sources for fuel. Therefore, oil and hydraulic fluid spillage should be prevented at all reasonable cost. The crash-resistance design criteria presented in Section 6.2 for fuel systems are generally applicable for oil and hydraulic systems also.

6.3.2 Oil and Hydraulic Fluid Reservoirs

Oil tanks and hydraulic reservoirs should not be located where spilled or sprayed fluid can readily be ingested into the engine or ignited by the engine exhaust.

Oil tanks and hydraulic reservoirs should not be located in the following areas:

- Near the bottom of the fuselage.
- In or above engine compartments.
- In electrical compartments.
- In occupiable areas.
- Under, in front of, or at the side of heavy masses, such as engines and transmissions, nor above landing gears.

Reservoir construction and mounting should be able to withstand 30-G forces applied in any direction.

Oil tanks should be constructed from flexible, crash-resistant materials that meet or exceed the strength and tear resistance required in MIL-T-27422 for fuel tank material.

Alternatively, a metal tank can be used if it is in a relatively safe area and is shielded and coated to prevent leakage in the event of a tank rupture.

6.3.3 Oil and Hydraulic Lines

6.3.3.1 **Construction.** Oil and hydraulic lines should consist of flexible hoses with steel-braided outer sheaths, where possible. If the hoses cannot elongate 20 percent without the hose assembly spilling fluid, 20 percent extra length should be provided to compensate for structural displacement during a crash. All hose assemblies must meet the requirements of Table 16 when tested as shown in Figure 54 (Section 6.2.3.1).

Where high-temperature operational requirements preclude the use of flexible hose, coiled metal tubing should be used in areas where large crash deformation is expected.

The number of line couplings should be kept to a minimum. Wherever possible, a single, one-piece hose should be routed through a bulkhead opening rather than attached to the bulkhead with a rigid connection. The opening should be 1 in. larger in diameter than the hose diameter, with the hose stabilized by a frangible panel or structure. However, self-sealing breakaway valves should be used wherever a line goes through a firewall so that the line will seal if the engine is displaced during crash impact.

Self-sealing breakaway valves should be used to connect flexible hoses to engines, oil tanks, hydraulic reservoirs, and system components if enough structural deformation to cause line elongation to the breakage point is probable.

When hydraulic or oil lines must be stabilized, they should be attached to the aircraft structure with frangible fasteners.

6.3.3.2 **Routing.** Hydraulic or oil lines should not be routed in electrical or occupiable areas unless they are shrouded to prevent spillage. Hydraulic or oil lines should not be routed in the following areas:

- Near the bottom of the fuselage.
- Over landing gears.
- Under, in front of, or at the sides of heavy masses, such as engines and transmissions.
- In the leading edges of wings.
- In areas of anticipated rotor blade impact.
- In any area where flammable fluids could be spilled or sprayed onto hot surfaces or ingested into the engine.
- Above electrical wiring.

The number of hydraulic and oil lines in the engine compartment should be kept to a minimum. The lines should be grouped together and enter the engine compartment in a protected location.

6.3.4 Oil and Hydraulic System Components

System components (e.g., pumps, valves, filters, actuators) must not be located in electrical compartments or occupiable areas. Components should not be located near the bottom of the fuselage or in the leading edges of the wings.

Components located in the engine compartment should be restricted to those absolutely necessary for engine operation. For example, oil filters must not be located here unless they are an integral part of the engine.

The construction and mounting of all system components must be able to withstand 30-G forces applied in any direction.

6.3.5 Oil Coolers

Oil coolers should not be located in the engine compartment, under the engine or transmission, or in any area where oil could be spilled or sprayed onto hot surfaces or ingested into the engine.

The oil cooler should be located as far as possible from anticipated impact areas.

The oil cooler mounting(s) should be able to withstand 30-G forces applied in any direction.

6.4 IGNITION SOURCE CONTROL CRITERIA

6.4.1 Electrical Systems

6.4.1.1 **Wiring**. Electrical wires should be routed along heavier structural members of the airframe wherever possible. Structural openings for wire passage should be 8 to 12 times larger in diameter than the wire. Sharp metal edges should be protected by grommets to prevent chafing. Wire bundles should be supported at frequent intervals along their length by frangible attachments to the aircraft structure.

Wires that must pass through areas of anticipated structural deformation should be approximately 20 to 30 percent longer than necessary. The extra length should be accumulated in the form of loops or S-shaped patterns and located at the areas of anticipated structural deformation.

Wires should be routed above or away from flammable fluid lines, and they should never be closely spaced between outer skin and fuel lines. Wires must not be routed near flammable fluid tanks unless the wires are shrouded to prevent arcing. Wires should not be routed in the following areas:

- Near the bottom of the fuselage.
- Over landing gears.
- In the leading edges of wings.

- In areas of anticipated rotor blade impacts.
- In areas of anticipated fuel spillage.
- Immediately adjacent to flammable fluid lines and vent openings.

Electrical wiring and components should be kept to a minimum in flammable fluid tank areas.

Nonsparking breakaway connectors should be used in areas where excessive tensile loads may be applied, such as the wing-to-fuselage joint. All wire connectors must be of the shielded, nonsparking type.

6.4.1.2 Batteries and Electrical Accessories. Batteries and electrical accessories should be located as far as possible from flammable fluid tanks.

Batteries and accessories should be housed in compartments built into the airframe. These compartments should be lined with flexible, nonconductive, fire-resistant panels as specified in Section 6.4.1.5.

Electrical wires should exit the batteries and inverters on their least vulnerable side. There should be one full 6-in.-diameter loop of extra wire at the battery and inverter connections to accommodate crash-induced structural deformation.

The battery and accessory mountings should withstand a force of 30 G applied in any direction.

6.4.1.3 Generators and Magnetos. If generators and magnetos are not engine mounted, they should be installed in compartments built into the airframe. These compartments should be located fairly high in the structure and as far as possible from flammable fluids. The compartments should be lined with panels as specified in Section 6.4.1.5.

Electrical wires should exit the generators and magnetos on their least vulnerable side regardless of their location. The generator and magneto mountings should withstand a force of 30 G applied in any direction.

6.4.1.4 Lights and Antennas. Lights and antennas should be located as far as possible from flammable fluids. Lights should be located as high as possible on the airframe structure. Landing lights should not be located in front of wing fuel tanks.

The wires that attach to the lights should contain a 6-in.-diameter loop near the connection to accommodate crash-induced structural deformation.

6.4.1.5 Liners and Shrouds. Nonconductive paneling should be used as a liner for all electrical compartments. The paneling materials should possess a minimum tensile strength of 250 lb/in. of width and allow a minimum elongation of 200 percent.

Nonconductive material should be used to shroud all electrical wiring that could be cut by deforming aircraft structure during crash impact. The shrouding material should meet or exceed a tensile load of 250 lb/in. of width and should possess a minimum elongation capability of 200 percent.

6.4.2 Shielding

Shielding should be used wherever necessary to prevent spilled flammable fluids from reaching potential ignition sources or occupiable areas.

6.4.2.1 **Spillage Barriers**. Fuel tanks should be isolated from the occupants by a minimum of two spillage barriers. These barriers may consist of the normal tank cavity chafing liner and the surrounding airframe structure. If the chafing liner is considered as a barrier, it must be continuous structure completely encasing the fuel tank.

6.4.2.2 **Firewalls**. Firewalls should be designed to withstand all survivable crash impacts without losing their structural integrity or sealing ability.

6.4.2.3 **Fire Curtains**. Fire curtains made from fire-resistant cloth may be used to protect occupiable areas or ignition sources from flammable fluid spillage. Fire curtains may be installed in addition to, but not in place of, the spillage barriers required in Section 6.4.2.1.

6.4.2.4 **Flow Diverters**. Drainage holes should be located in all flammable fluid tank compartments to prevent the accumulation of spilled flammable fluids within the aircraft. Drip fences and/or drainage troughs should be used to prevent the gravity flow of spilled fuels from reaching ignition sources, such as hot engine areas or electrical compartments.

6.5 INTERIOR MATERIALS SELECTION CRITERIA

6.5.1 General

All aircraft interior materials such as seat fabrics and cushions, interior wall insulations, and nonmetallic structural components must be flame resistant and produce the least amount of smoke and toxic gases possible. Currently the FAA flammability requirements specified in FAR 25.853 (Reference 67) are the only specific mandatory requirements for aircraft interior materials. The FAA amended the requirements in 1984 to add additional flammability tests for seat cushions, except for crewmember seats, and is adding the Ohio State University rate of heat release test procedure for interior ceiling and wall panels, partitions, etc. Interior materials must be screened so that those with the least smoke and toxicity emissions can be selected. Suitable screening tests are referenced in Section 6.5.3.

6.5.2 FAR 25.853 Flammability Requirements

Materials used in each compartment occupied by the crew or passengers must meet the following requirements:

- <u>Ceiling panels, wall panels, partitions, structural flooring, etc.</u> Must be self-extinguishing when tested vertically by applying a 1550 ^{o}F flame to the lower edge of the specimen for 60 sec. Average burn length not to exceed 6 in.; average flame time after removal of test flame not to exceed 15 sec. Drippings may not continue to flame more than an average of 3 sec. In addition, materials must meet the OSU heat release rate in a vertical position exposed to a total heat flux on the specimen of 3.5 watts per square centimeter. The average total heat release must not exceed 65 kilowatt-minutes per square meter, and the average peak heat release rate must not exceed 65 kilowatts per square meter.

- Floor coverings, textiles (including upholstery), seat cushions, paddings, insulations (except electrical insulation), etc. Must be self-extinguishing when tested vertically by applying a 1550 ^{o}F flame to the lower edge of the specimen for 12 sec. Average burn length not to exceed 8 in., average flame time after removal of test flame not to exceed 15 sec. Drippings may not continue to flame more than an average of 5 sec. In addition, seat cushions must meet an oil burner test. This test exposes the side of the seat cushion to a specified oil burner for 2 min. During the next 5 min. the burn length must not reach the side of the cushion opposite the burner and must not exceed 17 in. Also, the average percentage weight loss must not exceed 10 percent.

- Acrylic windows, signs, restraint systems, etc. May not have an average burn rate greater than 2.5 in./min when tested horizontally by applying a 1550 ^{o}F flame to the specimen edge for 15 sec.

See References 67 and 68 for the complete text of the regulations and test requirements.

6.5.3 Smoke and Toxic Gas Test Criteria

The FAA has not adopted criteria for smoke or toxic gas emissions from interior materials because the full-scale fire tests have demonstrated a correlation between flammability and smoke emission characteristics of the materials tested. Also, the full-scale tests showed that there was a significant correlation between flammability and toxic emissions and that severe hazard from toxic emissions does not occur until a flashover occurs. In addition, there has not been good correlation shown between any of the laboratory tests for smoke and toxic gases and full-scale fire tests. It should be emphasized, however, that these generalizations are true only for the materials that have so far been tested in the full-scale tests and only for the full-scale tests simulating a fuel fire outside of the fuselage. It is possible that in the future, after more work has been done on the laboratory tests, some criteria may be adopted.

In the meantime, screening tests should certainly be conducted on candidate materials and systems to enable the designer to select those materials with the lowest smoke and toxicity emissions and to preclude using materials which might generate high levels of smoke and toxic gases. It is recommended that materials be screened for smoke emissions using either the test procedure for the OSU release rate apparatus specified by NFPA 263 (Reference 69) or the modified NBS smoke chamber as outlined in Reference 70.

The screening method to distinguish materials producing more toxic combustion products than those from other materials should be performed using the NBS toxicity test method (Reference 71). In this test, one material is considered significantly more toxic than another material if the toxic concentrations generated differ by an order of magnitude.

If fire-retardant coatings are used for fabric and trim materials, the effects, if any, of routine maintenance and cleaning procedures must be assessed. If the coatings can be removed by routine cleaning procedures, the flammability and smoke/toxic fume tests should be repeated after a representative number of cleaning cycles.

6.6 DITCHING CRITERIA

6.6.1 General

Occupant survival during a ditching is highly dependent on egressing rapidly from the aircraft before it sinks. This is especially true in helicopters, which tend to roll inverted and sink very rapidly. Disorientation and poor underwater visibility further hamper successful egress. Available escape times from helicopters range from a few seconds to a few minutes. The availability of emergency exits, adequate emergency exit lighting, and helicopter flotation provisions can all increase the available escape time. Adequate and easily deployed ditching equipment increases the probability of survival after successful egress.

6.6.2 Emergency Exits

All U.S. Army aircraft should meet the criteria for emergency exits contained in Section 6.7. Passenger-carrying helicopters operating over water environments, however, should contain more and larger emergency exits than might normally be provided. Additional escape exits should be provided in the overhead, deck, and tail sections.

Explosively created exit systems should be considered because of their rapid initiation times and immunity to the crash environment. Linear-shaped charges should be placed around and extend beyond existing windows and hatches to preclude the problem of jammed or stuck exits. Strategically placed shaped charges in the overhead, deck, empty bulkhead spaces, etc., can provide the additional emergency exits required in the ditching environment. Criteria for these types of systems are contained in Section 6.7.

6.6.3 Underwater Emergency Lighting

Emergency exits should be lighted with high intensity lights if they are to be seen underwater. The required brightness of the lights depends on the turbidity of the water, the distance between the observer and the light, and the threshold sensitivity of the observer's eyes.

The escape hatch lights should have the highest brightness level of light permitted by other design conditions (up to 200 fL). Light tubes configured in an inverted U around each hatch are most effective for outlining escape hatches.

6.6.4 Helicopter Flotation Systems

An adequate number of helicopter flotation devices should be provided. Combinations of flotation methods, such as sponsons in conjunction with flotation bags, sealed hulls, etc., should be used.

Sponsons can help stabilize a helicopter in relatively calm seas. However, they must be quite large to be of any value in providing flotation to counteract the inherent instability due to a helicopter's high center of gravity. Calculated aircraft stability must be verified by data from tests performed on the aircraft or on a scaled model thereof.

The calculated stability afforded by flotation bags also must be verified by test data. To achieve maximum effectiveness, the bags must inflate simultaneously prior to or upon water contact at slow speeds. Reliability of a flotation bag system is of prime importance.

6.6.5 Ditching Equipment

Tie-down or stowage locations must be provided for life rafts, life preservers, survival kits, and miscellaneous ditching equipment. Restraint devices and supporting structures must be designed to restrain the equipment to static loads of 50 G downward, 10 G upward, 35 G forward, 15 G aftward, and 25 G sideward. All survival equipment must be readily available and easily released from restraining devices after ditching.

Life raft mountings and restraining devices must be located and designed so that rafts can be removed and deployed outside the aircraft within 30 sec from the time the release or removal action is initiated.

When exterior installations for life rafts or other survival equipment are provided, the mountings and restraining devices must be recoverable from an exit intended for use in ditching. Release mechanisms must be designed to minimize the possibility of jamming due to structural deformation incurred during ditching.

6.7 EMERGENCY ESCAPE AND RESCUE DESIGN CRITERIA

6.7.1 Emergency Exits

6.7.1.1 General. Exits of sufficient size and number must be provided to ensure that all occupants can evacuate the aircraft before postcrash conditions become intolerable, even if half of the exits are blocked. If a crash-resistant fuel system is not installed, the maximum number of personnel to be carried must be able to evacuate the aircraft within 10 sec. The allowable evacuation time can be extended to 30 sec if a crash-resistant fuel system is installed in the aircraft. The emergency exit criteria presented in this chapter are predicated on a 30-sec evacuation time.

6.7.1.2 Types of Exits. A Class C exit constitutes the minimum requirement for an emergency exit. (A Class C exit is a window, door, hatch, or other exit intended primarily for emergency evacuation). Class C exit closures must be capable of being removed from the exit opening within 5 sec regardless of the aircraft's attitude.

A Class B exit consists of a door, hatch, or other exit intended primarily for service or logistic purposes (e.g., cargo hatches and rear loading ramps or clamshell doors). Class B exits may be used instead of Class C exits if adequate emergency releases are installed. A Class A exit (doors, hatches, etc., intended primarily for normal entry and exit) generally may be used in lieu of a Class C exit; however, if either Class B or Class A openings are used in place of Class C exits, they must meet the 5-sec opening requirement.

6.7.1.3 **Size of Exits**. All exits must be sufficient in size and shape to allow 95th-percentile combat-equipped troops and aviators to pass through the exit at a rate of 1.5 sec per man or less. Therefore, Class C exits must be a minimum of 22 in. in diameter, or 22 in. square, with 6-in. radius corners, although larger exits are recommended. Other shapes may be used if the minimum dimensions are met or exceeded.

6.7.1.4 **Number of Exits**. Each flight crew member must have access to at least one usable emergency exit regardless of the attitude of the aircraft after impact. When sliding or clamshell canopies are used, Class C exits must be provided for crew escape in case the postimpact attitude of the aircraft prevents jettisoning of the canopy.

A minimum of two Class C exits (or equivalent) must be provided in troop/passenger sections, one on each side of the fuselage. Cockpit exits may not be counted toward this requirement. Additional exits must be provided whenever the ratio of seats to passengers exceeds the 1-to-10 ratio (e.g., if the capacity is 21, three exits are required). These requirements also apply to cargo compartments if the compartments have a capability for troop transport.

6.7.1.5 **Location of Exits**. Emergency exits must be equally divided between both sides of the aircraft to provide alternate means of escape if, for any reason, the exits on one side become blocked. If feasible, in order to prevent crowding during evacuation, side exits should not be located directly across from each other. At least one exit on each side must be well above the anticipated waterline during a ditching.

If the width of the fuselage between side exits is 5 ft or more, at least one additional Class C exit should be provided overhead so that easy access to an exit is available when the aircraft comes to rest on its side. If more than 20 occupants can occupy the troop/passenger section, one overhead exit should be provided for every 20 occupants. If overhead exits are not feasible, bottom or fore and/or aft exits may be provided instead. Alternatively, side exits may be located where interior aircraft structures or components can be used as steps to gain access to the upside exits. Such component-steps should be able to support at least 300 lb. They should also maintain their structural integrity and attachment to the aircraft when exposed to static loads of 50 G downward, 10 G upward, 35 G forward, 15 G aftward, and 25 G sideward.

Emergency exits should not be located in the following areas:

- In close proximity to the main landing gear.
- Under heavy components, such as engines and transmissions.
- In any area where it is necessary to move equipment, cargo, etc., to gain access to the exit.

- In any area where external components, such as engines or armament, will interfere with occupant escape.

- Near potential fuel spillage areas.

- Near major ignition sources, such as hot engines.

6.7.1.6 <u>Operation of Exits</u>. The method of releasing and opening an emergency exit should be simple, obvious, and natural to all personnel carried in the aircraft. All emergency exits should be capable of being completely opened within 5 sec after the person initiating the action first places his hand on the release handle.

Exit release mechanisms should permit release handle actuation and exit opening by one person using one hand. The releasing action should be natural to the position of the operator initiating the action and should be a continuous motion from start to finish without sharp changes in direction. Secondary operations should not be necessary. The final motion of the release handle should contribute to the opening of the exit.

Release handles must be located on the exit closures themselves, or immediately adjacent to the exit openings, so that they are readily accessible. However, the handles should not obstruct the removal of the exit closure or impede escape through the exit opening. Release handles in cockpits and troop compartments should be located so that crew members need not unlock their shoulder harnesses in order to actuate the release mechanism.

Accidental release of exits in flight should be prevented. Release mechanisms should be designed so that improper or incomplete closing of the exit closure will be obvious. Easily removable protective covers may be used to prevent inadvertent actuation of exit release handles.

It is essential that all emergency exits be designed so that rescue personnel can open them from outside the aircraft. Internal and external release mechanisms should be designed so that they can be actuated simultaneously without interfering with each other. Means to prevent icing of the outside release mechanisms and handle mounts should be provided.

Once the release mechanism has been actuated, only the single operation of pulling or pushing the exit closure into the clear should be necessary. All emergency exit closures should be designed to fall free or be easily pushed outward if the aircraft is not pressurized. In pressurized aircraft, exit closures should be removed inwardly, but if possible they should then be canted at an angle and pushed out the exit opening. "Push out"-type Class C exits should also be designed so that they can be pushed in from the outside by rescue personnel.

Emergency exits should be designed to permit removal of the exit closure in spite of seal vulcanization, ice accumulation, and moderate fuselage deformation. A peripheral clearance of at least 0.20 in., provided between the exit closure and its frame, will help accomplish this goal.

6.7.1.7 <u>Explosively Created Exits</u>. Explosive systems for cutting emergency exits through existing doors and windows and through fuselage structures should be considered. These systems provide the advantages of extremely rapid release times, simplicity of operation, and immunity to jamming. If an explosive exit system is incorporated in the aircraft, the following design criteria apply.

The arming/firing system should be designed for simple and rapid actuation of the explosive system, yet provide maximum safety against inadvertent actuation. Arming and firing should be accomplished in two separate and deliberate actions, with the arming function always under the control of the flight crew. The safe/arm mechanism should remain in its chosen position (armed or disarmed) until a deliberate action to change its position is initiated. The safe/arm mechanism should not change positions due to system failure, or due to any environmental or crash inputs. Disarming capability must be provided to permit safing the system when normal safing modes are inoperable.

The firing mechanism should be independent of any external energy source. Firing mechanisms should be located adjacent to each emergency exit so that each exit can be opened independently, from both inside and outside the aircraft.

The linear shaped charges used to cut the exit openings should be held securely in position against the aircraft structure. The size of the exit openings should conform to Class C requirements. The jettisonable section should be ejected outward. Energy-absorbing backup material should be placed behind the shaped charge to control the backblast of the explosive.

All explosives used in the system should possess as high a thermal limit as possible. The system should be able to function when exposed to ambient air temperatures up to 40 ^{o}F, yet not function during brief exposure (30 to 60 sec) to postcrash fires. The system should be designed to minimize the possibility of system actuation igniting any spilled fuel. Thus, the amount and duration of any exposed flame should be minimal.

6.7.1.8 __Access to Exits__. Access from aisles to all exits should be provided so that exits are not obstructed by any aircraft structures or components that would impede escape. The width of aisles at any point between seat rows must allow unobstructed movement of 95th-percentile troops with full combat equipment. Therefore, the aisle width should be at least 17 in. Where it is necessary to pass through seat rows to gain access to emergency exits, the longitudinal spacing between the rows should be sufficient to permit these troops to move at a rate consistent with the capacity of the exit (1.5 sec per man or less).

6.7.2 Emergency Lighting

6.7.2.1 __Interior Emergency Lighting__. Interior emergency lighting should provide sufficient illumination throughout cockpit and cabin areas to permit occupants to locate emergency exits and survival equipment, perceive escape paths, and avoid obstacles while moving toward the exits. Minimum average illumination in clear air along passageways leading to each exit and in front of each exit should be 0.05 fc measured 20 in. above the floor (excluding canopy aircraft).

6.7.2.2 Emergency Exit Lights. Supplementary emergency lighting units, with adequate brightness to permit occupants to identify exits, read exit operating instructions, and actuate exit release mechanisms during reduced visibility conditions (darkness, smoke, etc.), should be provided at or near each emergency exit. Exit lights should be mounted in the lower part of the cabin to the extent possible. All passenger/troop-carrying aircraft must contain internally illuminated exit signs with a minimum brightness of at least 25 fL, although brighter lights are strongly recommended. Aircraft whose mission requirements include troop transport over water should contain exit sign lighting that meets the requirements specified in Section 6.6.3. Canopy aircraft may be excluded from these requirements.

6.7.2.3 Exterior Emergency Lighting. For noncombat missions, exterior emergency lighting should be considered to illuminate the ground near each exit and in areas where escape and survival equipment will be deployed. The light intensity on the ground should be 0.02 fc minimum.

6.7.2.4 Structural Requirements. All emergency lighting units should be self-contained, explosion-proof, operable under water, and accessible for periodic maintenance. To ensure structural integrity and continued operation after a crash, the lighting system should be capable of withstanding the following crash loads: 50 G downward, 10 G upward, 35 G forward, 15 G aftward, 25 G lateral. The crash environment is more fully defined by the velocity changes presented in Table 2. Except for those lights directly destroyed by the crash, breakup of the fuselage should not render any portion of the lighting system inoperative.

6.7.2.5 Power Sources. All units should be capable of operating independently of the main aircraft lighting system. Emergency lighting power sources should be independent of the main power source of the aircraft. They should contain power sufficient to provide effective illumination for a minimum of 15 min.

6.7.2.6 Actuation of Lighting Units. Emergency lighting units should be actuated automatically in as many survivable accidents as possible. This can be accomplished by using inertia sensors capable of sensing lower-severity accidents. Sensor criteria should be identical to those specified for crash locator beacons in Section 6.8. An override switch to nullify the automatic feature when desired must be provided. Manual actuating switches should be provided so that emergency lights can be turned on prior to a crash if desirable.

6.7.3 Emergency Exit Markings

Emergency exits should be clearly marked both inside and outside the aircraft. In addition, instructions for releasing the exits should be clearly marked beside the exit release mechanisms.

All U.S. Army aircraft must be painted and marked according to the requirements of TB 746-93-2 (Reference 72). Although these requirements are summarized in Volume V of this guide, the reader is referred to TB 746-93-2 for complete details.

6.7.4 Crew Chief Stations

At least one crew chief station should be located in each troop compartment. The station should be located as near the main or emergency exits as possible and should provide complete surveillance of the troop compartment.

6.7.5 Alarm Systems

Aircraft with passenger or troop compartments should be equipped with an audible emergency alarm device that can be heard over the highest decibel noise level expected in the aircraft. Consideration should be given to providing visual as well as audible warnings.

6.8 CRASH LOCATOR BEACON DESIGN CRITERIA

6.8.1 General

Crash locator beacons may be fixed, portable, or deployable, as specified by the procuring activity according to its aircraft mission requirements.

Fixed equipment is permanently mounted in the aircraft. Although the transmitter, antenna, and power supply need not be contained in one package, their close proximity to each other will reduce the chances of connecting circuitry being damaged during crash impact.

Portable and automatically deployed beacons should contain the transmitter, antenna, and power supply in one package. Portable beacons must be easily removed from their installations by crew members, yet their installations must be secure enough to protect them from impact damage.

Automatically deployed beacons should be designed to withstand ground impact forces following their ejection. They should also be buoyant, self-righting, and stable when floating in water and not adversely affected by immersion in fresh or salt water for the life of the power supply.

Crash locator beacons may be either manually or automatically activated. Since automatic activation requires no previous action on the part of the crew, it is the preferred method. However, an arming switch should be provided so that automatic activation can be used or not, depending on the aircraft mission. A manual activation switch also should be provided so that the beacon can be activated if the arming switch is not on or if, for any other reason, the beacon is not automatically activated.

6.8.2 Crash Sensors

Although different types of crash sensors might be used, the current state of the art is such that inertia sensors are the preferred choice. Systems have been designed which include self-testing diagnostic features. Regardless of the type of sensor used, the sensor must be responsive to the majority of survivable aircraft accidents, including those accidents in which the crash forces and damage are minimal. At the same time, the sensor should ignore normal vibrational loads and flight loads up to the limits of maneuverability.

In order to sense 75 to 80 percent of light fixed-wing accidents, an inertia sensor should have a sensing threshold of 2 G. Although the 2-G threshold level is below the accelerations sometimes experienced during flight, the inertia sensor can be designed to filter out vibration and flight loads if it also must detect a velocity change typical of crash rather than operational conditions before it actuates.

Since most fixed-wing aircraft accidents have a major longitudinal component of velocity and force, a unidirectional inertia sensor mounted with the active axis forward in the direction of the longitudinal axis of the aircraft is sufficient. A longitudinal inertia sensor should be designed to actuate at a threshold of 2-G acceleration and a minimum velocity change of 3.5 ft/sec.

The above specifications are also satisfactory for rotary-wing aircraft in the longitudinal direction. However, since helicopters often have large vertical crash forces with minimal longitudinal forces, a vertically oriented crash sensor should be employed in addition to a longitudinal sensor. The vertical sensor should be designed to actuate at a higher acceleration level and velocity change. Specific levels for helicopter operations have been established in Reference 73.

The sensor should be able to withstand impact forces associated with severe survivable crashes and still function. Thus the sensor should withstand shock pulses equal to or greater than those required for the transmitter, power supply, and antenna.

The inertia sensor criteria should be based on crash forces typical of those experienced in the occupant compartment during survivable crashes. Therefore, the sensor should be located in an area that will experience crash forces representative of those in the occupant compartment. The sensor should, of course, be protected from possible impact damage.

The sensor should be mounted to rigid structure to prevent the amplification or attenuation of flight or crash loads that can occur with flexible structures. For the same reason, soft mounting materials, such as flexible straps or Velcro fasteners, must not be used.

6.8.3 Transmitters

Operating frequencies and transmitter signal characteristics and power should be determined by the procuring activity according to its own needs and the available detector systems.

The transmitter should be designed so that it can be either manually or automatically activated. An arm switch should be provided so that automatic activation can be selected or not, as desired.

A cockpit warning light or sound should be provided to alert the crew to inadvertent transmitter activation.

The transmitter should be located in an area that is least likely to be subjected to impact damage. The transmitter and its mounting should be designed to withstand the impact forces of a severe survivable accident without compromising the operation of the transmitter.

6.8.4 Antennas

The antennas, except for those used in portable and deployable beacons, are usually mounted outside the aircraft. The antennas should be located away from anticipated impact areas, such as the front or bottom of the aircraft, wing or tail surfaces likely to impact trees, etc., and those portions of helicopters apt to experience rotor blade strikes during impact. The antenna mounting should be able to withstand the decelerative forces of severe survivable impacts. Low profile antennas have been developed for the normal emergency frequencies.

6.8.5 Power Supplies

The crash locator beacon should have its own independent power supply so that it is not dependent on aircraft power for its operation. The power supply should be capable of providing the necessary power for optimum transmitter operation over the time period and under the environmental conditions specified for the particular aircraft.

If the power supply is not integral with the transmitter, it should be mounted to the aircraft in a location away from anticipated impact areas and should have an attachment strength equal to that of the transmitter.

All electrical wiring between components of the system should be protected from impact damage unless the components are packaged together. Protection can be accomplished by following the criteria in Section 6.4.1.1.

6.9 DESIGN CHECKLISTS

6.9.1 Fuel System Design Checklist

6.9.1.1 Fuel Tanks

	Yes	No	N/A
1. Are the fuel tanks located as far as possible from anticipated impact areas, occupiable areas, large weight masses, and primary ignition sources?	___	___	___
2. Are the fuel tanks located as high up in the structure as possible?	___	___	___
3. Are the fuel tanks located where there is no danger of puncture by a collapsing landing gear?	___	___	___
4. Are the fuel tanks located so that transmissions, engines, and similar massive components will not crush the tanks during a crash?	___	___	___
5. Are the fuel tanks relatively safe from penetrative damage by structural stringers and stiffeners?	___	___	___

	Yes	No	N/A
6. Can each fuel tank displace in the airframe structure without tearing or inducing leaks around the filler area, the fuel line entry and exit, the quantity indicator, and the tank-to-structure attachment points?	___	___	___
7. Do the fuel tanks have smooth, regular shapes, with the sump gradually contoured into the tank bottom?	___	___	___
8. Do all fuel tank concave corners have a minimum radius of 3 in., and all convex corners a minimum radius of 1 in.?	___	___	___
9. Do all fuel tanks meet or exceed the requirements of MIL-T-27422?	___	___	___
10. Do all fuel tank fittings meet or exceed the tank pullout strength specified in MIL-T-27422?	___	___	___

6.9.1.2 Fuel Lines

	Yes	No	N/A
11. Are all fuel lines made from flexible hose with a steel-braided outer sheath?	___	___	___
12. Do all hose assemblies meet the strength requirements listed in Table 17, Section 6.2.3.1?	___	___	___
13. Can all hoses elongate 20 percent without the hose assemblies spilling fuel?	___	___	___
14. Do fuel lines exit the fuel tank in one protected location?	___	___	___
15. Has the number of fuel lines in the engine compartment been kept to a minimum?	___	___	___
16. Are fuel lines routed along heavier structural members wherever possible?	___	___	___
17. Is as much of the fuel line as possible routed through the fuel tanks?	___	___	___
18. Are fuel lines routed as far as possible from occupiable areas and electrical compartments?	___	___	___
19. Are fuel lines routed as far as possible from all electrical equipment and wires?	___	___	___
20. Are fuel lines routed away from areas where large structural damage is likely during a crash?	___	___	___
21. Are fuel lines routed away from the exhaust system and high-temperature heating ducts?	___	___	___

	Yes	No	N/A
22. Are the fuel system lines designed with as few fittings as possible?	___	___	___
23. Are the fuel system lines designed so that uncut hoses are run through bulkheads rather than attached to the bulkheads with fittings?	___	___	___
24. Are self-sealing breakaway valves used wherever a fuel line goes through a firewall or bulkhead or is attached to the bulkhead?	___	___	___
25. Are lines entering and exiting in-line boost pumps made of flexible hose that is approximately 20 percent longer than necessary?	___	___	___
26. If fuel lines are not longer than necessary for in-line boost pumps, are self-sealing breakaway valves used in the lines near the boost pump?	___	___	___
27. Are self-sealing breakaway valves used at all points in the fuel lines where aircraft structural deformation could lead to line failure?	___	___	___
28. Are fuel line supports frangible to ensure release of the line from the structure during crash impact?	___	___	___
29. Will the frangible supports meet all operational and service loads of the aircraft?	___	___	___
30. Are all continuous lines running through bulkheads stabilized by frangible panels?	___	___	___

6.9.1.3 Frangible Attachments

	Yes	No	N/A
31. Are frangible attachments used at all attachment points between the fuel tanks and aircraft structure?	___	___	___
32. Do the specified frangible tank attachment separation loads exceed all operational and service loads by a satisfactory margin?	___	___	___
33. Are the specified frangible attachment separation loads between 25 and 50 percent of the loads required to fail the attached system or components?	___	___	___
34. Will the frangible attachments separate whenever the required loads are applied in all possible modes likely to occur during crash impacts?	___	___	___

	Yes	No	N/A
6.9.1.4 Self-Sealing Breakaway Valves			
35. Are breakaway valves installed in all fuel-tank-to-fuel-line connections, tank-to-tank interconnects, and at other points in the fuel system where aircraft structural deformation could lead to system failure?	___	___	___
36. Are the shapes of the breakaway valves remaining in the fuel tank basically smooth?	___	___	___
37. Are the breakaway valves recessed into the tank wall so that the tank half does not protrude outside the tank wall more than 1/2 in. after valve separation?	___	___	___
38. Do the specified breakaway valve separation loads exceed all operational and service loads of the aircraft?	___	___	___
39. Are the specified breakaway valve separation loads between 25 and 50 percent of the loads required to fail the attached components or lines?	___	___	___
40. Are the breakaway valves required to separate whenever the required loads are applied in the modes most likely to occur during crash impacts?	___	___	___
6.9.1.5 Fuel Drains			
41. Are all fuel line drain valves stabilized where necessary with frangible attachments?	___	___	___
42. Are all structural attachments of fuel tank drains made with frangible attachments?	___	___	___
43. Are all fuel tank drains recessed into the tank so that no part of the drain protrudes outside the tank wall?	___	___	___
6.9.1.6 Filler Units			
44. Are filler units attached to the aircraft structure with frangible attachments?	___	___	___
45. Are filler caps recessed into the fuel tank wall?	___	___	___
46. Are long filler necks avoided?	___	___	___
47. If filler necks are used, are they made from frangible materials and designed so that the filler cap stays with the tank after filler neck separation?	___	___	___

	Yes	No	N/A
6.9.1.7 Boost Pumps			
48. Can an engine-mounted, engine-driven boost pump be used in the aircraft?	___	___	___
49. If an engine-mounted suction system cannot be used, can an air-driven boost pump be used?	___	___	___
50. Do in-line boost pumps have a structural attachment capable of withstanding a 30-G load applied in any direction?	___	___	___
51. Are tank-mounted boost pumps fastened to the structure with frangible attachments?	___	___	___
6.9.1.8 Fuel Filters and Strainers			
52. Are fuel filters and strainers mounted outside the engine compartment wherever possible?	___	___	___
53. Do all strainers and filters have a structural attachment capable of withstanding a 30-G load applied in any direction?	___	___	___
54. Do all strainers and filters retain as small a quantity of fuel as possible?	___	___	___
6.9.1.9 Fuel Valves			
55. Has the number of fuel valves been kept to the minimum required for operation?	___	___	___
56. Are self-sealing breakaway valves used at all valve-to-fuel-line connections where crash-induced line failure is likely?	___	___	___
57. Are all small in-line valves fastened to the structure with frangible attachments?	___	___	___
58. Do large valves have a structural attachment capable of withstanding 30-G loads in any direction?	___	___	___
59. Are fuel shut-off valves located outside the engine compartment, either on the outside face of the firewall or at the fuel tank outlets?	___	___	___
6.9.1.10 Fuel Quantity Indicators			
60. Can float-type quantity indicators be used in this fuel system?	___	___	___

	Yes	No	N/A
61. If probe-type indicators are used, are they fabricated from material that either is frangible or possesses as low a flexural rigidity as possible?	___	___	___
62. Is a slightly rounded shoe incorporated at the probe bottom end of all probe-type indicators, or is the probe mounted at an angle toward the rear of the aircraft?	___	___	___
63. Are frangible attachments used where it is necessary to stabilize the indicator by fastening it to the structure?	___	___	___

6.9.1.11 Vent Systems

64. Are high-strength fittings used between the metal insert in the tank and the vent line?	___	___	___
65. If vent outlets must be supported, are they supported by frangible attachments to the structure?	___	___	___
66. Is the vent line made of wire-covered flexible hose?	___	___	___
67. Is the vent line routed so that it cannot be snagged in displacing structure during a crash?	___	___	___
68. Is a self-sealing breakaway valve used at the tank-to-line attachment if there is danger of the tank being torn free of the supporting structure?	___	___	___
69. Are vent lines routed inside the fuel tank in such a manner that spillage cannot continue after a roll-over accident?	___	___	___
70. If an antispillage vent valve is used inside the tank in lieu of the above items, will the valve remain fully open during all normal flight conditions?	___	___	___
71. Will the vent valve close in the extreme attitudes that will occur during a rollover?	___	___	___
72. Will the vent valve possess adequate venting capability under critical icing conditions in flight?	___	___	___
73. If the fuel system is to be pressure refueled, is a bypass system provided in case of tank overpressurization?	___	___	___
74. Is any spillage due to tank overpressurization released away from aircraft occupants and ignition sources?	___	___	___

	Yes	No	N/A

6.9.2 Oil and Hydraulic System Design Checklist

6.9.2.1 Oil Tanks and Hydraulic Reservoirs

	Yes	No	N/A
1. Are the tanks and reservoirs located as far as possible from anticipated impact areas, occupiable areas, large weight masses, and primary ignition sources?	___	___	___
2. Are the tanks and reservoirs located as high up in the structure as possible?	___	___	___
3. Are the tanks and reservoirs located where there is no danger of puncture from a collapsing landing gear?	___	___	___
4. Are the tanks and reservoirs located where transmissions, engines, and similar massive components will not crush them during a crash?	___	___	___
5. Are the tanks and reservoirs relatively safe from penetrative damage by structural stringers and stiffeners?	___	___	___
6. Can the oil tanks displace in the airframe structure and still not leak around the filler area, the fluid line entry and exit, the quantity indicator, and the tank-to-structure attachment points?	___	___	___
7. Are the hydraulic reservoirs constructed and mounted to withstand 30-G forces applied in any direction?	___	___	___

6.9.2.2 Oil and Hydraulic Lines

	Yes	No	N/A
8. Are all oil and hydraulic lines made from flexible hose with a steel-braided outer sheath wherever possible?	___	___	___
9. Do all hose assemblies meet the strength requirements listed in Table 17, Section 6.2.3.1?	___	___	___
10. Can all hoses elongate 20 percent without the hose assemblies spilling fluid?	___	___	___
11. Is coiled metal tubing used in areas where flexible hose cannot be used, but large structural deformations are expected?	___	___	___
12. Has the number of fluid lines in the engine compartment been held to a minimum?	___	___	___

		Yes	No	N/A
13.	Are fluid lines routed along heavier structural members wherever possible?			
14.	Are fluid lines routed as far as possible from occupiable areas and electrical compartments?			
15.	Are fluid lines routed as far as possible from all electrical equipment and wires?			
16.	Are fluid lines routed away from areas where large structural damage is likely during a crash?			
17.	Are fluid lines routed away from the exhaust system and high-temperature heating ducts?			
18.	Are the fluid system lines designed with as few fittings as possible?			
19.	Are the fluid system lines designed so that continuous hoses are run through bulkheads rather than attached to the bulkheads with fittings?			
20.	Are self-sealing breakaway valves used wherever a fluid line goes through a firewall or a bulkhead or is attached to the bulkhead?			
21.	Are self-sealing breakaway valves used at all points in the fluid lines where aircraft structural deformation could lead to line failure?			
22.	Are fluid line supports frangible to ensure release of the line during crash impact?			
23.	Are uncut lines running through bulkheads stabilized by frangible panels?			

6.9.2.3 Oil and Hydraulic System Components

		Yes	No	N/A
24.	Are all oil and hydraulic system components located as far as possible from anticipated impact areas, occupiable areas, and electrical compartments?			
25.	Are the components located in the engine compartment restricted to those absolutely necessary for engine operation?			
26.	Can the construction and mounting of all system components withstand 30-G forces applied in any direction without leakage?			

	Yes	No	N/A
6.9.2.4 Oil Coolers			
27. Is the oil cooler located outside of the engine compartment?	___	___	___
28. Is the oil cooler located as far as possible from anticipated impact areas, occupiable areas, and other potentially injurious components?	___	___	___
29. Can the oil cooler and connecting lines experience considerable deformation without leaking?	___	___	___
30. Can the oil cooler mounting withstand 30-G forces applied in any direction?	___	___	___
6.9.3 Ignition Source Control Checklist			
6.9.3.1 Electrical Systems			
1. Are wires routed as high up in the structure as possible?	___	___	___
2. Are wires routed away from areas of anticipated structural damage, i.e., landing gear failure, nose crush-in, etc.?	___	___	___
3. Are wires routed above or away from flammable fluid lines?	___	___	___
4. Are all wires routed through the structure so that extensive structural collapse or displacement can take place without breaking wiring?	___	___	___
5. Are wire bundles supported at frequent intervals by frangible attachments to the aircraft structure?	___	___	___
6. Are wires shielded by felt or similar protective covers in areas where crushing is likely?	___	___	___
7. Are wires to electrically operated boost pumps 20 to 30 percent longer than necessary?	___	___	___
8. Is all electrical wiring going through the fuel tank compartments shrouded?	___	___	___
9. Is wiring in the fuel tank compartment routed as high as possible in the compartment?	___	___	___
10. Are electrical wires in the fuel tank compartment 20 to 30 percent longer than necessary?	___	___	___

	Yes	No	N/A
11. Are batteries, generators, and inverters located in areas relatively free from structural collapse?	___	___	___
12. Are batteries, generators, and inverters located as far as possible from flammable fluids?	___	___	___
13. Are batteries and generators (unless engine mounted) housed in compartments built into the airframe?	___	___	___
14. Are battery, inverter, and generator mountings capable of withstanding a 30-G force applied in any direction?	___	___	___
15. Are the wires connecting the generator, battery, and inverter into the system located in relatively crush-free areas?	___	___	___
16. Are light bulbs and attaching wires on lower airframe surfaces designed to readily displace, rather than remain stationary and be broken?	___	___	___
17. Are all electrical compartments lined with a tough, nonconductive paneling?	___	___	___

6.9.3.2 Shielding

	Yes	No	N/A
18. Are fuel tanks isolated from the occupants by a minimum of two spillage barriers?	___	___	___
19. Are firewalls designed to withstand all survivable crash impacts without losing their structural integrity or sealing ability?	___	___	___
20. Are drainage holes located in all flammable fluid tank compartments?	___	___	___
21. Is the hot metal of the engine shielded from flammable fluid spillages?	___	___	___

6.9.4 Interior Materials Selection Checklist

	Yes	No	N/A
1. Do all interior materials meet the flammability requirements specified in Federal Air Regulation (FAR) 25.853?	___	___	___
2. Do all interior materials produce the lowest possible amount of smoke and toxic gases (see Section 6.5.3 for appropriate screening tests)?	___	___	___

	Yes	No	N/A
6.9.5 Ditching Provisions Checklist			
1. Are emergency exits larger and more numerous than normally required to meet minimum standards?	___	___	___
2. Are additional escape exits provided in the overhead, deck, and tail sections?	___	___	___
3. Have explosively created exit systems been considered?	___	___	___
4. Are emergency exits lighted with high intensity lights with a minimum brightness of 120 fL?	___	___	___
5. Even though escape lights meet the minimum requirement, is the brightness level of escape lighting the highest permitted by other design conditions (up to 200 fL)?	___	___	___
6. Has more than one aircraft flotation method been provided?	___	___	___
7. Does the flotation bag system have a high reliability?	___	___	___
8. Are tiedown or stowage facilities provided for life rafts and other ditching equipment?	___	___	___
9. Are equipment restraint devices and supporting structures designed to restrain the equipment to loads of 50 G downward, 10 G upward, 35 G forward, 15 G aftward, and 25 G sideward?	___	___	___
10. Is all survival equipment readily available and easily released after ditching?	___	___	___
11. Can life rafts be removed and deployed outside the aircraft within 30 sec?	___	___	___
6.9.6 Emergency Escape Design Checklist			
6.9.6.1 Emergency Exits			
1. Are the numbers, sizes, and locations of the exits such that a full load of troops and crew can evacuate in 30 sec when the aircraft is on its side?	___	___	___
2. Are all escape exits a minimum of 22 in. in diameter, or 22 in. square with 6-in. radius corners?	___	___	___

	Yes	No	N/A
3. Can all emergency exits be completely opened within 5 sec after the person initiating the action first places his hand on the release handle?	___	___	___
4. Does each crew member have access to at least one emergency exit regardless of aircraft attitude?	___	___	___
5. Are a minimum of two exits, one on each side of the fuselage, provided in troop/passenger compartments?	___	___	___
6. Is at least one exit provided for every 10 persons expected to occupy troop/passenger compartments?	___	___	___
7. Are emergency exit locations equally divided on each side of the aircraft?	___	___	___
8. If the width of the fuselage is 5 ft or more, are additional exits provided in the overhead, bottom, fore or aft sections of the aircraft?	___	___	___
9. Are all exit release mechanisms of the single motion type?	___	___	___
10. Is the number of different types of exit release handles held to a minimum?	___	___	___
11. Can all exits be opened from both the inside and outside of the aircraft?	___	___	___
12. Can the exits be opened even if the fuselage evidences considerable distortion?	___	___	___
13. Can the exits be easily operated when the aircraft is on its side?	___	___	___
14. Will removed or opened exit covers inherently be positioned so as to not block the exit openings nor interfere with occupant egress?	___	___	___
15. Is the exit opening operation designed to inherently resist jamming by loose objects?	___	___	___
16. Can an exit be opened easily when the operator is being pushed or crowded by other occupants?	___	___	___
17. During emergency evacuation, do all passengers have essentially the same distance to move during egress?	___	___	___

	Yes	No	N/A
18. Are aisles between seat rows wide enough to allow unobstructed movement of occupants (at least 17 in. minimum)?	___	___	___
19. If occupants must pass through seat rows to reach the exits, can they move to the exits at a rate that permits one person to exit every 1.5 sec or less?	___	___	___

6.9.6.2 Explosive Exit Systems

20. Are arming and firing accomplished in two separate and deliberate actions?	___	___	___
21. Is the arming function under the control of the flight crew?	___	___	___
22. Will the safe/arm mechanism remain in its pre-selected position regardless of system failure or environmental or crash inputs?	___	___	___
23. Is the firing mechanism independent of any external energy source?	___	___	___
24. Can the exits be opened independently of each other?	___	___	___
25. Are the explosive charges used to cut the openings held securely in position against the aircraft structure?	___	___	___
26. Are energy-absorbing backup materials placed behind the explosive charges?	___	___	___
27. Can the system function in ambient air temperature up to 400 °F, yet not function during 30- to 60-sec exposures to postcrash fires?	___	___	___
28. Are the amount and duration of any exposed flames from explosive actuation minimal?	___	___	___

6.9.6.3 Emergency Lighting

29. Does the interior emergency lighting provide sufficient illumination to permit occupants to locate emergency exits, survival equipment, and escape paths?	___	___	___
30. Is there an average illumination in clear air of 0.05 fc or greater measured 20 in. above the floor along passageways leading to exits?	___	___	___

		Yes	No	N/A
31.	Are supplementary lighting units located in the lower part of the cabin at or near each emergency exit?	___	___	___
32.	Do all internally illuminated exit signs have a minimum brightness of at least 25 fL?	___	___	___
33.	For noncombat missions, is exterior emergency lighting provided to illuminate the ground near each exit and the areas where escape and survival equipment will be deployed?	___	___	___
34.	Is the exterior light intensity on the ground at least 0.02 fc?	___	___	___
35.	Can the lighting system withstand the crash conditions listed in Section 6.7.2.4, and still function?	___	___	___
36.	Is emergency lighting power independent of aircraft power systems?	___	___	___
37.	Can the emergency lighting system be actuated both automatically and manually?	___	___	___

6.9.6.4 <u>Emergency Exit Markings</u>

		Yes	No	N/A
38.	Are emergency exits clearly marked both inside and outside the aircraft?	___	___	___
39.	Are instructions for releasing the exits clearly marked beside the exit release mechanisms?	___	___	___
40.	Do all exit markings meet the requirements of the Department of Army Technical Bulletin 746-93-2?	___	___	___

6.9.7 <u>Crash Locator Beacon Checklist</u>

		Yes	No	N/A
1.	Can the crash locator beacon be activated both automatically and manually?	___	___	___
2.	Is an inertia sensor used to automatically activate the beacon?	___	___	___
3.	Do the longitudinal inertia sensors in fixed wing aircraft meet the actuation limits stated in Section 6.8.7?	___	___	___
4.	Are both longitudinal and vertical inertia sensors provided in rotary-wing aircraft?	___	___	___

	Yes	No	N/A
5. Do the inertia sensors in rotary-wing aircraft meet the actuation limits stated in Section 6.8.2?	___	___	___
6. Is the inertia sensor mounted solidly to rigid structure located in an area that will experience crash forces representative of those in the occupant compartment?	___	___	___
7. Are the transmitter and antenna located in areas that are least subject to impact damage?	___	___	___
8. Can the transmitter and antenna withstand the crash forces listed in Section 6.7.2.4?	___	___	___
9. Does the crash locator beacon have its own independent power supply?	___	___	___
10. Is all electrical wiring between system components protected from impact damage?	___	___	___

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