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USAAVSCOM TR 89-D-22D

US ARMY
AVIATION
SYSTEMS COMMAND

AIRCRAFT CRASH SURVIVAL DESIGN GUIDE

VOLUME IV - AIRCRAFT SEATS, RESTRAINTS, LITTERS, AND COCKPIT/CABIN DELETHALIZATION

SIMULA INC.
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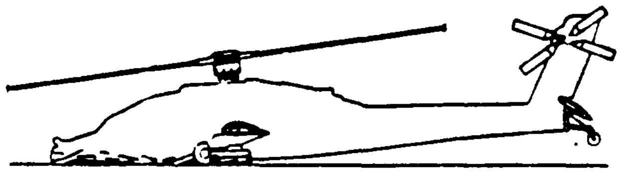
DECEMBER 1989



FINAL REPORT

Approved for public release; distribution is unlimited.

Prepared for

AVIATION APPLIED TECHNOLOGY DIRECTORATE
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FORT EUSTIS, VA 23604-5577

90 02 21 113

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.

(A)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
December 1989

3. REPORT TYPE AND DATES COVERED
Final FROM 9/86 TO 8/89

4. TITLE AND SUBTITLE
Aircraft Crash Survival Design Guide
Volume IV - Aircraft Seats, Restraints, Litters, and Cockpit/Cabin Delethalization

5. FUNDING NUMBERS
DAAJ02-86-C-0028

6. AUTHOR(S)
S.P. Desjardins, Richard E. Zimmermann, Akif O. Bolukbasi, Norman A. Merritt

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Simula Inc.
Phoenix, Arizona 85044-5299

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Aviation Applied Technology Directorate
U.S. Army Aviation Research & Technology Activity (AVSCOM)
Fort Eustis, VA 23604-5577

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
USAAVSCOM TR 89-D-22D

11. SUPPLEMENTARY NOTES
Volume IV of five-volume report

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

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 IV) contains information on aircraft seats, litters, personnel restraint systems, and hazards in the occupant's immediate environment. Requirements for design of seats, litters, and restraints systems are discussed, as well as design principles for meeting these requirements and testing for verification that the systems perform as desired. Energy-absorbing devices for use in seats are described, as are various types of cushions. Delethalization of cockpit and cabin interiors is discussed, including the use of protective padding and the design of controls for prevention of injury. Finally, computerized methods of analysis for evaluation of seats, restraints, and the occupant's immediate environment are presented. Keywords:

14. SUBJECT TERMS
Aircraft Design Guide, Seats, Cockpit/Cabin Delethalization, Restraint Systems, Design Data, Energy Absorption, Crashworthiness, Protective Padding, (KR)

15. NUMBER OF PAGES
254

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

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 (USASC), 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. Rakszawski, W. H. Reed, M. J. Reilly, S. H. Robertson, L. M. Shaw, G. T. Singley, III, A. E. Tanner, Dr. J. W. Turnbow, and L. W. T. Weinberg.

This volume has been prepared by S. P. Desjardins, Richard E. Zimmermann, Akif O. Bolukbasi, and Norman A. Merritt of Simula Inc.

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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, 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 survivability. Through a series of contracts with the Aviation Safety Engineering and Research Division (AvSER) of the Flight Safety Foundation, 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 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 revision 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.

This volume (Volume IV) contains information on aircraft seats, litters, personnel restraint systems, and hazards in the occupant's immediate environment. Following a general discussion of aircraft crash resistance in Chapter 1, a number of terms commonly used in discussing crash impact conditions, seats, and occupant protection are defined in Chapter 2. Chapter 3 presents design considerations for aircraft seats, and Chapter 4, principles for crash-resistant seat design. Energy absorption is discussed in Chapter 5.

Principles for cushion and personnel restraint system design are presented in Chapters 6 and 7, and strength and deformation requirements for seats and litters are stated in Chapters 8 and 10, respectively. Retrofit applications for seating systems are discussed in Chapter 9. Cockpit delethalization, including protective padding, is discussed in Chapter 11.

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.	28.35 grams	g
Pound	lb or #	0.454 kilogram	kg
Capacity (U.S. liquid)			
Fluidounce	fl oz	29.57 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 square centimeters	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}	16.39 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	4.448 newtons 4.448 x 10^5 dynes	N

1. BACKGROUND DISCUSSION

The overall objective of designing for crash resistance is to eliminate unnecessary injuries and fatalities in relatively mild impacts and minimize them in severe survivable mishaps. A crash-resistant aircraft will 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 in peacetime and in war. Results from analyses and research during the past several years have shown that the relatively small cost in dollars and weight of including crash-resistant 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. Every available subsystem must be considered in order to maximize the protection afforded to vehicle occupants. When an aircraft impacts the ground, deformation of the ground absorbs some energy. This is an uncontrollable variable since the quality of the impacted surface usually cannot be selected by the pilot. If the aircraft lands on an appropriate surface in an appropriate attitude, the landing gear can be used to absorb a significant amount of the impact energy. After stroking of the gear, crushing of the fuselage contributes to the total energy-absorption process. The fuselage must also maintain a protective shell around the occupant, so the crushing must take place outside the protective shell. The functions of the seat and restraint system are to restrain the occupant within the protective shell during the crash sequence and to provide additional energy-absorbing stroke to further reduce occupant decelerative loading to within human tolerance limits. Seat energy absorbers will function under most conditions of impact surface and attitude and are therefore, a highly reliable method of limiting occupant loads. The structure and components immediately surrounding the occupant must also be considered. 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.

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 those crash-resistant features that are most efficient for that 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 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 impact attitude or type of terrain impacted. 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 criteria.

Current helicopter 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 few crash critical components. For example, strengths and minimum crash energy-absorption requirements for seats and restraint systems 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 new seats in the cockpit for pilot, copilot, observer, and student in either rotary- or light fixed-wing aircraft should conform to the requirements of MIL-S-58095 (Reference 14), while passenger seats should conform to MIL-S-85510 (Reference 15).

Although higher levels of crash resistance can be more efficiently achieved in 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 program to retrofit all U.S. Army helicopters with crash-resistant self-sealing fuel systems (Reference 16), and the U.S. Navy program to retrofit the CH-46, SH-3, HH-3, and CH-53 helicopters (References 17, 18, and 19) 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 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 between the affecting parameters must be made in order to arrive at a final design that most closely meets the system'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.

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 • Postimpact - 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 • Anti-nose plowing bulkhead(s)	• Landing gear • Controlled structural collapse • Crash-resistant energy-absorbing seats • Shedding of large mass items - Engines - Transmissions - Rotor heads - External stores - Tail boom (Shed items must not impact occupied areas) • Impacted surface (soft ground, etc.)	• Emergency egress - Occupant release from seats - Door/exit opening - Accessibility of exits • Minimization of fire potential - Crash-resistant fuel systems - Low-flammability hydraulic fluid - Nonsparking materials in areas of potential ground contact

2. DEFINITIONS

2.1 AIRCRAFT COORDINATE SYSTEMS AND ATTITUDE PARAMETERS

Positive directions for velocity, acceleration, and force components and for pitch, roll, and yaw are illustrated in Figure 1. 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 1, with x, y, and z referring to the longitudinal, lateral, and vertical directions, respectively.

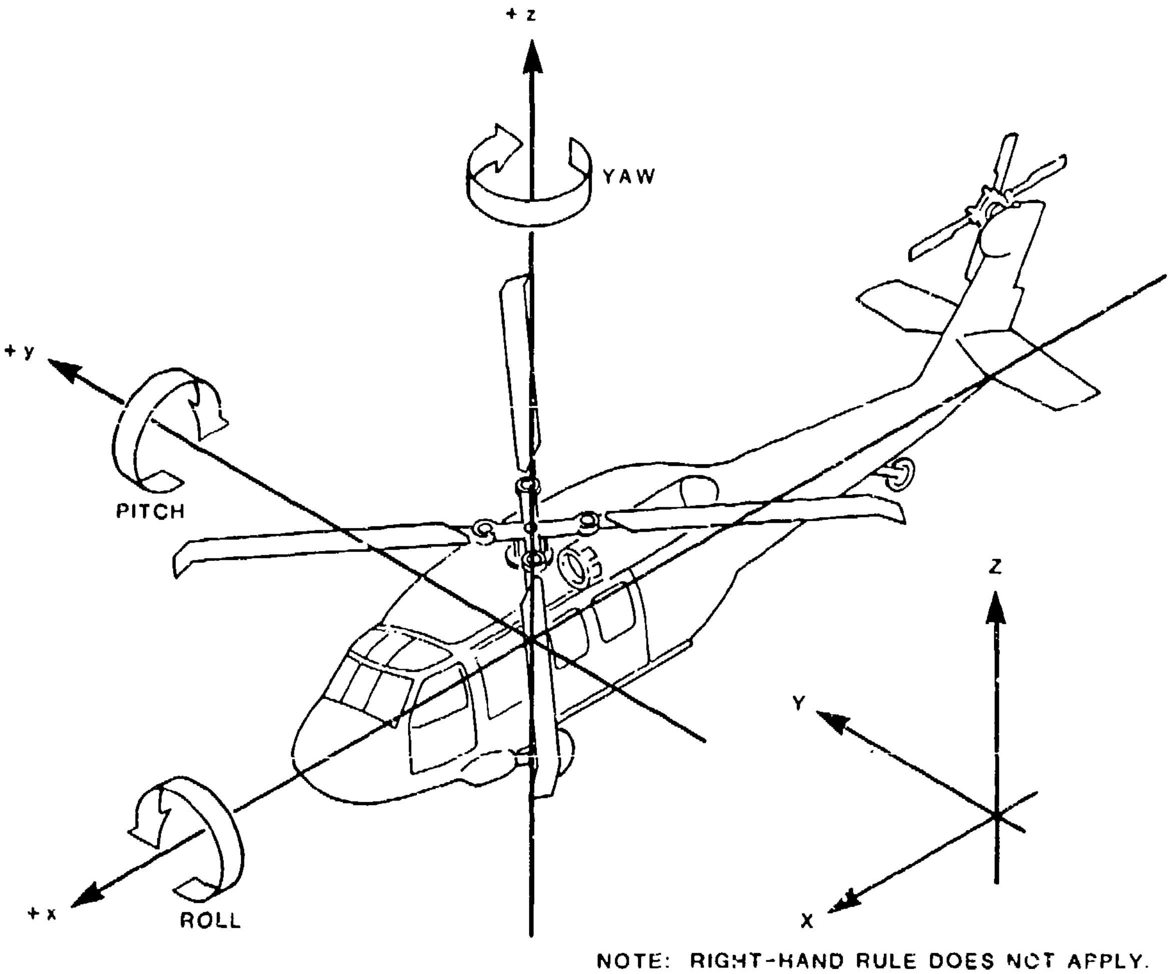


FIGURE 1. AIRCRAFT COORDINATES AND ATTITUDE DIRECTIONS.

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 the crash environment, unless otherwise specified, all acceleration values are those at a point approximately at the center of the floor of the fuselage.

- 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. Within the extremely short duration range of abrupt accelerations (0.2 sec and below), 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 due to gravitational attraction at sea level (g); 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.

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 2, the major impact should be considered ended at time t_2. Elastic recovery in the structure will tend to reverse the direction of 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 7.2 of Volume III.

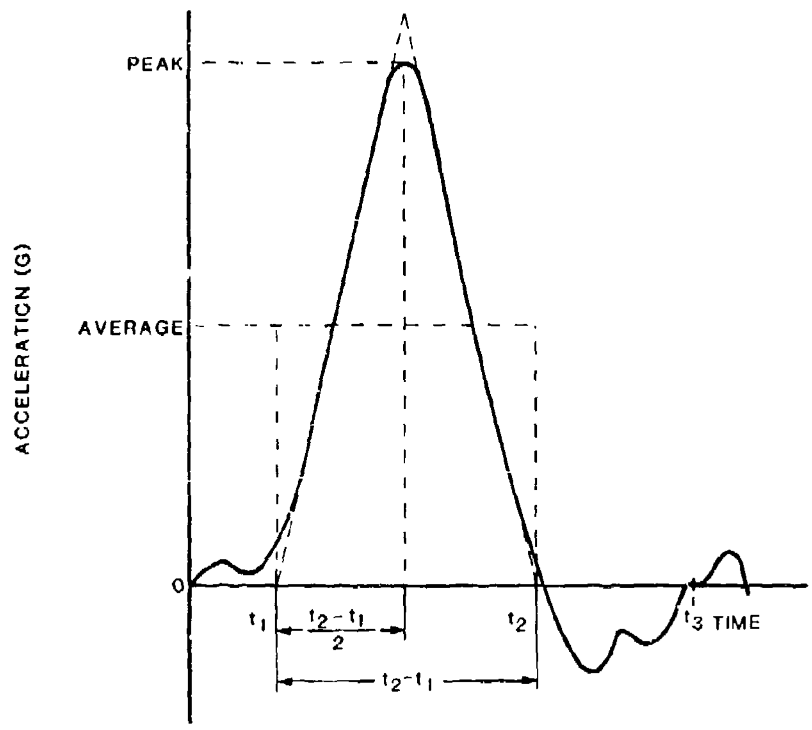


FIGURE 2. TYPICAL AIRCRAFT FLOOR ACCELERATION PULSE.

Longitudinal Velocity Change

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 before rebounding into the air 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 the 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.

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 input decelerative force (ratio of output to input). This amplification is a result of the dynamic response of the system.

- Transmissibility

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

2.6 CRASH SURVIVABILITY TERMS

- Survivable Accident

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.

- Survival Envelope

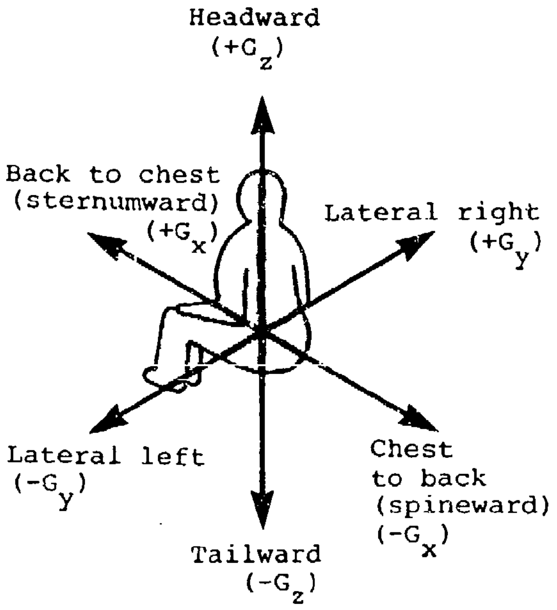
The range of impact conditions--including magnitude and direction of pulses and duration of forces occurring in an aircraft accident--wherein the occupiable area of the aircraft remains substantially intact, both during and following the impact, and the forces transmitted to the occupants do not exceed 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.

2.7 OCCUPANT-RELATED TERMS

- Human Body Coordinates

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 3 (Reference 20). 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 3. TERMINOLOGY FOR DIRECTIONS OF FORCES ON THE BODY. (REFERENCE 20)

- 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 environments is a function of many variables including the unique characteristics of each 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 types of spinal fractures, but typically the fracture is an anterior wedge or a 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 head 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.

- Submarining

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 on the buckle at the middle of the lap belt.

- Effective Weight

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.

- Iliac Crest Bone

  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.

- Lap Belt Tiedown Strap (also Negative-G Strap, Crotch Strap)

  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 4 FROM REFERENCE 21)

- Design Eye Position

  A reference datum point based on the eye location that permits the specified vision envelope required by MIL-STD-850B (Reference 22), 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.

- Horizontal Vision Line

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

- Back Tangent Line

  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.

- Buttock Reference Line

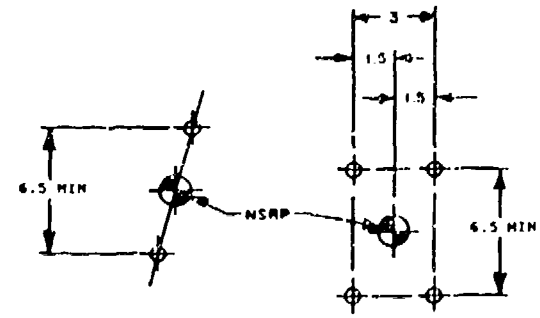
  A line in the midplane of the seat parallel to the horizontal vision line and tangent to the lowermost natural protrusion of a selected size of occupant sitting on the seat cushion.

- Neutral Seat Reference Point (NSRP)

  The intersection of the back tangent line and the buttock reference line. The seat geometry and location are based on the N.RP. 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.

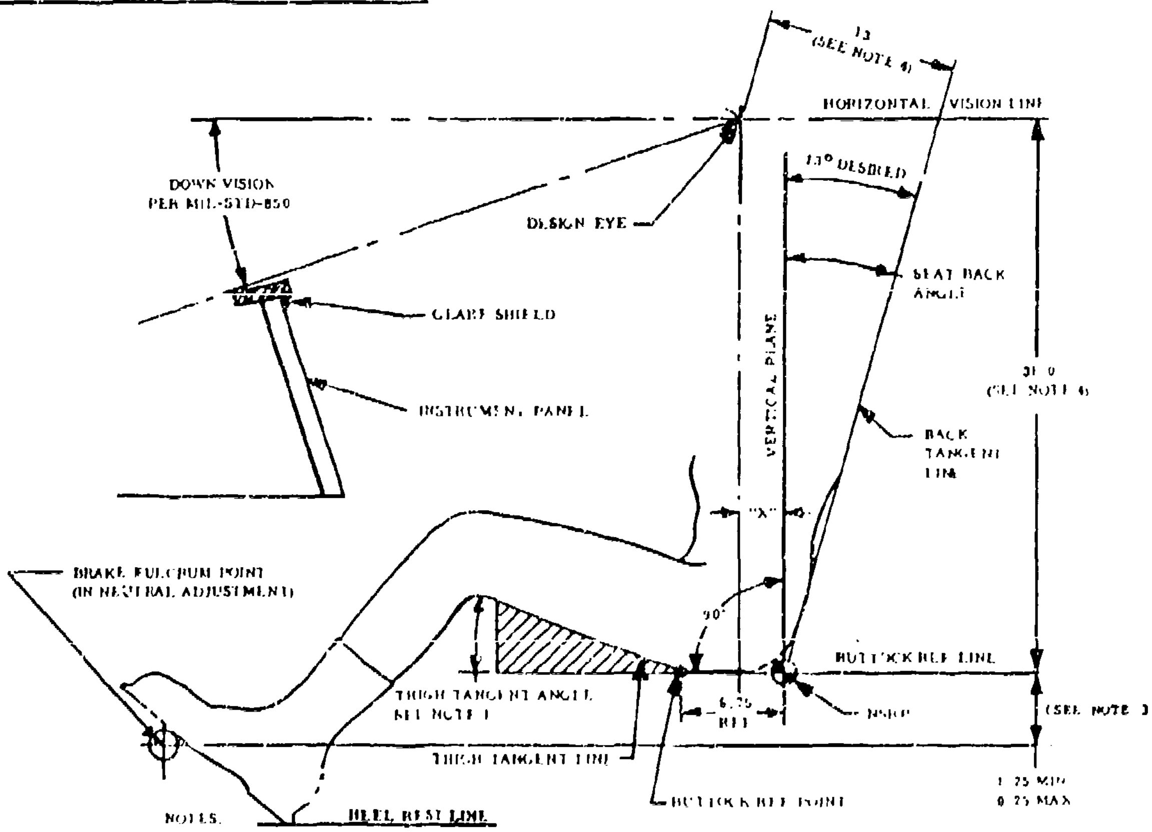
DISTANCE FROM DESIGN EYE POSITION TO VERTICAL PLANE OF NEUTRAL SEAT REFERENCE POINT FOR VARIOUS SEAT BACK ANGLES

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



2-WAY SEAT ADJUSTMENT (SEE NOTE 2)

4 WAY SEAT ADJUSTMENT (SEE NOTE 2)



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 SEAT ADJUSTMENTS SHOWN ARE FOR THE 5th PERCENTILE FEMALE THROUGH 95th PERCENTILE MALE PILOT POPULATION.
3. THE VERTICAL DIMENSION RANGE FROM NSRP TO BRAKE FULCRUM POINT DOES NOT INCLUDE VERTICAL SEAT ADJUSTMENT DIMENSIONS.
4. DIMENSIONS BASED ON 13° SEAT BACK ANGLE.

FIGURE 4. SEATING GEOMETRY. (REFERENCE 21)

- Buttock Reference Point

  A point 5.75 in. forward of the seat reference point on the buttock reference line. This point defines the approximate vertical and longitudinal position of the 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.

- Heel Rest Line

  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 magnitudes of 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 that 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.

- <u>Limit Load</u>

  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.

- <u>Load Limiter, Load-Limiting Device, or Energy Absorber</u>

  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.

- <u>Specific Energy Absorbed (SEA)</u>

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

- <u>Bottoming</u>

  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 comes into contact with the floor.

- <u>Bulkhead</u>

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

3. PRIMARY DESIGN CONSIDERATIONS

3.1 INTRODUCTION

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, the occupant's strike envelope should be minimized, and surrounding structure should be delethalized.

3.2 OPERATIONAL ENVIRONMENT

Several environmental and operational factors other than those associated with crash resistance affect the design of an adequate seating system. Because of their importance in overall design, these factors are mentioned briefly prior to the more detailed presentation of information concerning crash resistance.

3.2.1 Comfort

The comfort of an aircraft seat is a safety-of-flight factor rather than a crash-safety-design factor. An uncomfortable seat can induce pilot fatigue in a short period of time. Pilot fatigue is an indirect cause of aircraft accidents. Comfort is thus of primary concern and must not be unduly compromised to achieve crash safety.

Comfort is influenced by several factors, including the vibrational environment. Adequate comfort also involves maintenance of adequate body angles and load distributions. Therefore, thigh tangent angles and seat back angles are influential in body comfort. If the back angle is less than 13 degrees, the occupant's back will be required to counteract too much forward moment resulting from the weight of the body acting through centers of gravity forward of the spinal column. As the back angle is increased beyond 13 degrees, the center of gravity is moved back and the moment is reduced, which provides for much greater comfort. If the thigh tangent angle is too low, too much effort will be required to maintain the lateral orientation of the legs. If the cushion supports the lateral position of the legs, comfort will be improved. Also, increasing the thigh tangent angle seems to rotate the pelvis to the rear, effectively moving the center of gravity aft and providing a rearward moment in the pelvis that reduces the forward moment on the spine. A thigh tangent angle of 5 to 20 degrees is required by MIL-STD-1333 (Reference 21); however, it is recommended here that tangent angles greater than 10 degrees be used to maximize comfort and to reduce submarining tendencies.

Another aspect of comfort includes the width of the seat. Too narrow a seat can exert lateral forces on the sides of the body or force the body to be held forward out of the constraints of the seat bucket, again increasing discomfort. Maximum seat widths should be provided consistent with the space available in the aircraft, including consideration for the volume around the seat needed for lateral deflection during crash stroking and for items such as the collective control. Minimum inside seat width shall be 19 in.

The surface upon which the occupant sits has a major influence on comfort. The function of this surface is to spread the contact load over the largest possible area, thereby decreasing high pressure points and preventing restriction of blood flow in these areas. In the past, this has been accomplished by nets or by extremely thick, soft cushions. Although such solutions provided comfort for prolonged flights, this practice is not recommended, because the low spring rates of these nets or cushions usually make them hazardous in crash situations. These low spring rates allowed large relative velocities to build up between the occupant and the airframe or seat during the imposition of decelerative loads and increased the loading on the occupant. Thus, the cushion should provide adequate distribution of loads but not allow excessive motion during crash loading.

Another aspect of comfort is thermal ventilation. The thermal ventilation requirement for seat cushions is particularly important in hot, humid climates. The close contact between the buttocks or the back and the interfacing cushions can result in an elevation of temperatures coincident with collection of moisture through perspiration. For thermal comfort, provision should be made for air circulation to carry the hot, humid air out of this interface area.

3.2.2 Seat Adjustments

Passenger seats are not usually adjustable; however, in most cases, adjustment is mandatory for crewseats. First, the cockpit and crew station have been designed for a particular eye position. This eye position is associated with the size of a 50th-percentile male occupant; consequently, occupants of smaller or larger stature may not be located efficiently if seat adjustment is not provided. Theoretically, the seat adjustment enables the eyes to be positioned at the optimum point for each occupant. Typically, a ±2.5-in. vertical adjustment from the neutral seat reference position is required to account for the variation in male occupant size. A ±2.5-in. fore-and-aft adjustment is also required to permit the desired repositioning of the eye and for locating the occupant at the proper distance from controls, pedals, etc. For inclusion of 5th-percentile female pilots, a ±3.25-in. vertical adjustment range from an appropriately adjusted NSRP is necessary. Of course, human factors should be considered in the design of adjustments. Adjustment mechanisms should be easily found and easy to use, and required adjustment motions should be precise, allowing the occupant to easily get into the most comfortable position without a great deal of distraction. Further, there should be an efficient verification that the seat is firmly locked into the chosen position.

MIL-S-58095 requires that the seat adjustment controls be located on the forward right side of the bucket for vertical adjustment and forward left side for longitudinal adjustment. However, in the case of seat-support assemblies which are connected to the bulkhead, instead of the floor there may be no separate longitudinal adjustment; the vertical adjustment may automatically shift the seat position forward or aft as the seat is moved upward or downward. The inertia reel control should be on the forward left side of the bucket. The position of the levers should not change relative to the occupant when the seat is adjusted. The locking mechanism should be released by a forward movement of the controls and automatically lock, and indicate lock by aft movement, when the controls are released. Movement and force requirements should not exceed MIL-STD-1472 (Reference 23) limits.

The position of the collective control stick should be considered when the inertia reel control is located. If it is not, certain positions of the stick may block access to the inertia reel control.

If a fixed-load energy absorber is not used, it is preferable that any variable-load energy absorber (VLEA) adjustment dial be positioned so that it can be operated while the occupant is seated. If this is not possible, since it must be seen while being adjusted, the VLEA adjustment dial should be located so that the pilot or copilot may adjust it prior to being seated.

System designers should avoid routinely covering every eventuality of occupant size and weight when preparing system specifications. For example, requiring all occupant weights to be supported under the full loads in all vertical positions may result in a severe weight penalty (such as accommodating the largest (heaviest) occupant in the full-up position). It should be established that large occupants can and will use this position before this penalty is accepted. Therefore, specifications should be as specific as possible consistent with mission requirements.

3.2.3 Vibration Damping

By its basic nature, the helicopter includes many vibration sources, primarily as a result of the relatively large number of moving parts. Typical critical frequencies are associated with numbers of blades and rotor speed. Critical conditions are located at multiples of the main rotor speed; for example, one, two, four, and eight per revolution. Each helicopter design must consider such effects on occupant environment. For example, on four-bladed main rotors, the four-per-revolution frequency is typically between 4 and 5 Hz and 18 and 20 Hz. This driving frequency will be present constantly during cruise; therefore, it is highly desirable that the resonant frequency of the seat, both empty and occupied, fall outside the 4- to 5-Hz and 18- to 20-Hz frequency range. Other frequencies, such as eight per revolution, can also be a problem. For startup and shutdown conditions, the resonant frequency of the seat should be high (not lie in the range of 2 to 25 Hz), and considering the eight-per-revolution frequency it would be desirable, but perhaps not practical, to keep the natural frequency above 40 Hz.

Seat vibrational problems are often difficult to solve because the required size and general structure of the seat seem to control the occupied seat natural frequency rather than the design options that lie within the limits of weight and cost. However, the occupied seat natural frequency must be considered since seat vibration can be very distracting to the occupant, for example, in the lateral direction where the thighs touch the sides of the bucket.

Stiffening of the structure is extremely costly in weight; however, in certain situations it may be the only viable solution to the problem. Dampers that can be added to the seating system normally consist of sprung and damped masses. These mechanisms are heavy and their use would usually be unacceptable in a production aircraft. Isolation of the seat components by dash pots or elastomeric bearings may provide possible solutions to this problem.

During environmental testing in accordance with MIL-S-58095 the seat will be subjected to sinusoidal sweeps from 4 to 50 Hz. Sweeps at 0.1 G with a minimum duration of 7 min. will be conducted in three axes. Test will be repeated in the full up, intermediate, and full down positions with a 50th-percentile dummy occupant. The allowable transmissibility of the seat system will be included in the detail specification of the seat.

To summarize, consideration must be given to the vibrational characteristics of the seat in the vibrational environment of the specific aircraft for which the seat is designed.

3.3 DESIGN CRASH IMPACT CONDITIONS

3.3.1 Dynamics and Kinematics

When an aircraft crashes, any number of loading combinations can be imposed on the seat. This is true for rotary- or fixed-wing aircraft. It would not be useful to try to identify each and every loading combination; however, studies indicate the combinations of loadings that must be dealt with in the design of the seat and restraint system. For example, the stall-spin accident typical of light fixed-wing aircraft can produce high lateral loadings, the resultant of which can be oriented in any direction in the longitudinal-lateral or yaw plane. Studies of helicopter crashes show high incidences of side impacts or rollover after impact for some classes of helicopters (Reference 24).

As an example of the dynamics and kinematics of an aircraft crash, consider one of the new generation helicopters crashing in a nose-up or flare orientation. The tail boom or tail wheel may strike the ground first, followed by rotation of the aircraft around a pitch axis. Then, the gear will strike the ground, and, if it is a wheeled landing gear, the tires will begin to flatten, absorbing a small amount of energy. When the rim contacts the ground, the wheel may fail as the lower oleo strut begins stroking. After completion of the lower oleo stroke, the second stage will begin and energy-absorbing stroke will continue until the fuselage impacts the ground. If the ground is relatively soft, the ground will deform under the loading of the wheels and absorb some energy. As the fuselage impacts, the softer ground will deform again while the fuselage structure is deforming. As the fuselage structure deforms, additional energy is absorbed. At this point in the sequence, the loads can achieve the significant magnitudes required to initiate energy-absorbing stroke of the seat. The landing gear are designed to stroke at a lower load than that required to activate the vertical energy-absorbing system in the seats; thus, stroking of the gear will occur prior to vertical stroking of the seat. This will typically result in energy-absorbing stroke of the gear followed by an increase in fuselage loading when the fuselage impacts the ground and begins to crush. During some part of the crash sequence, the seat and fuselage may be stroking together. The decelerative loads may increase and the fuselage will eventually be stopped and may begin to rebound. Depending on the conditions of the particular crash, the seat may go on stroking until it either absorbs the residual energy of the supported mass or bottoms at the end of its stroke. Thus, the seat may be the last item in the load path of interest to remain in motion during the crash sequence.

One important point here can be used to advantage by the seat designer. In a crash with combined loading, extremely high longitudinal or lateral loads can be applied to the seat after stroking of the energy-absorbing gear and during fuselage crushing. However, once the fuselage has come to a stop, crash loading is no longer exerted on the seat and it may continue its stroke until either the residual energy or the seat stroke is expended. This can be important to the designer. For example, consider a seat design that includes only vertical energy-absorbing stroke. The seat is not required to withstand the high combined loads throughout its complete vertical stroke, only that portion of the stroke while the lateral/longitudinal crash loading is applied.

For those aircraft using wells, or depressions, in the floor under the seat to provide increased stroke distance below the floor, the seat must be guided sufficiently to clear the sidewalls of the well to utilize that additional distance. In a seat with a low lateral spring rate or lateral load attenuation, the seat may move laterally to the point where it no longer lines up with the well under the seat pan during the application of the longitudinal/lateral loading. If the longitudinal/lateral loading is removed soon enough, the seat may be able to return to alignment and still stroke into the well under the seat. However, this occurs only if the longitudinal/lateral loading (in certain cases) has produced elastic, rather than plastic, deformation. If the deformation has been plastic, removal of the load will not cause the seat to return to its original over-the-well position but will allow it to continue its vertical stroke in the deflected configuration. On the other hand, if the elastic deformation is not damped sufficiently, or if the distance above the well is not sufficient, the rebound of the seat may carry it beyond the well on the other side without sufficient time to return to center as it goes through the floor plane. These motions should be considered during seat design, development, and integration phases to minimize the seat's weight while providing the desired crash-resistant performance.

Several factors should be considered during the design of a seat that uses a well to increase available stroke. First, as much clearance as possible should be left between the outside of the seat pan and the inside of the well, preferably at least 1 in. This will allow for reasonable deflection from the no-load position without creating impact or interference hazards. The next consideration is that the seat be made stiff in the lateral direction to limit the extent of deflection but without imposing too high a weight penalty. Designing a seat with energy-absorbing stroke in the lateral direction is not recommended, since this may compromise the all-important vertical stroke. Usually, at the sides of the pilot/copilot seats are collective controls and consoles that do not permit sufficient lateral motion of the seat to avoid hazardous interference with the vertical stroke. Since the vertical stroke is the only required energy-absorbing stroke, its blockage will significantly degrade the degree of seat crash resistance. Additionally, studies indicate a high frequency of thorax and head injuries (Reference 25). Allowing the seat to move either laterally or longitudinally unnecessarily increases the risk of head or chest impact on surrounding structure.

One could infer from the above discussion that energy-absorbing strokes in the lateral or longitudinal directions are not desirable and serve to increase the overall hazard to the occupant. This general statement is true, but the degree of hazard or benefit will depend on the configuration of the specific aircraft and the location of the seat within the aircraft. In certain aircraft, space will be available for seats that stroke in more than just the vertical direction, and, when it is available and will not be hazardous, it may be advantageous to include it in the seat system design.

Because of the cabin location of troop seats, they typically have a less hazardous area surrounding them than crew seats and do not have to stroke into wells. Troop seats are frequently load limiting in the longitudinal and lateral as well as vertical directions. This three-dimensional load limiting reduces occupant decelerative loading and the crash loads on the seat structure in the transverse direction in comparison to a vertical-only load-limiting seat. Lower loading of the seat allows a lighter seat design. In the case of a side-facing seat, load limiting along the seat's lateral axis is necessary if the occupant decelerative loading during the specified aircraft forward crash impact conditions of Volume II is to be kept within human tolerance limits for lateral decelerations.

In reviewing the crash dynamics and kinematics of aircraft, it becomes quite apparent that all combinations of orientations, loading, and load directions can exist. (Volume II presents a detailed discussion of crash impact dynamics and kinematics.) It should also be remembered that the seat is designed to absorb only a portion of the crash energy required to decelerate the occupant in a tolerable environment. There are numerous crash orientations in which the aircraft has a lateral component of impact velocity, whether it results from a lateral drift of the aircraft or from its attitude at impact. These components of velocity can produce high landing gear loads, which, in some cases, may cause failure before absorbing significant energy. Consider the case of an aircraft impacting the ground with a high roll angle. Loss of the landing gear results in the aircraft fuselage impacting the ground without the reduction in energy normally attributed to the stroking of the gear. Therefore, systems analyses must take this factor into account. As an example of the possible dangers, it might be decided that landing gear should absorb all the crash energy associated with the 42-ft/sec vertical impact; therefore, seat stroking would not be required. The results of applying this logic to hardware would seriously reduce the overall crash resistance of the aircraft in those crashes where the full energy absorption of the gear could not be realized. Therefore, it is recommended that seats contain at least the minimum energy-absorbing stroke defined in this document, regardless of the energy absorption capacity of the gear.

After a helicopter crashes, the rotating main rotor may strike the ground or other obstacles and roll the helicopter onto its side. Because of the high center of gravity, the helicopter may roll over without any added lateral impulse from the main rotor blades after gear failure. In any case, the kinematics of crashed helicopters can be quite complex and violent, and the helicopter may come to rest in any orientation. Because of these kinematics, loads are specified in all directions for seats. This subject will be covered in more depth later in this volume; however, the crash kinematics of these aircraft demand strength requirements in all directions, including upward and aftward. In this regard, it should be remembered that the seat may have used a significant portion of its available vertical stroking distance during the major impact. If the aircraft should then follow through with a flip, or land on its back, it is preferable that the system maintain the seat near its final stroked position rather than allowing the seat to return to its original position. Upward travel could be hazardous if the top of the fuselage were crushed and the occupant were free to travel unrestrained back toward his initial position. Head and/or neck injuries could result.

For crew seats, some energy absorbers will themselves prevent reverse motion. However, if the energy absorber design is such that the energy absorber will not prevent the seat from rebounding, to avoid occupant injury due to roof collapse some means should be used to prevent the upward movement of the seat after stroking, such as the use of a ratchet mechanism in the guide tubes or rails that will permit only downward movement of the seat.

In summary, it must be remembered that, to produce a crash-resistant design, systems analyses must consider likely combinations of loadings, including potential losses of energy-absorbing structure such as landing gear throughout the full [illegible]tion of the seat and the aircraft.

3.3.2 Design Conditions

The design impact conditions for light fixed- and rotary-wing aircraft are presented in Volume II and are repeated here in Table 2. All seats, restraint systems, and litters should be designed for these impact velocities and provide the desired performance in the design crash environments.

TABLE 2. SUMMARY OF DESIGN CONDITIONS FOR ROTARY- AND LIGHT FIXED-WING AIRCRAFT

Impact Direction	Velocity Change (ft/sec)
Longitudinal	50
Vertical	42
Lateral*	25
Lateral**	30

*Light fixed-wing, attack, and cargo helicopters.
**Other helicopters.

3.3.3 Structural Distortion

Structural distortion of the airframe and its resulting loading of the seat must be considered in the design stages. For example, a ceiling-mounted seat may experience lower loads than a floor-mounted seat because of the distortion or deflection of the ceiling and supporting walls. However, additional stroke distance may be required due to the inefficiency of the stroke provided by distortion of the airframe when compared to that of a load-limited seat. The effective stroke of a seat considered to be rigidly attached (no energy absorbers between the seat and ceiling) to the ceiling also must be considered. If the seat pan is 12 in. from the floor of the aircraft and the ceiling of the aircraft is expected to distort downward on the order of 12 in., careful consideration must be given to eliminating rebound rather than increasing total stroke, which could result in bottoming. In the practical case, the ceiling probably distorts something less than the distance between the seat pan and the floor of the aircraft; therefore, energy-absorbing stroke should be provided in the seat to maximize usage of the available space. A systems analysis should be applied to this situation to establish the correct combination of variables. Computer simulations may assist in evaluating the combined occurrence of seat stroke and structural deformation.

A considerable amount of the downward motion of an aircraft ceiling may be elastic. If so, it is advantageous to eliminate the rebound from this elastic distortion from a ceiling-supported seat. Consideration could be given to a device that allowed vertical downward motion of the seat but restrained it from following the ceiling during its elastic rebound. A ceiling which will support the applied loads up to the initiation of seat stroking with low deflections eliminates the problem. Efficient use of ceiling-mounted seats can then be achieved.

A major consideration in providing crash-resistant seating systems is the possibility of a local distortion in the part of the aircraft to which the seat is attached. For example, a floor-mounted seat may have to withstand severe distortions as a result of underfloor and floor deformations caused by impact forces. If the aircraft crashes on uneven ground or encounters rocks or stumps, distortions of the underfloor structure can occur. The seat structure or seat attachment to the floor should be adequate to permit these distortions without producing failure of the seat structure or its attaching mechanisms. It should be noted that the forces causing this distortion cannot be resisted by the seat structure. In other words, it is not feasible to build a seat strong enough, if rigid, to maintain the attachment to the aircraft in these situations. The crash loads causing the distortion will, in most cases, exceed any strength that can be designed into the seat, thus, producing failures if not adequately accounted for in the design.

Likewise, distortion of bulkheads in bulkhead-mounted seats presents the same problem. It is likely that local distortion of a bulkhead will not be of the magnitude of the distortions that occur in the floor structure of an aircraft. Rocks and stumps can produce extremely large local deformations of structures which support floor-mounted seats, but will not be involved in distortion of bulkheads and bulkhead structure. Consequently, the distortion requirements for seat mountings on bulkheads are less severe. A search of USASC crash records identified no known cases of bulkhead-mounted seat loss due to bulkhead distortion or fracture of attaching structure.

It is expected that sidewalls will deform more than transverse bulkheads, although they would not be as susceptible to rocks and stumps as floors. The deformation would usually be one of the walls buckling outward near the floor and changing the lateral and vertical relationships between attachment points. However, in helicopters, sidewall-mounted seats are not usually pilot or copilot seats and therefore are usually not of he stiffness that would create a problem in the environment described. Fc fixed-wing aircraft, the aircraft/seat interface should be designed tc be compatible by allowing flexibility in the seat, in the attachments, in stiffening the sidewall of the aircraft, or by simply not attaching rigid seats to sidewalls. Floor, bulkhead, and sideward warpage requirements are presented in Section 4.4.5, Joint Deformation.

3.4 APPLICABILITY OF CRITERIA

The recommendations in this volume apply to all categories of U.S. Army aircraft. Those recommendations having application to a specific class or category of aircraft only are indicated.

3.5 ACCEPTANCE CRITERIA

In addition to operational requirements specified in other design guide documents, seats and litter systems should be designed to provide occupant protection under crash conditions as specified in Volume II. Appropriate stress analyses, tests, and operational requirements outlined in this volume should be met by every seat, restraint, litter system, and by the cockpit and cabin interior prior to acceptance.

3.6 SELECTION CRITERIA

Crash-resistant seats, restraint systems, litter systems, and cockpit and cabin materials should be evaluated on the basis of the occupant protection provided and on their anticipated reliability and serviceability under the operational and potential crash conditions expected.

4. DESIGN PRINCIPLES FOR SEATS AND LITTERS

4.1 INTRODUCTION

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 where the energy-absorbing systems of multi-unit seats are rendered ineffective due to less than full 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 prevented by use of an adequate restraint system of much lighter weight than that required for other seat orientations. The rearward-facing seat is recommended.

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 Chapter 7. The 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 occupants 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. This arrangement does not provide adequate crash protection. The use of side-facing seats is least desirable for crash safety; however, 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).

4.2 LITTERS AND THEIR ORIENTATION

The supine position of a litter patient is ideal for resisting vertical impacts. The contact area is the maximum possible, and the decelerative forces act transversely to the body. For current litters, the major problem occurs as a result of impact forces in the lateral/longitudinal plane. The relatively flat litter surface makes it difficult to provide an adequate restraint harness to resist these loads. The current practice of wrapping two lengths of webbing around the litter offers a degree of restraint oriented transversely to the body. If loose litter straps are used, only frictional forces prevent the body from sliding off the litter in the lengthwise direction.

Litters should be installed laterally, where practical, to provide more positive restraint for expected combined crash forces. A lateral litter orientation also will prevent the litter from becoming completely detached from its current supports as occurs in a longitudinal orientation explained in Reference 26. The litter should withstand all of the conditions previously described for the seats.

4.3 MATERIALS

Designers should select materials that offer the best strength-to-weight ratios while still maintaining sufficient ductility to prevent brittle failures. The guidelines in this section will alert the designer to certain material properties that can contribute to improved structural designs. These properties include ultimate strength, elongation, and energy-absorbing capabilities. The standard method for selecting materials using elastic analysis is adequate for most conditions in the working life of an article. For crash resistance, however, only one application of the maximum load is expected, and the behavior of the material beyond the yield point generally is important.

The degree of ductility needed in a seat's basic structural parts 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.

Castings are not recommended for use in primary load paths. In general, their quality is more difficult to verify and reproduce, and their ductility and fracture toughness are less than for forgings.

The effects of stress corrosion (for example, selection of 7075 aluminum alloy in a T73 condition rather than T6) must be considered, as well as hydrogen embrittlement due to heat treating or various processing steps such as pickling (for example, 17-4PH stainless steel). In short, adherence to all the normal engineering design principles is required.

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

4.4 STRUCTURAL CONNECTIONS

4.4.1 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. These factors are intended to allow for misalignment of holes, stress concentrations, and fatigue. Fatigue is not generally a factor in the design of a seat or litter system fitting, since high loading of the fitting would be a one-time situation. Therefore, the safety factor 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 in the longitudinal and transverse directions. For the best failure mode, bolts, pins, and joints should be designed to fail in bearing.

4.4.2 Riveted Connections

The guidelines for riveted joints are presented in MIL-HDBK-5, and it is recommended that these guidelines be followed (Reference 27).

4.4.3 Welded Connections

Welded joints can be 100 percent efficient; however, the actual efficiency is dependent upon the skill of the welder, the process used, and the inspection procedures followed. 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. Welded joints may result in stress concentrations and misaligned parts in a manner similar to bolted joints; therefore, 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.

4.4.4 Seat Attachment

Cockpit seats are either bulkhead or floor mounted. Acceptable means of attaching seats to the cabin interior are listed below (refer to Section 3.3.3 for a discussion of ceiling-mounted seats):

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

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

3. Wall 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 of 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.

4.4.5 Joint Deformation

Floor distortions as a result of impact can cause failure of the seat structure or tiedown connections in an aircraft crash (see Figure 5). A floor distortion can take the form of a bulge or dish in the floor surface between the seat tiedown connections. This produces a rotation of the seat relative to the floor surface, resulting in a connection failure if the deflection limits for the attachments are exceeded. A twisting or warping of the floor surface can also take place, producing distortion loads in the seat structure. Seat or connection failure can result from the additional loads imposed. The seat designer must anticipate possible floor bulging or warping and take appropriate measures in seat structural design to minimize the adverse effects.

For basically rigid seat structures that are distorted, the critical design parameter appears to be the torsional rigidity of the seat pan, bucket, and/or structural members. If the torsional rigidity is low, only small forces are introduced. However, for stiff seat members, the warpage forces may produce a structural failure or impose a preload that, when coupled with crash inertial loads, results in failure. A high torsional rigidity in the seat pan may arise from integrating stiff lateral cross tubes between side trusses so that the tubes must also twist with the seat pan. Consequently, it may be desirable to connect the cross tubes to the seat pan in such a way that the seat pan is free to twist independently of the cross tubes or to design the crossmembers to be soft in torsion. Integrally armored crew seats are stiff and difficult to release from the support structure in order to permit distortion. One method used successfully to solve this problem has been a three-legged seat. The three support points can follow the floor movement without distorting the seat structure because the seat is free to tip (Reference 28).

To prevent seat connection failures induced by floor distortion, structural joints should be capable of large angular displacements in all directions without failure. A seat designed properly for structurally integral load limiting would also satisfactorily accommodate floor buckling and warping under crash conditions. Figure 6 illustrates the floor or bulkhead warpage requirements by MIL-S-58095 and MIL-S-85510 prior to performing static tests of a seat as a complete unit using the actual seat airframe tiedown attachments. The unit must be able to withstand specified loads without separation of a primary load-carrying member or deflection beyond stated limits. 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.

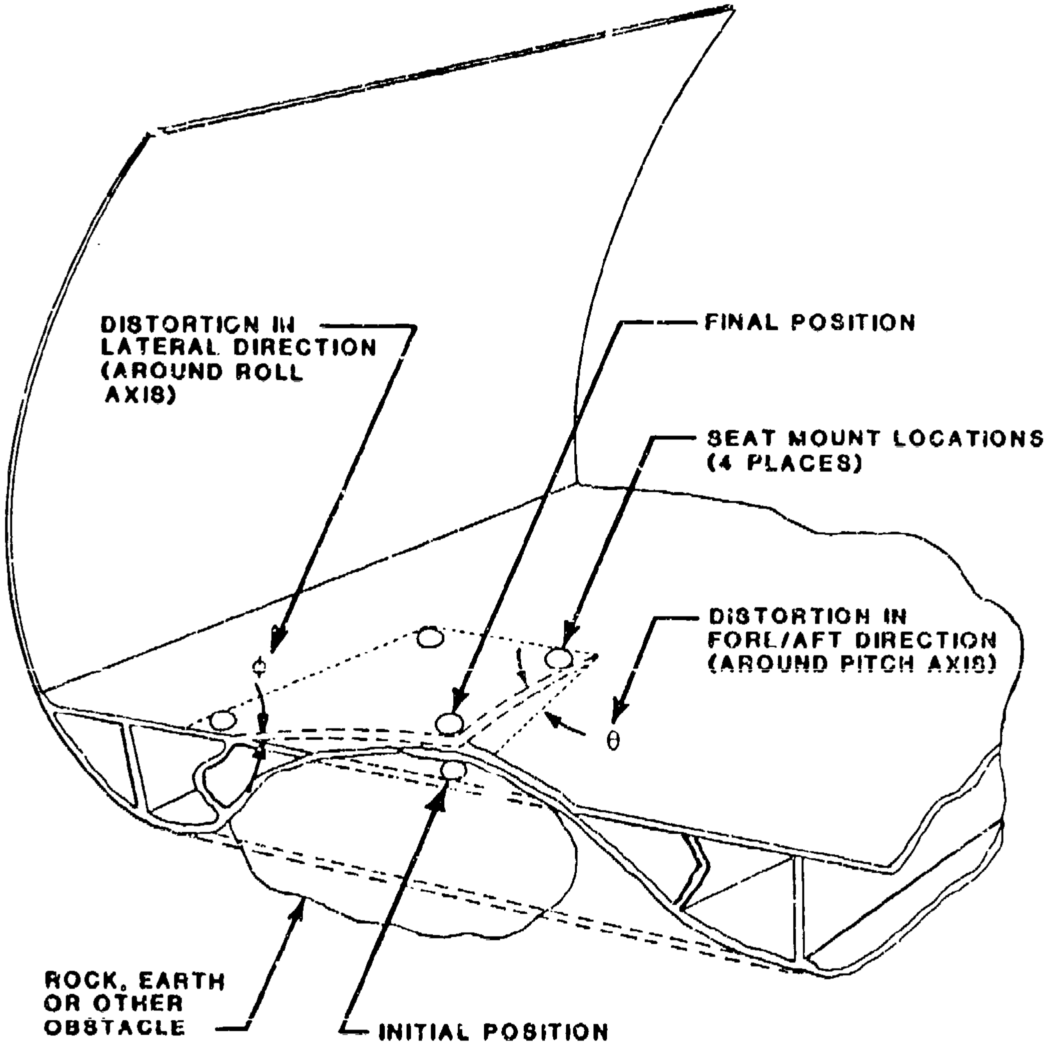


FIGURE 5. SKETCH ILLUSTRATING BUCKLING OR "DISHING" FORMATION.

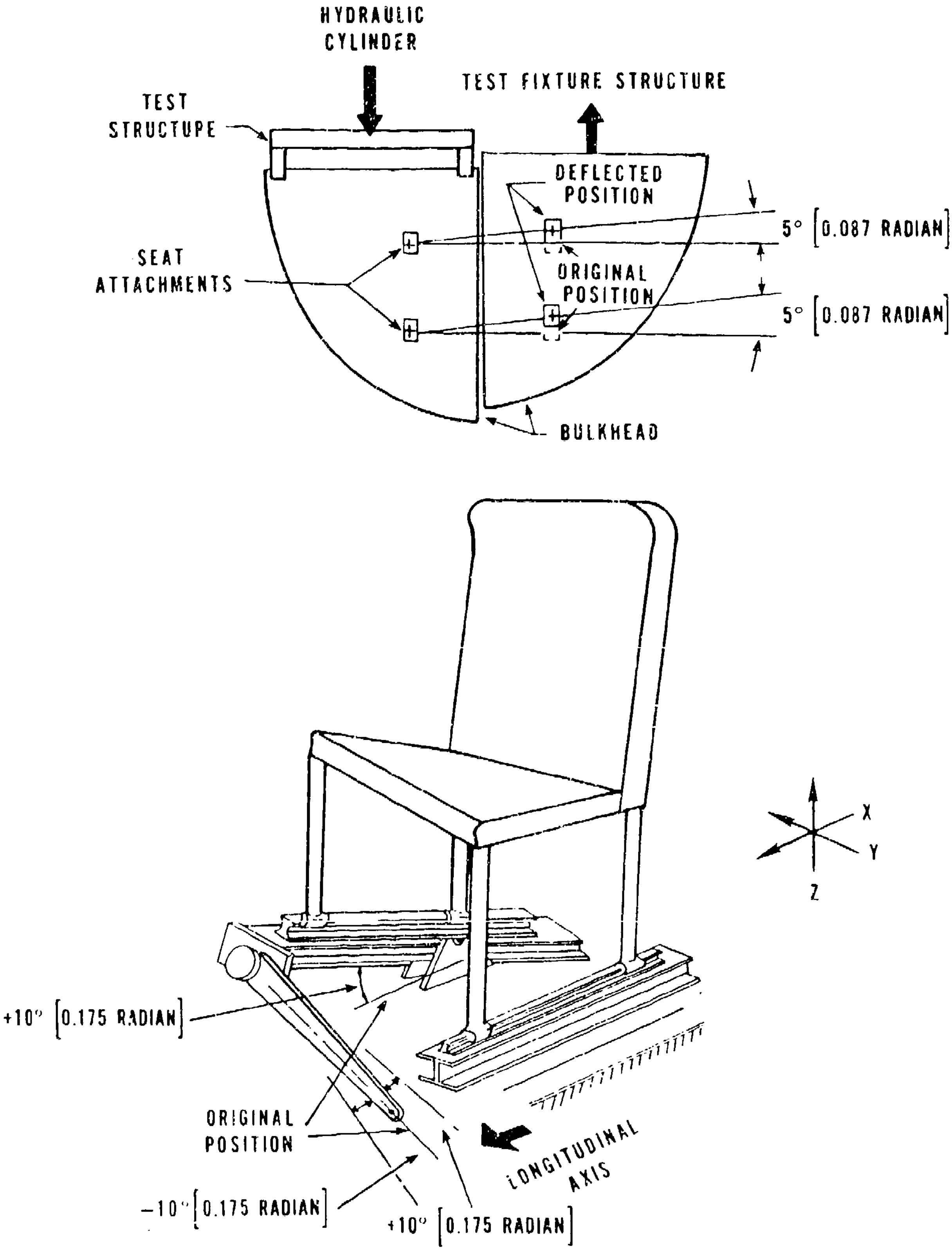
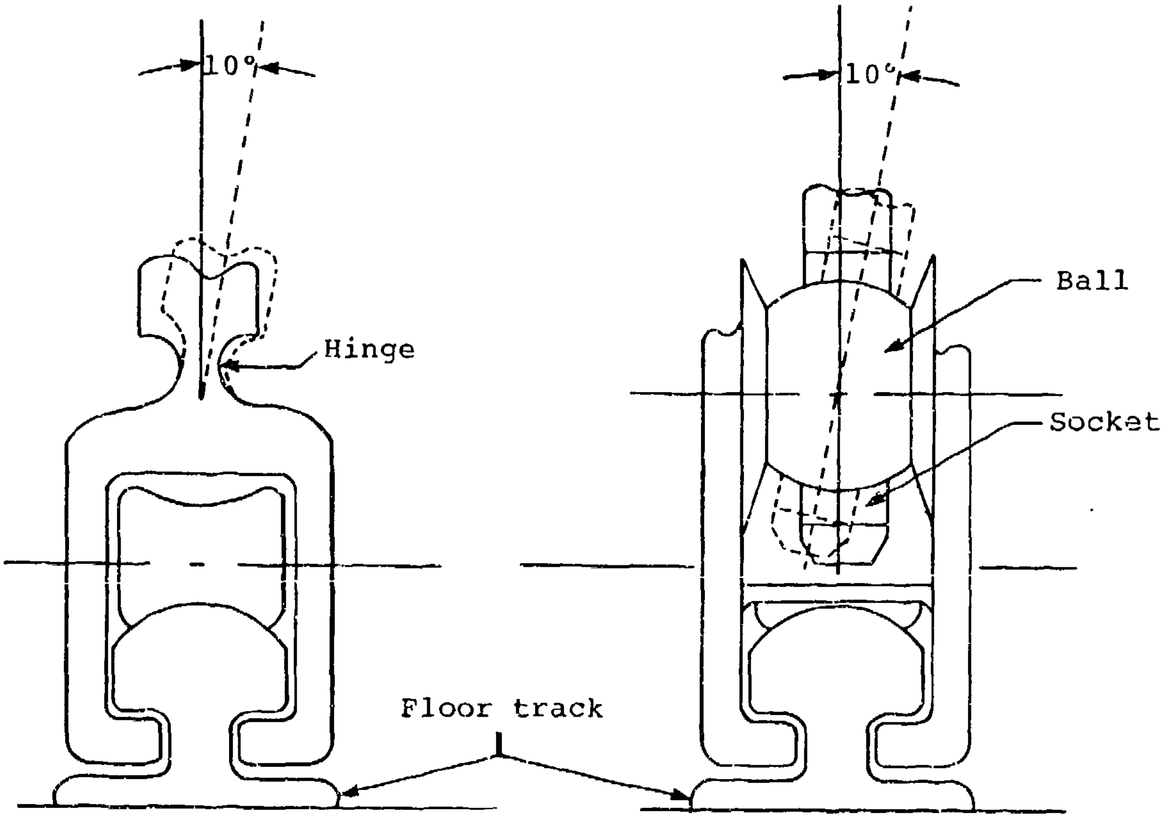


FIGURE 6. FLOOR OR BULKHEAD WARPAGE REQUIREMENT FOR STATIC LOADING OF SEAT. (REFERENCE 14)

With respect to the floor surface and to accommodate rotations that result from floor bulging, several design configurations may be considered. Two of these are presented below and are illustrated in Figure 7.

- A deliberate plastic hinge of sufficiently ductile material may be incorporated into the tiedown connection design. This plastic hinge would be required to permit yielding without failure up to a rotation angle that exceeds the maximum anticipated as a result of floor bulging. The hinge also would be required to carry the associated compressive, tensile, and shear loads in order to retain the seat while yielding in bending.

- A structural release such as a ball-and-socket joint may be used to permit relative rotation.



(a) Plastic hinge

(b) Ball-and-socket joint

FIGURE 7. CONCEPTS FOR RELEASE OF FLOOR-DISTORTION-INDUCED MOMENTS.

Other methods, such as a combination of a plastic hinge about one axis and rotation about an axle or pin oriented along a perpendicular axis, are acceptable also. The joint must be capable of sustaining large tension, compression, and shear forces during and after rotation.

The effect of not providing for relative seat leg-to-floor rotation can be illustrated by an actual example. The rear legs of a crewseat on early models of a U.S. Army helicopter were attached to a base frame with castings as illustrated in Figure 8. These castings failed repeatedly in accidents as a result of combined axial and bending stresses acting at the region of stress concentration. Studies showed that the seat could sustain a longitudinal decelerative force nearly twice as great when the bending moment at the juncture between the rear leg and the track fitting was removed.

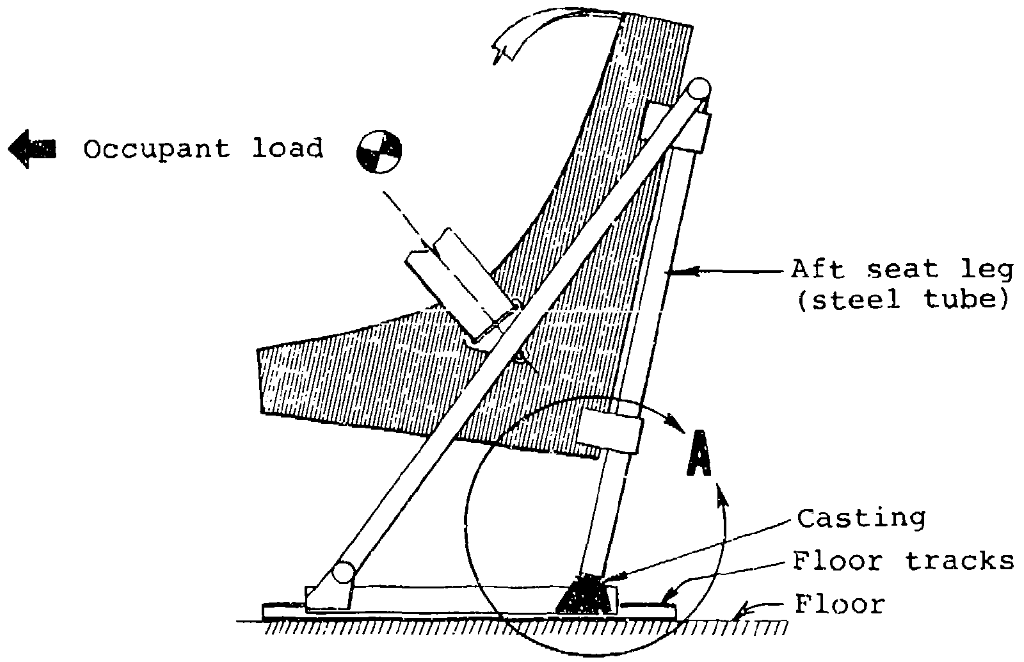


FIGURE 8. AFT SEAT LEG CASTING ATTACHMENT.

This modification is illustrated in Figure 9. The moment was relieved by cutting the corners off the casting so that only the section around the center bolt remained. The joint was thereby changed from a fixed- to a pinned-end configuration. Subsequent tests showed improved load-carrying capacity.

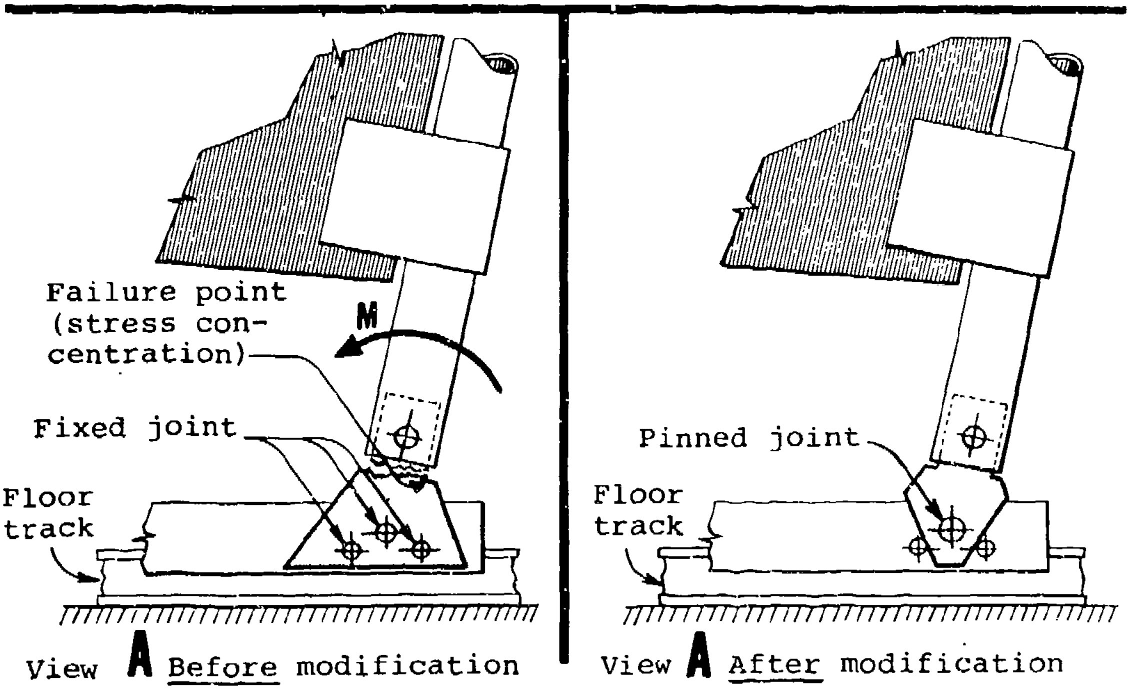


FIGURE 9. AFT SEAT LEG CASTING ATTACHMENT MODIFICATION.

Other methods of relieving torsion and moments include using spherical bearings and slotting holes through which bolts pass. For example, if a cross-member is required to move torsionally during floor warping, slots that relieve the loads can be provided for fasteners at end fittings. This is illustrated in Figure 10. Figure 11 illustrates an example of a fully released joint acted on by two torsional loads and a moment.

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 that of the floor. This is probably due to the bulkhead being less vulnerable to local planar distortion caused by items such as rocks and stumps impacted by the underfloor structure. A possible bulkhead distortion configuration is shown in Figure 12. 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. One technique for accomplishing this is with spherical bearings, as illustrated in Figure 13.

Combined sidewall-mounted and floor-mounted seats require the same considerations as bulkhead-mounted seats. As mentioned previously, 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. Although the angles are not known, it is expected that they may reach 25 degrees.

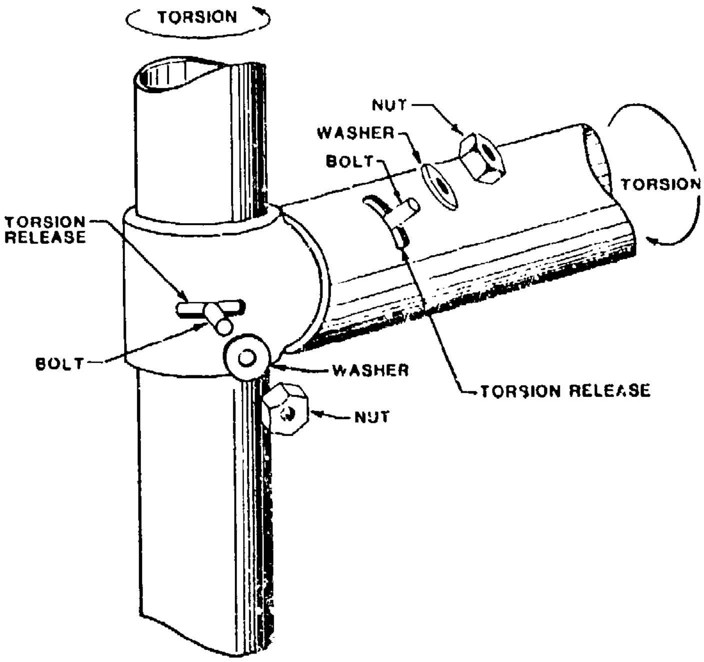


FIGURE 10. TORSIONAL RELEASE OF JOINTS.

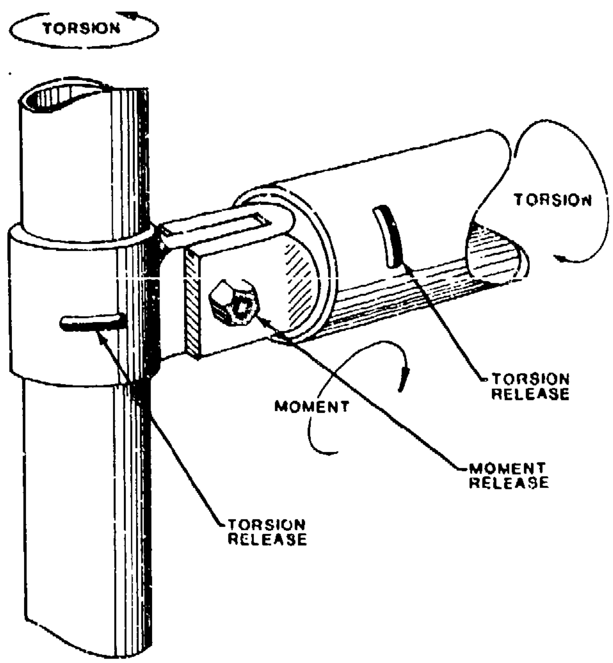
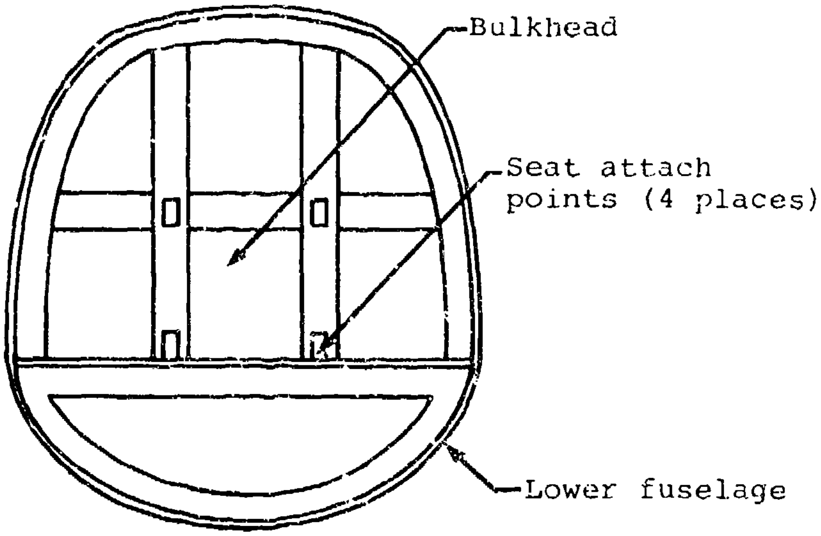
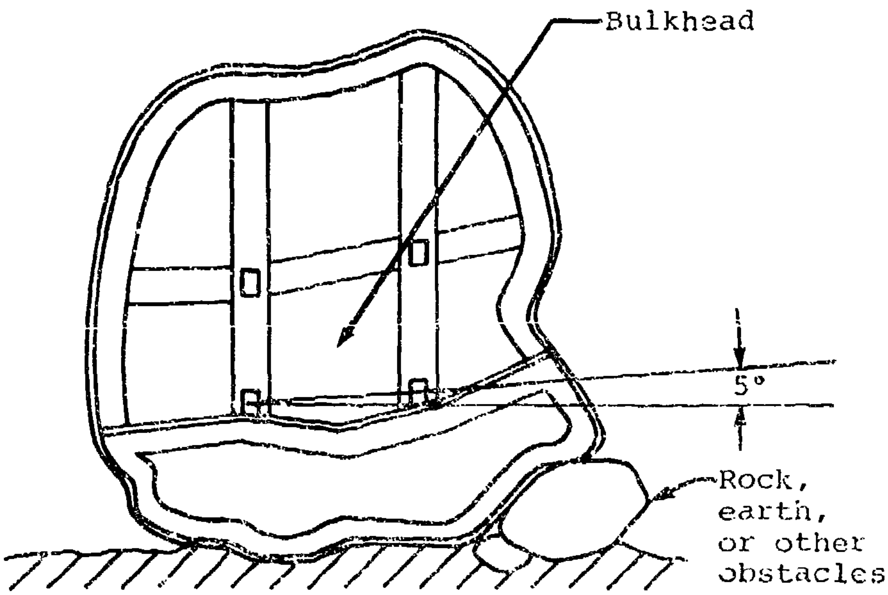


FIGURE 11. FULLY RELEASED JOINT.



(a) Initial configuration



(b) Postcrash configuration

FIGURE 12. BULKHEAD IN-PLANE WARPING.

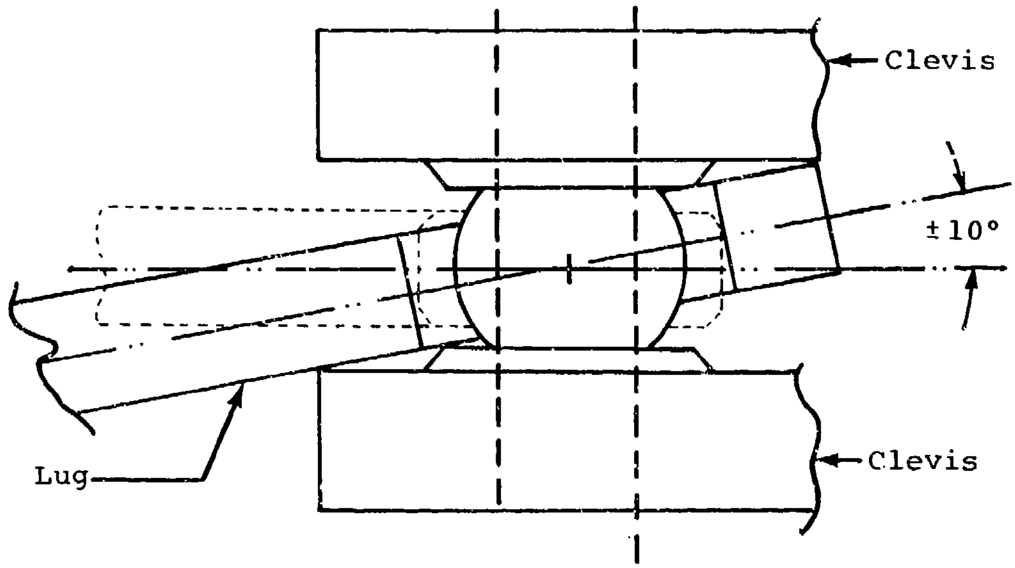


FIGURE 13. UNIVERSAL RELEASE OF A JOINT.

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 14. 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. To illustrate, take the case of a seat strut attached through a release to the front floor track. During longitudinal loading in the forward direction, the strut is loaded in compression and applies a large downward load at the release. Any eccentricity between the load vector and the centroid of the underfloor beam will produce torsional loading around the beam's longitudinal axis. The beam must possess the capability to resist this torsional load through either its own torsional strength or that of its supporting structure.

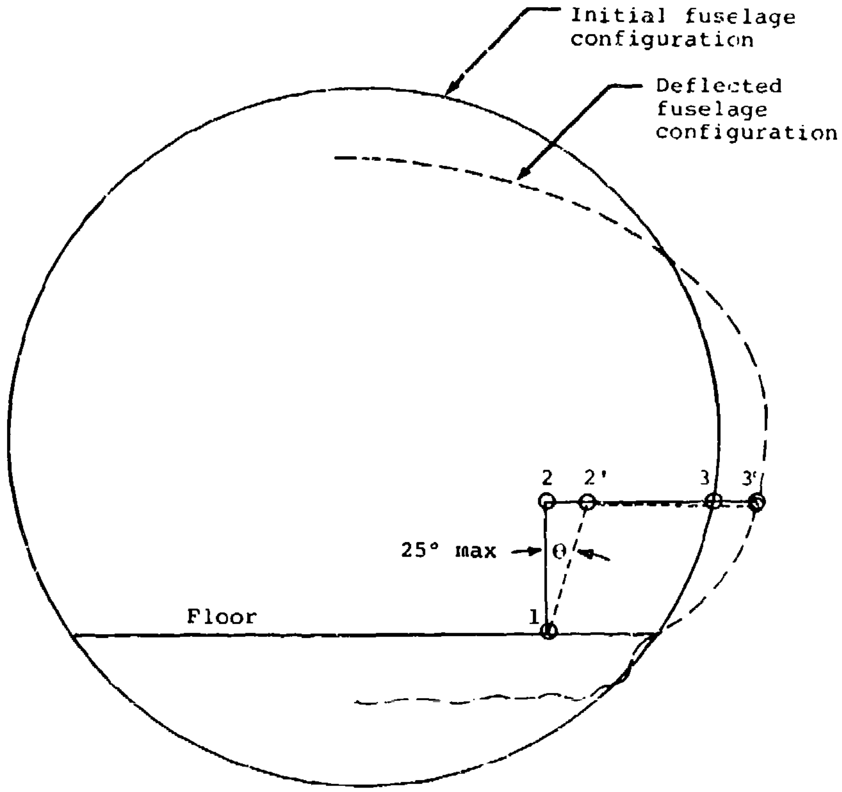


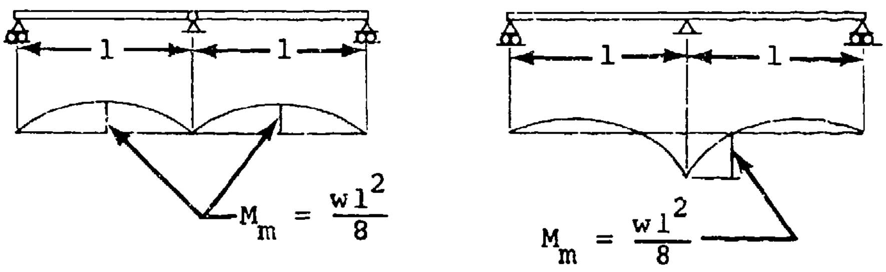
FIGURE 14. PIN JOINT RELEASES ORIENTED TO ALLOW ROTATION AROUND AN AIRCRAFT ROLL AXIS.

4.5 STRENGTH

4.5.1 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 avoid permanent deformation is necessary because of fatigue problems and, perhaps, other considerations. In a crash situation, however, where only one application of maximum load is expected, fatigue is not a factor, and the final configuration 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. As a matter of fact, it is advisable for certain items in the load path to use the rupture strength as listed for many materials in MIL-HDBK-5 (Reference 27). The concepts of limit analysis (see Section 4.5.2) or, in some circumstances, large deformation analysis may be employed to make the best use of materials in certain components.

It may appear that the only difference between an elastic stress analysis and an ultimate strength analysis is that the former is more conservative. However, a more significant distinction is demonstrated by a comparison of two designs having the same maximum stresses for elastic behavior but decidedly different load-carrying capacities when the loads exceed the elastic limits. For example, consider the following two similar designs: (1) two simple beams spanning three supports and (2) a continuous beam spanning the same three supports, as illustrated in Figure 15.



(a) Two simple beams (b) Continuous beam

FIGURE 15. COMPARISON OF ANALYSIS METHODS FOR SIMPLE BEAMS.

For a uniformly distributed load, w, the bending moment diagrams are as shown (assuming elastic behavior). It is noted that in each case the maximum bending moment is $wl^2/8$ and each design has the same stress. There is a temptation to equate the designs from a strength viewpoint. However, considering design (1), if the load is gradually increased, the bending moment at the center of each span will eventually equal the moment resistance capability of the beam. For a ductile material, a yield hinge would form then at these maximum moment points. Additional load could not be accepted without a mechanical collapse. This critical load would represent a realistic ultimate capacity for the beams. On the other hand, when a yield hinge occurs in design (2) under similar circumstances, it would occur at the middle support and, hence, not produce a collapsing mechanism. The load, w, could be further increased without collapse until a second set of yield hinges forms between the supports. Only then would collapse occur. It is intuitively evident, and may be demonstrated by analysis, that design (2) sustains a much greater ultimate load than does design (1), yet the difference is not discernible from elastic analysis. The design of an entire occupant retention system, ignoring inelastic post-yield behavior, would result in components of varying ultimate strengths, some much stronger than others. The overdesigned components do not increase the strength of the system. It is desirable that all components work at the same allowable strength level just before failure.

A 1963 study of the restraint system used in three U.S. Army aircraft indicated that the strengthening of a few weak links in the tiedown chain improved the crash strength of these systems by a factor of 2 with only minor weight increases (References 29 through 31). A simple example of the benefit of strength analysis beyond the elastic limit is the improvement in the tiedown strength of the crewseat floor track in one of the three aircraft. In the existing arrangement, the seat leg may be positioned directly above a pair of seat track tiedown bolts (Figure 16). The elongation of the bolts prior to their failure would not be sufficient to permit bending in the floor track; thus, no appreciable load could be transmitted to the adjacent pair of bolts. To improve the ultimate strength of this connection, it was suggested that aluminum collars, which compress at a load slightly less than the breaking strength of the bolt, be added beneath the nut. Thus, the collars would yield prior to failure of the center bolts and permit the track to bend and transmit some load to the adjacent bolts. This arrangement approximately doubled the ultimate tiedown strength of the floor track while adding a negligible amount of weight.

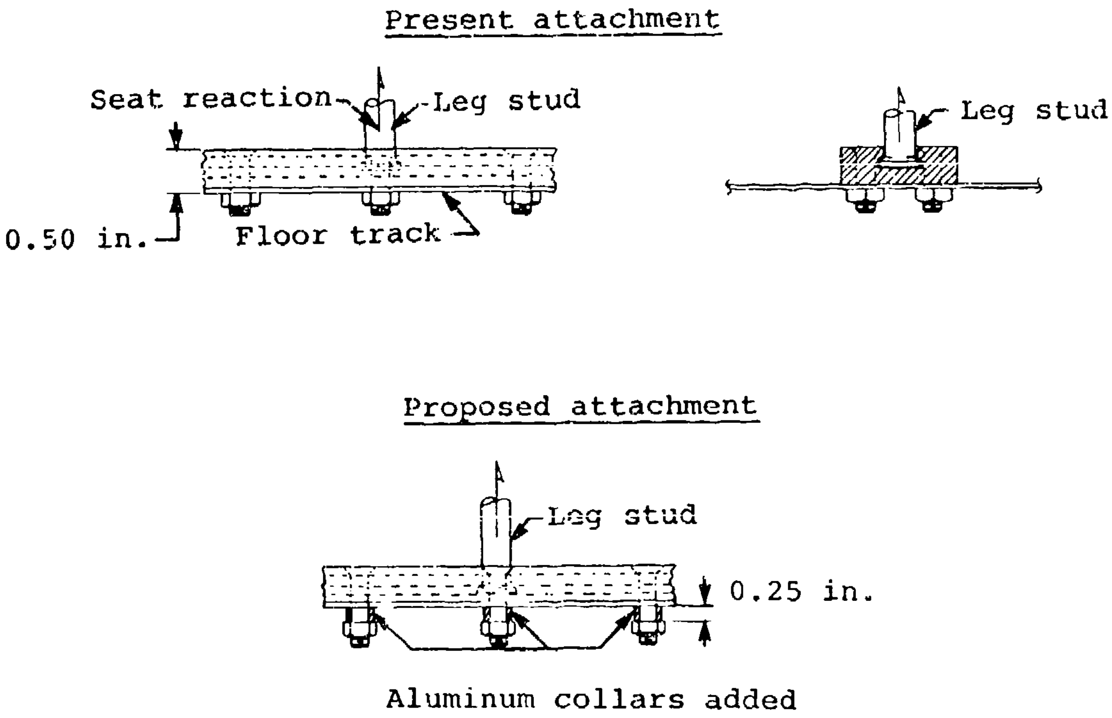


FIGURE 16. SEAT LEG ANCHORAGE TO FLOOR TRACK.

4.5.2 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 conditions for the materials, and consistent geometry considerations. The principles of limit analysis are well developed by a number of authors (References 32 and 33, for example). 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, on the other hand, 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.

4.5.3 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.

4.5.4 Strain Concentrations

Handbook stress concentration factors 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. For further information on the subject, see pages 69-73 of Reference 34.

4.6 RESTRAINT SYSTEM ANCHORAGE

The design requirements for occupant restraint systems are presented in Chapter 7; however, the seat designer should consider the effect of the anchorage of the restraint system on the characteristics of the seat design. The restraint system should be anchored to the seat rather than to basic aircraft structure.

If the restraint system 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, the loosening of the belt would permit the occupant to "submarine" under the belt or to move laterally. When the harness is anchored to the seat structure, the problem of maintaining a snug harness is reduced.

An advantage of attaching the shoulder harness to basic aircraft structure is the large reduction in overturning moment on the seat. To improve this attachment, a simple load-limiting device might be incorporated into the shoulder harness anchorage to allow for longitudinal or vertical movement of the seat. On some aircraft, where room allows it, another option is to locate the anchor point far enough to the rear of the seat to allow vertical energy-absorbing stroke of the seat with only a rotation of the shoulder strap about the anchor point on the shoulder harness guide. If the distance is sufficiently large, the fore-and-aft motion resulting from the strap swinging in an arc can also be insignificant.

4.7 CRASH ENERGY ABSORPTION

4.7.1 General

The average magnitude of a crash force is a function of the input velocity and the stopping distance. The stopping distance is controlled basically by the crushing of the airframe and landing gear in a given direction coupled with the gouging of the impact surface. The average magnitude of the deceleration of a given point of the aircraft may be calculated from the following equation:

$$a = \frac{v_o^2 - v_f^2}{2S} \text{ or } \bar{G} = \frac{v_o^2 - v_f^2}{2gS} \qquad (1)$$

where a = average deceleration, ft/sec^2

$\bar{G}$ = average deceleration, G

v_o = initial velocity, ft/sec

v_f = final velocity, ft/sec

g = acceleration due to gravity, 32.2 ft/sec^2

S = total displacement of the point of the aircraft with respect to the ground, ft

It can be seen from the equation that the magnitude of the deceleration is inversely proportional to the stopping distance. In the case of a rigid structure impacting a nonyielding surface, the deceleration would be infinite.

Some crushing of structure and soil reduces or attenuates the deceleration to finite levels. Often, however, there is insufficient crushing to attenuate deceleration magnitudes to human tolerance levels. Tolerable levels can be achieved by increasing the stopping distance. The extra stopping distance may be provided by using: (1) additional crushable airframe structure, (2) energy-absorbing landing gear, (3) a seat design that possesses an energy-absorption mechanism(s) (load-limiting or controlled seat motion), or (4) a combination of methods (1), (2), and (3).

The energy-absorption capability of a seat structure is of considerable importance in evaluating the seat dynamic strength. Due to extension of the restraint harness, compressibility of the soft human tissue under the harness, penetration into the seat cushion, and relative movement of body parts, the occupant's center of gravity acquires a velocity relative to the airframe during an abrupt deceleration.

Depending upon the magnitude and duration of the deceleration pulse, as well as the nature of the connection between the occupant and the seat structure, the maximum relative velocity may be large. The seat structure, in order to perform its intended retention function, must then either (1) possess the capability of sustaining the maximum inertial force imposed by the deceleration of the occupant and the seat without collapse, or (2) possess 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 elasticity of the restraint system and cushion can result in significant dynamic overshoot. Computer simulation and experimental observation have shown that overshoot factors range from 1.2 to 2.0, necessitating 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 seat motion behavior (load limiting) offers the more practical approach to seat design. 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 limiting load. The seat should absorb enough energy without failure to stop the motion of the occupant relative to the aircraft at force levels within human tolerance limits to provide the intended protective function.

In an attempt to eliminate common misconceptions regarding the role of energy-absorbing seats, a few introductory comments are made:

- The seat energy-absorbing system does not absorb all the seat-occupant energy associated with the impact velocity. The seat experiences the total velocity change; however, much of the energy is absorbed by deforming earth, stroking landing gear, and deforming structure.

- The absorption of energy by the above processes produces the triangular-shaped deceleration versus time pulse used as the design input to the seat.

- The seat energy-absorbing stroke simply lengthens the stopping distance of the occupant by allowing seat stroking to occur as the other energy-absorbing processes are nearing completion. In a crash in which the aircraft comes to rest in the major impact, much of the seat stroke can occur after complete deceleration of the aircraft fuselage. Thus, after the fuselage stops, the seat may continue to stroke until the seat-occupant kinetic energy has been exhausted.

- Disregarding dynamic response differences, the same stroking distance is required to decelerate any mass at a given deceleration magnitude. Therefore, lighter people do <u>not</u> require shorter strokes than heavier people for the same deceleration magnitudes. Of course, loads required to decelerate occupants of different weights at equal deceleration magnitudes vary with occupant weight.

- The first comment explains why it is detrimental to allow slack to develop in the restraint system or seat attachments. If the occupant is allowed to continue to move with little or no restraint through any significant portion of the energy-absorbing process <u>anywhere in the system</u> (not just in the seat and restraint system), a great deal more stroke or a much higher load will be required to decelerate the occupant. If the occupant moves with little restriction until the fuselage stops moving, the occupant will then require the same stopping distance as the fuselage to experience the same G loads as the fuselage. Since this stroke is not available, the loads would be high.

Aside from the seat structure, there are other areas within the aircraft where energy absorption may find application. Protective padding, generally plastic foam, should be used where structure is likely to be impacted by the occupant, particularly where head impact is concerned. Deforming structure such as sheet metal behind the foam also is helpful in such items as instrument panels, glare screens, etc. Characteristics that aid in the selection of foams for such applications are discussed in Section 11.9. Also, energy-absorbing webbing for restraint systems and litters is discussed in Section 7.4.4.

4.7.2 <u>Principle of Energy Absorption - Illustration</u>

As an example of the energy-absorption allocations, rewrite equation (1) for stopping distance as follows:

$$S = \frac{v_0^2 - v_f^2}{2g\bar{G}} \qquad (2)$$

Assuming that $v_0 = 42$ ft/sec, $v_f = 0$, and the average deceleration produced by deforming terrain, flattening tires, stroking energy-absorbing gear, and crushing fuselage is 10 G:

$$S = \frac{42^2}{(2)(32.2)(10)} = 2.73 \text{ ft} = 32.87 \text{ in.}$$

Thi stroke is 2.73 times the minimum required for the seat; however, the loads are well within human tolerance limits. If the entire cumulative stroke could be accomplished at 14.5 G, which is assumed to produce a deceleration environment tolerable to humans in this direction, the total distance is

$$S = \frac{42^2}{(2)(32.2)(14.5)} = 1.89 \text{ ft} = 22.67 \text{ in.}$$

Obviously, 22.67 in. of stroke is impractical for a seat, so the crash energy-absorption function must be a combination of energy-absorbing landing gear, crushable airframe structure, and seat energy absorption. The following example illustrates how the seat and airframe (including the landing gear) combine to limit decelerative loading of the occupant, assuming rigid body mechanics, a triangular deceleration input pulse, and a seat energy absorber load-deflection curve with the same rise time as the input pulse and a constant limit load.

The triangular deceleration-time plot is an assumed, idealized input to the system. In actual practice, the dynamic response of the system as measured on any individual component does not match this form because of the differing dynamic properties of the components as discussed in Section 4.7.3.2. The displacement of the seat/occupant system relative to the airframe is computed using the following notation:

Let G_m = maximum airframe deceleration in the vicinity of the seat attachment, G

G_L = maximum seat/occupant system deceleration, G

K = G_L/G_m, t_L/t_m (limited to 0.5 or less)

t_m = time at maximum airframe deceleration (one-half input pulse duration), sec

t_L = time to reach maximum system deceleration, sec

t = time, sec

v = velocity, ft/sec

v_a = velocity of airframe at any time t, ft/sec

v_s = velocity of seat/occupant system, ft/sec

v_L = common airframe and system velocity at $t = t_L$, ft/sec

v_0 = initial impact velocity, ft/sec

Let g = acceleration due to gravity, ft/sec^2

a = airframe acceleration, ft/sec^2

a_s = seat/occupant acceleration, ft/sec^2

S = displacement, ft

S_a = airframe displacement, ft

S_s = seat/occupant system displacement, ft

The airframe acceleration in the interval $0 \leq t \leq t_m$ is given by

$$a = -G_m gt/t_m \tag{3}$$

where the minus sign indicates a deceleration. The velocity during the same interval, starting from an initial value of v_o, can be found by integration of Equation (3):

$$v_a = v_o + \int_0^t a\,dt$$

$$= v_o - \int_0^t G_m g\left(\frac{t}{t_m}\right)dt$$

$$= v_o - \frac{G_m gt^2}{2t_m} \tag{4}$$

The airframe displacement at time t_m is then

$$S_a = \int_0^{t_m} v_a\,dt$$

$$= \int_0^{t_m}\left(v_o - \frac{G_m gt^2}{2t_m}\right)dt$$

$$= v_o t_m - G_m g t_m{}^2/6 \tag{5}$$

For the interval $t_m < t \leq 2t_m$, the airframe acceleration is

$$a = -G_m g + G_m g(t - t_m)/t_m \tag{6}$$

and the velocity,

$$v_a = v_o - \frac{1}{2} G_m g t_m + \int_{t_m}^{t} a\,dt$$

$$= v_o + G_m g(t_m - 2t + \frac{t^2}{2t_m}) \tag{7}$$

so that, at $t = 2t_m$

$$v_a = v_o + G_m g(t_m - 4t_m + 2t_m)$$

$$= v_o - G_m g t_m \tag{8}$$

Since the peak deceleration G_m is that required to bring the aircraft to rest at time $2t_m$,

$$v_a = 0 = v_o - G_m g t_m$$

and

$$v_o = G_m g t_m \tag{9}$$

The airframe displacement at $2t_m$ is then

$$S_a = v_o t_m - G_m g t_m^2/6 + \int_{t_m}^{2t_m} V_a dt$$

$$= v_o t_m - G_m g t_m^2/6$$

$$+ \int_{t_m}^{2t_m} [v_o + G_m g(t_m - 2t + \frac{t^2}{2t_m}] dt$$

$$= 2v_o t_m - G_m g t_m^2 \qquad (10)$$

Substituting Equation (9) into Equation (10) the total airframe displacement is

$$S_a = v_o t_m - G_m g t_m^2 \qquad (11)$$

The acceleration of the seat/occupant system matches that of the airframe for $0 \leq t \leq t_L$, where t_L is determined by the limiting deceleration G_L. Using Equations (4) and (5), the velocity and displacement of the seat at t_L can be found as follows:

$$v_s = v_o - \frac{G_m g t_L^2}{2t_m}$$

$$S_s = \int_0^{t_L} (v_o - \frac{G_m g t_L^2}{2t_m}) dt$$

$$= v_o t_L - \frac{G_m g t_L^3}{6t_m} \qquad (12)$$

For $t_L \leq t \leq t_f$ where t_f is the same when the seat/occupant system comes to rest,

$$a_S = -G_L g \tag{13}$$

and the system velocity in this interval is given by

$$\begin{aligned} v_S &= v_o - \frac{G_m g t_L^2}{2t_m} + \int_{t_L}^{t} a_S dt \\ &= v_o - \frac{G_m g t_L^2}{2t_m} - G_L g(t - t_L) \end{aligned} \tag{14}$$

Since $v_S = 0$ at $t = t_f$, Equation (14) can be used to find the final time t_f

$$0 = v_o - \frac{G_m g t_L^2}{2t_m} - G_L g t_g + G_L g t_L$$

Introducing the variable

$$K = G_L/G_m = t_L/t_m \tag{15}$$

the time t_f can be written

$$t_f = t_m(\frac{1}{K} + \frac{K}{2}) \tag{16}$$

Using Equation (15) to substitute for t_i and G_L in Equations (12) and (14), the seat/occupant system displacement at t_f is found by

$$S_s = v_o K t_m - \frac{G_m g K^3 t_m^2}{6} + \int_{Kt_m}^{t_f} (v_o + \frac{K^2 G_m g t_m}{2} - K G_m g t)dt$$

$$S_s = G_m g \left[(1 + \frac{K^2}{2}) t_m t_f - \frac{K^3 t_m^2}{6} - \frac{K t_f^2}{2} \right]$$

$$= G_m g t_m^2 (\frac{1}{2K} + \frac{K}{2} - \frac{K^3}{24}) \qquad (17)$$

The stroke distance required by the seat is the displacement of Equation (17) less that of the airframe, which is given by Equation (11):

$$\text{Stroke, } S = G_m g t_m^2 (\frac{1}{2K} + \frac{K}{2} - \frac{K^3}{24} - 1) \qquad (18)$$

The above result also can be obtained geometrically, using the velocity and displacement curves shown in Figure 17. For further clarification, this somewhat simpler procedure is presented below.

The velocity of the airframe at time t is equal to the initial velocity plus the change in velocity from t = 0 to t = t,

$$v_t = v_o + (a)\frac{t}{2} \qquad (19)$$

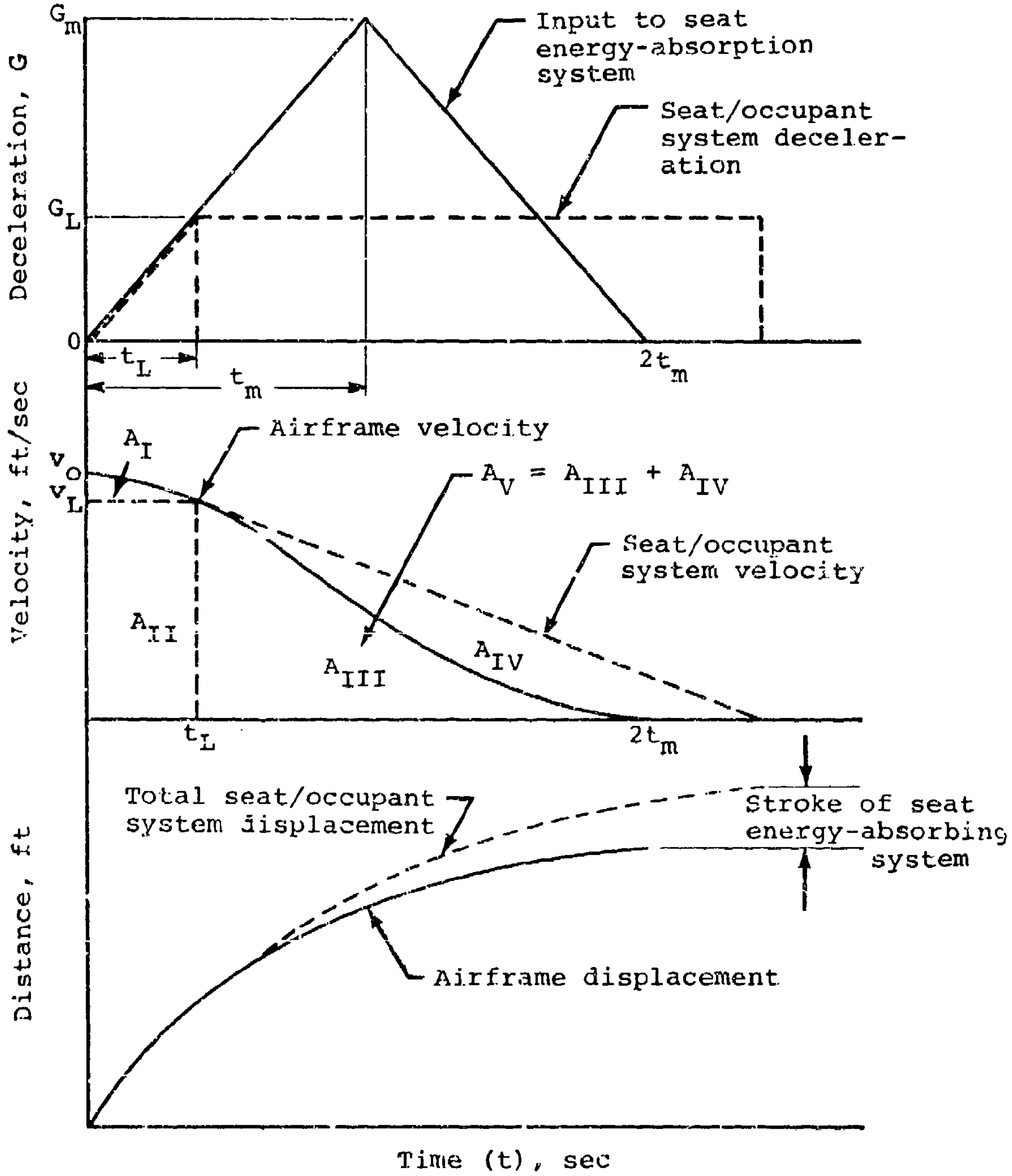


FIGURE 17. DECELERATION-TIME, VELOCITY-TIME, AND DISTANCE-TIME CURVES USED IN ANALYSIS OF SEAT/OCCUPANT DISPLACEMENT WITH RESPECT TO THE AIRFRAME.

Substituting the value of a from Equation (3),

$$v_t = v_o + \left[\frac{-G_m g t}{t_m}\right]\left(\frac{t}{2}\right)$$

$$v_t = v_o - \left[\frac{-G_m g t^2}{2t_m}\right] \tag{20}$$

Now, assuming that the airframe comes to rest so that $v(t = 2t_m) = 0$, the total velocity change can be said to equal the initial velocity. Since this corresponds to the total area under the deceleration versus time curve,

$$v_o = G_m g t_m \tag{21}$$

Substituting Equation (21) into Equation (20) yields

$$v_t = G_m g t_m - \frac{G_m g t^2}{2t_m} \tag{22}$$

Using Equation (22), we can now compute the common velocity of the airframe and the system at time t_L:

$$v_L = G_m g t_m - \frac{G_m g t_L{}^2}{2t_m} \tag{23}$$

The change in velocity in the time interval t_L is

$$\Delta V = v_o - v_L \tag{24}$$

Substituting Equations (21) and (23) into Equation (24) yields

$$\Delta V = G_m g t_m - (G_m g t_m - \frac{G_m g t_L^2}{2t_m})$$

$$\Delta V = \frac{G_m g t_L^2}{2t_m} \tag{25}$$

The areas of interest in the velocity-versus-time graph in Figure 17 can be calculated now using the relationships just derived together with geometrical considerations.

Recognizing that the curve describing the velocity of the airframe consists of the two parabolic segments shown in Figure 18, connected at time t_m, it can be seen that A_I is the area under a parabola of base t_L and height Δv. Therefore,

$$A_I = \frac{2}{3}\left(\frac{G_m g t_L^2}{2t_m}\right) t_L = \frac{G_m g t_L^3}{3t_m} \tag{26}$$

Area A_{II} is simply a rectangle of base t_L and height v_L, so that

$$A_{II} = t_L\left(G_m g t_m - \frac{G_m g t_L^2}{2t_m}\right) = G_m g t_L t_m - \frac{G_m g t_L^3}{2t_m} \tag{27}$$

Since the system is undergoing a constant deceleration beginning at t_L, area A_V can be represented by the relationship

$$A_V = \frac{v_L^2}{2G_L g}$$

Substituting from Equation (23) and noting that $G_L = KG_m$,

$$A_V = G_m g t_m - \left(\frac{G_m g t_L^2}{2t_m}\right)^2 \frac{1}{2KG_m g} \tag{28}$$

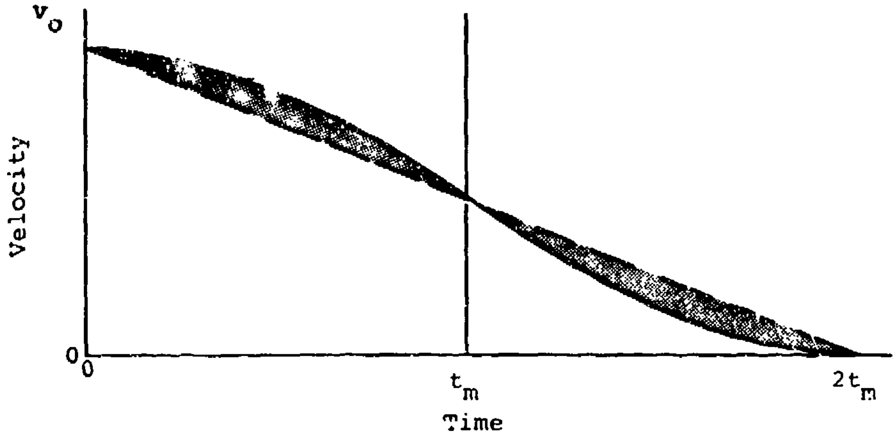


FIGURE 18. AIRFRAME VELOCITY-TIME CURVE.

The area sought as representing the energy-absorption stroke of the seat is A_{IV}. In order to solve for this area, A_{III} must first be established. A_{III} can be determined by noting that, due to the triangular shape of the acceleration pulse, the airframe velocity curve consists of two parabolic segments meeting at the midpoint of the curve, as shown in Figure 18.

If a straight line is constructed joining v_o and $2t_m$, the two shaded areas bounded by the curve and the line can be shown to be equal since they are both between parabolic curves described by the same basic equation and a secant. The total area under the curve can then be said to be the same as the area of the triangle formed by the coordinate axes and line connecting v_o and $2t_m$. Therefore,

$$A_I + A_{II} + A_{III} = \left(\frac{v_o}{2}\right) 2t_m = V_o t_m = G_m g t_m^2 \qquad (29)$$

and

$$A_{IV} = (A_I + A_{II} + A_V) - (A_I + A_{II} + A_{III}) \qquad (30)$$

Substituting from Equations (26), (27), (28), and (29) yields

$$A_{IV} = \frac{G_m g t_L^3}{3t_m} + G_m g t_L t_m - \frac{G_m g t_L^3}{2t_m} +$$

$$\left(G_m g t_m - \frac{G_m g t_L^2}{2t_m}\right)^2 \frac{1}{2KG_m g} - G_m g t_m^2$$

Simplification and substitution of Kt_m for t_L yields

$$A_{IV} = S = G_m g t_m^2 \left(\frac{K}{2} + \frac{1}{2K} - \frac{K^3}{24} - 1\right) \tag{31}$$

which is the same as Equation (18).

Equation 18 was derived based on the assumption that the seat/occupant system was still decelerating after the input pulse ended (time $2t_m$). This assumption may not always apply. A system could be designed such that the seat energy absorber stroked for a time, but stroking stopped before the input pulse ended. This would require a higher limit load (G_L), but the reduced stroking distance could be an advantage, especially if space is limited. This is illustrated in Figure 19.

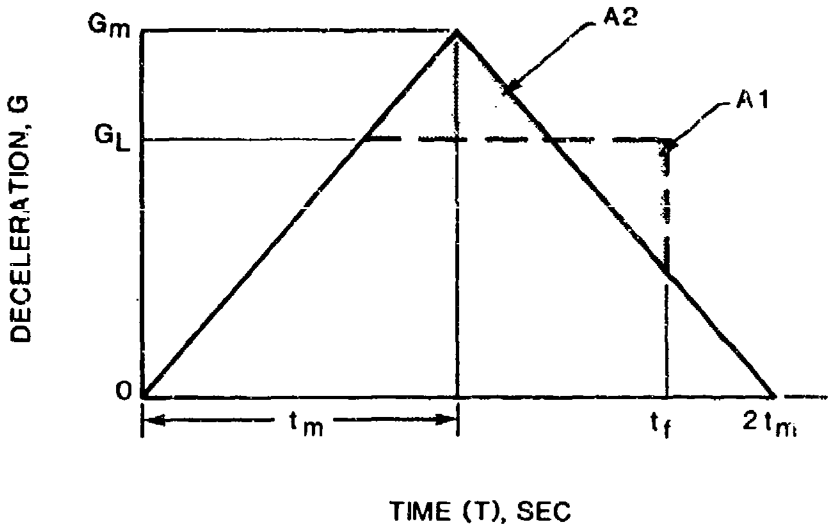


FIGURE 19. DECELERATION-TIME PLOT FOR $t_f < 2t_m$.

If the stroking stops before time $2t_m$, it can be shown by the same integration process illustrated previously that the stroking distance is

$$S = G_m g t_m^2[5.093K^3 - 12.36K^2 + 9.449K - 2.178] \tag{32}$$

A determination of whether the stroking stop time is greater or less than time $2t_m$ can be made with the equation

$$t_f = [2 - K - \sqrt{2}(K-1)]t_m \tag{33}$$

This equation is derived from the requirement that the velocity dissipated outside of the input pulse (A_1) must equal the velocity not dissipated under the input pulse (A_2).

Generally, this will correspond to the condition that

$$\text{Equation 18 applies if } K \leq 0.586 \text{ or } t_f \geq 2t_m$$

$$\text{Equation 32 applies if } K > 0.586 \text{ or } t_f < 2t_m$$

As an example, consider a triangular pulse representing a change in velocity of 42 ft/sec with

$$G_L = 14.5 \text{ G}$$

$$G_m = 48 \text{ G}$$

$$t_m = 0.027 \text{ sec}$$

$$K = \frac{14.5}{48} = 0.30$$

$$t_f = [2 - 0.30 - \sqrt{2}(0.30 - 1)]t_m = 2.69t_m$$

Since $t_f > 2t_m$, the required stroke is then calculated from Equation 18:

$$\text{Stroke} = (48)(386)(0.027)^2 \left(\frac{0.30}{2} + \frac{1}{2(0.30)} - \frac{(0.30)^3}{24} - 1\right)$$

$$= 11.02 \text{ in.}$$

Test data show this stroke to be less than that required. Much of this difference can be attributed to system inefficiencies. It has been found in tests that an efficiency of approximately 80 percent can be expected from a rod-bending sled decelerator and a wire-bending seat load limiter (References 35 and 36). Therefore, correcting the calculated distance yields 11.02/0.8 = 13.78 in. It must be realized that 13.78 in. is probably a valid stroke for systems with little or no friction, such as ceiling-mounted troop seats. For seats guided by sliding or rolling components, friction adds to the resistive force, thus producing an apparent increase in efficiency. However, in general, large frictional resistance is not desirable because of the variation of the net resistive force and hence occupant decelerative loading as a function of loading direction. Review of the above indicates that the 12-in. minimum seat stroke required for the design pulse (used in the above calculations) is not always adequate and should not be compromised unless other provisions are included to reduce the residual energy that the seat is required to absorb.

Also, as discussed in Reference 37, the stroking distance can be determined by the use of dynamic computer simulations, such as program SOM-LA, which is described in Section 4.8.2. Figure 20 shows stroke data for six seat tests with different limit loads. A 40-G, 45-ft/sec test pulse was used. The seat stroke is shown compared with predictions using Equation 18 and Program SOM-LA. This correlation is a function of seat design and test facility, and is not always as good as shown. Usually, the results of Equation 18 should be considered a minimum stroke distance, and allowance for additional stroke should be provided.

4.7.3 Dynamic Response

4.7.3.1 Effective Weight. The concept of effective weight has been used to account for masses supported by components other than the stroking portion of the seat, e.g., the seat occupant's lower legs supported by the floor during vertical loading. The effective weight of the occupant plus the weight of the movable portion of the seat is multiplied by the limit-load factor (G) during calculation of the required stroking load. The technique is not completely accurate, because rigid bodies do not adequately simulate the dynamic response of the actual system. Seat designs should be analyzed dynamically and then tested to substantiate their dynamic response and to demonstrate that they provide the desired degree of occupant protection.

4.7.3.2 Theoretical System Response. A major design factor influencing the seat response is the movable seat mass. For very light seats, the gross response of the occupant can be estimated using the approximate mass of the occupant acting on the seat (80 percent when considering the vertical direction as discussed later in this chapter). However, when the seat mass increases to values typical of integrally armored crew seats, interaction between the mass and spring properties of the seat and occupant can become significant. The occupant and seat components then realize sharp deceleration excursions, i.e., spikes.

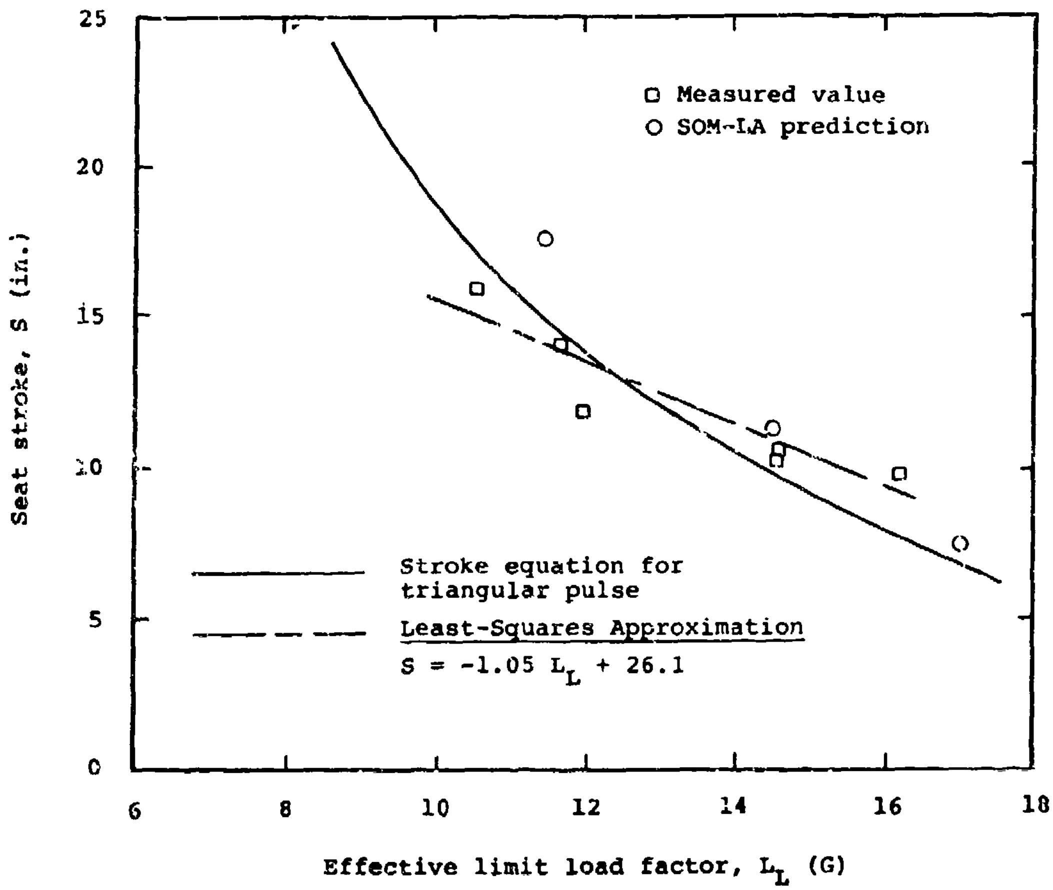


FIGURE 20. ENERGY ABSORBER LIMIT LOAD SERIES, MAXIMUM SEAT STROKE. (REFERENCE 37)

The dynamics of the problem are illustrated in Figure 21, which presents the theoretical response of an integrally armored crew seat and occupant to an input crash pulse as calculated by a digital computer analysis (described in Reference 26) and summarized in Section 4.8.7. The analysis simulates the occupant by three lumped masses representing the head, chest, and pelvis. The cushion and seat are represented by two additional masses. The five masses are connected by damped springs in the model.

The response curves for the seat structure, occupant pelvis, and chest are shown as functions of time for the indicated input excitation. The seat used was an energy-absorbing, integrally armored model set to stroke at 18 G (18 times the effective weight of the occupant plus movable seat). The armored seat bucket weighed 40.6 lb, and the energy absorber provided a trapezoidal force-versus-deformation characteristic. It can be seen that the dynamic response of the seat and segments of the body are not independent of one another and vary as the model springs load and unload.

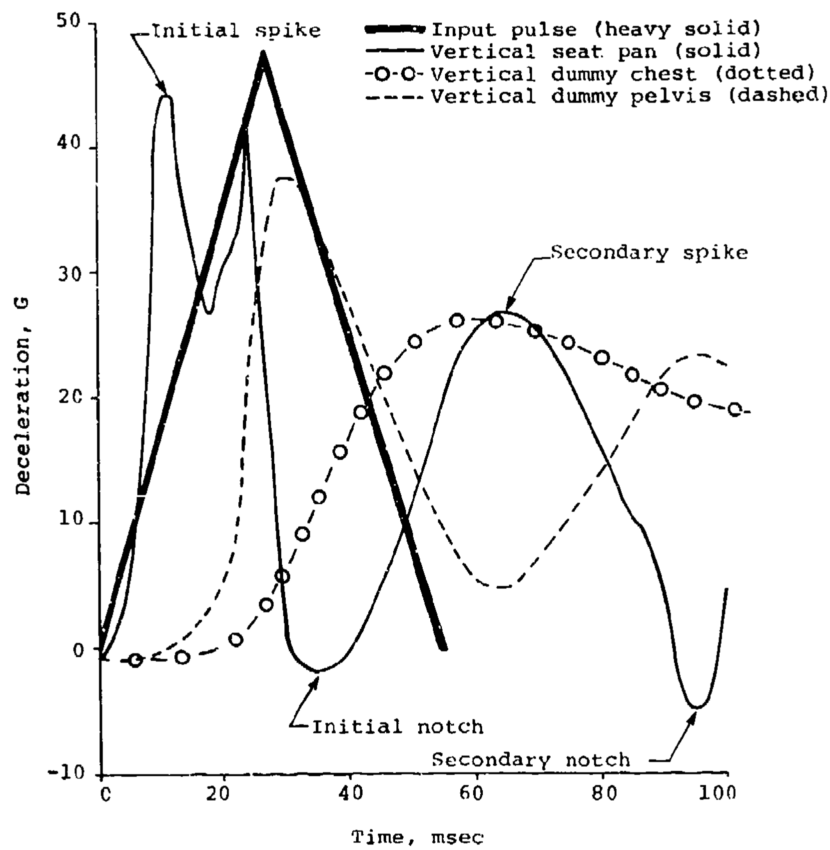


FIGURE 21. DECELERATION VERSUS TIME FOR VARIOUS COMPONENTS OF SEAT AND OCCUPANT. (REFERENCE 28)

Initially, the seat pan deceleration lags the input pulse as the springs representing the flesh and the cushion as well as the elastic spring of the seat structure are loaded. The stroking force of the energy absorber was sized for a deceleration of a particular mass, and the effective mass is not yet being applied to the seat structure because of the incomplete spring compression. Therefore, the seat pan deceleration exceeds the deceleration required to effect the force necessary to stroke the energy absorber. The seat pan deceleration approaches 43 G before the cushion and flesh springs compress to the point that significant deceleration of the pelvis begins. As deceleration of the pelvic mass increases, an increasing reaction force is applied in the downward direction on the seat pan. The seat pan deceleration decreases from 43 G to approximately 27 G as the effective mass is increased.

Because the input decelerative loading is still increasing and the chest inertial load has not yet been applied to the system, both the seat pan and the pelvic decelerations increase. As the spring representing the buttocks flesh and cushion bottoms out, the pelvic deceleration continues to increase, further loading the seat pan and decreasing its deceleration. It can be seen that the seat pan experiences a small acceleration under the combined loading of the occupant's pelvis and chest.

As the chest deceleration increases, the decelerations of the seat pan and the pelvis tend to normalize near the G level corresponding to the limit-load factor of the energy-absorbing system.

In summary, the limit load must be set at a load factor considerably below the tolerable level in order to limit the occupant response to a tolerable level, particularly for seats of high movable mass.

4.7.3.3 Empirical System Response. Prior to 1979, several programs were conducted in which crash-resistant armored seats were dynamically tested (References 17, 28, and 38 through 40). These programs included drop tests in which the seats' response to decelerative loading in the vertical direction was measured. Two types of tests were conducted. In the first type, the impact velocity vector was parallel, but in the opposite direction, to the loading and along the vertical axis of the seat, the yaw axis related to the aircraft (upward and perpendicular to the aircraft longitudinal axis). In the second type, the seat was pitched forward 30 degrees and rolled 10 degrees relative to the aircraft axis system. These dynamic tests demonstrated a characteristic deceleration-time history very similar to that theoretically predicted (see Figure 20). The characteristic shape has been evident in essentially all tests to date; however, the magnitudes of the spikes and notches vary. The characteristic shape of the seat pan deceleration-versus-time history includes a high initial spike followed by a deep notch that sometimes passes through zero and actually becomes an acceleration rather than a deceleration. This notch is followed by a second high spike followed by various waveforms, damping out and usually centering around the load factor used in sizing the energy-absorption system loads.

The explanation of the characteristic waveform is associated with the inherent dynamic response of the seating system and its occupant. As explained previously, total coupling of the seat and its occupant is not achieved since the occupant consists of masses connected by body members, such as the spinal column and neck, which are not rigid.

Further, because the dummy is seated on simulated buttocks flesh and a comfort cushion, it is not rigidly connected to the seat pan. Since the energy-absorbing mechanism of the seat must be set for a given load (calculated by multiplying the effective weight of the occupant and movable part of the seat by the desired limit-load factor), the actual deceleration measured on the seat pan will vary inversely to the coupled weight (w_t) according to the relationship $a = F/w_t$, where a represents the deceleration in G units, F, the load in pounds resisting the stroke of the seat, and w_t, the coupled weight in pounds. The term coupled, as used here, simply indicates that the applicable connecting springs are compressed sufficiently to result in the body segment being decelerated in phase at approximately the same rate as the seat pan (as would a rigidly attached mass).

A deceleration applied to the seat pan initially decelerates the movable seat mass only. Consequently, deceleration of the seat pan reaches a large magnitude as indicated by the initial spike in Figure 22. As the cushion and the simulated flesh on the buttocks compress, the deceleration of the pelvic mass increases. As the spinal column compresses, the deceleration of the chest increases. The deceleration of these masses increases as a result of the increased load in the connecting members. The connecting members act as springs between the body segments. Therefore, the greater the compression, the higher the load, and the higher the deceleration of the body segments.

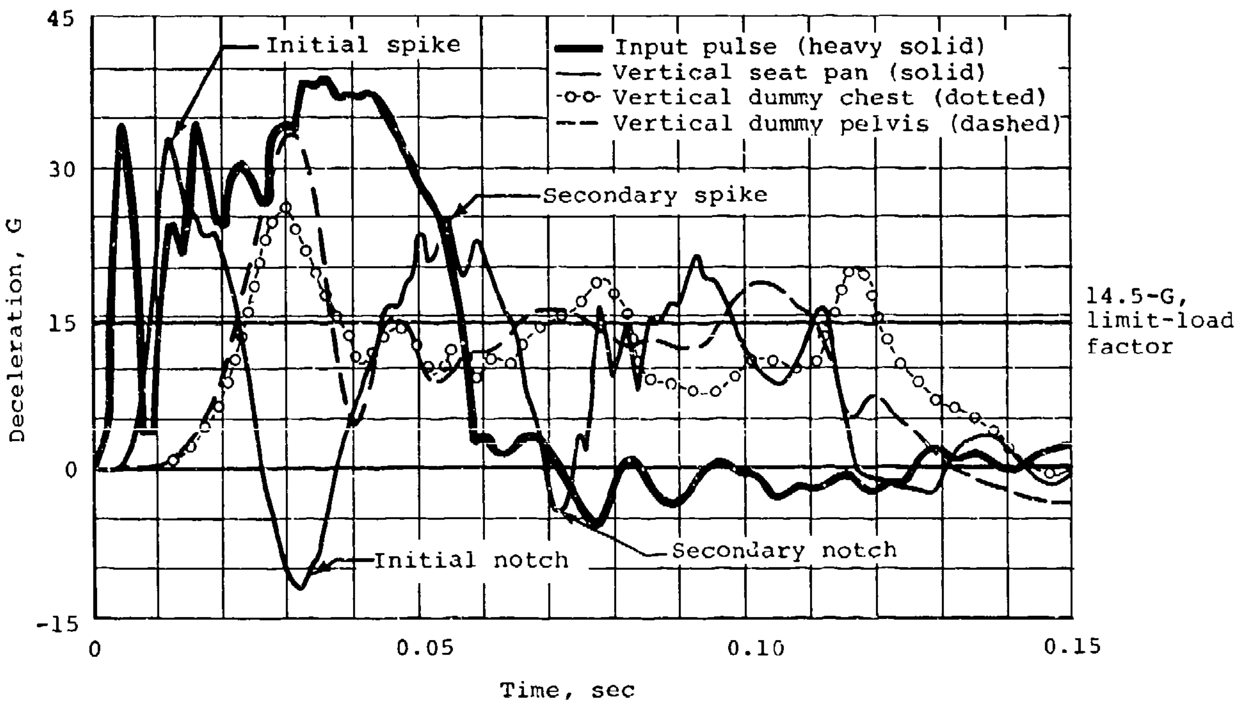


FIGURE 22. TYPICAL SEAT PAN, DUMMY CHEST, AND DUMMY PELVIS RESPONSE TO VERTICAL CRASH LOADING. (REFERENCE 41)

As an illustration, consider Figures 23, 24, and 25, where the figure of a seat occupant is compared with a system of springs and masses. When the initial deceleration of the seat pan commences, the springs in the body are unloaded as illustrated in Figure 23. Therefore, large loads cannot immediately be applied to the body segments. As the pulse continues, the body segments continue to move under the resistive load of the partially compressed springs, thus decelerating more slowly than the seat and building up a velocity relative to the seat pan. Eventually the velocities of the body segments and the seat pan must all approach a common value. This usually occurs later in the sequence, after the secondary spike. In the interval,

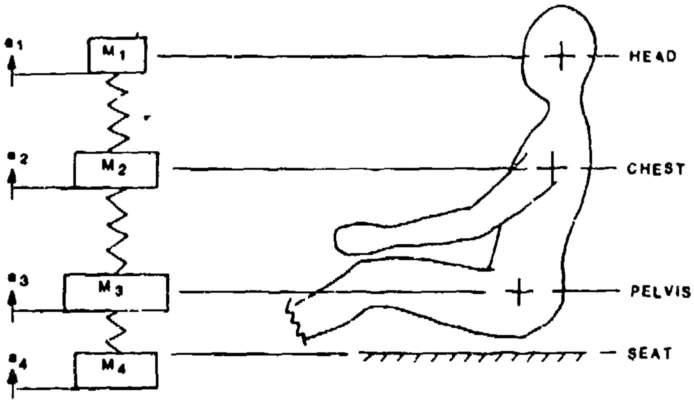


FIGURE 23. INITIAL CONDITION, NO LOAD.

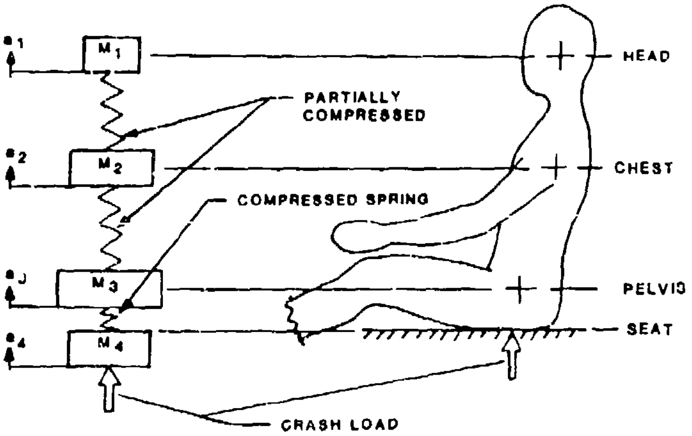


FIGURE 24. ONSET OF DECELERATION LOAD WHEREIN PELVIC AREA IS RESPONDING TO DECELERATION LOAD, BUT THE UPPER TORSO AND HEAD ARE NOT.

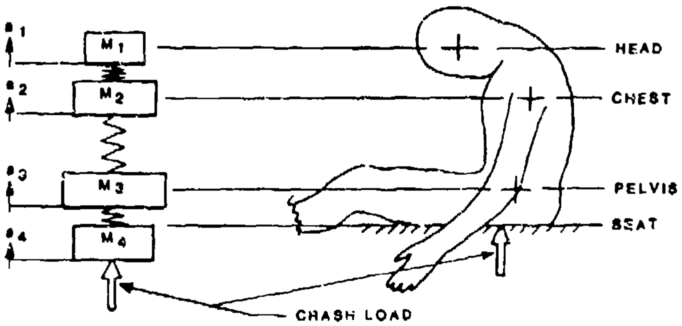


FIGURE 25. HIGH-DECELERATION LOAD, SPRINGS COMPRESSED.

the deceleration of the seat pan responds as a function of energy absorber force, input pulse, seat and dummy weight, and spring and damping characteristics.

Initially, the seat pan deceleration reaches a high value (initial spike). This occurs because the resistive force in the energy-absorbing system was set at a given value considering the weight of the movable portion of the seat and the occupant. The seat pan is decelerated initially at a magnitude consistent with the force of the energy-absorbing mechanism divided by only the weight of the movable part of the seat, which is considerably less than the design weight (the weight of the movable portion of the seat and the effective weight of the occupant). Thus, the magnitude of initial seat pan deceleration will always exceed the limit load factor for which the energy-absorbing system was designed.

Eventually, the cushion and buttocks springs are compressed, and the pelvic mass loads into the seat pan (see Figure 24). The increase of the coupled mass decreases the deceleration of the seat pan from its initial peak. The seat pan deceleration then decreases drastically as evidenced by the initial notch in the deceleration-time history. At times, when the deceleration actually turns into an acceleration, it simply means that the mass of the pelvis is receiving a relatively high deceleration and the reaction load is high enough to accelerate the seat pan toward the aircraft floor. It is apparent that the magnitude of this notch is a strong function of the spring rate of the seat. Since the spine normally is still not compressed significantly, it is not carrying high loads. This is evidenced by the small decelerations measured in the chest, which is being supported by the spine.

Since this is a dynamically loaded spring system, the springs associated with the buttocks and the cushion can overshoot as they bottom out during the sequence and then unload again. The unloading permits the seat pan deceleration to rise again to the secondary spike on the trace. As the pelvis unloads, the reaction load on the seat pan decreases and the seat pan deceleration spike can be extremely high. Note that the high deceleration of the seat pan does not necessarily correlate with the high deceleration of the pelvis or chest. From the data reviewed, both analytical and empirical, it is generally the opposite; i.e., the unloading of the pelvis and/or the chest produces the spike in the seat pan deceleration.

As the cushion and buttocks again load up and the pelvis deceleration increases, the high seat pan deceleration of the second spike is decreased. Also, the two characteristic deceleration spikes are usually followed by an increased compressive load in the spine and a buildup of deceleration of the chest. Eventually, the phasing of the decelerations of the various system segments begins to converge toward the average load factor for which the limit load of the energy-absorbing system was designed, as illustrated in Figure 25.

It is informative to note (see Figure 22) that the peak decelerations of the seat pan do not necessarily coincide with peak decelerations of the human occupant and thus are not necessarily hazardous to occupant safety. The Eiband human tolerance data of Volume II, repeated here in Figure 26 for ease of reference, do not present information on the seat pan deceleration

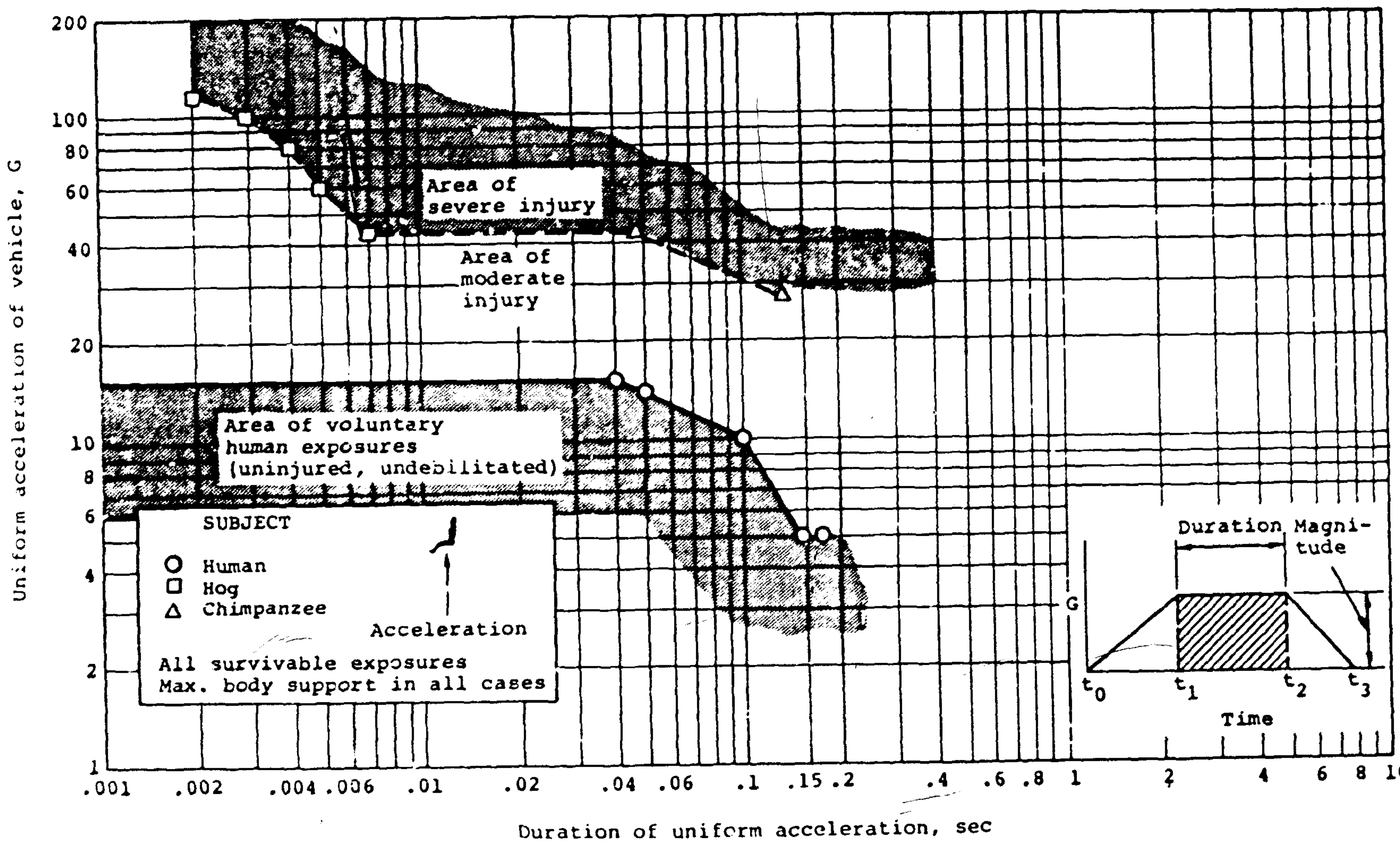


FIGURE 26. DURATION AND MAGNITUDE OF HEADWARD ACCELERATION ENDURED BY VARIOUS SUBJECTS.

excursions from the average, or uniform, acceleration experienced by the vehicle, ~~and are~~ therefore not informative on the subject.

If the Eiband criteria are to be used, it is recommended that average seat pan decelerations be developed as follows:

At a load level G_L, a horizontal line is drawn, intercepting the deceleration-time plot as shown in Figure 27. The duration of each deceleration excursion is measured and summed to determine the total time in which the G_L deceleration level is exceeded:

$$t_L = t_{1L} + t_{2L} + t_{3L} \cdots t_{NL}$$

This process is repeated to obtain t_L values at other load levels. These values of t_L versus G_L are plotted as a curve in Figure 27.

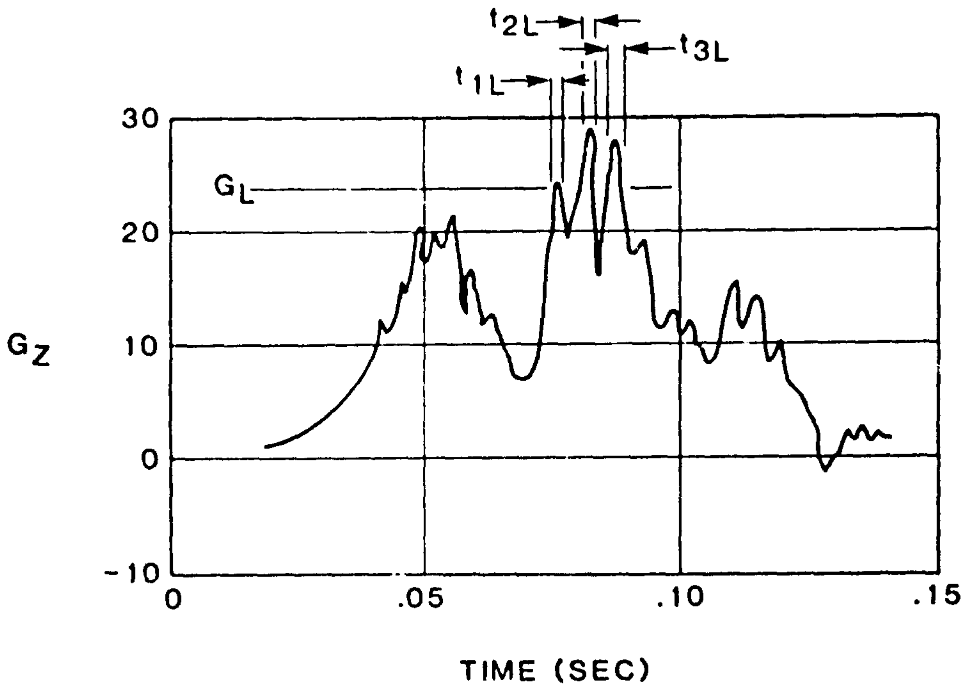


FIGURE 27. TYPICAL G_Z VERSUS TIME PLOTS.

This procedure is required because the human body is approximately a 10-Hz system and cannot respond in phase with higher frequency inputs. Thus, summing the duration of the deceleration excursions provides a more objective indicator of the seat performance under the specified test condition.

The response phenomena described above comprise the predictable response of the occupant/seat system the input pulse. The high decelerations measured on the seat pan are not necessarily correlated with high decelerations of the occupant; however, this does not imply that the seat will provide the required protection. The entire deceleration history to which the occupant is exposed must be considered. As pointed out, low decelerations of the seat pan may be accompanied and caused by high loads imposed on the occupant. Thus, it was imperative that additional information relative to human tolerance to transient loading in the vertical direction be obtained and that the criteria for designing vertical energy attenuating systems for seats be refined and made more comprehensive.

A study intended to identify more efficient ways to design an energy-absorbing seat (Reference 37) explored the effect of 13 different variables on the dynamics of the seat/occupant system. These variables are listed in Table 3. It can be seen that many variables can affect system response, and tests must be carefully controlled to obtain repeatable results. Reference 37 quantifies the effect for all listed variables for specific conditions. The report concluded, among other things, that seat pan acceleration is a poor indicator of test severity or injury potential. It recommended that spinal load and moment be utilized for predicting injury instead.

Subsequent research reported in Reference 41 enhanced the information on human tolerance. This work was initiated in May 1979 and continued through December 1985 under the sponsorship of the Aviation Applied Technology Directorate of the U.S. Army Aviation Research and Technology Activity (AVSCOM)

TABLE 3. VARIABLES AFFECTING SEAT/OCCUPANT DYNAMICS

Test Pulse	Dummy	Seat
Amplitude	Type	Orientation
Velocity Change	Size	Movable Mass
Rate of Onset	Biofidelity**	Cushion Stiffness
Pulse Shape*		Frame Spring Rate
		Energy Absorber Limit Load
		Energy Absorber Load Versus Stroke Curve

*Related to test facility differences.
**Compared to cadaver.

with the cooperation of the U.S. Army Aeromedical Research Laboratory and the U.S. Air Force Aerospace Medical Research Laboratory. Dynamic testing conducted at the Wayne State University Bioengineering Center included 15 crash tests with unembalmed human cadavers as occupants of seats provided with energy absorbers. The type and location of spinal injuries which occurred in the test program were found to be representative of those that have occurred to live subjects under actual crash conditions. The predominant spinal injury was an anterior wedge compression fracture in the thoracic vertebra 8 to lumbar vertebra 3 region with the highest incidence in the T12 and L1 vertebral segments. It was reasonably assumed that (1) a spinal fracture is caused by an applied spinal load that is proportional to the energy absorber limit-load setting and (2) the ability of a vertebral segment to resist the applied load is directly related to its ultimate compressive strength.

Measured data included applied axial spinal load and vertebral compressive strength. Ideally, the applied axial spinal load would have been measured at the actual site of the fracture during the dynamic test with the cadaver. However, an invasive measurement procedure on the cadaver could in itself alter the test results. Therefore, the procedure used was to conduct additional dynamic tests using a modified Part 572 anthropomorphic dummy. A six-axis load cell was incorporated at the base of the elastomeric spine in the dummy at a spot analogous to the L5 vertebral position in a human, and the tests conducted duplicated the specific test conditions from the cadaver test series.

Then compression tests to failure were made on vertebra from each cadaver in order to determine its ultimate compressive strength. Since the L5 vertebral level corresponded to the approximate location of the load cell in the instrumented dummy, the L5 ultimate compressive load for each cadaver was used to determine the applied spinal load to strength ratio (SLSR).

In this study several correlations were developed. Figure 28 shows that the ultimate compressive load of the various vertebral segments is greater at the lower levels of the spine. It is also greater for U.S. Army aviators than for the U.S. adult civil flying population, which is considered due to the lower average age of the aviators. Figure 29 shows a correlation between peak lumbar spinal load and energy absorber limit-load factor. Figure 30 presents spinal injury rate as a function of SLSR. Finally, Figure 31 shows that spinal injury rate can be predicted from the effective energy absorber limit-load factor. For example, at a limit-load factor of 14.5 G a spinal injury rate of about 20 percent would be predicted for Army aviators and about 45 percent for the adult civil flying population. This is discussed further in Section 4.7.3.6.

4.7.3.4 Tailoring of Energy Absorber. Results of analyses conducted under a U.S. Navy-sponsored program (Reference 42) indicated that the force-versus-deformation characteristic of the energy-absorbing system can be shaped to enable more efficient use of the stroke distance available. However, tests using this concept, as reported in Reference 37, did not verify this prediction. The test devices were actually less efficient with higher injury indicies. It is recommended that tailored energy absorbers not be used unless the benefits can be substantiated by test.

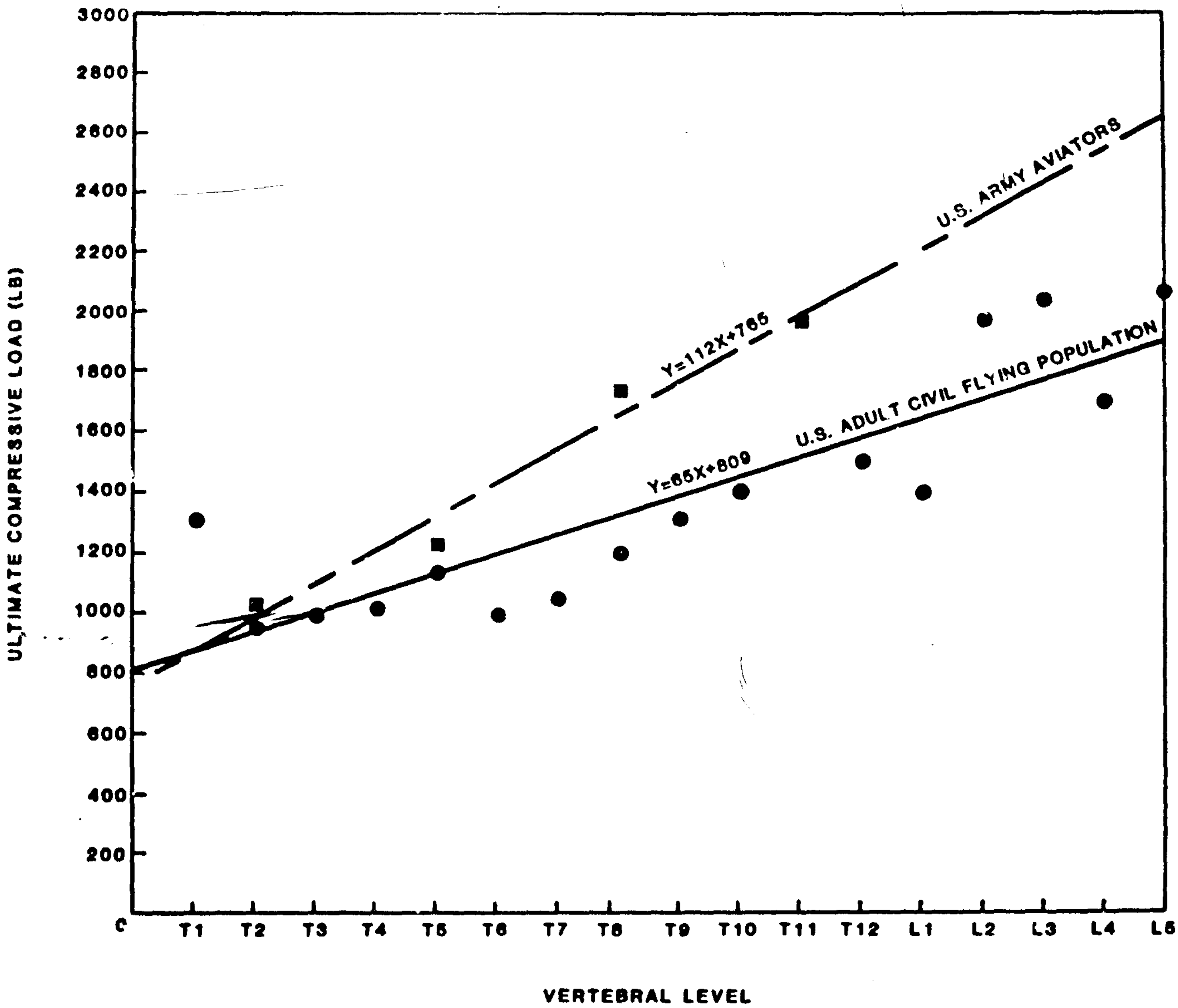


FIGURE 28. VERTEBRAL ULTIMATE COMPRESSIVE STRENGTH FOR VARIOUS POPULATIONS. (REFERENCE 41)

4.7.3.5 Adjustable Multiple Limit-Load Devices. Since stroke distance is limited in aircraft cabins and more so in aircraft cockpits, it is extremely important to make efficient use of the available distance. Energy absorbers that stroke at a given limit load are sized for the effective weight of the 50th-percentile occupant. This implies that the majority of occupants will stroke at or near the optimum load. However, very large or very small occupants can both be subjected to more severe impact conditions than the average-size occupant.

Consider first the case of a very small occupant. Since the seat is designed to stroke at 14.5 G for the average-sized occupant, the small occupant will

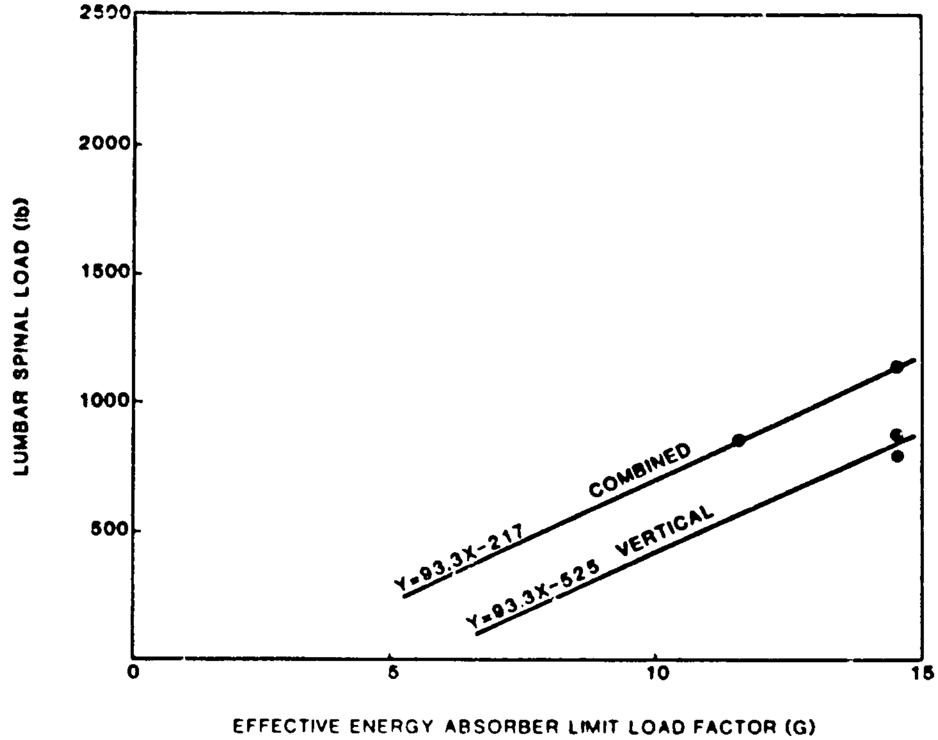


FIGURE 29. CORRELATION BETWEEN PEAK LUMBAR SPINAL LOAD MEASURED IN THE INSTRUMENTED ANTHROPOMORPHIC DUMMY AND ENERGY ABSORBER LIMIT-LOAD FACTOR. (REFERENCE 41)

stroke at a higher G load. While the stroking force of the energy absorber is the same, the higher G loads, due to less system mass, may be injurious to the occupant.

With the same constant-load energy absorber, a large occupant will experience a proportionally lesser G load during the early portion of a severe crash. However, because he is stroking at a lower G load, with more kinetic energy, he will stroke farther. The stroking distance of a seat is often limited to only 12 to 18 in.; an inefficient use of this limited space can result in an impact between the seat/occupant system and the aircraft floor. If this happens, the heavier occupant could be exposed to higher-level acceleration at the end of the stroke in the more severe crashes. In a minor impact, the lower kinetic energy would not require as much stroke.

To offer each size crewmember equal optimal protection in a severe crash, the energy absorber load should vary such that the occupant deceleration is constant and independent of occupant size. A fixed-load energy absorber is typically used for troop seats because of cost and weight constraints and also the operational problems of training troops to adjust it properly. However, because of the light weight of troop seats and great variations in equipment weight, a VLEA could be very beneficial on a troop seat.

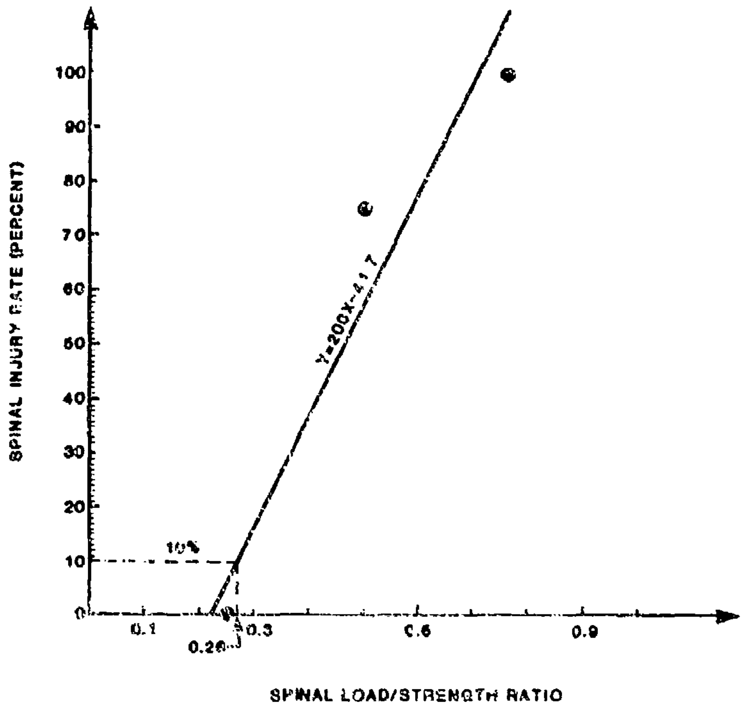


FIGURE 30. SPINAL INJURY RATE AS A FUNCTION OF SPINAL LOAD/ STRENGTH RATIO (SLSR). (REFERENCE 41)

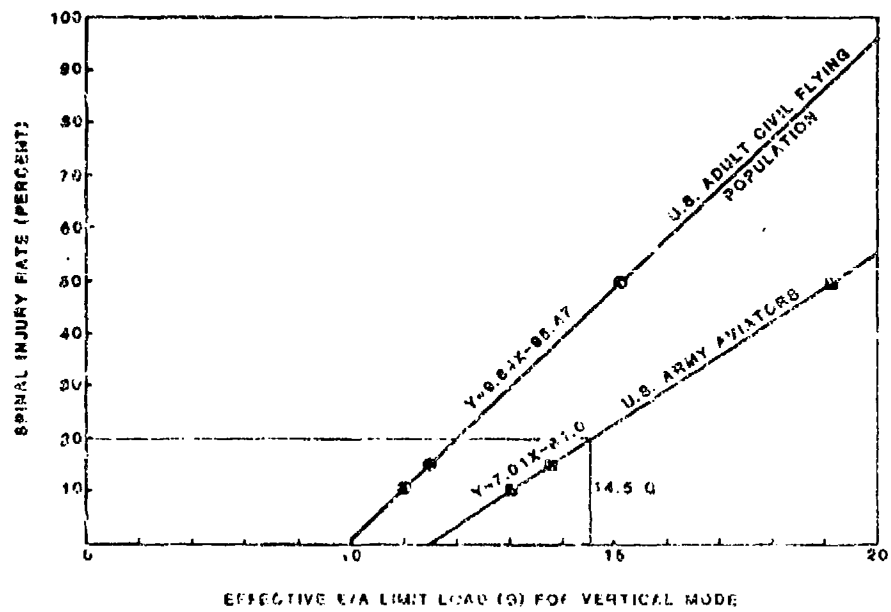


FIGURE 31. CORRELATION BETWEEN THE ENERGY ABSORBER LIMIT-LOAD FACTOR AND SPINAL INJURY RATE. (REFERENCE 41)

Variable-load energy absorbers (VLEA) can be controlled either passively (requiring no action by the occupant) or actively (requiring a conscious action by the occupant). The passive device would require a considerably more sophisticated control system. It would need to be a force/time integrating system, since the limit load of the energy absorber could not be a function of the dynamic loading of the seat associated with occupants simply sitting down hard. This type of device has not been developed; the cost and weight may be prohibitive, since an actively controlled device is neither complex nor costly. To achieve most of the advantages offered by an active system, the load would not have to be infinitely adjustable but could be applied in several increments. The occupant or crewmember would simply turn a dial or move a lever to a weight range best fitting the occupant's weight.

Active types of systems have been developed and are in production on several crewseats at this time. Development work on a self-adjusting passive system has been performed, and some promising results have been obtained.

A development program for a manually operated system identified several possible methods, as described in Reference 43. One concept utilized an inversion tube which was sized for the load corresponding to the 5th-percentile occupant. Additional load was obtained from a mechanism which deformed the tube after it was inverted. The amount of additional deformation was determined by a hand control on the seat. At the 5th-percentile setting there was no secondary deformation and at the 95th-percentile setting there was sufficient secondary deformation to produce the optimal stroking load. If the occupants dial in their proper weights, the stroking load in G's will be constant from the 5th- to 95th-percentile. The secondary deformation process consists of ball bearings indenting the wall of the tube. Testing is described in Reference 44. This system has been used on production crewseats, and examples are presented in References 18 and 19. A system utilizing wire benders rather than inversion tubes has also been developed for the V-22. Relative positioning of the wire rollers provides the necessary load variation. This concept is described in Reference 41.

The use of a self-adjusting passive VLEA system was researched as described in Reference 45. In that study, a fluid-controlled system was designed, built and tested. The results were promising, but further development will be required before such systems can be used on operational seats. A self-adjusting system is desirable because misuse of the hand-adjusted system could be hazardous. For example, a 5th-percentile occupant sitting in a seat with a 95th-percentile setting would be at greater risk than if he were in a standard seat with an effective 50th-percentile setting. Such misuse could result from failure to adjust the seat prior to flight or from misadjustment due to ineffective training and a misunderstanding of system function. A crewmember erroneously believing that more load means more protection, for example, might deliberately enter a high setting. A self-adjusting system would avoid all possible human operator errors.

Previous studies (Reference 28) have indicated that a total excursion of approximately 6 G results from using a single limit load set for the 95th-percentile occupant weight. The 6-G excursion can be essentially eliminated with either type of variable-load energy absorber. This would allow decelerations of all occupants to be nearly identical and enable use of essentially the same stroke distance for the same decelerative loading and input crash severity for all occupant weights. Variable limit-load energy absorbers should, therefore, be incorporated in the vertical direction in all new crash-resistant seating systems, and retrofit should be considered for seating systems now in use that include stroking capabilities together with replaceable energy absorbers. MIL-S-58095 requires the use of VLEA's for crewseat, but no troop/passsenger seat specifications have the requirement at present.

4.7.3.6 Energy-Absorber Limit Load. Selecting the limit load for either a fixed load or a VLEA device consists of a difficult trade-off between acceleration-induced injury during stroking and acceleration-induced injury at the end of the stroke if the seat bottoms out in a severe crash. If the stroke load is too low, there will be little chance of injury during stroke but a high probability of bottoming out in a severe impact. If the stroking load is too high, the seat will seldom bottom out, but some spinal injuries may occur if the impact causes stroking. The stroking load must usually be selected so that a small percentage of injury occurs during stroke to protect against bottoming out. Tests with cadavers, described in Reference 41, established a relationship between the probability of injury and stroking load. This is shown in Figure 31. Usually, a 14.5-G limit load with a corresponding injury rate of 20 percent is recommended. The curve based on the cadaver data is believed to be conservative. Actual crash data of the UH-60, which has a 14.5-G limit load, shows an injury rate of 15 percent or less, and all injuries were not serious fractures. For the U.S. civil population, as opposed to Army aviators, the second curve shows a limit load of 12.0 G for a 20 percent injury rate. Since the average age of the civil population is greater than that of Army aviators, the difference illustrates the reduction of spinal strength with age.

4.8 COMPUTERIZED METHODS OF ANALYSIS

4.8.1 General

Prediction of occupant and seat structure response to dynamic loading is a complex engineering problem. The use of computer-aided design in these cases is essential, since the dynamic interaction of the occupant and the seat/restraint system is much too complex for analysis by manual techniques.

A number of dynamic models of the human body have been developed for use in crash survivability analysis. These models vary in complexity and possess from 1 to 40 degrees of freedom (References 46 through 63). One-dimensional models have been used in prediction of human body response to an ejection seat firing (Reference 64 through 66), which, if the body is tightly restrained, can be approximated as a one-dimensional phenomenon. However, a vehicle crash generally involves a horizontal component of deceleration, which forces rotation of body segments with respect to each other. If no lateral component of deceleration is present, a two-dimensional model will suffice, provided the restraint system is symmetrical. However, lateral loading is common in helicopter accidents. Also, the diagonal shoulder belt used in some troop/passenger restraints is asymmetrical and may cause lateral motion of the occupant even in the absence of a lateral deceleration. Therefore, for a model to be generally useful in restraint system evaluation, it must be capable of predicting three-dimensional motion, and several three-dimensional kinematic models made up of interconnected rigid links have been developed (References 47, 53, 56 and 62). Subsequent sections of this chapter describe the models for use of seat and restraint system designers.

4.8.2 Program SOM-LA

Program SOM-LA (Seat/Occupant Model - Light Aircraft) has been developed under the sponsorship of the Federal Aviation Administration (FAA) for analysis of aircraft seats and restraint systems under crash impact conditions. The program combines a dynamic model of the human body with a structural model of the seat structure. It provides the design engineer with a tool to analyze the structural elements of the seat as well as evaluate the dynamic response of the occupant during a simulated crash impact.

The original model was described in a report that was published by the FAA in 1975 (Reference 67). A number of modifications have been made to the model since then to improve simulation quality and add desirable output. Several testing programs have been conducted by the FAA Civil Aeromedical Institute (CAMI) to provide data for validation of the mathematical model. The final model and its validation are described in Reference 68, with instructions for use of the computer program in Reference 69. The program has been validated by tests of crash-resistant military helicopter crewseats and general aviation seats.

Program SOM-LA includes a three-dimensional model of the aircraft occupant, consisting of 12 rigid segments, as shown in Figure 32. The midtorso, lower neck, shoulder, and hip joints are ball-and-socket type, each possessing three rotational degrees of freedom. The upper neck, elbow, and knee joints are hinge-type joints, each adding 1 degree of freedom. In total, the occupant possesses 29 degrees of freedom. Rotations at the body joints are resisted by torsional springs and dampers, whose characteristics depend on user selection of human or dummy occupant.

External forces are applied to the body segments by the seat cushions, the floor, and the restraint system. The four available restraint system configurations consist of a lap belt alone or combined with a single diagonal belt over either shoulder, or a double shoulder belt. A lap belt tiedown strap may be used with the double shoulder belt system. The restraint loads are transmitted to the occupant through ellipsoidal surfaces to the upper and lower torso segments, and the points of application depend on current belt geometry. The capability of the belts to move relative to the torso surfaces allows simulation of submarining under the lap belt as well as prediction of the lateral motion which may result with a single diagonal shoulder belt.

For calculation of external forces exerted on the occupant by the seat cushions and restraint system, and for prediction of impact between the occupant and the aircraft interior, 26 surfaces are defined on the body. These surfaces are ellipsoids, spheres, and cylinders, as shown in Figure 33.

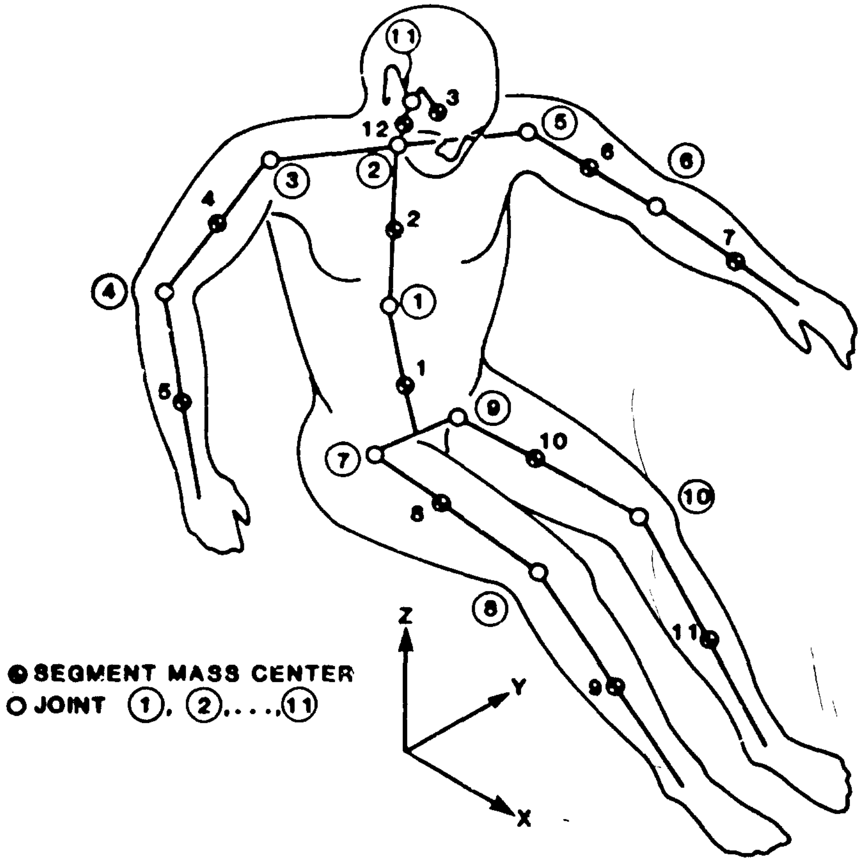


FIGURE 32. SOM-LA TWELVE-SEGMENT (THREE-DIMENSIONAL) OCCUPANT MODEL.

In order to achieve more economical program solutions for cases where occupant response is expected to be symmetrical with respect to the X-Z plane, a two-dimensional version of the occupant model is also included in SOM-LA (Figure 34). Although all forces applied to this model, such as those of the restraint system, are computed three-dimensionally, its response is restricted to symmetric plane motion. All segments remain parallel to the X-Z plane, and both arms move identically, as do both legs. Because of the potential for vertebral injury in aircraft accidents that involve a significant vertical component of impact velocity, the two-dimensional occupant model is configured to include beam elements in both the torso and neck to provide a measure of vertebral loading. The two-dimensional model has a total of 11 degrees of freedom.

The user may select either a finite element model of the seat structure or a simplified seat representation. The finite element seat analysis includes triangular plate, beam, and spring elements. It has the capability to model large displacements, nonlinear material behavior, local buckling, and various internal releases for beam elements. The simplified seat option can be used

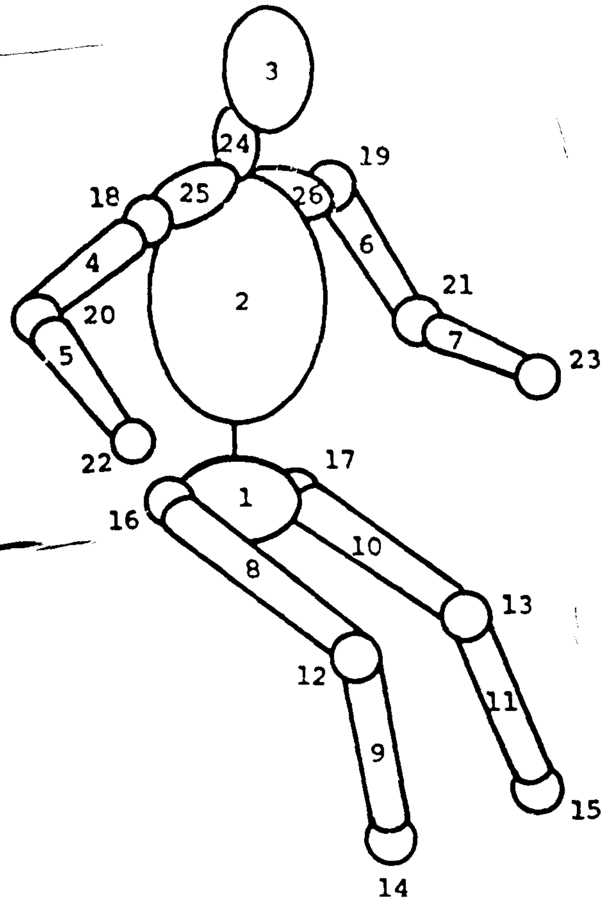


FIGURE 33. SOM-LA OCCUPANT MODEL CONTACT SURFACES.

to model very rigid as well as energy-absorbing seats, as shown in Figure 35. The bucket is assumed to be rigid, the vertical energy-absorber is modeled by a nonlinear transitional spring element, and the frame elasticity is modeled by a torsional spring element.

Input data include force-deflection information for the cushions and belts; crash conditions, in terms of initial velocity and attitude and time variations of six acceleration components; occupant description; seat design data; and, if the prediction of impact with the aircraft interior is desired, a description of the cabin surfaces. Output data include time histories of occupant segment positions, velocities, and accelerations; restraint system loads; seat deflections and forces; details of contact between the occupant and the aircraft interior (velocity, contact point and time, but not contact forces); and several measures of injury severity. The injury criteria used in the program are all computed from segment accelerations. The dynamic response index (DRI) provides an indication of the probability of spinal injury due to a vertical acceleration parallel to the spine. The Severity Index is calculated for the chest and head, and the Head Injury Criterion of Federal Motor Vehicle Safety Standard 208 is also computed.

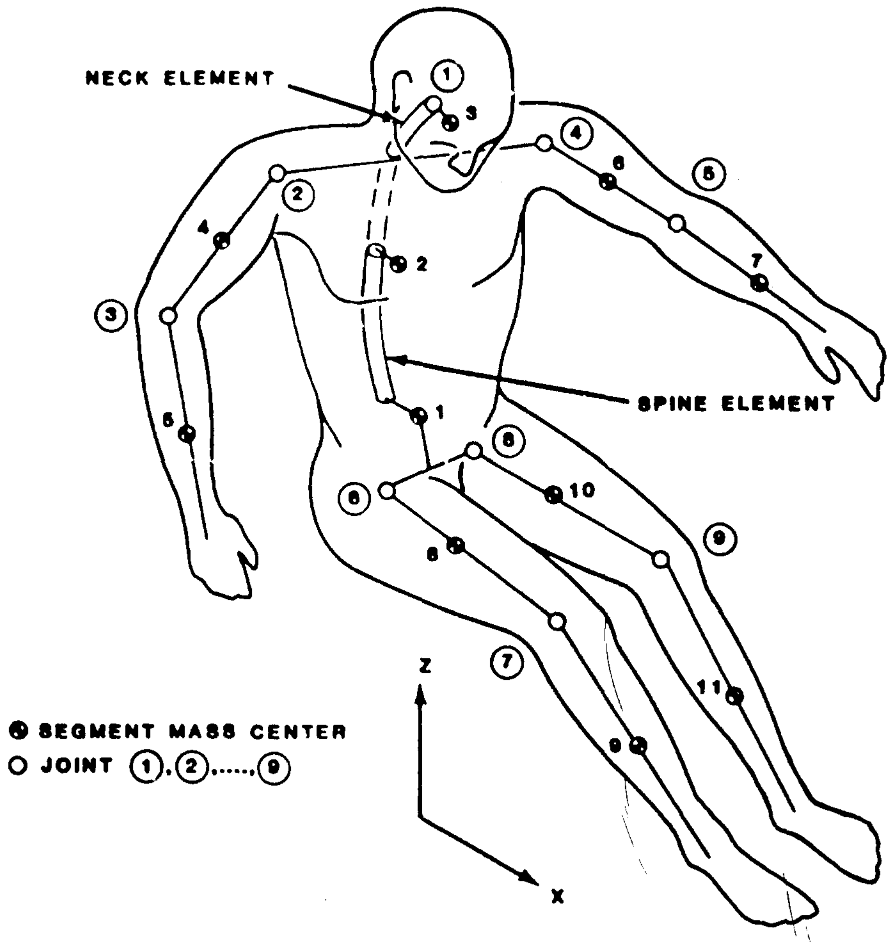


FIGURE 34. SOM-LA ELEVEN-SEGMENT (TWO-DIMENSIONAL) OCCUPANT MODEL.

Work on further program model improvements and validation is continuing. The program improvements currently underway include incorporating beam elements for torso and neck into the three-dimensional occupant model similar to the current two-dimensional occupant model as well as providing a general program restart capability.

4.8.3 Program SOM-TA

Program SOM-TA (Seat/Occupant Model - Transport Aircraft) has also been developed under the sponsorship of the Federal Aviation Administration for analysis of multiple occupant transport aircraft seats and restraint systems under crash impact conditions. It combines dynamic models of the occupant(s) with a structural ~~model of~~ the seat structure (Figures 36 and 37). The program allows simulation of one, two, or three occupants of the same or different sizes.

The seat and occupant models in Program SOM-TA are based on those currently used in Program SOM-LA. The occupant model has been modified to include secondary impact between the occupant(s) and the seat back in front. The

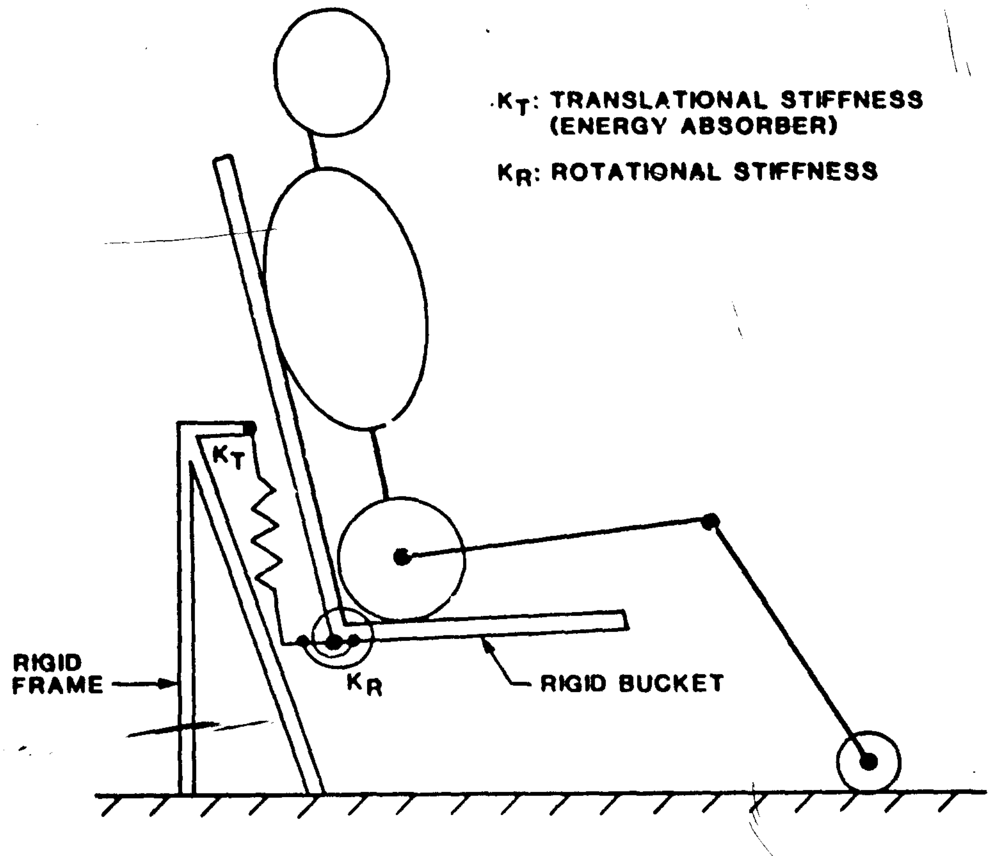


FIGURE 35. SOM-LA ENERGY-ABSORBING SEAT MODEL.

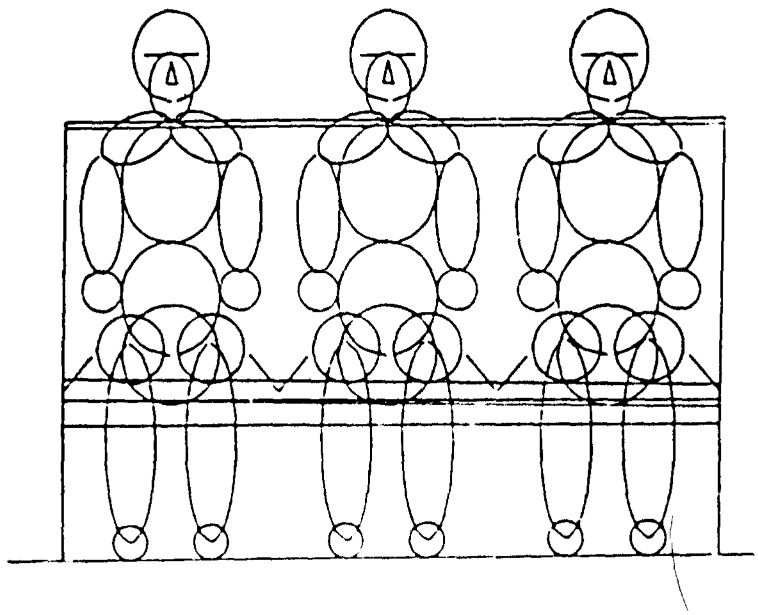


FIGURE 36. SOM-TA TRIPLE-OCCUPANT MODEL.

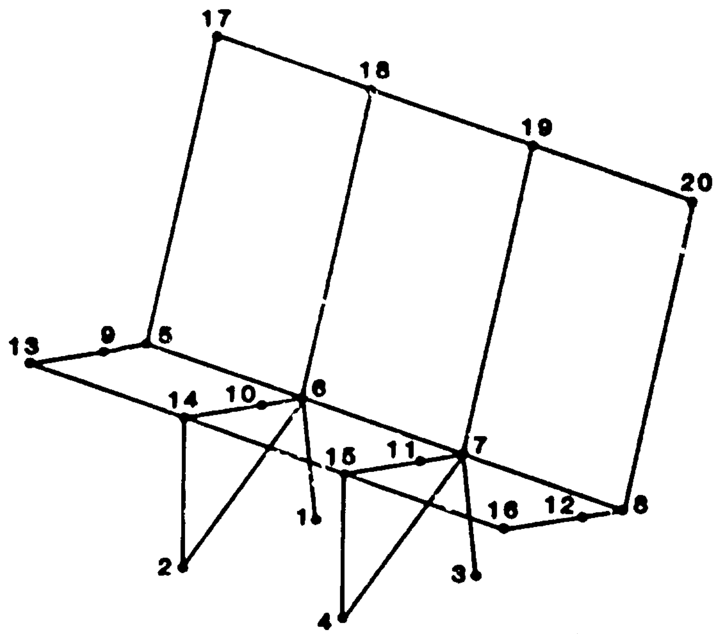


FIGURE 37. SOM-TA SEAT STRUCTURE FINITE ELEMENT MODEL.

finite element seat model capacity has been increased to accommodate more complex transport seat structures. The seat model has also been modified to allow simulation of warped floors.

A testing program has been conducted by CAMI to provide data for validation of Program SOM-TA. The final model and its validation are described in Reference 70, with instructions for use of the program in Reference 71.

4.8.4 Calspan Corporation - CVS

Probably the most sophisticated biomechanical model of the human body intended for crash simulation is the Calspan Corporation Crash Victim Simulator (CVS). Originally reported in 1972 (Reference 47), the program includes a body dynamics model with 40 degrees of freedom and a contact model that generates forces from contact with vehicle surfaces. The extensive validation effort has included the following experiments:

- Static bench tests with a spherical membrane and spherical contact surfaces to validate the air bag shape and contact force algorithm.
- Pendulum tests with a dummy torso form restrained and decelerated with an air bag to further validate this algorithm.

- Tests with instrumented anthropomorphic dummies on an impact sled at 20 and 30 mph with both belt and air bag restraints, in which both planar and nonplanar dummy responses were produced.

- A head-on, laterally offset, car-to-car crash test, with the primary vehicle containing two instrumented anthropomorphic dummies.

A graphics display model provides rather sophisticated three-dimensional views of occupant response, as shown in Figure 38. Present capabilities of the program, a user manual, and a description of its validation are presented in Reference 49.

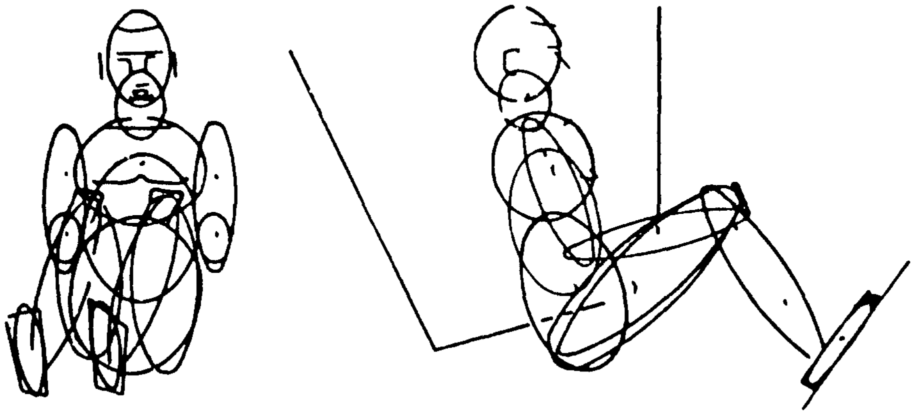
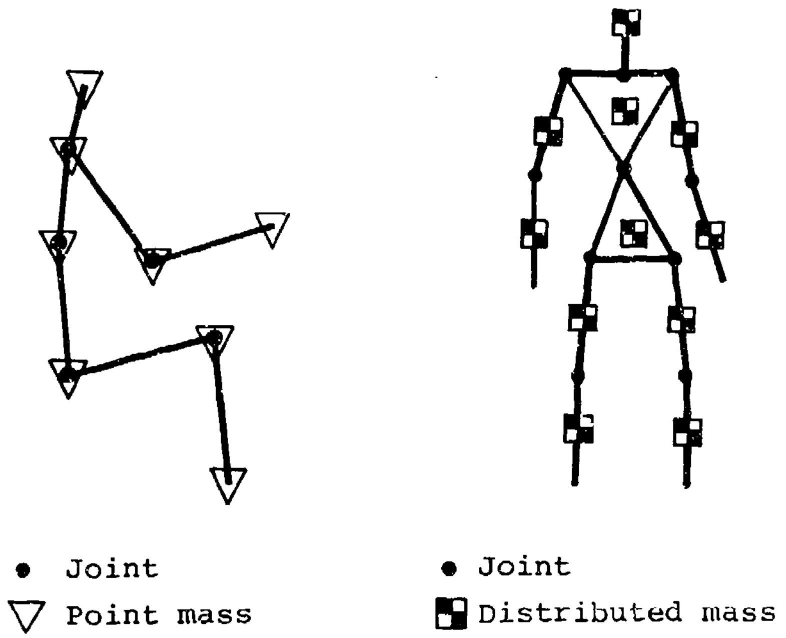


FIGURE 38. CVS GRAPHICS DISPLAY MODEL.

4.8.5 PROMETHEUS

In 1972 Boeing Computer Services began work on modification of a two-dimensional occupant model called SIMULA, which had been developed earlier by Dynamic Science, Inc. and Arizona State University. Their final product, which includes interactive, user-oriented capabilities, is called PROMETHEUS (Reference 61).

PROMETHEUS simulates a crash victim with either a two-dimensional, seven-link, side-facing mathematical model, shown in Figure 39(a), restrained by a seat belt and shoulder harness, or an eleven-link, forward-facing, unrestrained model, shown in Figure 39(b). A nonlinear finite element model of the impacting structure is incorporated. A new, fast differential equation solver was developed for the program to efficiently compute the transient response of the finite element vehicle structure and rigid-link occupant in a crash situation. The program is an interactive, user-controlled system designed for the rapid analysis/data edit/reanalysis cycles necessary for efficient parametric studies. PROMETHEUS input aids include free-field data input and an on-line data edit capability. Output provides user-selected time history and occupant configuration plots, as well as abbreviated output lists for rapid scan of results. The program operates on the CDC 6600 computer in either a batch or an interactive mode.



(a) Side-facing model (b) Forward-facing model.

FIGURE 39. PROMETHEUS OCCUPANT MODEL.

4.8.6 Air Force Head-Spine Model

Under the sponsorship of the U.S. Air Force Aeromedical Research Laboratory, a three-dimensional, discrete model of the human spine, torso, and head was developed for the purpose of evaluating mechanical response in pilot ejection. It was developed in sufficient generality to be applicable to other body response problems, such as occupant response in aircraft crash and arbitrary loads on the head-spine system. There are no restrictions on the distribution of direction of applied loads, so a wide variety of situations can be treated. The model is described in Reference 72.

The anatomy is modeled by a collection of rigid bodies, which represent skeletal segments such as the vertebrae, pelvis, head, and ribs, interconnected by deformable elements, which represent ligaments, cartilageneous joints, viscera, and connective tissues. Techniques for representing other aspects of the ejection environment, such as harnesses and the seat geometry, are included. The model is valid for large displacements of the spine and treats material nonlinearities. The elements of the model are illustrated in Figure 40.

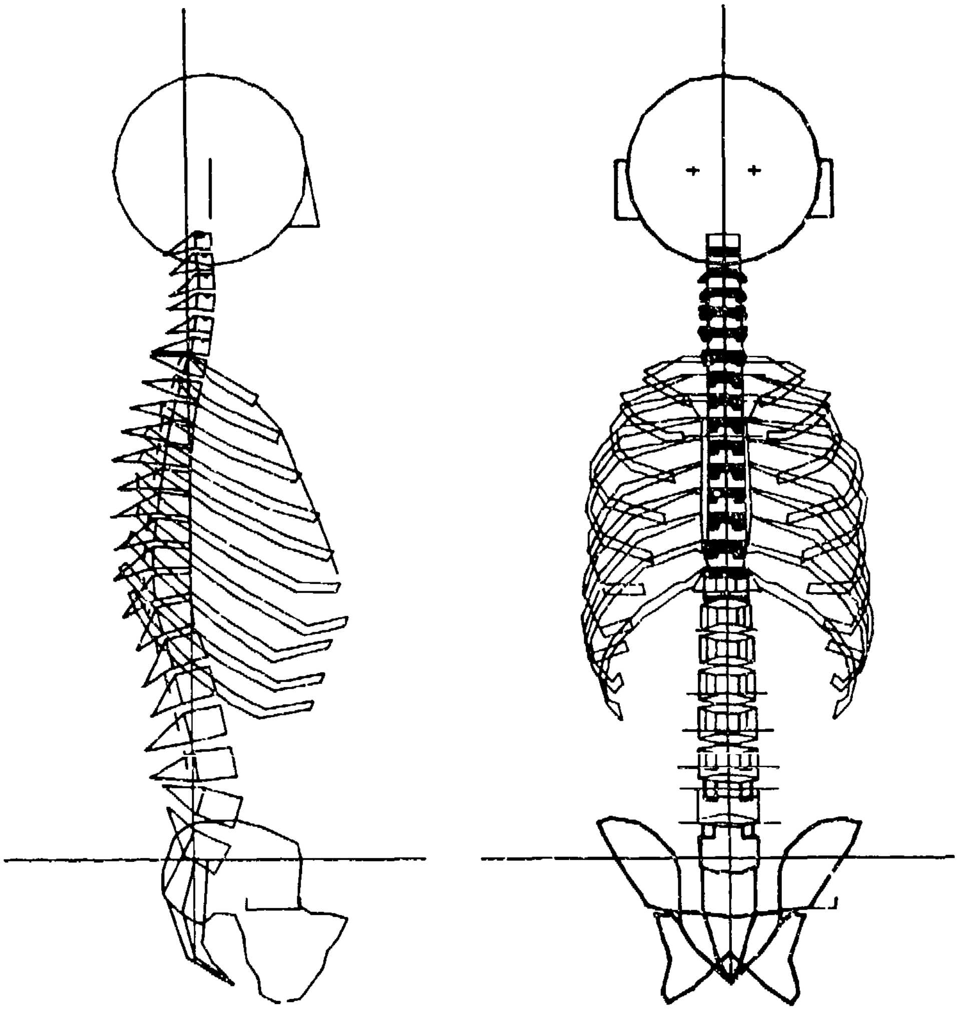


FIGURE 40. THREE-DIMENSIONAL HEAD-SPINE MODEL. (REFERENCE 72)

The basic model is modular in format, so that components may be omitted or replaced by simplified representations. Thus, while the complete model is rather complex and involves substantial computational effort, various simplified models that are quite effective in duplicating the response of the complete model within a range of conditions are available. Three methods of solution are available for the analysis: direct integration in time by either an explicit, central difference method; by an implicit, trapezoidal method; or by a frequency analysis method.

A variety of conditions have been simulated, including different rates of onset, ejection at angles, effects of lumbar curvature, and eccentric head loadings. It has been shown that large initial curvatures and perfectly vertical acceleration loadings result in substantial flexural response of the spine, which cause large bending moments. It has been further shown that the combination of the spine's low flexural stiffness, initial curvature, and mass eccentricity are such that stability cannot be maintained in a 10-G ejection without restraints or spine-torso-musculature interaction.

The complete models were used mainly to study the effects of the rib cage and viscera on spinal response. The flexural stiffness of the torso is increased substantially by a visceral model, even though it has no inherent flexural stiffness. In addition, the viscera provide significant reductions in the axial loads.

4.8.7 One-Dimensional Seat/Occupant Models

Although a three-dimensional simulation should be used for complete prediction of aircraft occupant dynamics in investigating restraint system properties or cockpit configurations to eliminate secondary impact hazards, the more simple one-dimensional models also may be useful in crashworthy seat analysis. For example, a model such as that illustrated in Figure 41, provides an economical means of optimizing energy absorber characteristics, which would be simulated by spring K_1. Energy absorber force deflection characteristics might be varied while searching for the most favorable occupant response, evidenced by a minimum of spinal deflection, head acceleration, etc. The most notable difficulty with the use of such a model lies in obtaining valid occupant properties, i.e., masses and spring characteristics. One such model that has been used in seat evaluation is described in Reference 73.

Another widely known one-dimensional model is used to compute the Dynamic Response Index (DRI). The DRI is a predictor of spinal injury due to $+G_z$ acceleration and is based on the response of a single-degree-of-freedom model as described in detail in Volume II.

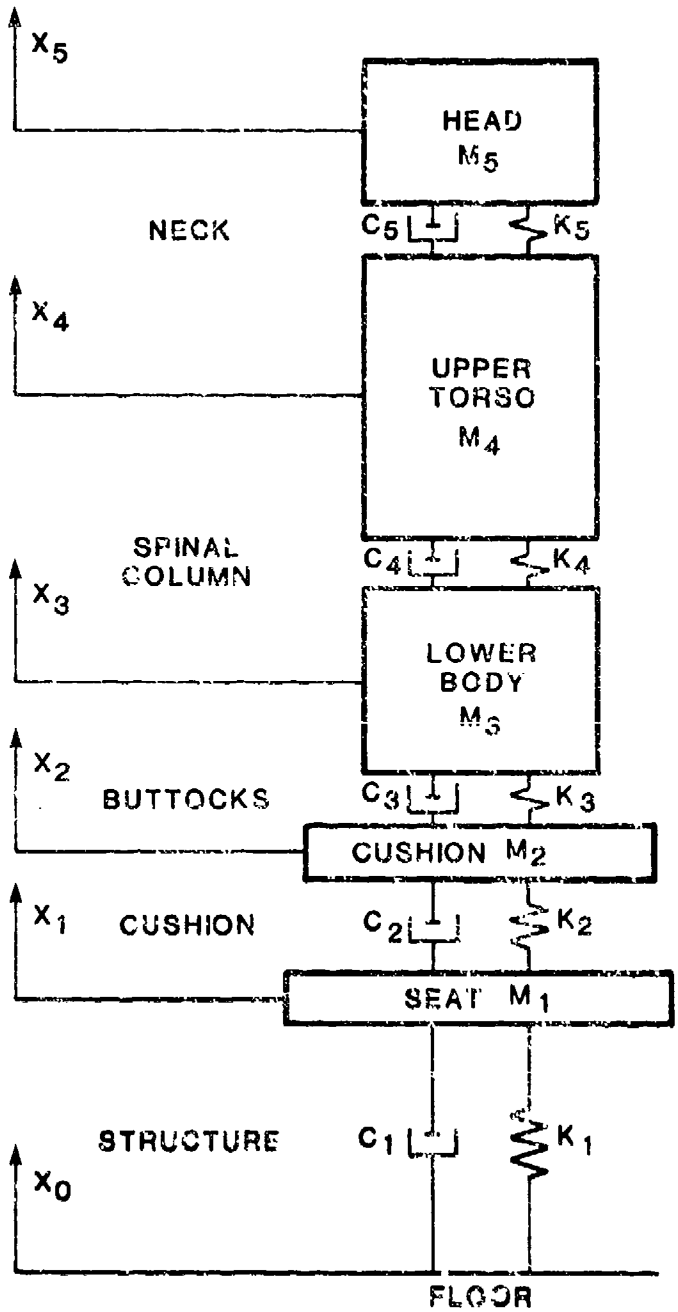


FIGURE 41. LUMPED-PARAMETER MODEL OF SEAT, SEAT CUSHION, AND OCCUPANT.

5. ENERGY-ABSORBING DEVICES

5.1 INTRODUCTION

A multitude of devices for absorbing energy and limiting loads have been proposed, developed, and tested. As demonstrated earlier, the kinetic energy of a moving mass can be absorbed by applying a force over a distance; this is the primary mechanism for absorbing crash energy. For the same energy, the larger the distance through which the force acts, the lower the average load on the mass. 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.

Past experience has shown that plastic deformation of material, primarily metal, results in a reasonably efficient energy-absorbing process. Consequently, most load-limiting or energy-absorbing devices use that principle. Desirable features of energy absorbers are as follows:

- The device should stroke at a constant, predictable 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, depending on the system design.)
- The device should be as light and small as possible.
- The specific energy absorption (SEA) should be high.
- The device should be economical.
- 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, and should be protected from corrosion.
- The device(s) should decelerate the occupant in the most efficient manner possible while maintaining the loading environment within the limits of human tolerance.

The discussion that follows refers to load limiters as separate devices. This is not meant to imply that load limiters must be separable devices at the exclusion of the integral design concept wherein the structure itself is designed to collapse in a controlled and predictable fashion. Rather, the discussion is presented in this way to simplify portrayal of different methods of absorbing energy and limiting loads.

Research on simple, compact, load-limiting devices has been conducted by the Government and by private industry. These data are recorded in References 74 through 86. A brief discussion of some of the more common energy-absorption devices and concepts applicable to seats is presented in the following text and in Table 4.

In Table 4 long-term reliability refers to the ability of the device to perform its function without benefit of maintenance throughout the life of the aircraft. The weight used in calculating SEA values includes the necessary end fittings required to apply the load except as noted.

Pertinent characteristics of each device listed in Table 4 are discussed in Section 5.2. The concepts that have found use in actual seat designs are presented first.

5.2 TYPES OF ENERGY ABSORBERS

5.2.1 Wire or Strap Bending

This device uses the force required to bend a metal wire or strap around a die or roller(s). It can be as simple as a steel wire threaded through a perforated plate or a wire wound around rollers. One characteristic that may be a problem with this device (as with all devices affected by or utilizing friction from metal-to-metal contact) is that an initial peak load higher than the normal stroking load is induced. This initial load increase can be reduced or eliminated by providing initial slack in the wire when passing it over the rollers. These devices, by themselves, do not have the ability to sustain compressive loads. However, by anchoring both ends of the wire and attaching the seat bucket to the rollers, compressive as well as tensile loads can be sustained.

Two variations of the wire-bending device have been developed and used in the ceiling- and floor-mounted troop seat illustrated in Figure 42. The two tension-type devices at the top of the troop seat are shown in greater detail in Figure 43.

In the analysis of energy absorbers for the troop seat, reported in Reference 75, wire of varying diameter was investigated in order to produce a notched force-deflection curve as recommended in Reference 42. It was concluded that the notched force-deflection curve was not suitable for lightweight troop seats due to the sensitivity of the system response to location of the notch in the load-versus-deflection characteristic. A fixed location for the notch was not compatible with the various dynamic response phasing resulting from the wide range of troop and equipment weights. The trapezoidal force-deflection curve produced by the constant limit-load device, although not as efficient theoretically and ideally as the notched curve for a specific dynamic condition, appeared to be more tolerant of the wide range of seat occupant weights. Figure 43 shows the force-deflection characteristics of that device.

TABLE 4. COMPARISON OF LOAD-LIMITING DEVICES FOR 1000- TO 4000-LB LOADS

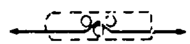
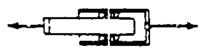
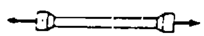
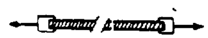
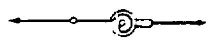
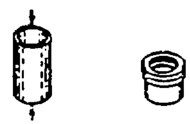
Device Description	Energy-Absorption Process	Operation Sketch	Tension or Compression	SEA[a] (ft-lb/lb)	Stroke-to-Length Ratio[b]	Long-term Reliability	Ability to Sustain Rebound Loads	Constant Load Level	Potential Application
Strap/wire over die or roller	Metal bending and friction		T and C[c]	1,200[d]	Good - T Poor - C	Good to excellent	Zero to excellent[c]	Excellent	Seat strut or support
Inversion tube	Hoop tension/compression and bending		T and C	1,800	Excel - T Poor - C	Excellent	Excellent	Excellent	Seat support
Rolling torus	Cyclic compression and bending		T and C	1,500	Good - T Avg - C	Fair to good	Excellent	Good	Seat strut or support
Honeycomb compression	Buckling of membrance "columns"		C	2,500 - 3,500	Average	Good	Poor[e]	Fair	Seat strut or support
Basic metal tube or plate	Elongation of metal		T	3,400 - 4,500	Poor	Good to excellent	Poor[e]	Fair	Seat support
Basic stranded cable	Elongation of stainless steel		T	3,400 - 4,500	Poor	Excellent	Zero	Fair	Seat support or brace
Tube Expansion	Hoop tension and friction		T and C	600[f]	Good to T Poor - C	Good	Poor[e]	Good	Seat support

TABLE 4 (CONTD). COMPARISON OF LOAD-LIMITING DEVICES FOR 1000- TO 4000-LB LOADS

Device Description	Energy-Absorption Process	Operation Sketch	Tension or Compression	SEA[a] (ft-lb/lb)	Stroke-to-Length Ratio[b]	Long-term Reliability	Ability to Sustain Rebound Loads	Constant Load Level	Potential Application
Tube flaring	Hoop tension, friction, and bending			1,000 - 8,000 15,000 (Composite)	Good to excellent	Good	Poor[e]	Fair	Seat strut
Housed pulley	Shear and bending of sheave housing		T	Unknown	Good	Good	Zero	Good	Seat support
Folding tube	Successive buckling or crushing of tube due to axial compression	 Before After	C	25,000 - 30,000 (Al tube) 9,000 - 33,000 (Composite tube)	Average	Good	Good	Good	Floor mount
Rolled tube	Progressive tube crushing		T and C	1,000 - 2,000	Good	Good	Poor[g]	Good	Seat Support

(a) SEA is very dependent on materials and design. To be directly comparable the devices would need to be designed for the same application. The SEA values for the first three devices listed, those now being used in operational energy-absorbing seats, are reasonably comparable.
(b) In some cases, final length is significant; in other cases, initial length is significant.
(c) Simplest devices operate in tension (T) only; a recently developed troop seat strut is capable of tension (T) or compression (C) (Section 5.2).
(d) Specific energy measured for device that operates in tension or compression.
(e) This device could be rated higher if an integral rebound device were incorporated into the design.
(f) This value is based on the compressed tube device tested. This value could be doubled in a more efficient design.
(g) Can be improved by use of a secondary deformation process.

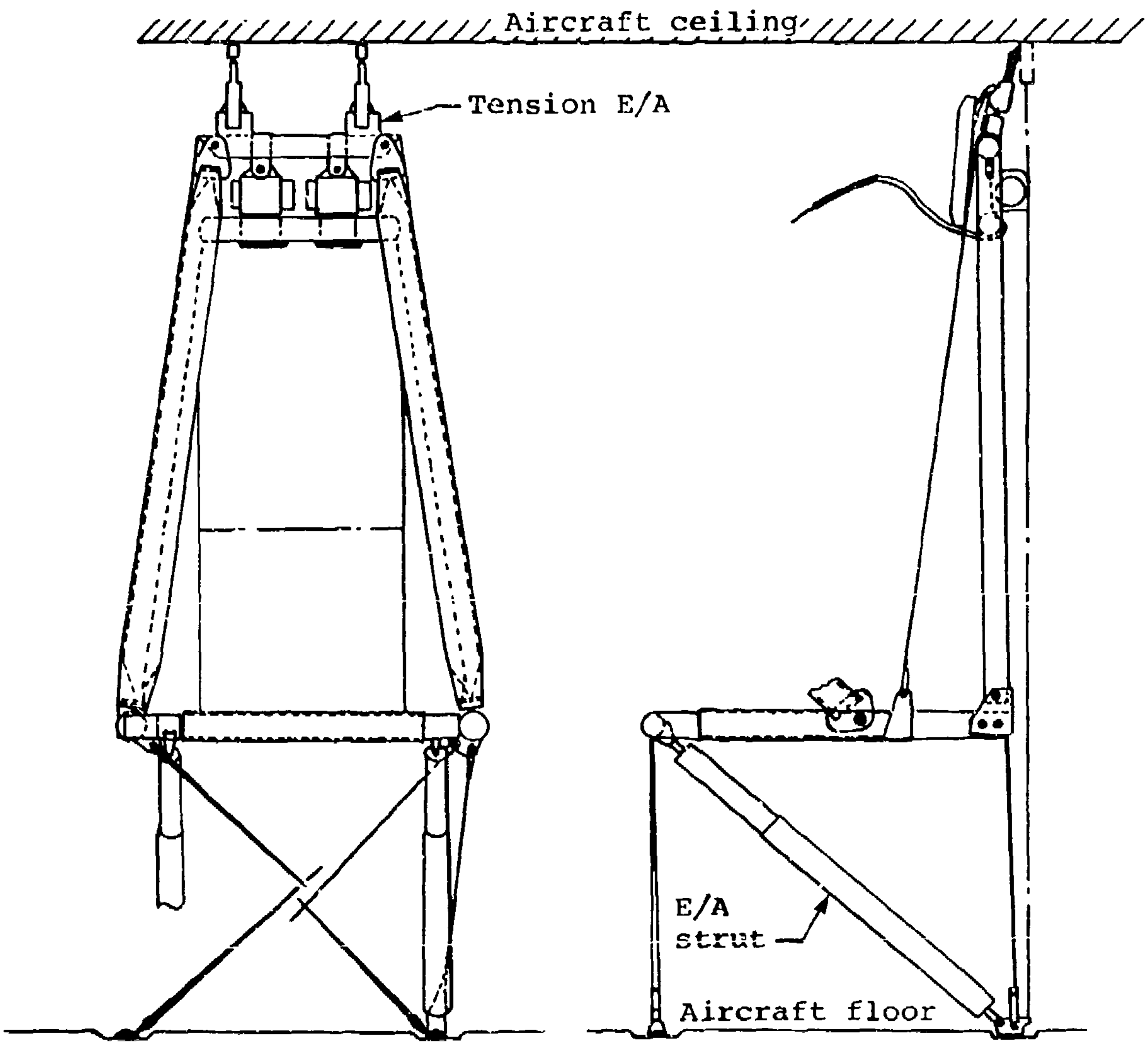


FIGURE 42. CRASH-RESISTANT TROOP SEAT. (REFERENCE 75)

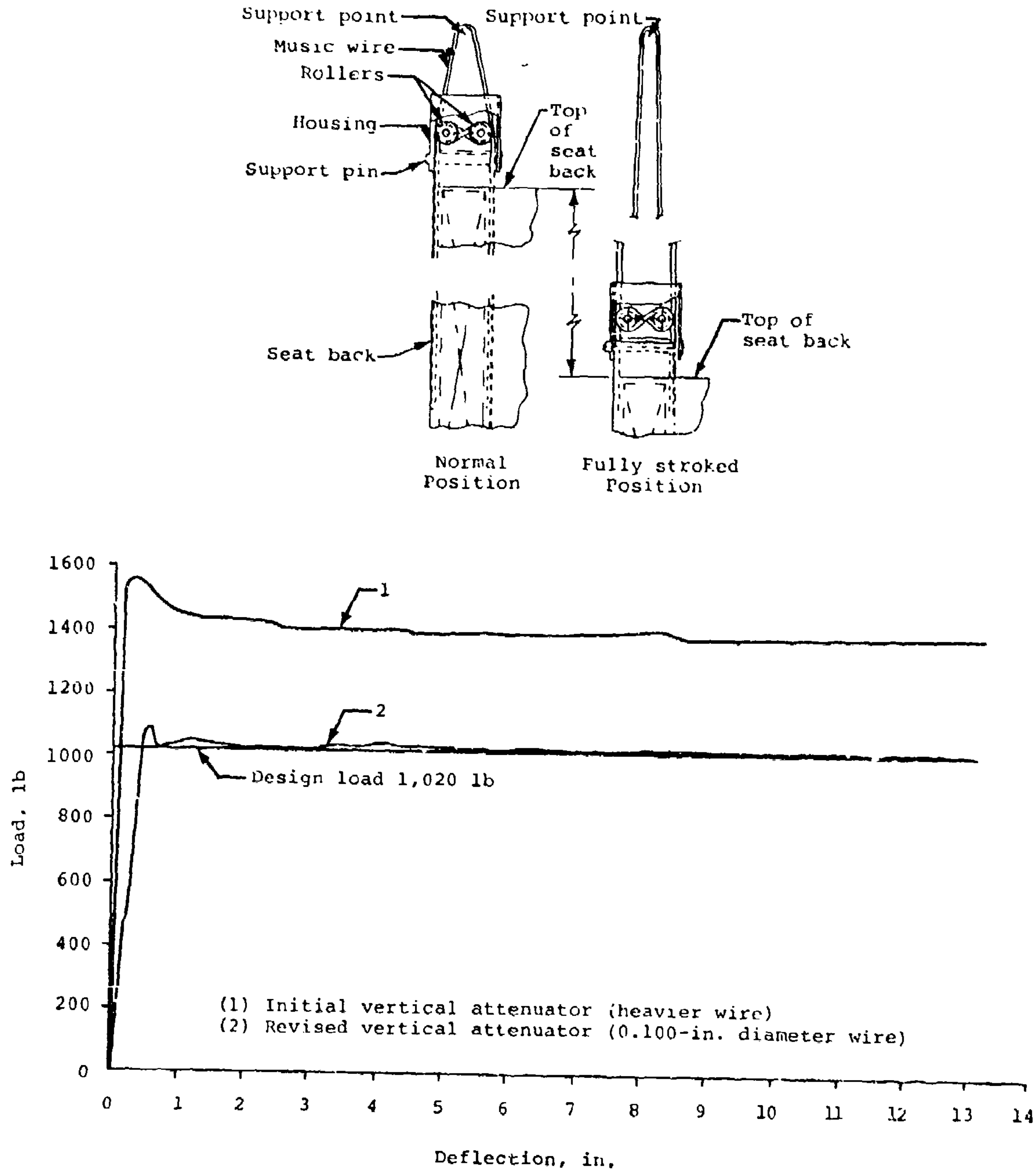


FIGURE 43. TROOP SEAT TENSION ENERGY ABSORBER INCLUDING CHARACTERISTICS FOR TWO WIRE DIAMETERS.

The other variation of the wire-bending energy absorber used in the above mentioned troop seat, and shown in Figure 44, is capable of functioning in tension or compression. The device is contained in two telescoping aluminum tubes. A cap is placed on the inner end of the inner tube. Music wire of 0.100-in. diameter, in the shape of a hairpin, is looped through the cap, and the two free ends are secured to a stud in the outer end of the inner tube. A trolley consisting of three rollers sandwiched between two plates bends the wire as the trolley moves back or forth on the wire. The trolley is pinned to the outer tube, and slots are provided in the inner tube wall to allow passage of the pin connecting the trolley to the outer tube. Stainless steel wire, rather than music wire, has been used in some other applications for greater ductility and corrosion resistance. Seats using this type of device are now installed in some helicopters. Their most frequent use is in troop or passenger seats.

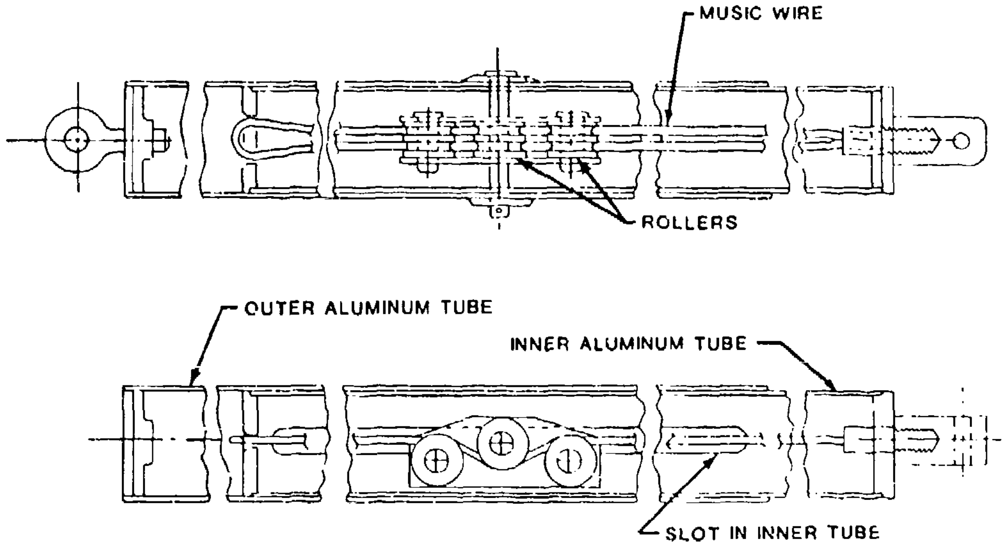


FIGURE 44. TUBULAR STRUT WIRE-BENDING ENERGY ABSORBER. (REFERENCE 35)

5.2.2 Inversion Tube

This device uses the force required to invert (to turn inside-out or outside-in) a length of metal tubing The concept was developed by an American automobile manufacturing company for incorporation into steering columns to produce controlled collapse loads (see Reference 76). No real disadvantages have been noted in experimental tests to date except with those loaded in compression. In dynamic tests of troop seats (Reference 87) using these devices in compression, there was a tendency for the outer and inner tubes to misalign, which resulted in failure and crippling of the inner tube. However, this problem can be solved by using an internal guide to keep the initial eccentricity from developing. It is possible that atmospheric corrosion could occur in the closed space between the inner and outer tube walls, especially in the bend radius. It has been suggested that this potential problem might be solved by injecting a low-density, closed-cell plastic foam into the small volume between the inner and outer tube walls to prevent moisture penetration of this area. Also, the tubes could be plated and/or coated to protect them from corrosion.

The materials used so far in inversion tubes have been 3003-H14 aluminum and mild steel, as described in References 76 through 78. It is possible that an annealed, higher strength alloy steel, such as 4130 or stainless steel, could yield even higher specific energy absorption values than those shown in Table 4. However, the aluminum devices that are in use are both compact and lightweight.

Figure 45 illustrates a specific design concept of the inversion tube energy absorbers (Reference 88). The load curve is essentially flat for the entire stroke distance after the initial peak. However, the static load may vary from the dynamic load by approximately 10 percent. Seats using this type of energy absorber are used in U.S. Army, Navy and Air Force helicopters.

5.2.3 Rolling Torus

Early versions of this energy absorber consisted of a number of torus elements located in the annular space between two telescoping cylinders. Modification of this concept has resulted in the substitution of a continuous helix of stainless steel wire for the toroidal elements. The interference fit between the cylinders and tori, or wire, causes the wire to roll when axial loads are applied. The cyclic plastic deformation of the rolling tori or wire helix and elastic deformation of the tubes effect the energy absorption. The cylinders remain intact and do not plastically deform when subjected to impact loading. The impact force is transmitted through the tubes to the tori or wire helix. Dynamic testing of these devices is reported in Reference 82.

The load limiters using wire as the working medium (Figure 46) are normally made with cylinders that range from 1 to 2 in. in diameter with a wall thickness of approximately 0.035 in. The wire ranges between 0.030 and 0.035 in. in diameter and is of 300 series stainless steel. These bidirectional devices may be used several times until fatigue failure of the wire occurs. An investigation of a lighter weight aluminum energy absorber of this type is documented in Reference 89.

Devices of this type can be single or multiple staged. The multiple-staged energy absorbers include three tubes with helices of wire between the walls of the outer tube and the center tube, and between the center tube and the inner tube. In operation, one helix of wire is rolled to the end of its stroke and then the second stage is initiated and rolled. Staged energy absorbers provide increased stroke distance without an appreciable increase in pre-stroked envelope.

The device produces a somewhat jagged load-versus-deformation characteristic as can be seen in Figure 46. Further, the interference contact between the tori and the cylinders, the closed spaces between the tube walls, and the spaces between the wire wraps are prime areas for corrosion. This potential should be considered during the development, test, and usage of this device.

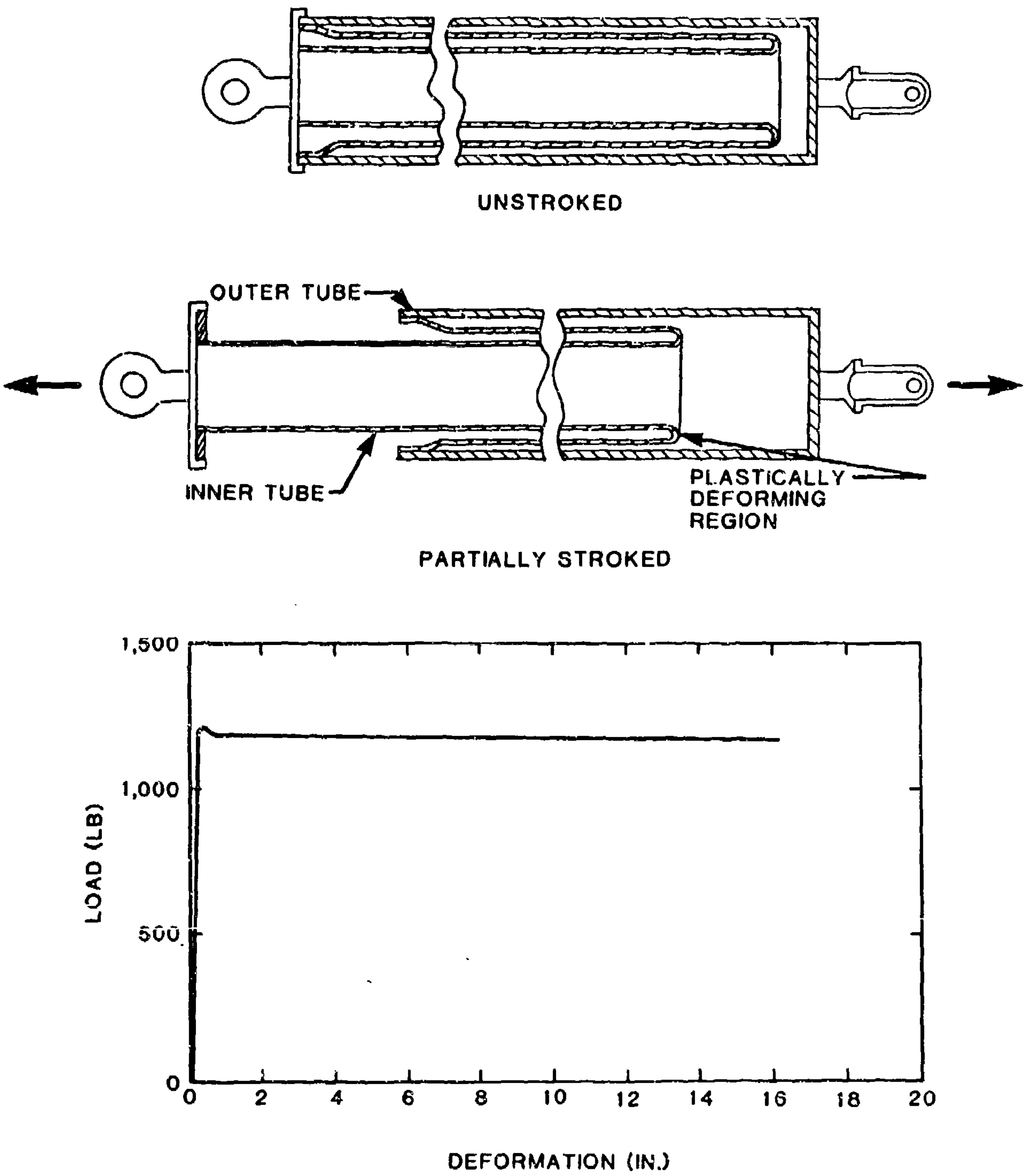


FIGURE 45. INVERSION TUBE CONCEPT WITH TYPICAL FORCE-DEFORMATION CHARACTERISTIC.

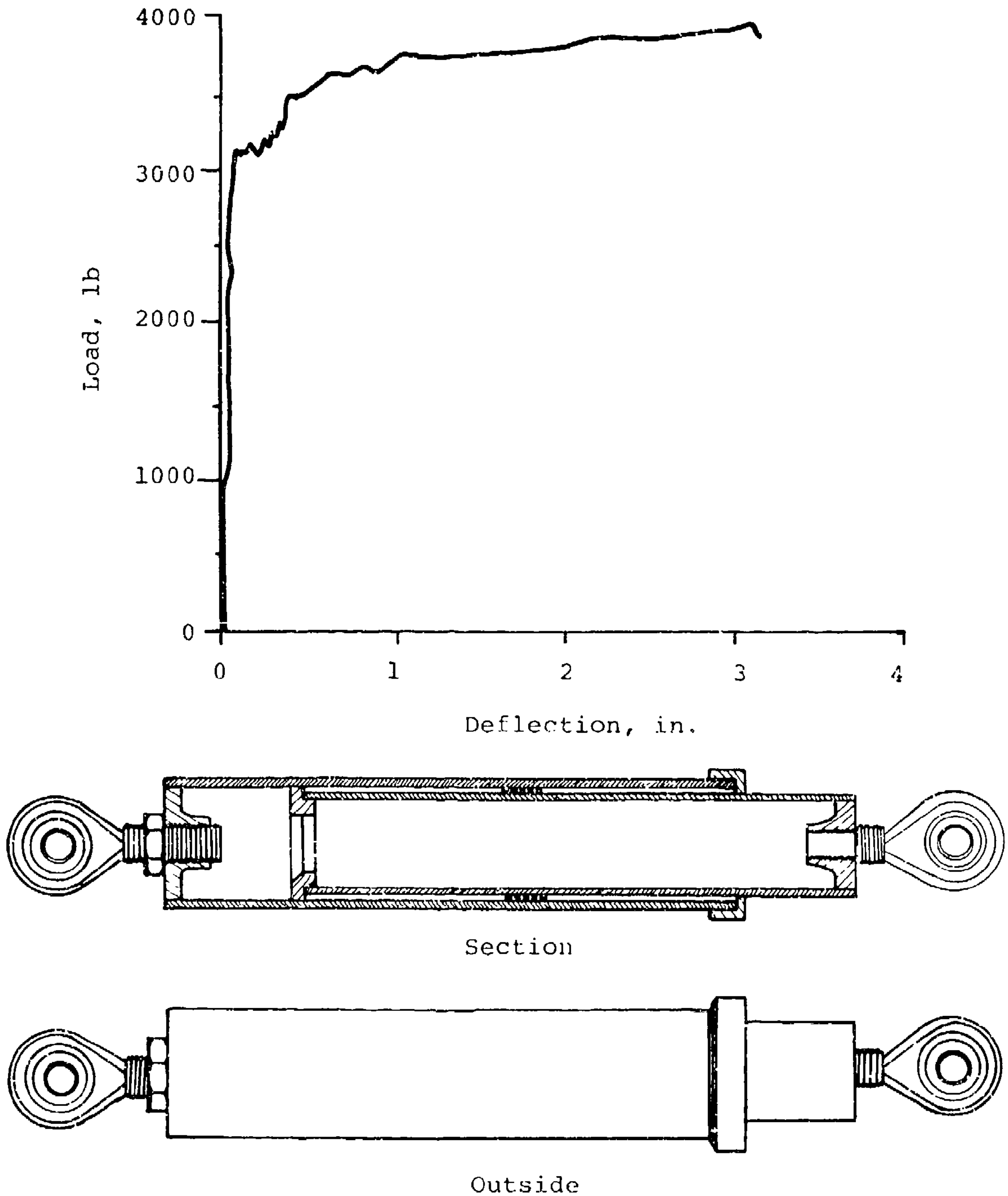


FIGURE 46. ROLLING TORUS ENERGY ABSORBER.

Seats with energy-absorbing mechanisms utilizing this device are now in use in a modified U.S. Marine helicopter (Reference 17) and in the Army's UH-60A utility helicopter.

5.2.4 Crushing Honeycomb

This device uses the force required to crush or deform a column of low-density material. In order to provide sufficient column stability and transverse load resistance, it appears that most applications will require a telescoping cover to give additional bending strength. Table 4 shows this device to be above average in all categories with the exception of rebound load ability. Rebound load capacity could probably be added by the incorporation of a suitable mechanism that allows movement in only one direction.

This device, besides being used on seats, is used as a load limiter in the main landing gears of some helicopters. In these applications, the crushable material is installed above the oleo piston as outlined in Reference 79. The energy-absorption ability of these devices has been responsible for preventing major structural damage to several aircraft in severe accidents.

To date, the best crushable material for use in this type of device appears to be corrugated aluminum foil backed by flat foil and cemented at the nodal points, as illustrated in Figure 47. Further research information on the development of crushable aluminum columns may be found in Reference 80. The Sikorsky ACAP* helicopter landing gear used this type of energy absorber in both the main and nose gears.

5.2.5 Extension of Basic Metal Tube, Rod, or Flat Strap

This concept uses the inherent plasticity of certain ductile metals which elongate under a relatively constant force. The primary problem with this device is strain concentration at the end connections. Research to date indicates that annealed stainless steel in the AISI 300 series is least susceptible to strain concentrations because of its excellent ductility (45 to 50 percent).

The flat strap device was evaluated for use as a vertical load limiter for a pilot's seat by the U.S. Naval Aircraft and Crew Systems Technology Directorate, now part of the U.S. Naval Air Development Center, and was found to perform satisfactorily (Reference 90). Since a flat strap sustains only minimum compressive loads, a separate rebound device would be necessary for application in personnel seats.

The thin-walled tube will perform in much the same manner as the flat strap, and it has the advantage of sustaining higher compressive loads, although this capability is still inadequate. Typical load elongation characteristics of a 0.02-in. wall by 0.50-in.-diameter stainless steel tube, based on two static amd twelve dynamic tests, are illustrated in Figure 48. It is desirable that the tube elongate throughout its length rather than locally, for example, at the end attachments. A successful method of achieving nearly

*Advanced Composite Airframe Program.

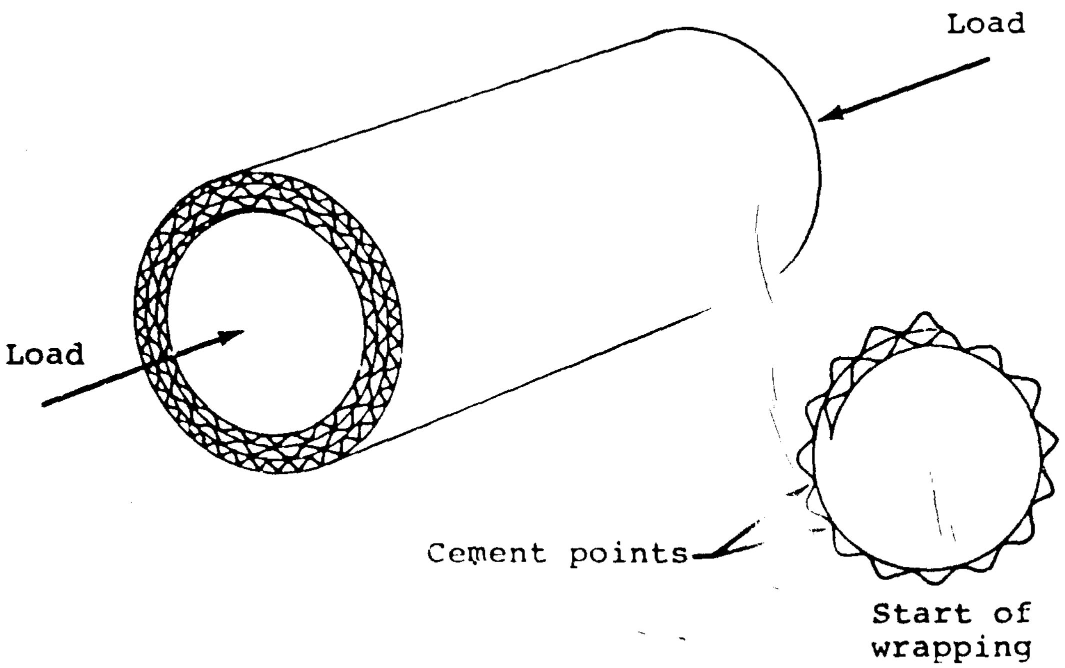


FIGURE 47. ILLUSTRATION OF CORRUGATED ALUMINUM FOIL FORMED INTO ANNULAR COLUMN.

uniform elongation is the use of a low-modulus bonding agent between the tube and the appropriate end fitting (see Reference 78). Angled, fish-mouthed, or zig-zag welds have also been used for successful end attachments.

Rods perform in much the same manner as straps or tubes and are less sensitive to surface imperfections than straps.

5.2.6 Elongation of Basic Stranded Cable

This device has the same characteristics as the basic metal tube or flat strap; however, the flexibility of a cable obviously has advantages for some load limiter applications. The cable end fittings are capable of sustaining the ultimate load of the cable under static and dynamic conditions. This device appears to be most applicable to bracing lightweight seats, such as troop and gunner seats and is now being used in this application. However, dynamic ultimate load capability is often much less than static.

5.2.7 Tube Expansion or Compression

This device uses the force required to expand the diameter of a tube as a hardened, oversized rod, tube, or die is drawn through it, or to compress a rod or tube as it is drawn through a die. The force required to overcome friction also contributes to the energy absorbed by this device and unless this friction is carefully controlled, the load may be unpredictable. The

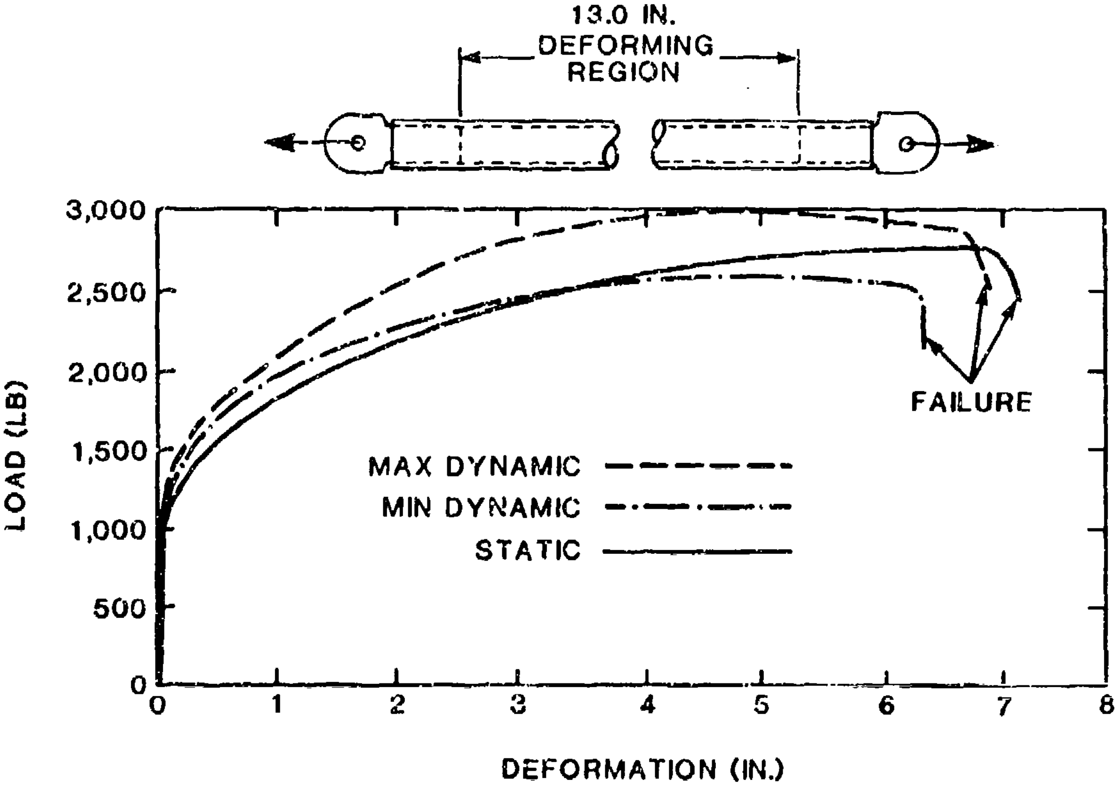


FIGURE 48. COMPARISON OF DYNAMIC AND STATIC LOAD-ELONGATION CURVES FOR STAINLESS STEEL TUBES.

frictional resistance of the device tested in Reference 78 (a compression tube device with a rigid outer cylinder) was reduced by lubrication, but the device exhibited an initial peak load as indicated by point A in Figure 49.

It can be seen in Figure 49 that the stroke of this device was limited to 4 in. and that the failure load was about three times the stroking (sustained) load. Thus, the tested device had a safety factor of at least 3 to 1 built into it, and this fact partially accounted for the poor specific energy rating shown in Table 4. It can be seen in the figure that the maximum variation in the stroking load was from 1,300 to 1,600 lb, or about 21 percent. A version of this device is now being used in two foreign helicopter seats.

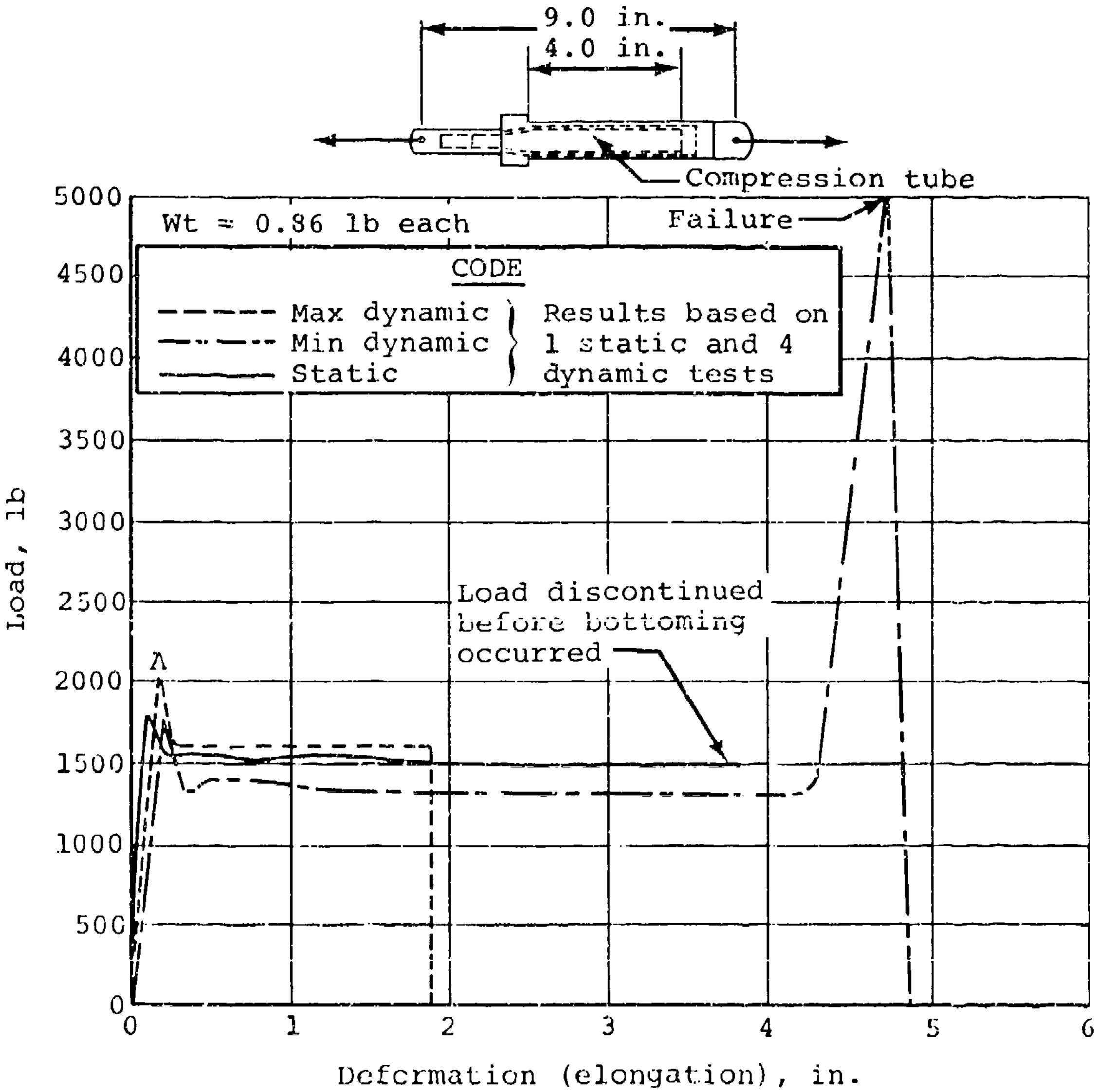


FIGURE 49. COMPARISON OF DYNAMIC AND STATIC LOAD-DEFORMATION CURVES FOR COMPRESSION TUBES.

5.2.8 Tube Flaring

This device simultaneously uses the forces required to expand the diameter of a tube to the failure point and to bend the tube walls through 90 degrees. The tube wall either shatters into fragments or rolls up into spirals around the periphery of the tube, as illustrated in Figure 50. A review of Reference 80 indicates that the above processes are sensitive to the ratio of the wall thickness to the die radius and that ratios of less than 0.3 are likely to result in a rolling process, while ratios of greater than 0.4 are likely to result in the fragmentation on the basis of tests using 2024-T3 aluminum tubes.

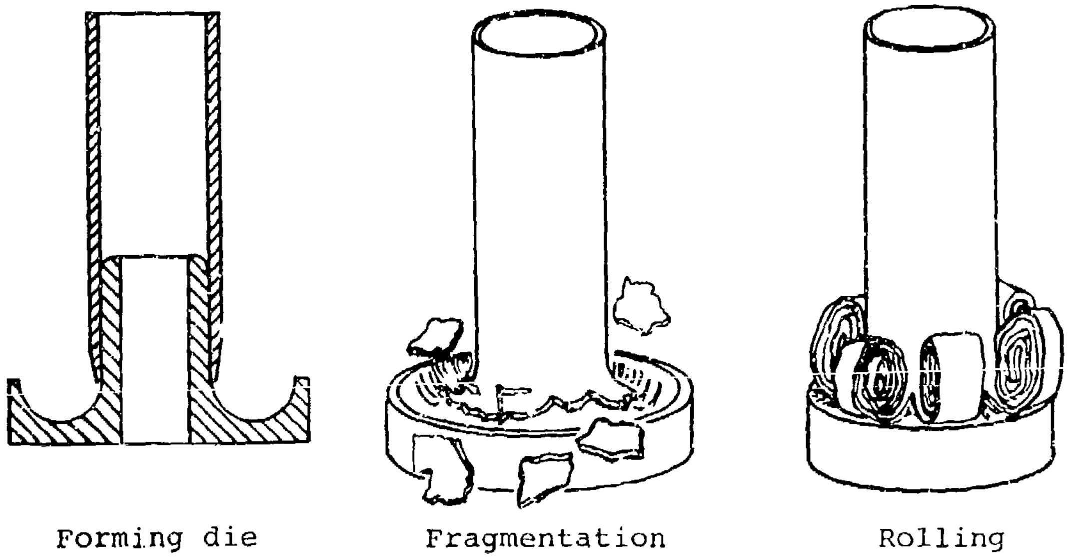


FIGURE 50. ILLUSTRATION OF FRAGMENTATION AND ROLLING PROCESSES IN TUBE-FLARING DEVICE.

This concept has been evaluated for an experimental crewseat by the U.S. Naval Aircraft and Crew Systems Technology Directorate, now part of the U.S. Naval Air Development Center, as described in Reference 82. The device was used as the vertical energy absorber in the seat. The device also was used as the vertical load limiter for an experimental troop seat, as described in Reference 75.

The device cannot sustain rebound forces because only a minimum rebound resistance is provided by friction between the tube and the forming die. However, a mechanism was installed in the forming die to grip the tube against rebound movement.

5.2.9 Housed Pulley

The housed-pulley load limiter is shown in Figure 51. A cable is wound around the pulley and is passed out of the device through a hole in the housing. A tensile load on the cable causes the pulley to rotate. Rotation is allowed by the cable splitting the housing. The plastic deformation of the casing material affects the energy absorption. The device is unidirectional and operates under tensile loading only.

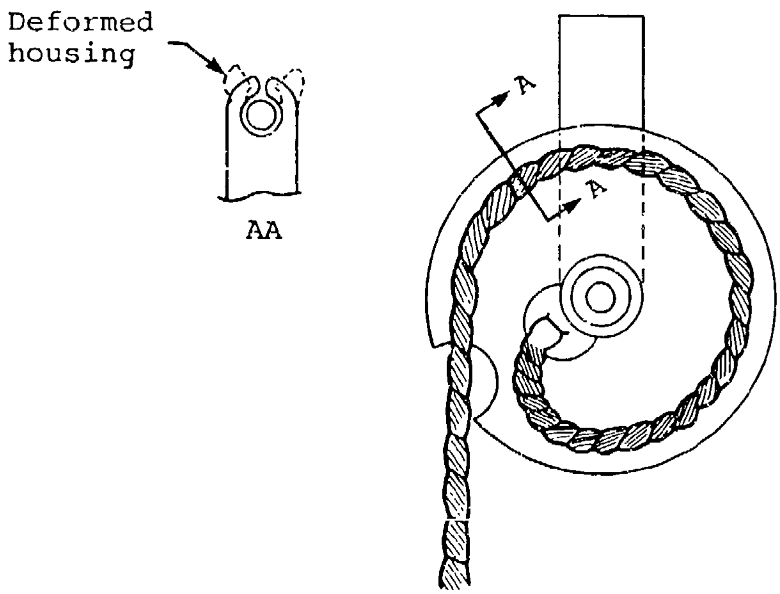


FIGURE 51. TENSION-PULLEY LOAD LIMITER.

It has been used in cargo restraint systems and energy-absorbing troop seats, as described in Reference 91.

5.2.10 Folding Tube

A folding tube absorbs energy by successive buckling or crushing of the tube by axial compression. It is made of aluminum or composites. See Section 5.3 for a discussion of energy absorbers made of composite materials.

5.2.11 Rolled Tube

This energy absorber is described in References 83 and 84, and is shown in Figure 52. It uses a roller cage rigidly attached to the inner tube of a telescopic housing to flatten a probe tube rigidly attached at one end to the outer tube of the telescopic housing. One end of the telescopic housing is

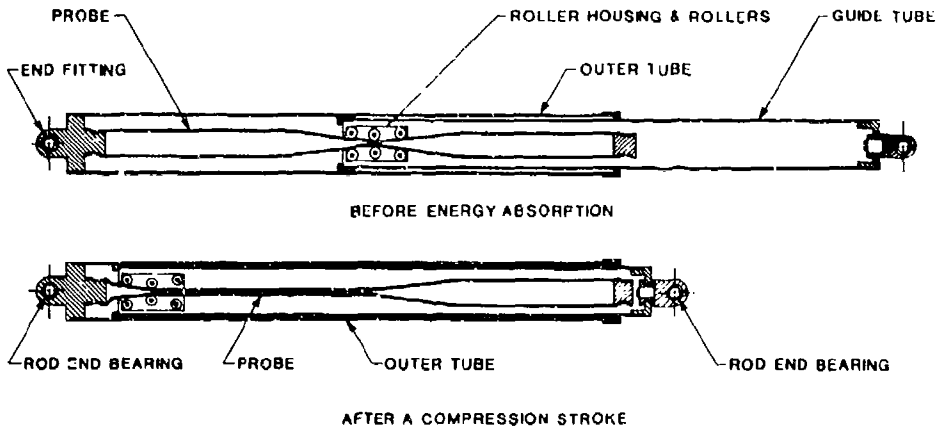


FIGURE 52. ROLLED-TUBE ENERGY ABSORBER. (REFERENCE 84)

attached to the seat and the other end is attached to the aircraft structure. The roller cage, which can contain various numbers of rollers, is located at the pre-flattened middle portion of the probe tube so that the device can be used for either compression or tension loads.

These have been applied to a troop passenger seat, where six energy absorbers were used. The two attached to the seat back and to the ceiling keel function only in an extension mode, while the four attached diagonally to the seat pan and the cabin floor can function in either an extension or a retraction mode depending on the impact direction and resultant load forces.

5.3 ENERGY ABSORBERS MADE OF COMPOSITE MATERIALS

Growing interest in composites has led to numerous studies of methods to use them to make more efficient energy absorbers. A summary of some of this work follows. A study (Reference 85) was made of the specific energy absorption, postcrushing energy release, and postcrushing integrity of tubes of various composite materials and the results compared with those of aluminum tubes. Static compression and vertical impact tests were performed on 128 tubes. Composite compression tube specimens were fabricated with both unidirectional tape and woven fabric prepreg using graphite (carbon fibers)/epoxy, Kevlar*/epoxy, and glass/epoxy. The matrix material was either Narmco 5208 or Fiberite FM934, both of which contain the same epoxide base MY720 and are compatible resins. The fibers were Thornel** 300 Graphite, Kevlar 49, or E-glass. Nominal ply thicknesses and fabric style are listed in Table 5. A belt wrapper was used to lay prepreg materials on a metal mandrel to fabricate 30.5-cm (12.0-in.) long and 3.81-cm (1.50-in.) inside diameter tubes. After curing at 176 ^{o}C (350 ^{o}F), 10.16-cm (4.00-in.) long composite tube test specimens were cut, and the ends were machined.

*Kevlar is a registered trademark of E. I. Du Pont de Nemours & Co., Inc.
**Thornel is a registered trademark of Union Carbide Corporation.

TABLE 5. COMPOSITE PREPREG MATERIALS

Fiber/Matrix	Nominal Cured Ply thickness cm (in.)	Type
T300/5208	.0330 (.0130)	24 x 24 plain weave fabric
T300/5208	.0139 (.0055)	Tape
Kevlar 49/5208	.0254 (.0100)	285 style fabric
Kevlar 49/5208	.0139 (.0055)	Tape
E-Glass/5208	.0254 (.0100)	1581 style fabric
E-Glass/934	.0254 (.0100)	Tape

As shown in Figure 53, one end of each composite tube was chamfered and notched so that crushing could be initiated without causing catastrophic failure. Figure 54 shows how modifying the end of the tube greatly reduced the initial peak load without affecting the sustained crushing load.

Thirty combinations of materials and ply orientations were tested, and the failure modes and energy absorption mechanisms for all tubes were examined. Reference 85 contains data on ply thicknesses, fabric style, number of plies per tube, wall thicknesses, test equipment, test procedures, and detailed test results. Plies varied from 4 to 9 and ply angles varied from ±15 to ±90°. $[\pm 45^F]$ Gr/E denotes graphite/epoxy woven fabric plies applied first at +45 degrees and then at -45 degrees. $[0^T{}_{Gr}/\pm 45^F{}_K]$ denotes graphite/epoxy tape plies applied first at 0 degrees, then Kevlar/epoxy fabric plies applied at +45 degrees and next at -45 degrees.

The SEA correlates with the angle θ for $[0/\pm\theta]$ composite tubes. This designation indicates that the plies are first applied at 0 degrees with respect to the longitudinal axis of the tube, then at a $+\theta$ angle (for example, +45 degrees), then at a $-\theta$ angle (-45 degrees). If this cycle is done three times, the tube will contain nine plies of either fabric or tape.

Figures 55 and 56 compare a typical load-deflection curve of a composite tube with that of an aluminum tube. For the composite tube, after static crushing was initiated, the load required to sustain crushing remained relatively constant. Comparison of the energy absorbed for the materials and ply orientations investigated was made on the basis of specific energy absorbed (SEA). For the aluminum tube, the typical load-deflection curve indicates large

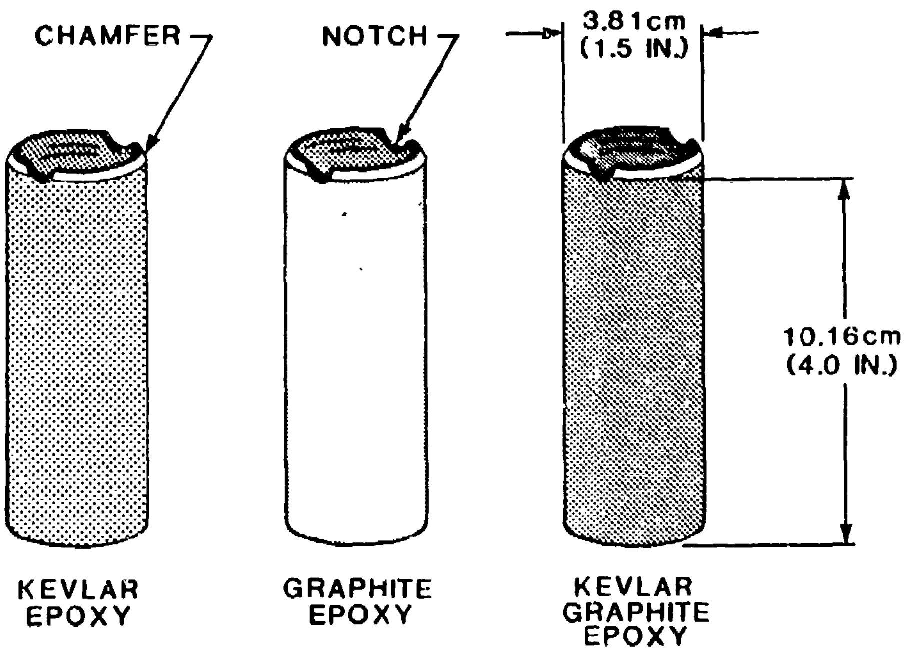


FIGURE 53. COMPOSITE TUBE SPECIMENS WITH CHAMFERED AND NOTCHED ENDS. (REDRAWN FROM FIGURE 1 OF REFERENCE 85)

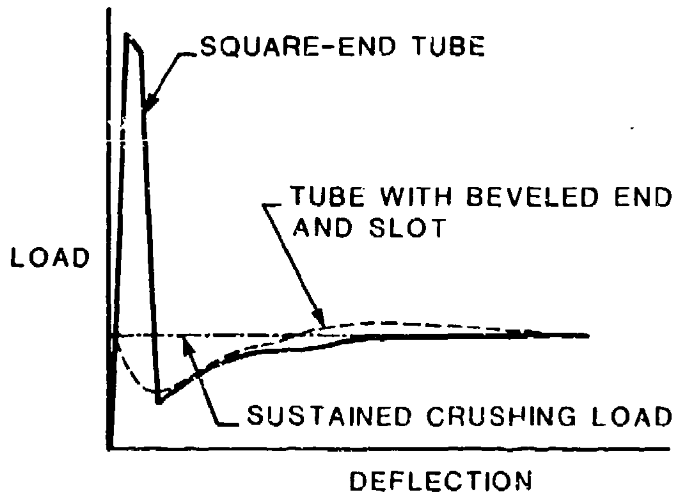


FIGURE 54. EFFECTS OF END GEOMETRY ON LOAD-DEFLECTION RESPONSE OF COMPOSITE TUBE. (REFERENCE 85)

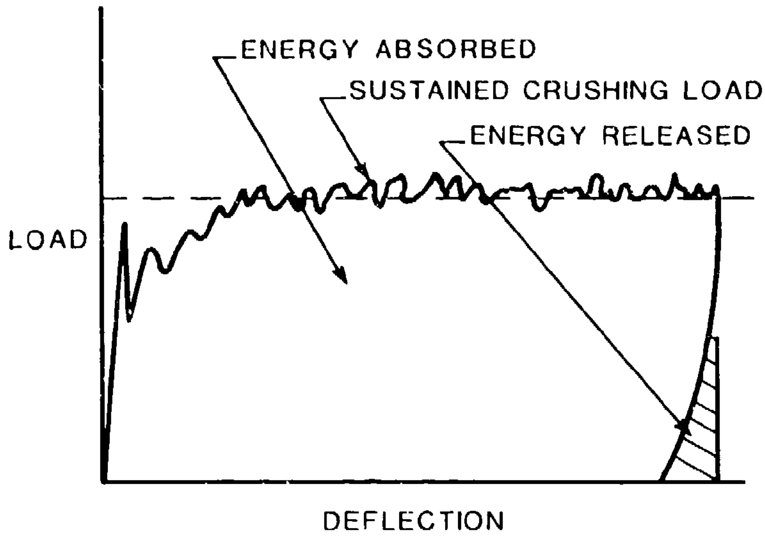


FIGURE 55. TYPICAL LOAD-DEFLECITON CURVE OF COMPOSITE TUBE. (REFERENCE 85)

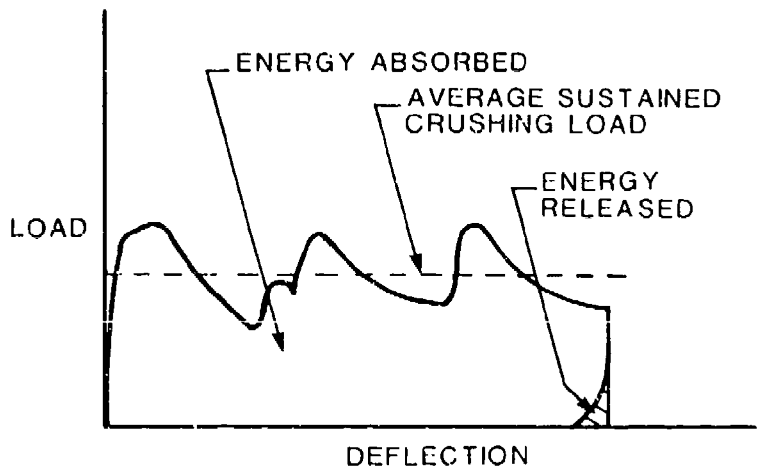


FIGURE 56. TYPICAL LOAD-DEFLECTION CURVE OF ALUMINUM TUBE. (REFERENCE 85)

deviations from the average sustained crushing load. The deviation was cyclic and is attributed to the successive formation of local buckles. Figure 57 shows some statically crushed composite tubes. Table 6 lists average values of SEA for three hybrid composite tubes and two aluminum tubes.

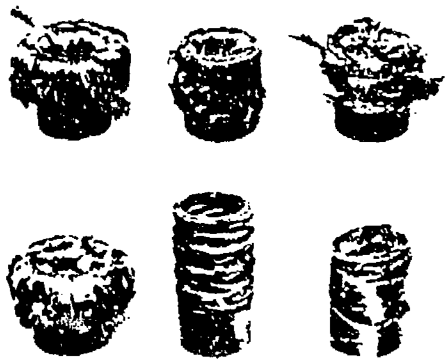


FIGURE 57. STATICALLY CRUSHED COMPOSITE TUBES. (REFERENCE 92)

Energy absorption is only one requirement for a crash-resistant structure. Postcrushing structural integrity is also important because the structure must remain intact to provide protection for the occupants. Based on the energy absorption tests, the Kevlar tubes were the only composite tubes that exhibited postcrushing integrity, while the aluminum tubes exhibited excellent postcrushing integrity.

Graphs of values of SEA for the three types of composite tubes versus angle θ are shown in Figure 58. For $\theta<45$ degrees, the graphite tubes absorbed the most energy. For $\theta>60$ degrees, SEA for each material is comparable. However, the results suggest that longitudinally oriented graphite fibers absorb more energy than longitudinally oriented Kevlar or glass fibers. The [±45] graphite tubes absorbed more energy than [±45] Kevlar or glass tubes, and the [0/±15] graphite tubes absorb even more energy. The energy absorption of hybrid composite materials was only slightly better than that of single-type fiber composites with the same ply orientation. The static and dynamic tests produce essentially the same energy absorption, failure modes, and postcrushing integrity.

With respect to energy absorption failure mode, graphite and glass tubes failed in a brittle mode, while the Kevlar and the aluminum tubes failed in a plastic accordion mode. Postcrushing energy release was insignificant for all tubes.

Further studies on this subject are reported in Reference 92.

TABLE 6. HYBRID COMPOSITE TUBE AND ALUMINUM TUBE DATA

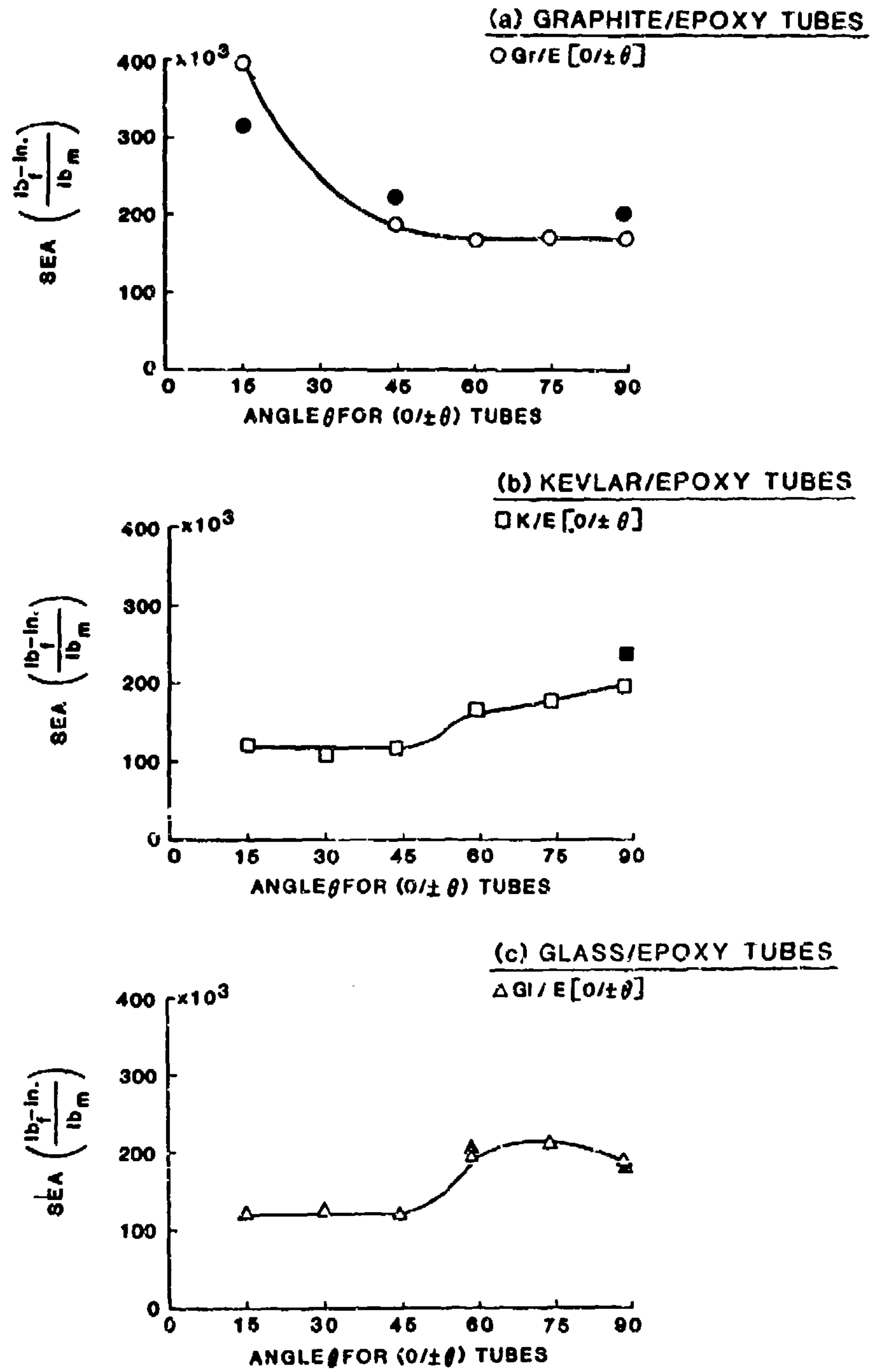
Ply Orientation	Number of Plies	Wall Thickness* cm (in.)	SEA $\left(\frac{lb_f - in.}{lb_m}\right)$
$\left[0_{Gr}/\pm 45^F_{Gl}\right]$	6	.1414 (.0557)	177 377
$\left[0_{Gr}/\pm 45^F_{K}\right]$	6	.1084 (.0427)	202,903
$\left[0_{K}/\pm 45^F_{Gr}\right]$	6	.1757 (.0692)	138,982
6061 Aluminum Dia. 2.54 cm (1.00 in.)		.1473 (.0580)	309,941
6061 Aluminum Dia. 3.81 cm (1.50 in.)		.2438 (.0960)	354,133

F = Fabric   Gr = Graphite
K = Kevlar   Gl = Glass

Epoxy matrix material used in all composite tubes.

*Average of [illegible] specimens.

Graphite-epoxy composite crushable tubes were used to meet the energy-absorbing requirements for a three-passenger seat in a remotely controlled crash of a Boeing 720 aircraft performed at the NASA Dryden Flight Facility at Edwards Air Force Base, California (Reference 93). For this large aircraft application, forward rather than vertical acceleration is of major concern, and the seat was designed to stroke forward when occupied by three anthropomorphic dummies subjected to a combined vertical and longitudinal impact. Using a tube nominal base inside diameter of 1.0 in., a 10-ply and a 12-ply graphite-epoxy tube, each 8.30 in. in length, were prepared. Each ply had a nominal 0.0055 in. thickness and wrap angle of ±60 degrees to the centerline of the tube. A taper and four circular notches were machined on one end of the tubes to reduce the initial peak spike load without affecting the sustained crushing load. In development tests at Langley Research Center, about 5 in. of each composite tube crushed in absorbing the dummies' kinetic energy during a 14-ft drop. Figure 59 depicts the crushable tube and how it was applied to the passenger seat. Unfortunately, the device does not appear to be compatible with tensile applications.



NOTE

SOLID SYMBOLS REPRESENTATIVE OF DYNAMIC TESTS

FIGURE 58. EFFECT OF PLY ORIENTATION ON SPECIFIC SUSTAINED CRUSHING STRESS. (REFERENCE 85)

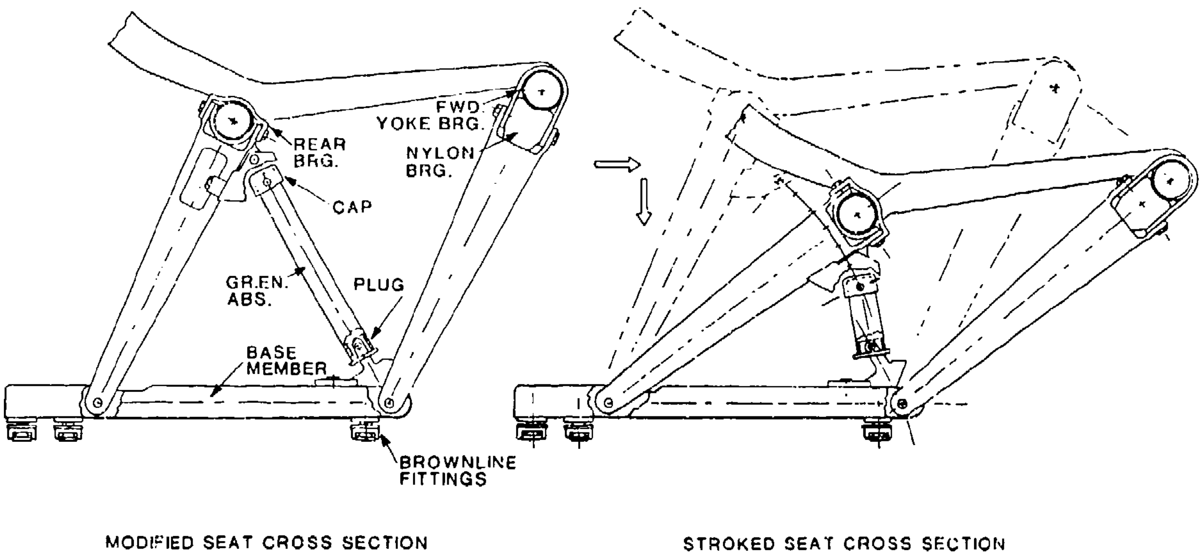


FIGURE 59. ENERGY-ABSORBING PASSENGER SEAT. (REFERENCE 93)

5.4 ENERGY-ABSORBING SEAT STRUCTURE

Attempts have been made to design seats which absorb energy for occupant protection without the use of an external energy absorber attached to the seat (Reference 94). One such crew seat used S-shaped 4130 tubular steel front legs that were designed to form plastic hinges to limit the load and provide energy absorption. The concept is illustrated by the seat shown in Figure 60 (Reference 95). The crewseat tested by NASA and reported in Reference 94 is similar to the one in Figure 60, except that the back legs are slanted forward to permit deformation at a lower load.

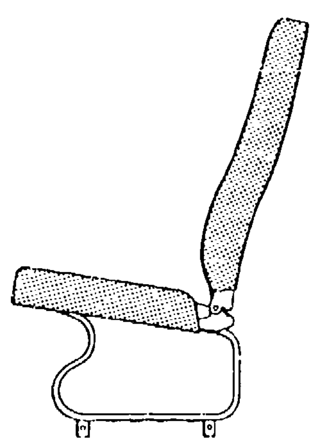


FIGURE 60. SEAT WITH ENERGY-ABSORBING LEGS. (REFERENCE 95)

Such integral energy-absorber concepts as the one shown are attractive due to low cost and light weight. Unfortunately, they are inefficient energy absorbers. Also, they are unstable, unless other means such as cables are used for stabilization, and their performance is dependent upon the direction of impact. The design concept shown may not stroke for certain crash attitudes and may tip rather than stroke effectively in others. No successful military crew seat has been designed using such a concept. It is possible, however, that such a concept might be adapted to a troop seat in combination with ceiling-attached energy absorbers.

5.5 LONG-TERM ENVIRONMENTAL EFFECTS

Some energy absorbers are more susceptible to environmental deterioration than others. Those with relatively small or fragile components may not function consistently over the life of the aircraft even though they may pass the environmental test specified in MIL-S-58095 and MIL-S-85510. Such devices should be subjected to a long-term test and/or should have change-out intervals assigned to assure correct performance in the event of a crash. These criteria should be included in the detailed specification for the seat system.

For example, several randomly selected sets of energy absorbers could be pulled from the field and subjected to static load deflection tests to verify compliance with required limit load tolerances. The number of samples tested should at least comply with the requirements of MIL-S-58095 (two from each lot of 200 or less, five from each lot of 201 to 500). If the samples do not pass the tests, all units of the lot should be replaced in the field and a change-out time should be established. At the end of the selected change-out time, sampling and testing should be repeated to assure that the change-out time assures satisfactory performance.

5.6 SELECTION OF AN OPTIMUM LOAD LIMITER

An optimum load-limiting system cannot be selected on the basis of the data presented above. The data should be used as guidelines with due consideration to the requirements for each specific application.

6. SEAT CUSHIONS

6.1 INTRODUCTION

A study (Reference 96) of back pain experienced by U.S. Army helicopter pilots indicated that vibration had little or no role in the etiology of the back symptoms reported by these pilots. It was postulated that the primary etiological factor for these symptoms is the poor posture that pilots assume for extended periods while operating helicopters. Seat cushions, of course, are intended to increase the comfort, safety, and operating efficiency of the pilot.

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 should have adequate clearance to prevent contact between the occupant and seat structure and diaphragms 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. In the past, the comfort requirement was met by providing very thick, soft, foam cushions that allowed the occupant to sink in deeply, thereby producing a contour and spreading the load around the person's buttocks so as to decrease local high pressure and eliminate point loading. This approach provided both immediate and long-term comfort. A method of providing thermal comfort was to force air through the cushion, or to use stretched net cushions, which provided contouring and load spreading as well as the free passage of air. The passage of air allows the evaporation of sweat and thus achieves the desired cooling effect.

Crash-safety considerations require a minimal thickness of foam to minimize or eliminate vertical motion of the pelvis during high vertical loadings. According to MIL-S-58095, the total thickness of the compressed cushion at the buttock reference point should be minimized to between 0.5 and 0.75 in. at 1 G. This requirement conflicts with the method chosen for providing pressure comfort described in the previous paragraph, and constitutes a problem that must be solved to provide an acceptable cushion.

One approach producing the desired compromise between crash safety and comfort uses a cushion base with a contour that matches the average buttocks configuration as closely as possible. This wraparound configuration spreads the load and decreases localized pressure without resorting to soft foams. Additional comfort layers of foam can then be added to the base, and the cushion base can be equipped with slots or holes which allow for fore-and-aft passage of air to provide the desired cooling. A layer of rate-sensitive foam can be used on top of the base to provide a contour transition softer than the base. This layer must either be open celled or holes must be provided to allow for vertical movement of air. A layer of soft, open-celled foam can be used on top of the rate-sensitive foam to provide the initial comfort material and to also provide vertical and horizontal air motion. The entire cushion can be covered with a fire-retardant, open, nylon material to provide for wear and abrasion resistance.

Other methods of achieving the desired effect are available. One is to include the basic provisions just described but to achieve the thermal effect plus some loading comfort by the use of special coverings such as lamb's wool. This type of cover uses the lamb's skin with a small depth of combed and clipped wool on the occupant interface surface. These covers need holes cut through the leather to allow free passage of air for cooling as previously discussed.

To meet the required crash-resistant characteristics, the optimum aircraft seat cushion should:

- Be lightweight
- Possess flotation capabilities
- Be nonflammable
- Be nontoxic; will 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.

6.2 REQUIREMENTS

For seats of light movable weight (less than 30 lb), cushions should be used for comfort only. The maximum uncompressed thickness for a properly contoured cushion should be 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. Viscoelastic and loading-rate-sensitive materials, such as discussed previously, can be used to accomplish this goal. 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 conditions of interest.

6.3 ENERGY-ABSORBING CUSHIONS

The use of ~~load-limiting~~ cushions in lieu of load-limiting seats is undesirable for two reasons:

- The downward movement of the torso into a crushable seat cushion produces slack in the restraint harness. This slack could allow injury during subsequent longitudinal or lateral acceleration in forward-facing seats by contributing to dynamic overshoot and/or by allowing the lap belt to move upward into the soft portion of the abdomen. For an aft-facing seat, this slack is not as significant for longitudinal accelerations but applies to the lateral direction. Submarining of the occupant may also occur with this type of cushion.

- A crushable cushion does not make optimum use of the available stroke distance since space must be allowed for the crushed material. A crushable cushion can be only approximately 75 percent as efficient as a mechanical load-limited system that allows the seat to stroke completely to the floor.

Crushable cushions are impractical in rotary- and light fixed-wing aircraft because of the long stroke distance required to attenuate high vertical loads. 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 (see Reference 97 for further information on energy-absorbing cushions).

Recent research has indicated that rigid crushable foams can be used more economically than honeycombs for energy absorption without reduction in performance. Foams are much easier to form and are less costly than metallic honeycomb materials and are therefore recommended for this use.

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. The net elastic-stretch limitation might be achieved by including a stiffer net, such as a steel or aluminum woven material under the net support.

6.5 OTHER CUSHIONS

In most cases the back cushion will not play a significant role in the crash dynamics; however, it will influence comfort and can influence the injury tolerance of the spine. The 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 6.2. Lumbar supports, particularly those that are adjustable by the occupant, are desirable for comfort and for safety reasons. A firm lumbar support that holds the lumbar spine forward increases the tolerance to $+G_z$ loading.

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 the thicker cushion, the provisions of Section 11.9 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.

7. DESIGN PRINCIPLES FOR PERSONNEL RESTRAINT SYSTEMS

7.1 INTRODUCTION

Crash injury accident statistics indicate that failure of personnel restraint harnesses has been a frequent cause of injuries and fatalities in U.S. Army aircraft accidents. This is unfortunate because body restraint is relatively easy to control. Adequate restraint in a crash can mean the difference between life and death, since evacuation from a burning or sinking aircraft is considerably improved if no prior injury or debilitation has occurred. It is the intent of this section to provide general criteria and guidelines for the design of personnel restraint systems to reduce injury or debilitation in a crash situation. Design criteria for cargo restraint systems are presented in Volume III.

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 8.4 should be conducted to ensure that a restraint system is acceptable.

Numerous methods of restraining the human body have been proposed, investigated, and used. Some of these have proven to be exceptionally good and some have left much to be desired. However, there are certain qualities that a harness should possess if it is to be used routinely for military flights. These desirable qualities are listed below:

- Comfortable and light in weight.
- Easy for the occupant to put on and take off even in the dark.
- Contain a single-point release system that is 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.
- 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.
- Provide sufficient restraint in all directions to prevent injury due to decelerative forces in a survivable crash.
- 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.

7.2 TYPES OF SYSTEMS

7.2.1 Aircrew Systems

The existing military lap belt and shoulder harness configuration with a center tiedown strap, as shown in Figure 61, is the accepted standard crew harness for use by U.S. Army pilots. The lap belt tiedown strap resists the upward pull of the shoulder straps and prevents the belt's displacement into abdominal tissue. The tiedown strap should be narrow enough, within limits of acceptable strength, to minimize leg rubbing encountered by the wearer during antitorque or rudder pedal operation. An alternate side lap belt tiedown configuration was used on some aircraft where shorter seat pans precluded use of a tiedown strap.

ITEM IDENTITY

1. BUCKLE ASSEMBLY
   - A. SINGLE-POINT RELEASE BUCKLE
   - B. TIEDOWN STRAP
   - C. ADJUSTOR
2. LAP BELT ASSEMBLY
   - A. LAP BELT
   - B. ADJUSTOR
3. SHOULDER HARNESS ASSEMBLY
   - A. INERTIAL REEL
   - B. INERTIAL REEL STRAP
   - C. LOWER SHOULDER STRAP
   - D. ADJUSTOR

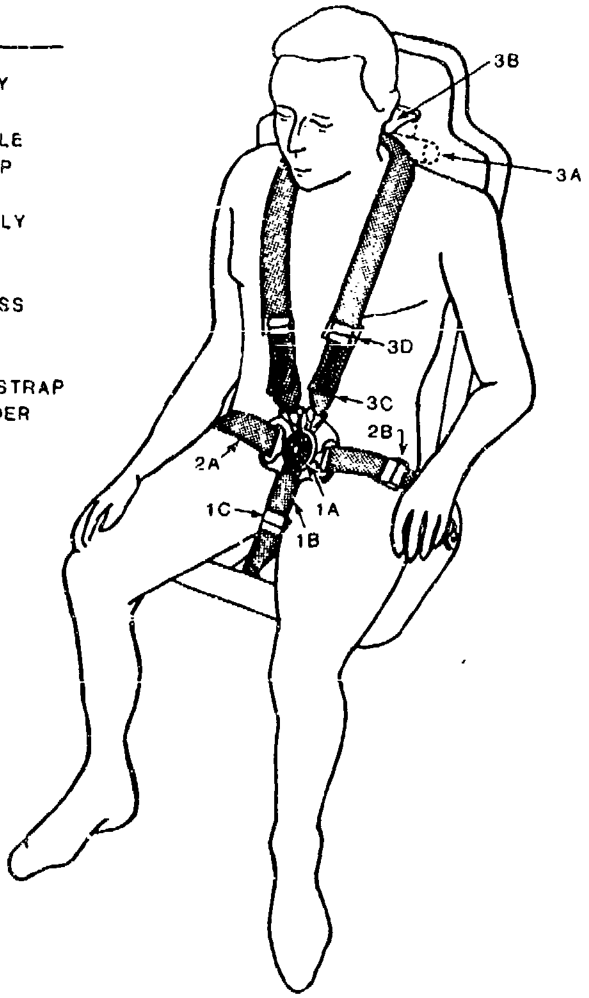


FIGURE 61. BASIC AIRCREW RESTRAINT SYSTEM. (REFERENCE 14)

The configuration shown in Figure 62 provides improved lateral restraint due to the addition of the reflected shoulder straps. This system, which resulted from the investigation reported in Reference 98, consists of one dual-spool inertia reel or two separate inertia reels with two reflected straps, a shoulder harness collar assembly, a lap belt assembly including retractors, and a buckle assembly. The buckle assembly consists of a single-point release buckle permanently attached to the tiedown strap. The tiedown strap consists of a fixed-length strap for any specific seat and cushion design, and an anchor fitting that connects the strap to the seat pan beneath the seat cushion. The left- and right-hand lap belts, connected at the single-point release buckle, are attached to the seat or aircraft structure through automatic lock/unlock retractors.

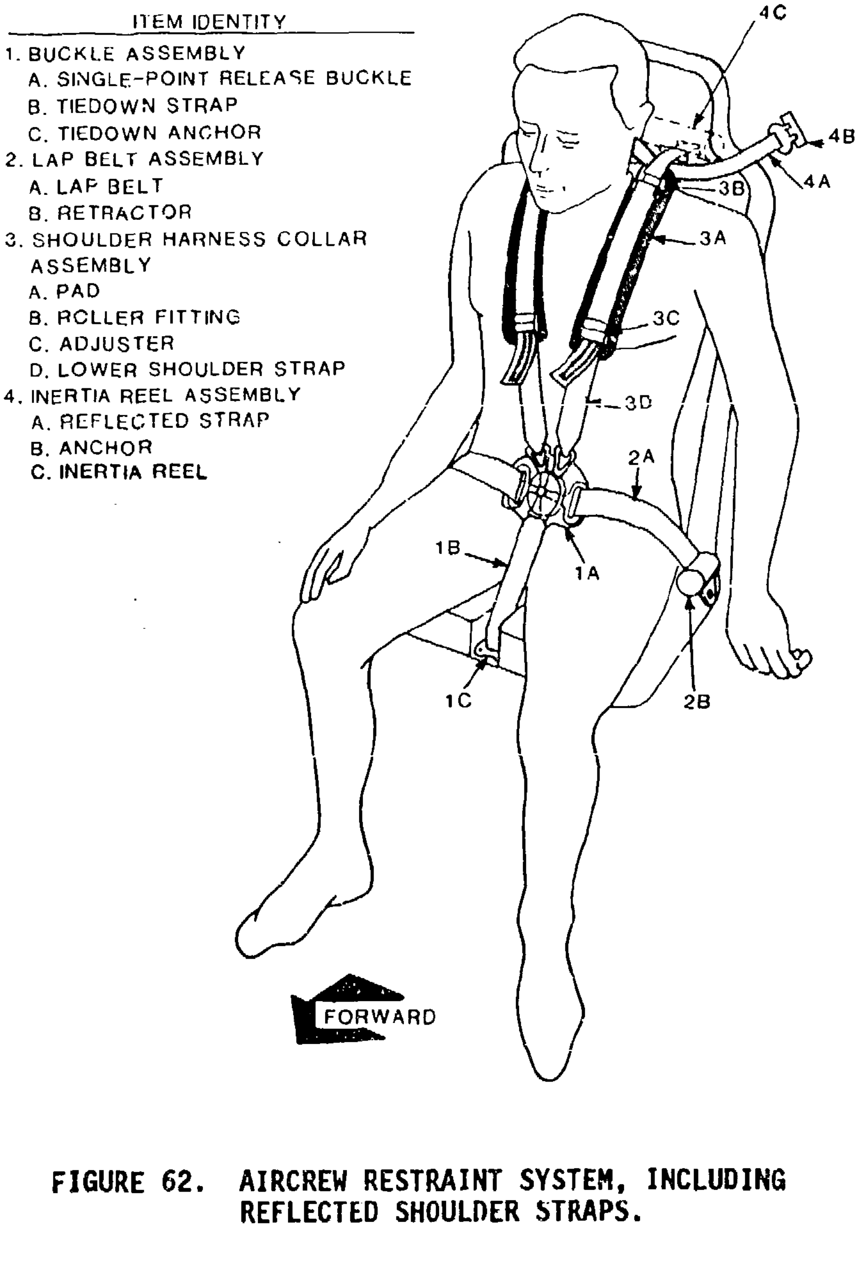


FIGURE 62. AIRCREW RESTRAINT SYSTEM, INCLUDING REFLECTED SHOULDER STRAPS.

The shoulder harness collar assembly consists of a pad in the form of a collar fitting around the crewman's neck, over which the shoulder harness straps are routed. The lower shoulder straps connect to the bottom of the collar assembly through the adjusters. The reflected straps pass through the roller fittings at the top of the collar. Each reflected strap is extended forward from an inertia reel, looped through the roller fitting, and then directed rearward to the opposite side of the seat back. These straps are attached to the seat through anchor fittings on the reflected ends and through inertia reels at the other end. The lap belt straps, tiedown strap, and lower shoulder straps are all connected at the single-point release buckle. Details of the hardware in these systems are discussed in Section 7.5.

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 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.

Aft-facing passengers do not need a tiedown strap, since the seat back provides the primary restraint; however, a shoulder harness is required to provide adequate support in crashes that produce significant vertical, lateral, aft, or rebound loads.

It is difficult to provide adequate restraint for side-facing passengers with a lap belt and shoulder harness alone. Leg restraint would also be preferred but is not practical because of operational requirements. A reflected shoulder strap and side belt strap offers a more practical solution, but they too have met with resistance because of weight and cost considerations. Belt side straps, extending from the lap belt high on the thigh to the seat pan forward of the lap belt anchor, shown in Figure 63, help to hold the belt in place over the pelvic region as well as provide more area to resist the pressure from the pelvis. The reflected shoulder strap provides improved upper torso restraint.

Two systems that resulted from the investigation reported in Reference 99 are shown in Figure 64. The Type II troop restraint system was designed to mount on a forward-facing or aft-facing troop seat 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 was designed to mount on a side-facing troop seat and differs from the Type II restraint by having a single shoulder strap that passes diagonally across the occupant's upper torso. It should pass

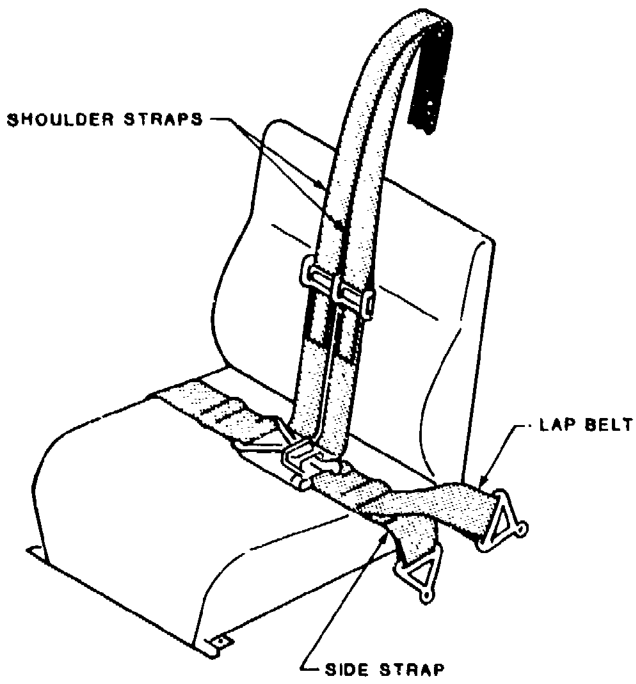


FIGURE 63. LAP BELT UTILIZING SIDE STRAP.

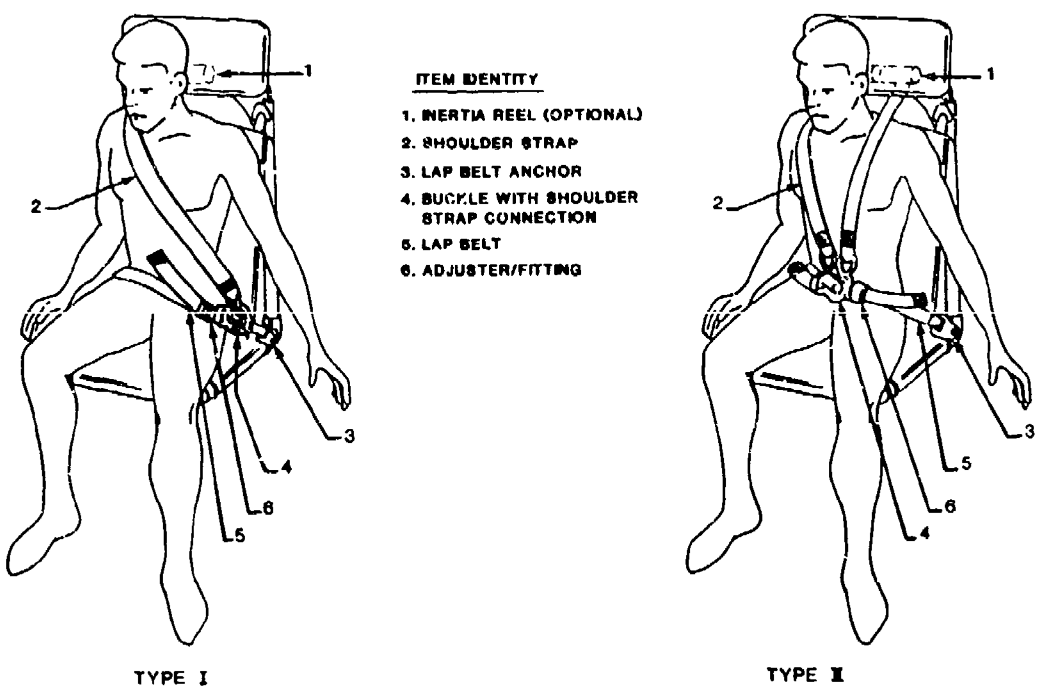


FIGURE 64. AIRCRAFT TROOP/PASSENGER RESTRAINT SYSTEMS.

over the shoulder closer 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.

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 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 100 and is shown in Figure 65. It consists of a lap belt with inertia reels on each side of the seat and two shoulder straps connected in an inverted-Y arrangment 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 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 crewmember from falling out of the aircraft.

7.2.4 Inflatable Systems

An automatically inflatable body and head restraint system 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 66, 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 the crash (Reference 101). The concentration of strap loads on the body are reduced because of the increased bearing surface provided when the restraint is inflated, 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 102 and 103.

7.2.4.1 Proposed Restraint System Using Dual Inertia Reels and Torso/ Shoulder Inflatable Bags. The basic five-point restraint system shown in Figure 61, currently used in the U.S. Army's UH-60A Black Hawk and AH-64A Apache helicopter crewseats, does not employ inflatable bags. While this system meets MIL-S-58095 specifications, Army aircraft accident statistics show that more than 39 percent of the major and fatal injuries to Army aviators occur in the head and upper torso (see Volume II). The upper torso of the human body can significantly compress (up to 2.5 in.) under vertical

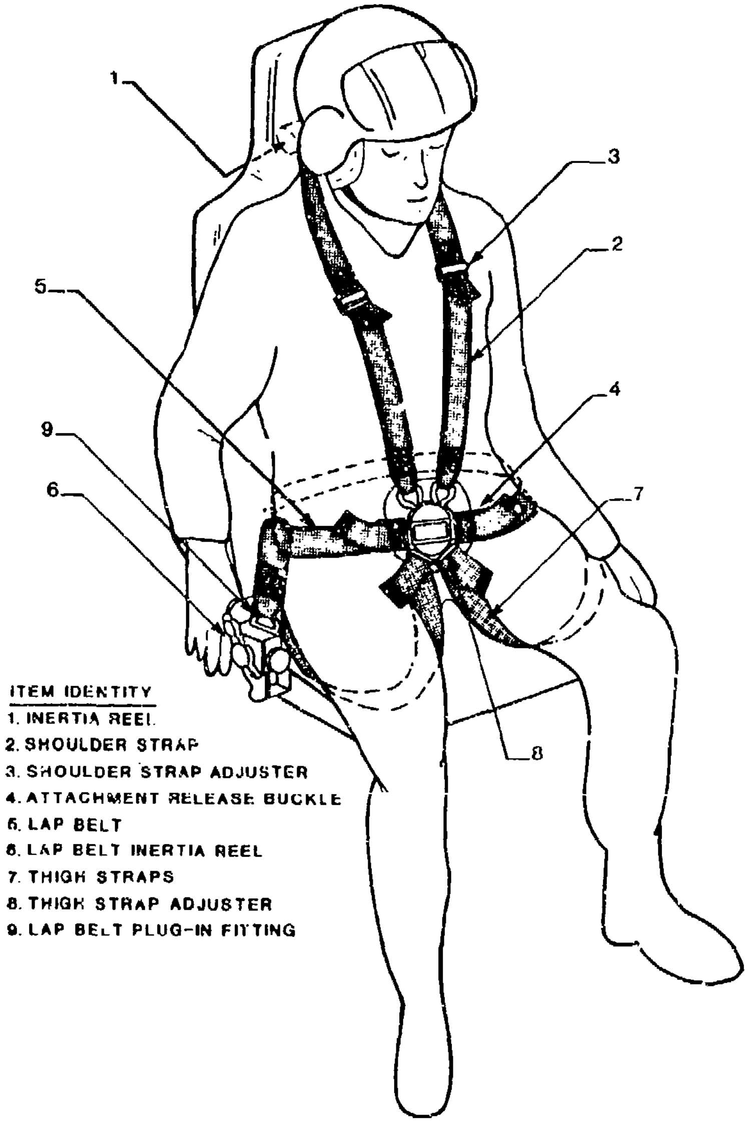


FIGURE 65. GUNNER RESTRAINT SYSTEM. (REDRAWN FROM REFERENCE 100)

loads and thus generate "slack" in an apparently snug restraint system. Thus an occupant restraint system which limited torso and head excursion under crash conditions by minimizing the slack generated could reduce the number and severity of occupant injuries.

A concept to modify the basic restraint system to improve upper body restraint is shown in Figure 67. In this modification,dual inertia reels (one reel for each of the two shoulder straps) and two combination torso/shoulder inflatable bags are used. Deflated, the bag is stowed in accordion folds beneath the strap. A standard pyrotechnic gas generator activated by a standard omnidirectional crash sensor is used to inflate the bag. The

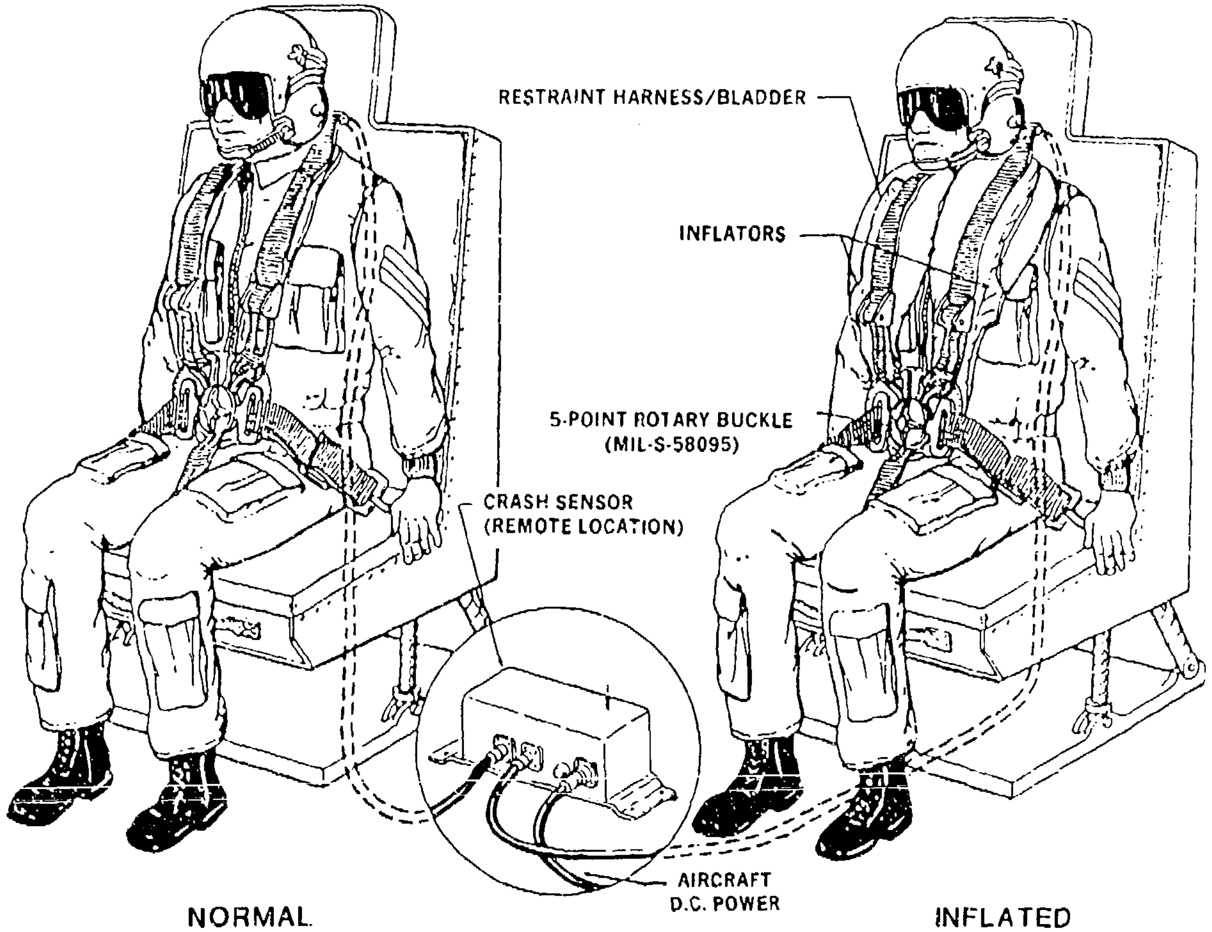


FIGURE 66. INFLATABLE BODY AND HEAD RESTRAINT. (REFERENCE 102)

torso/shoulder bag is designed to restrict movement of both the upper torso and the head during a crash. In so doing, it reduces the strike envelope and also reduces the potential for injury due to flailing.

A previous inflatable head/neck restraint design which was developed by the U.S. Navy at NADC is described in Reference 104.

7.2.4.2 Comparison of Restraint Systems Using Living Baboons. A French investigation used ten living baboons as seat occupants for a comparison of the effectiveness of five types of three-point restraint systems, including one with a pre-inflated shoulder belt (Reference 105). The belt was made up of cylindrical nylon and when inflated was 90 mm in diameter and 550 mm in length. When non-inflated and accordion-pleated, it was 60 mm wide. The other types contained: (1) a static system, (2) a belt with an automatic retractor, (3) a load-limited belt, and (4) a preloaded belt. Dynamic sled runs were made to produce frontal impacts against an orthogonal frontal

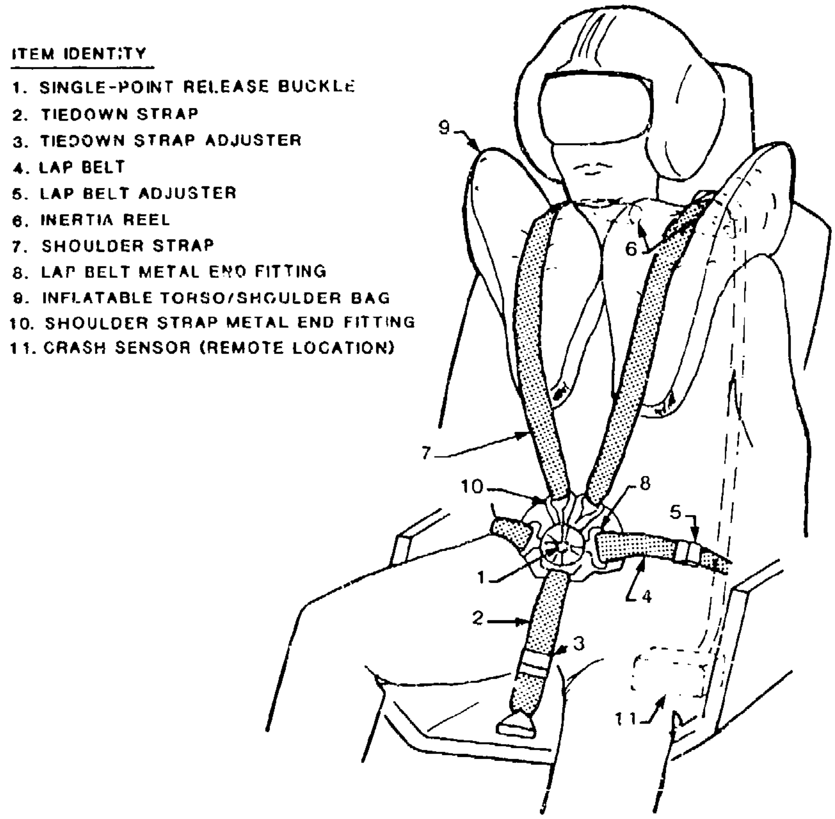


FIGURE 67. PROPOSED MODIFICATION OF BASIC AIRCREW RESTRAINT SYSTEM.

barrier. Seventy-eight test runs were made at impact velocities of 48, 55, and 60 km/h. The results indicated:

1. The 48 km/h impact velocity seemed to be the threshold for serious lesions on the baboon in the case of the static or retractor belt. The retractor allowed a belt displacement of 30 to 70 mm, which reduced the efficiency of that restraint system.

2. The load-limited belt (using a textile-ripping device) was difficult to adjust and had a narrow efficiency range. Too low a calibration caused large head movements, but a higher calibration caused too large a stroke of the load-limiting device.

3. It was difficult to optimize the ignition time when using the preloaded belt, which employed a linear pyrotechnical tightener.

4. The pre-inflated belt was the most efficient. It enabled the baboon to sustain higher crash severities without injury. It reduced body displacement and thoracic stresses.

7.2.4.3 <u>Operation of an Inflatable Body and Head Restraint System (IBAHRS) During a Crash Test</u>. On July 8, 1981, the Army's Aviation Applied Technology Directorate and the NASA-Langley Research Center jointly conducted a full-scale crash test of the YAH-63 advanced attack helicopter (Reference 101). An IBAHRS was included on one crewseat in this test. The IBAHRS had three main subassemblies: the harness/bladder/inflator, the crash sensor, and the DC power source (24-volt battery). The inflatable restraint harness was a modified MIL-S-58095 five-point type similar to that shown in Figure 65. A bladder of porous neoprene-coated nylon was securely attached to the underside of each of the shoulder straps. Uninflated, the bladders were folded and stowed in a nylon cover held fast to the restraint webbing by velcro strips. Positioned inside the lower portion of each bladder was a small pyrotechnic gas generator. The inflator was triggered by an electric current to a squib located within the generator. The nontoxic gases produced inflate the bladders within 0.020 sec. When a crash is detected by the sensor, located remotely from the restraint harness, a switch closes, allowing current to flow from the storage capacitor to the squibs. A 50th-percentile dummy in the copilot/gunner seat was used to test the IBAHRS.

During the crash test, the squib located within the left shoulder harness bladder did not fire due to an electrical malfunction. However, the squib located within the right shoulder harness bladder did fire. A peak bladder pressure of 22 lb/in.^{2} was recorded 0.058 sec. after initial aircraft contact, but the generated gas was completely dissipated in less than 0.050 sec. The observed data indicated that to properly protect the occupant the harness bladders need to stay inflated at least 0.300 sec. It was recommended that the basic inflator (gas generator)/ bladder design be modified to produce a pressure-time curve which will sustain the inflated bladders for 0.500 sec. It was also recommended that a nonporous bladder material be used and that the propellant charge within the inflator be modified to reduce the onset time and extend the burn time.

7.3 <u>GENERAL DESIGN CRITERIA</u>

7.3.1 <u>Comfort</u>

For obvious reasons, comfort must not be compromised by crash-survival requirements. For example, a lap belt with an adjustment fitting located directly over the iliac crest bone would provide a constant source of irritation that would result in eventual fatigue to the wearer. The main comfort consideration for restraint harnesses is the absence of rigid hardware located over bony portions of the torso. Also, webbing that is too wide or too stiff causes discomfort.

7.3.2 <u>Emergency Release Requirements</u>

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 in water. 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. An excessive force could hinder rapid emergency release, while a light force could cause inadvertent release. Further, release should be possible even 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 64, 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. As a result of an investigation of restraint system design criteria reported in Reference 93, the fitting angles illustrated in Figure 68 are recommended.

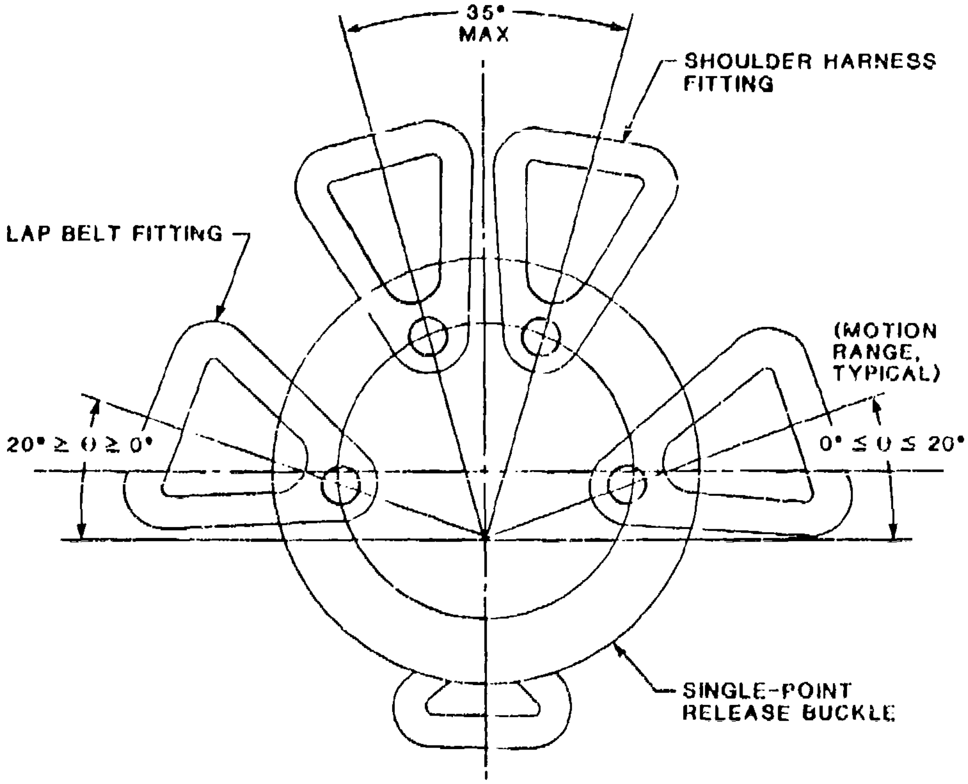


FIGURE 68. BUCKLE FITTING ATTACHMENT AND MOTION ANGLES.

Eliminating fitting rotation in the flat plane of the buckle during loading may prove to be difficult in lightweight systems. If the integrity of the attachment of the fitting within the buckle can be compromised by rotation, then rotation should be completely eliminated. Experience has shown that it is better to design the attachment of the fitting within the buckle to be insensitive to rotation, i.e., a round pin in a round hole rather than a flat-faced dog which must seat on a flat face of a slot, than to rely on restraining the fitting against rotation. 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 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 control sticks should open the device. It was mentioned earlier in this volume that required cockpit dimensions should be reviewed. It appears that the occupant can be placed too close to the cyclic control stick in helicopters and that a fully retracted cyclic control stick 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 stick 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.

7.3.3 Lap Belt Anchorage

The anchorage points for the lap belt may be located either on the seat bucket or on the basic aircraft structure. If the anchorage is located on the basic aircraft structure, the movement of the seat under the action of load-limiting devices should be considered to ensure that the lap belt restraint remains effective regardless of seat position. If the seat includes longitudinal load limiting, attachment of the lap belt to the basic structure is not practical, and 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. In an accident with high combined vertical and longitudinal impact forces, the restrained body will tend to sink down into the seat (where the magnitude of the displacement depends on cushion properties) and almost simultaneously be forced forward. This movement is illustrated in Figure 69. If the lap belt angle is too small the belt can tend to slip over the iliac crests of the pelvic bone, allowing the pelvis to rotate under the belt. The inertial load of the hips and thighs tend to pull, or submarine, the lower torso under the belt. Lower torso restraint is then accomplished through lap belt loading of the soft abdominal portions of the body, possibly causing visceral injury, as illustrated in Figure 69.

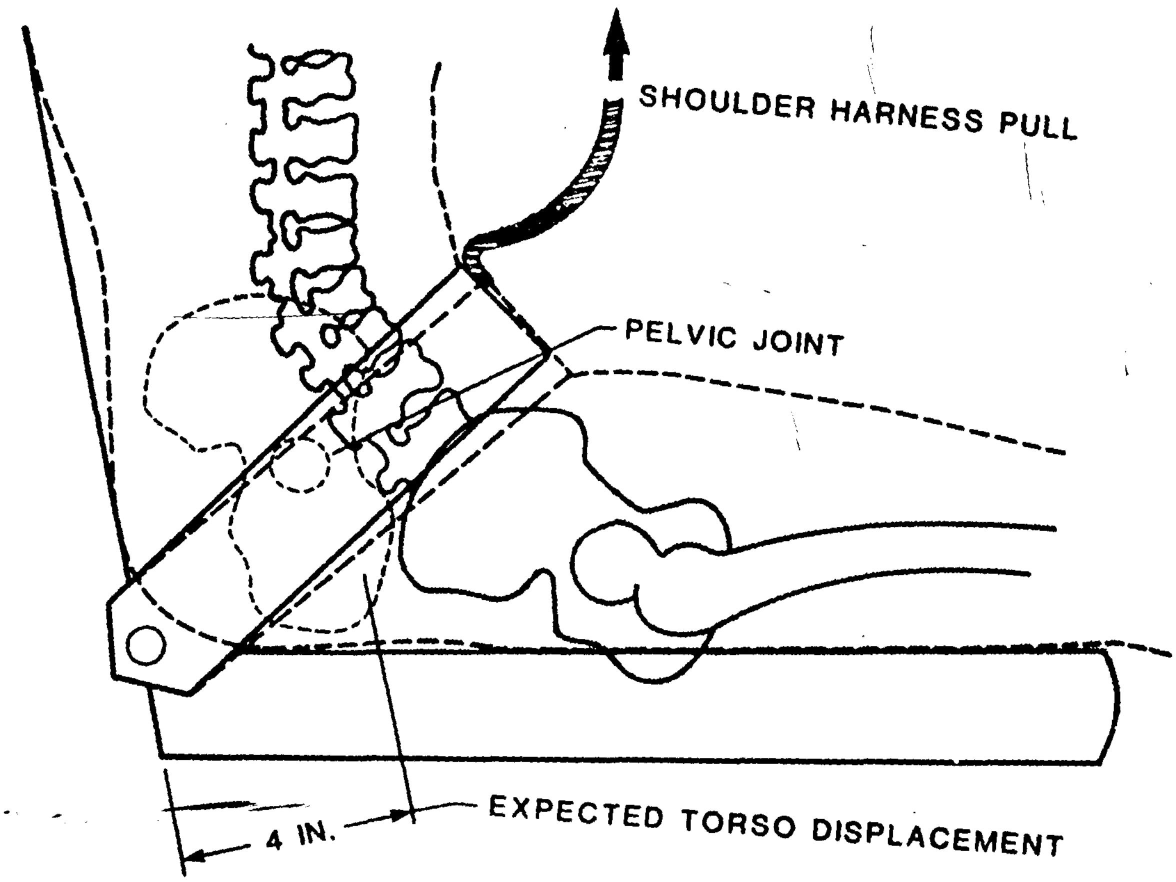


FIGURE 69. PELVIC ROTATION AND SUBMARINING CAUSED BY HIGH LONGITUDINAL FORCES COMBINED WITH MODERATE VERTICAL FORCES.

To counteract the tendency for submarining, the lap belt angle can be increased; however, the load in the belt increases for a given torso deceleration. Further, additional forward motion occurs because of the increased deflection of the webbing caused by the increased loading and the greater forward rotation of the lap belt. However, as the webbing is loaded, it presses down into the thighs of the occupant and reduces submarining by providing an additional longitudinal component of restraint load.

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 accomplish these objectives, 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 70. Further, it is desirable to locate the anchor point at or below the buttock reference line for 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

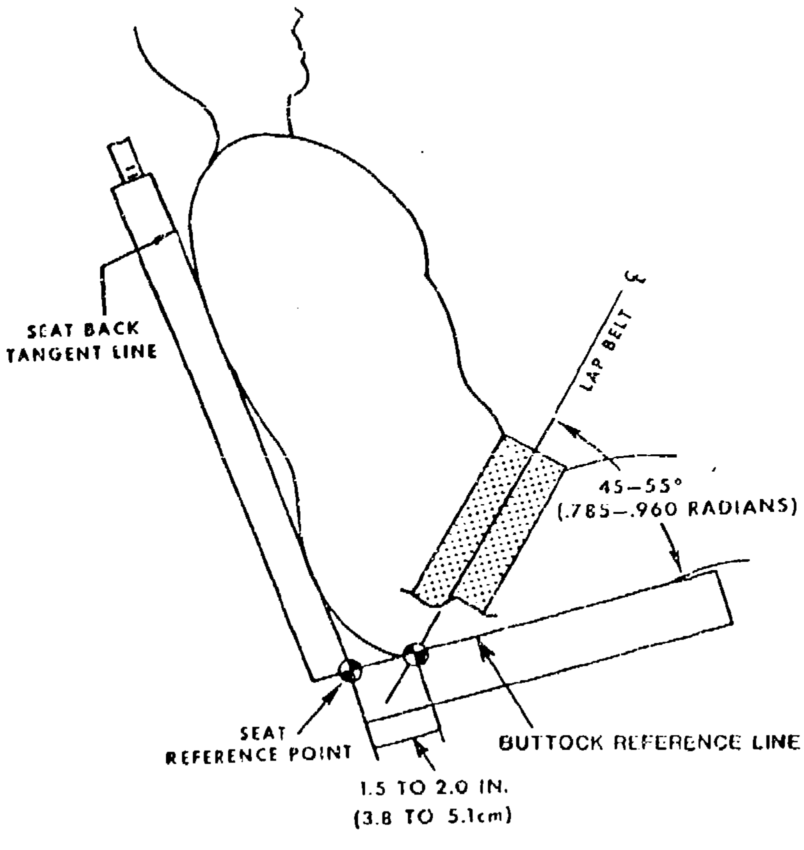


FIGURE 70. LAP BELT ANCHORAGE GEOMETRY. (REFERENCE 14)

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. 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.

Submarining can be reduced by ensuring that the lap belt is tight, as shown in studies reported in Reference 106. Thus, care should be taken to train occupants to tighten the lap belt to the maximum consistent with comfort and to not loosen the belt anytime during flight.

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.

7.3.4 Shoulder Harness Anchorage

The shoulder harness or inertia reel anchorage can be located either on the seat back structure or on the basic aircraft structure. 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. Location of the anchorage on the basic aircraft structure will relieve a large portion of the overturning moment applied to the seat in 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 71.

Any installation that causes the straps to pass over the shoulders at an angle below the horizontal adds additional compressive force to the seat occupant's spine as shown in the lower sketch of Figure 71. A shoulder harness pull-off point at least 26.5 in. above the buttock reference line is needed to ensure that the straps do not apply an excessive downward load on the spine of a 95th-percentile male occupant; however, this dimension should not be increased, because then the harness would not provide adequate restraint for the shorter occupant.

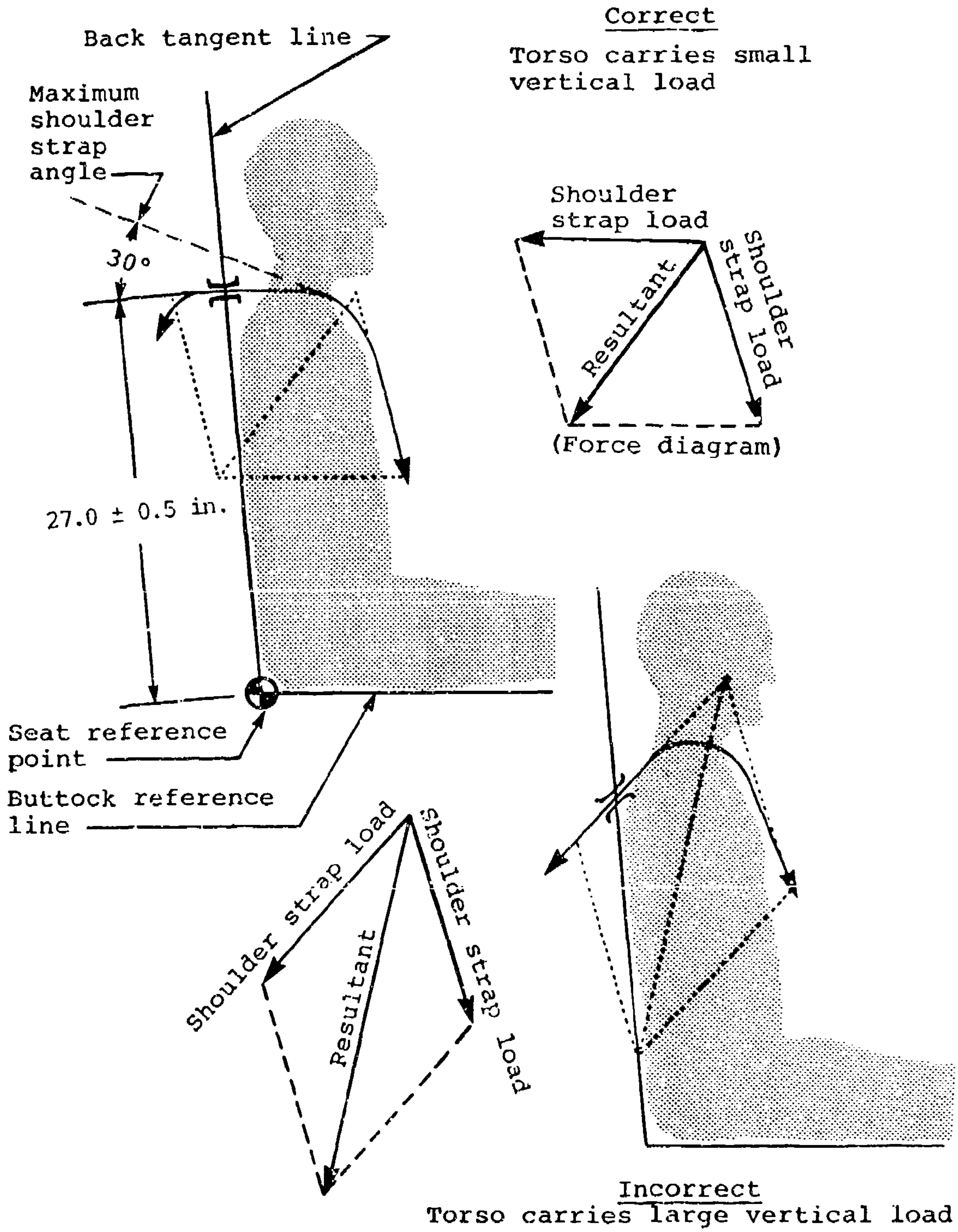


FIGURE 71. SHOULDER HARNESS ANCHORAGE GEOMETRY.

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.

7.3.5 Lap Belt Tiedown Strap Anchorage

When the upper body is thrown forward against the shoulder straps, an upward pull is exerted on the lap belt. Without a lap belt tiedown strap, the tendency is for the belt to be pulled up over the iliac crests and into the soft solar plexus area, with the likelihood of injury to the abdominal viscera, as previously shown in Figure 69. A tiedown strap attached to the buckle in the center of the lap belt prevents this upward belt movement. It is recommended that the tiedown strap anchorage point 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. The side straps used on the OH-58 shortens the lap belt and reduces lap belt rotation, thus holding the lap belt against the iliac crests. They may be used to advantage if the seat pan is too short to accommodate the proper anchorage of a tiedown strap.

7.3.6 Advantages of a Negative-G Strap

A lap belt tiedown strap, also called a negative-G strap, has two purposes: (1) to prevent "submarining" or movement of the torso under the lap belt during forward-facing ($-G_x$) impact accelerations and (2) to provide better mechanical coupling between the seat and its occupant during low-frequency flight vibrations, sustained $-G_z$ acceleration maneuvers, and adverse aircraft motions which may occur if the aircraft becomes uncontrollable. Inadequate $-G_z$ restraint degrades ability to control the aircraft and in some aircraft causes helmet-canopy contact. The Air Force made a laboratory study (Reference 107) to provide an adequate experimental substantiation for recommending negative-G strap incorporation into Air Force restraint systems. The primary objective of the study was to evaluate human response to forward-facing ($-G_x$) and vertical ($+G_z$) impacts in operational USAF restraint systems with and without a negative-G strap.

Volunteer subjects (20 men and one woman) were used for the tests, and to minimize the potential injury to the subjects the tests were conducted at presumed subinjury impact acceleration levels. They were conducted with and without a negative-G strap attached to the buckle of the lap belt on the top end and anchored to the seat pan centerline at a point 38.1 cm forward of the seat reference axis. Horizontal impacts were carried out on a horizontal accelerator, while vertical impacts were carried out on a vertical drop tower.

The tests demonstrated that negative-G strap incorporation into either the PCU-15/P or the conventional double shoulder strap restraint configuration reduced the tendency toward torso submarining during forward-facing impact, improved occupant-seat coupling during free fall, and improved vertical impact protection. Tables 7 and 8 present the results of the horizontal and vertical tests, respectively, using the conventional restraint both with and without a negative-G strap.

TABLE 7. HORIZONTAL TEST PHASE: NEGATIVE-G STRAP EFFECTS

Response Parameter	Conventional Restraint Without Strap	Conventional Restraint With Strap	Conventional Restraint Difference (%)
	(n = 18)		
Resultant Head Acceleration (G)	16.7 ±3.6	17.8 ±5.4	7
Resultant Chest Acceleration (G)	16.1 ±2.2	17.3 ±2.1	7
Total Shoulder Strap Load (N)	2,760 ±449	3,240 ±556	17*
Total Lap Belt Load (N)	7,530 ±911	8,250 ±1,240	10*
Vertical Seat Load (N)	5,940 ±[illegible]92	6,800 ±1,350	14*
	(n = 15)		
Resultant Knee Displacement (cm)	23.7 ±5.3	19.7 ±4.1	20**

Data presented are means ± S.D. for maximum accelerations, loads, and displacements.

n = number of matched pairs. Value of n is different for photogrammetric data due to partial data loss.

*Means are statistically different by the Wilcoxon paired-replicate rank test ($2\alpha \leq 0.05$).

**Means are statistically different by the Wilcoxon paired-replicate rank test ($2\alpha \leq 0.01$).

TABLE 8. VERTICAL TEST PHASE: NEGATIVE-G STRAP EFFECTS

Response Parameter	Conventional Restraint Without Strap	With Strap	Difference (%)
	(n = 15)		
Resultant Head Acceleration (G)	12.8 ±0.9	12.0 ±0.9	7*
Resultant Chest Acceleration (G)	16.5 ±1.9	15.2 ±1.0	9*
Total Shoulder Strap Load (N)	327 ±166	168 ±203	95*
Total Lap Belt Load (N)	559 ±177	378 ±106	48*
Resultant Free-Fall Seat Load (N)	1,210 ±383	1,820 ±478	50*
Resultant Impact Seat Load (N)	8,400 ±937	7,900 ±1050	6*

Data presented are means ± S.D. for maximum accelerations and loads.

n = number of matched pairs. Value of n is different for photogrammetric data due to partial data loss.

*Means are statistically different by the Wilcoxon paired-replicate rank test ($2\alpha \leq 0.05$).

No medical contraindications to negative-G strap incorporation were found in this study. The perceived risk to negative-G strap incorporation is primarily the potential for injury of the groin or genitalia during a $-G_x$ impact. This might occur with a loosely adjusted lap belt or a negative-G strap attachment located too far aft.

7.3.7 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 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.

An adjuster in the lap belt tiedown strap is often desirable to accommodate variations in occupant size. However, high loads in this strap usually result in adjuster slippage and thus some compromise in the function of the tiedown strap.

7.3.8 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 adjusters 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.

7.3.9 Webbing Width and Thickness Requirements

Selection of the optimum webbing width for a lap belt and shoulder harness must be based on two conflicting requirements: (1) maximum width for lowest pressure and (2) minimum width for maximum comfort and minimum hardware weight. Webbing requirements are discussed in detail in Section 7.4.

7.3.10 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. Ductility in restraint harness hardware is not as critical when energy-absorbing provisions are incorporated into the seat, because the maximum loading of the system is limited. Thus, it would be possible to specify low-ductility materials on load-limited seats and to specify high-ductility, moderate-strength materials on nonload-limited seats. Such a specification could possibly lead to the inadvertent installation of low-ductility harness fittings on rigid, nonload-limited seats. For example, it is known that 20-G-strength shoulder straps have been mistakenly installed in place of 40-G straps. To prevent such a possibility, it is recommended that wherever applicable all harness fittings should be made of equivalent high-ductility materials to ensure their interchangeability. A minimum elongation value of 10 percent (as determined by standard tensile test specimens) is recommended for all metal harness-fitting materials. The 10-percent elongation value can be achieved with copper-base aluminum alloys, low-carbon steels, and stainless steel. 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 immune as possible to brittle failures.

7.3.11 Structural Connections

7.3.11.1 Bolted Connections. Safety margins of 15 and 25 percent for shear and tensile bolts, respectively, are recommended by most aircraft companies for the manufacture of basic aircraft structure. These margins are intended to allow for misalignment of holes, stress concentrations, and fatigue strength reductions; however, the bolt's fatigue strength is not a factor for a one-time maximum loading as occurs in a crash. Thus, it is concluded that the safety margins for shear and tensile bolts in restraint systems can be reduced to 5 and 10 percent, respectively.

Good aircraft engineering practice also 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. Wherever possible the bolts should be designed for shear rather than tension. Because of the vibation environment in which the seats operate, all fasteners that affect the structural integrity should be self-locking or lock-wired.

7.3.11.2 <u>Riveted Connections</u>. Riveted joint design guidelines are presented in MIL-HDBK-5, "Metallic Materials and Elements for Aerospace Vehicle Structures" (Reference 27). This handbook is recommended as a guide for restraint system hardware design.

7.3.11.3 <u>Welded Connections</u>. Welded joints can be 100 percent efficient; however, they may be only 50 percent efficient, depending upon the skill of the welder. Since welded joints can be completely acceptable and in some cases superior to bolted or riveted joints, it is not reasonable to prevent the use of this type of joint if strict inspection procedures are used to ensure that all welded joints are adequate. 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.

Welded joints may contain stress concentration points and misaligned parts in a manner similar to bolted joints; therefore, the cross-sectional area of the basic material in a welded joint should be 10 percent greater than the area needed to sustain the design ultimate load.

7.3.11.4 <u>Plastic Strength Analysis</u>. Plastic analysis methods should be used for strength determination wherever applicable in order to obtain maximum-strength hardware at the lowest possible weight. Plastic analysis makes maximum use of the strain energy available in ductile metals. References 32 and 33 cover this subject.

7.4 WEBBING AND ATTACHMENTS

7.4.1 Properties

The maximum load to be sustained by restraint harnesses can be determined by a review of seat load-deflection requirements (Chapter 8). The curves shown there include the effects of dynamic overshoot loads. The maximum load shown is 35 G for the cockpit seat, where the seat structure provides for little elongation. The required load is reduced as the deformation is increased. Although the restraint harness could be designed to varying loads in accordance with the energy-absorber G level used in the seat, it is believed to be more practical and foolproof to design a single-strength restraint harness that can be interchanged with all seats of similar configuration and orientation. The main advantage of a single-strength harness would be the assurance that it could be interchanged between load-limited seats and nonload-limited seats without fear that an understrength harness might be installed. On this premise, the design strength of all forward-facing and side-facing restraint harnesses should be equal to or greater than the strength of the cockpit seats. At first, this solution might seem to be too conservative because of the lower load levels required for cabin seats; however, closer scrutiny indicates that the asymmetrical nature of the forces on the harness in the side-facing seats could result in loads just as high as those experienced in the forward-facing cockpit harness for a more symmetrical loading.

The distribution of the total load on the various harness components is not easily determined; however, these forces have been fairly well approximated by theoretical calculations and by experimental test data. The test data have been obtained from tests on restrained 95th-percentile anthropomorphic dummies under a variety of test conditions.

The elongation of all webbing used in the harness must be minimized to decrease overshoot. Dynamic tests conducted with anthropomorphic dummies and several tests with cadavers have been used to develop the occupant restraint harness requirements shown in Table 9. Dynamic testing of polyester webbing has demonstrated the dynamic elongaton to be approximately 60 to 75 percent of the static elongation under the same load, as illustrated in Figure 72 (References 75 and 108).

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

	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 should 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 should be plugged into the buckle and the buckle attached to a movable fixture. The webbing should be adjusted to fit a 95th-percentile occupant. The test should proceed as described in Section 4.7.7.3 of MIL-S-58095, 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 should be tested together, and the inertia reel webbing and its stitching to the two shoulder straps should demonstrate a minimum strength of 5,000 lb while loading both shoulder straps and 3,000 lb when loading one strap.

(3) The inertia reel should be tested to demonstrate an ultimate strength of 5,000 lb when following the procedures of Section 4.3.3.1 of MIL-R-8236E.

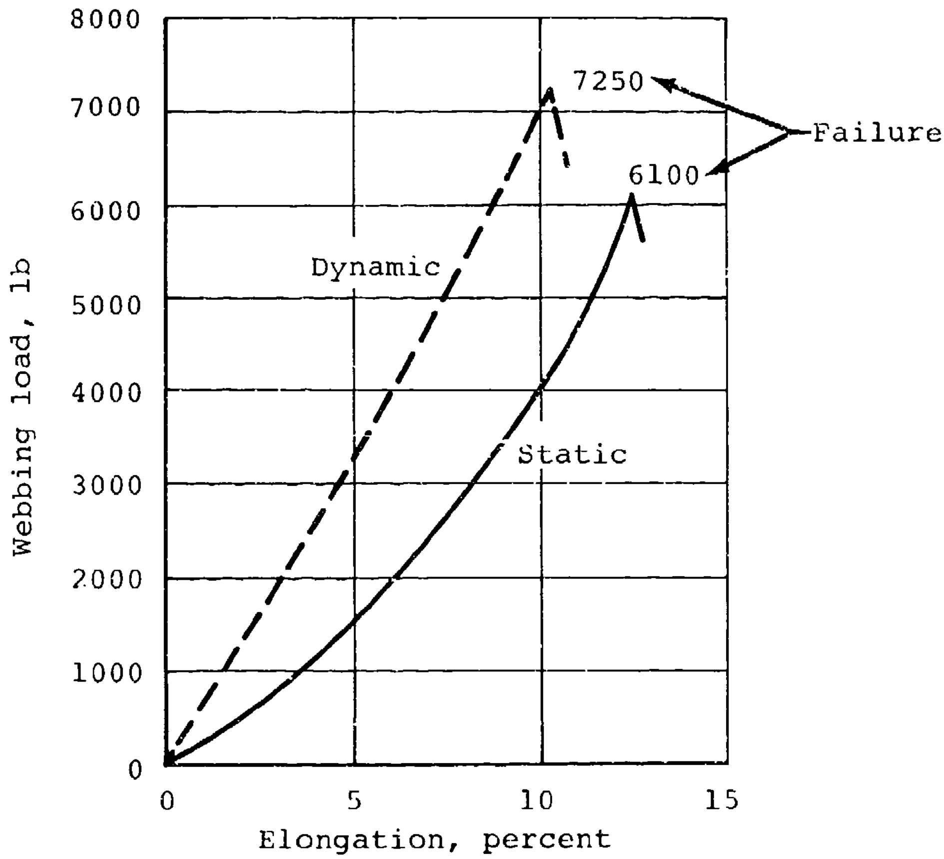


FIGURE 72. LOAD ELONGATION CHARACTERISTICS FOR MIL-W-25361 (TYPE II) POLYESTER WEBBING FOR STATIC AND RAPID LOADING RATES.

Research reported in Reference 109 developed load elongation curves with strain rate as a parameter for polyester and nylon webbing. Computer modeling of webbing strain rate effects was developed and validated against test data.

7.4.2 Width and Thickness Requirements

Selection of the optimum webbing width for a lap belt and shoulder harness must be based on two conflicting requirements: (1) maximum width for lowest pressure and (2) minimum width for maximum comfort and minimum hardware weight. The widths specified in Table 10 are believed to be a good compromise between these conflicting requirements. 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. Such damage is more likely to occur in the neck region during a lateral loading or in the pelvic region during a forward loading. Although requirements based on early investigations using nylon webbing specified a minimum thickness of 0.090 in., it has since been

TABLE 10. MINIMUM WEBBING WIDTH REQUIREMENTS

Webbing Identity	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.

determined that state-of-the-art webbing materials must be thinner in order to achieve the desired low elongation. No significant problem of injuries caused by the thin webbing has been observed with this low-elongation webbing, which has seen extensive automotive use. Therefore, based on currently available materials, a minimum thickness of 0.045 in. is considered acceptable.

7.4.3 Webbing Attachment Methods

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 good performance. The basic stitch pattern used in these harnesses is a "W-W" configuration for single-lapped joints. Research by the U.S. Naval Aerospace Recovery Facility (NARF) at El Centro, California, has reaffirmed the adequacy of basic "W-W" stitch patterns. This research also concluded that a larger size cord (No. 6) with fewer stitches (4-1/2 to 5 per in.) gave a superior performance to the No. 4 MIL-T-7807 cord then used on MIL-W-25361 webbings. However, it was later shown that the heavier thread is not compatible with the new low-elongation polyester webbing (Reference 110). For this webbing a smaller diameter cord offers the advantages of reduced webbing fiber damage and the ability to be used with automatic sewing machines. MIL-S-58095 has subsequently been revised to stipulate the use of the 27-lb strength No. 3 nylon thread at 6 to 9 stitches per inch, as shown in Figure 73.

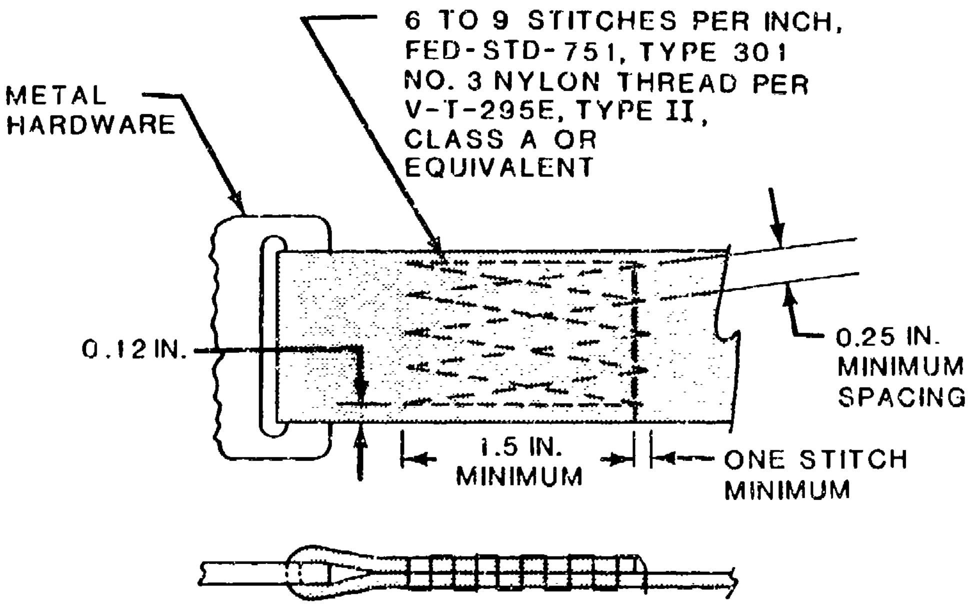


FIGURE 73. STITCH PATTERN AND CORD SIZE.

The use of the 27-lb thread and an 80-percent efficiency results in a minimum strength of 130 lb/in. (6 stitches x 27 lb/stitch x 0.8 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.

The strength of stitched joints can be expected to decrease with age because of normal weather exposure and because of the normal dust and grit collection between the webbing surfaces. The grit and dust can gradually abrade the cords over a period of time. 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.

An example of establishing the total seam length is given:

Assume: A single-lapped joint, 27-lb cord strength, with a 4,000-lb joint load.

Then, the minimum stitch strength is

$$(27)(6)(0.80) = 130 \text{ lb/in.}$$

and the minimum seam length is

$$\frac{4,000}{130} = 31 \text{ in.}$$

Therefore, the total seam length is

$$(31)(1.3) = 40 \text{ in.}$$

The total seam length is achieved through placing many short lengths in a rather small area. Several patterns have been developed and tested; however, the W-W as described below is still preferred. 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.

Unpublished data from comparative tests of five stitch patterns performed by NARF indicated better performance of two new stitch patterns over the basic W-W pattern. The data from this research are reported here with permission of NARF.

The five stitch patterns tested are shown in Figure 74. These patterns were sewn in Types XIII and XXII of MIL-W-4088 nylon webbing used for parachutes. Three samples of each stitch pattern were tested. Table 11 shows the results of the first test series. Because of the low number of total stitches, the results were inconclusive, and a second test series was performed. Patterns 2 and 5 were eliminated from the second series. Table 12 shows the results of the second test series. It relates the performance of the two stitch patterns, 1 and 4, to the performance of pattern 3, the W-W pattern, for the two different types of webbing. Stitch patterns 1 and 4 exhibited better strength properties than pattern 3 (WW) when Type XIII webbing was used. Pattern 4 did not perform as well when Type XXII webbing was used, while pattern 1 again indicated better strength characteristics than did pattern 3.

The W-W stitch pattern, as shown in Figure 73, is still recommended until more conclusive information on these or other stitch patterns becomes available.

7.4.3.2 <u>Webbing Wrap Radius</u>. The wrap radius is the radius of the fitting over which the webbing is wrapped at buckles, anchorages, and adjusters, as illustrated in Figure 75. Detailed information on just how small this radius can be before the strength of the webbing is affected is not available; however, the 0.062-in. minimum radius shown is based upon the geometry of existing high-strength restraint harnesses. This radius should be carried around the ends of the slot as shown in Figure 75 to preclude edge cutting of webbing if the webbing should be loaded against the slot end.

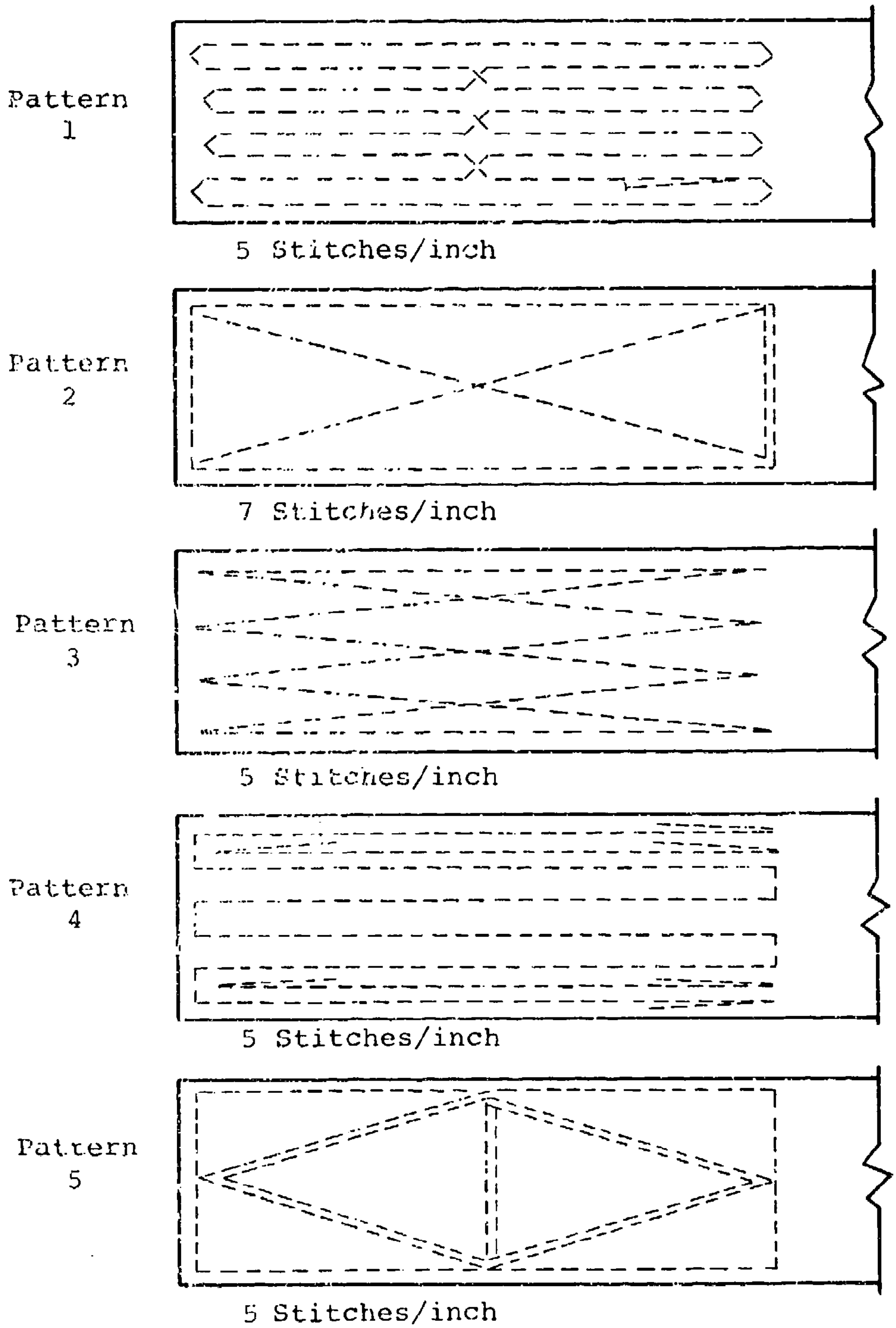


FIGURE 74. STITCH PATTERNS TESTED.

TABLE 11. BREAKING STRENGTH OF STITCH PATTERNS (TEST SERIES ONE)

	Sample No.	Webbing and Stitch Type									
		A-1(a)	A-2(a)	A-3(a)	A-4(a)	A-5(a)	B-1(a)	B-2(a)	B-3(a)	B-4(a)	B-5(a)
Breaking Strength (lb)	1	4835	5040	5645(b)	4975	5150	5450	5960	5430	5315	5550
	2	4675	4640(b)	5680(b)	4880	4935	5420	5780	5620	4650	5420
	3	4545	5060(b)	5190(b)	4740	4500	5710	5695	5665	5570	5120
Average Breaking Strength (ABS) (lb)		4685	4913	5505	4865	4862	5527	5812	5572	5178	5363
ABS/ABS for Pattern 3		0.851	0.892	1.00	0.884	0.883	0.992	1.04	1.00	0.929	0.963
Approximate Total Stitches		200	190	190	190	180	200	190	190	190	180
ABS/Stitch (lb)		23.43	25.86	28.97	25.61	27.01	27.64	30.59	29.33	27.25	29.79
ABS/Stitch/ABS for Pattern 3		0.809	0.893	1.00	0.884	0.932	0.942	1.04	1.00	0.929	1.02

(a) A designates MIL-W-4088 Type XIII nylon webbing.
B designates MIL-W-4088 Type XXII nylon webbing.
Numerals 1, 2, 3, 4, and 5 designate stitch patterns as shown in Figure 74.
(b) Webbing broke.

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 76. This reduces the weight and size of attachment fittings; however, it can also cause premature webbing failure because of the compressive force applied by the top layer of webbing to 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 4,000-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.

TABLE 12. BREAKING STRENGTH OF STITCH PATTERNS (TEST SERIES TWO)

	Sample No.	Webbing and Stitch Type A-1[a]	A-3[a]	A-4[a]	B-1[a]	B-3[a]	B-4[a]
Breaking Strength (lb)	1	4400	4410[b]	4540	6340	6420	6215
	2	4710	4740	5080	6480	6490	6060
	3	4820	4360	4870	7200	6500	6070
Average Breaking Strength (ABS) (lb)		4643	4503	4830	6673	6470	6115
ABS/ABS for Pattern 3		1.03	1.00	1.07	1.03	1.00	0.945
Approximate Total Stitches		260	270	270	260	270	270
ABS/Stitch (lb)		17.86	16.68	17.89	25.67	23.96	22.65
ABS/Stitch/ABS for Pattern 3		1.07	1.00	1.07	1.07	1.00	0.945

(a) A designates MIL-W-4088 Type XIII nylon webbing.
B designates MIL-W-4088 Type XXII nylon webbing.
Numerals 1, 3, and 4 designate stitch patterns as shown in Figure 74.
(b) Jaw separation 20-in. minimum. All other tests at 2-in. minimum.

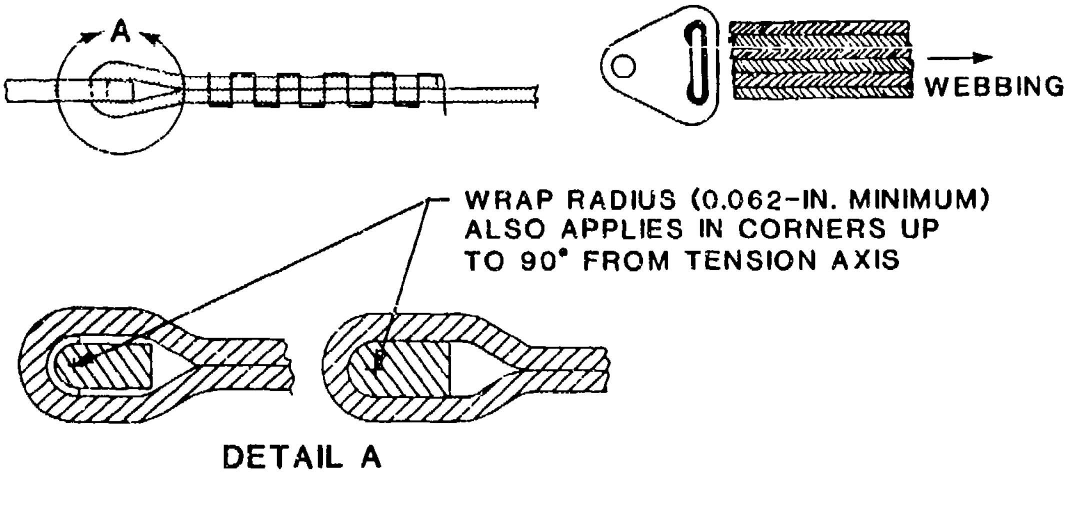


FIGURE 75. WRAP RADIUS FOR WEBBING JOINTS.

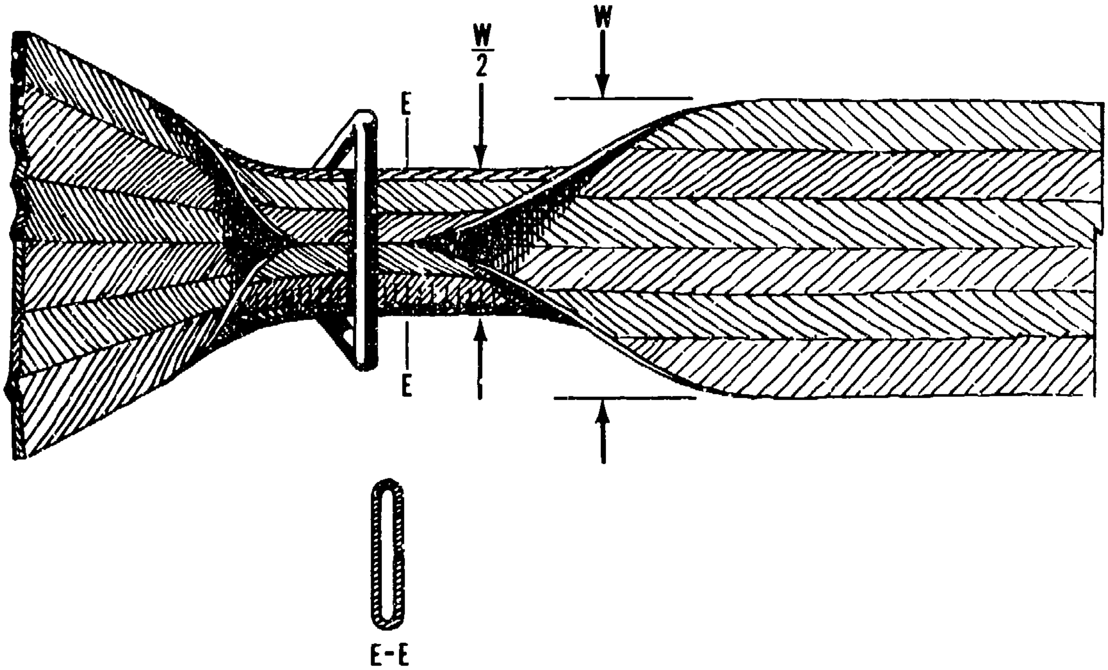


FIGURE 76. WEBBING FOLD AT METAL HARDWARE ATTACHMENT.

7.4.3.4 <u>Surface Roughness of Fittings</u>. A surface roughness of no more than RMS-32 is recommended to prevent fraying of the webbing due to frequency of movement over the metal.

7.4.4 <u>Energy-Absorbing Webbing</u>

Energy-absorbing restraint system webbing has been considered for limiting loads on the occupant. The potential advantages of energy-absorbing webbing are reduction of maximum load exerted by the webbing on the occupant and reduction of the amount of elastic energy stored in the webbing. Webbings of this type have been developed and are described briefly here for information purposes. They are not recommended for use in seating systems for the reasons presented below.

The principle of energy absorption for the first webbing material depends on a core wrap of fiberglass that breaks at a design load; then, the outer cover of nylon wrap takes over the loading, gripping the fiberglass until it breaks again. The construction of the webbing varies, depending on the type of force-versus-percent-of-elongation curve desired. For this webbing, the general shape for the force-versus-elongation curve includes a linear elastic region followed by a region of constant force.

The construction of the second type of energy-absorbing webbing differs greatly from the first. It is made of polyester, and the energy absorption is produced by the filaments themselves. The polyester filaments are heat shrunk from their original sizes, and they do not return to the shrunk dimensions after the load application. This has the effect of plastic deformation, and this property provides the energy-absorption capability of the material. The general shape for the force-versus-elongation curve for this webbing is a constant rate in pounds per inch which makes inefficient use of stroke distance.

A third type of energy-absorbing webbing material has been evaluated for parachute applications at the U.S. Naval Aerospace Recovery Facility. The material is made by stitching together two pieces of webbing. The two pieces of webbing separate (peel) at a constant load by breaking the stitches holding them together. The constant breaking force can be varied by increasing or decreasing the number of stitches.

Because of other considerations, including primarily the increased potential for secondary impacts of occupants, energy-absorbing webbing is not recommended for use in seating systems. The limited room available in aircraft requires that the strike envelope be minimized. Therefore, the use of the lowest elongation available is specified.

7.5 RESTRAINT SYSTEM HARDWARE

7.5.1 General

The restraint system configured for use in a particular location in an aircraft will include various hardware selected on the basis of a trade-off among such factors as crash resistance, weight, and cost. An aircrew system meeting the requirements of MIL-S-58095 that has been developed is illustrated in Figure 77. The system shown in Figure 78, which is defined by a draft military specification (Reference 111), offers improved protection but is heavier and more expensive. For example, it includes two inertia reels for the reflected shoulder strap system, which reduces both lateral and forward motion. Its use may be warranted where space is a problem and strike envelopes need to be minimized. Also, this system's use of lap belt retractors rather than adjusters provides greater convenience in ingress, greater comfort by eliminating the adjuster, and greater crash safety by eliminating slack (preload held on the lap belt by torsional spring in retractor). The weight of the system shown in Figure 77 is 5.50 lb and that of the system in Figure 78, 8.50 lb, with the difference due mostly to the additional inertia reel and the two lap belt retractors of the latter system.

The various hardware components involved in a state-of-the-art restraint system are described below. Information on production items is included where available.

7.5.2 Buckles and Emergency Release

The buckle is of the single-point release type for all systems and provides positive release of all strap fittings (with the exception of the one to which it is permanently attached). These capabilities should help prevent entrapment of a wounded occupant.

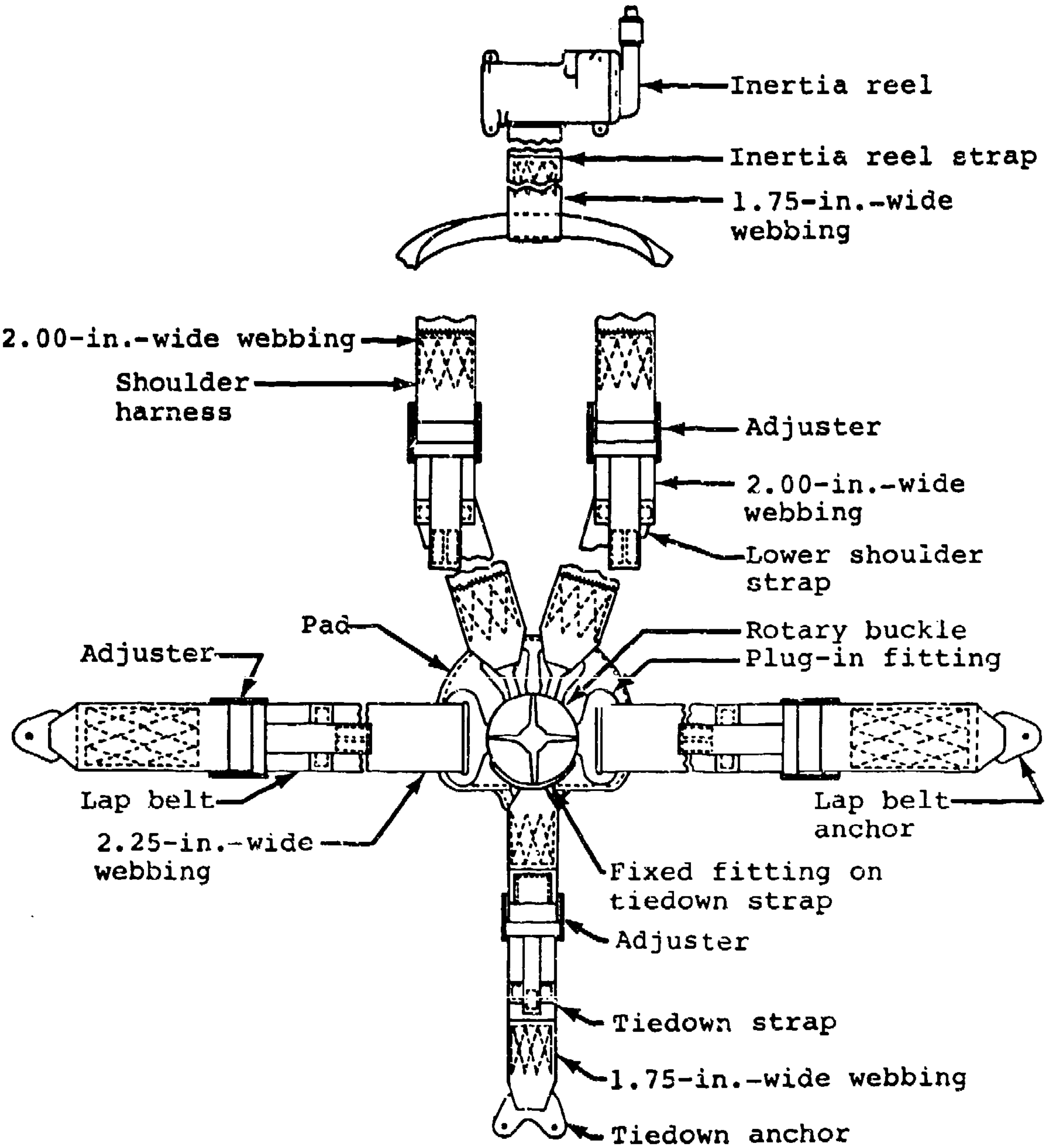


FIGURE 77. AIRCREW RESTRAINT SYSTEM.

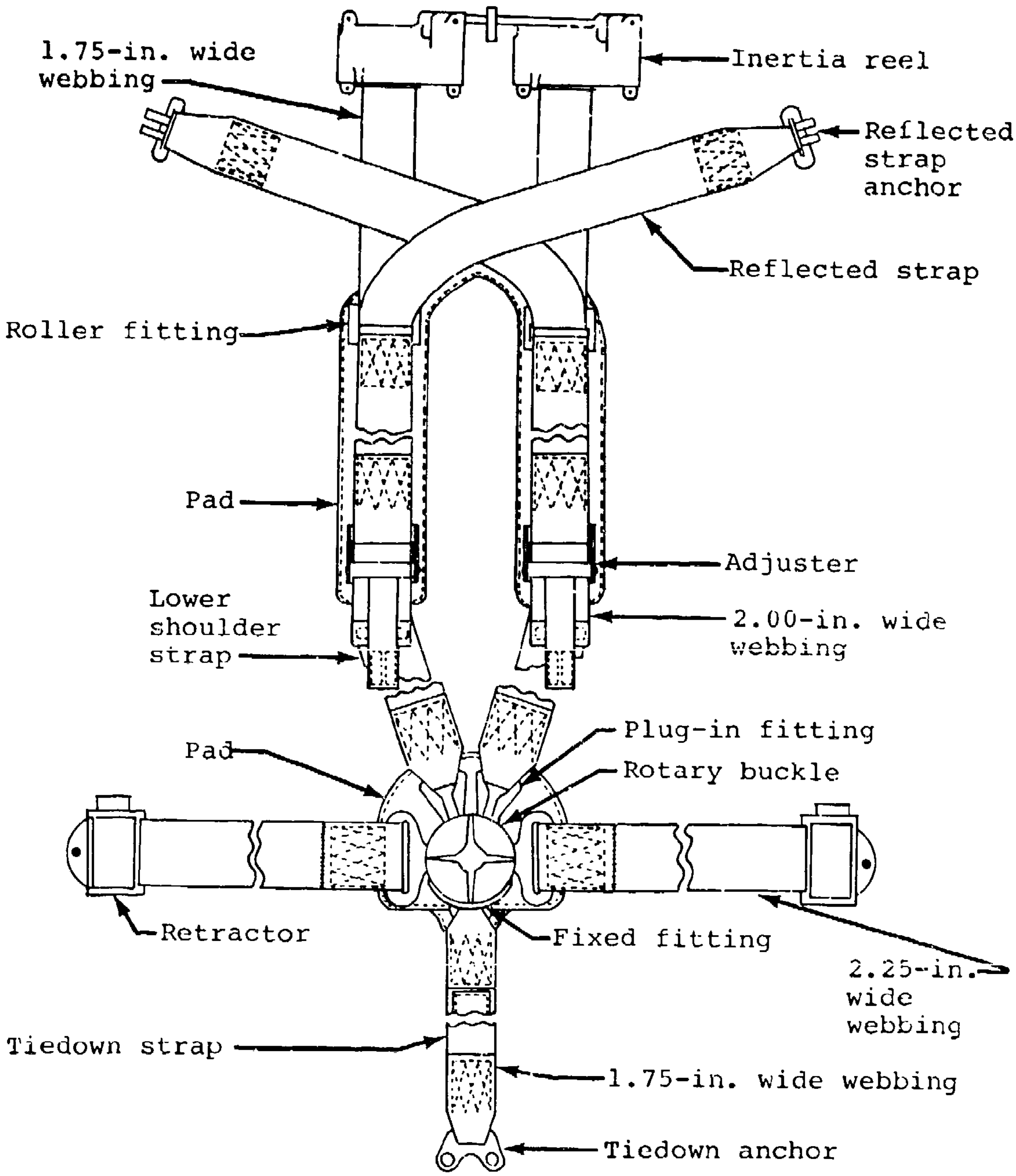


FIGURE 78. REFLECTED SHOULDER STRAP RESTRAINT SYSTEM. (REFERENCE 111)

7.5.2.1 Aircrew Restraint Buckle. To facilitate egress in emergencies, a rotary-release buckle provides the advantage of operation by a force applied in many directions. In one existing buckle, each fitting can be inserted and locked separately. When the release handle is rotated, springs move the fittings far enough so that none will reengage when the handle is released. This is an example of a desirable feature that will protect against a potential hazard created by a fitting relocking upon release of the handle. For example, if one lap belt fitting relocks, it could partially restrain the occupant as he attempts an emergency egress.

7.5.2.2 Troop/Passenger Restraint Buckle. The restraint systems recommended for troop seat installations, as shown in Figure 64, include a single-point, lift-lever release buckle that is permanently attached to one of the lap belt straps. The lift-lever release mechanism replaces the rotary release here for the convenience of troops or passengers who, because of infrequent system use, might find it easier to use in emergencies since it resembles automotive hardware (References 75, 99, and 112). The design of such a buckle is described in Reference 98.

7.5.3 Adjustment Hardware

The lap belt length adjusters should be located either at the center of the lap belt near the attachment-release buckle or at the side of the hips of the occupant below the iliac crests of the pelvis. Shoulder strap adjusters should be located as low on the chest area as possible to avoid a concentrated pressure over the collarbones of the seat occupant. It should be possible for the seat occupant to make strap adjustments easily with either hand. A downward pull on the free end of the shoulder harness straps tightens the shoulder harness. Depending on the type of adjuster, a pull on the free end of the lap belt straps either towards or away from the buckle tightens the lap belt. Adjustment hardware should be spring loaded so that strap length adjustments do not change in flight. A nominal 1.5-in. tab shall remain outside the adjusters when the restraint is at its maximum extension. Adjuster creep should not occur when the following test is performed: A 10-lb weight shall be attached to webbing passing through the adjuster and the webbing marked at the adjuster. The adjuster shall first be lifted vertically so that the weight hangs freely. The motion should then be reversed to release the load in the strap. This sequence shall be repeated 5,000 times. Mass acceleration shall not exceed 2.5 G. At the completion of the test, there shall be no slippage at the mark.

7.5.4 Inertia Reels, Control, and Installation

7.5.4.1 Inertia Reels and Controls. The basic function of the inertia reel is to give the crewmember full freedom of movement during normal operating conditions while automatically locking the shoulder harness during an abrupt deceleration.

The freedom of movement is obtained by spring-loading the reel cable or webbing to which the shoulder straps are attached. This allows the shoulder harness to be extended without apparent restraint of the shoulders (only 6 lb at maximum extension). The reel will constantly take up any slack.

Inertia reels currently installed on the crewseats of U.S. Army aircraft are designed in accordance with the requirements in Reference 113. There are two basic types of MIL-R-8236 reels. The first, the impact-sensitive type, requires a 2- to 3-G deceleration on the inertia reel housing itself to lock automatically. Normal flight loads, including severe turbulence, will not activate this reel.

The second basic type, the rate-of-extension type reel, although mechanically different, ser~~ves the~~ same purpose. Its automatic operation depends on the rate at which the inertia reel strap is reeled off, which makes it a function of the rate of upper torso displacement away from the seat back, regardless of direction. The automatic operation of this reel can be checked at any time by a jerk on the shoulder straps. The shoulder harness, after being locked automatically, reels up the slack in the strap every time the occupant moves toward the seat back.

A third type of reel is a combination of the basic types. It is a dual mode inertia reel that locks under either vehicle or strap acceleration. Since it can react more quickly to inertial forces than to webbing acceleration, this reel should increase the probability that it will lock when used. The amount of strap extension occurring before the reel locks may also be minimized. A prototype dual action reel has been fabricated for testing at the Naval Air Development Center (NADC). All types of reels have identical control levers, usually mounted under the seat pan, on the seat side, or at some other convenient location. The lever has two positions--manual and automatic. The manual position permits the pilot to lock the reel if rough conditions are anticipated, or at any other time warranted. Normally, the control lever should be in the automatic position to allow the wearer to lean forward easily and reach all controls without first having to release the control lever. MIL-R-8236 requires that all reel types lock automatically before the shoulder harness webbing travels more than 0.5 in. during an emergency deceleration.

To achieve automatic locking before the shoulder harness webbing travels more than 0.5 in., the total pre-lock delay time must be kept to an absolute minimum. Crash simulation tests at NADC have shown that the existing rate-of-extension inertia reels do not always lock when exposed to longitudinal impact pulses well within potentially survivable levels because of inherent characteristics of the strap acceleration sensing mechanism. To ensure that the locking occurs under the automatic locking mode, it is recommended that dual- mode reels be considered and that inertia reel component qualification include dynamic testing in the automatic-locking mode at crash impact conditions specified in MIL-S-58095.

In addition to the MIL-R-8236 type reel, which has the function of preventing further strap extension, there are power-haulback reels which 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.

7.5.4.2 Inertia Reel Installation in Rotary- and Fixed-Wing Aircraft. Accident statistics indicate that rotary-wing aircraft frequently impact on their sides or impact vertically with little longitudinal deceleration. Therefore, it is concluded that all rotary-wing and VTOL aircraft should incorporate the rate-of-extension type reel, because a unidirectional ($-G_x$) acceleration (needed to actuate the impact type reel) might not be present in all rotary-wing or VTOL aircraft accidents.

On the other hand, the study of about 92 fixed-wing aircraft accidents, described in Volume II, revealed that only one accident occurred in which no longitudinal ($-G_x$) acceleration was present. Therefore, a unidirectional (impact) type reel may be adequate for fixed-wing aircraft. However, 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. The shoulder straps must be maintained at the correct angle with respect to the wearer's shoulder at all times, as described in Section 7.3.4. 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. Excessive webbing loading of the housing can produce housing and/or webbing failure as the housing is not designed as a contact surface for loaded webbing.

7.5.5 Retrofitting of Energy-Absorbers in Restraint Systems

Retrofitting of energy absorbers into the seat occupant restraint system can reduce restraint loads and alter the relationship between load and aircraft deceleration. See Section 9.2 for a description of this application.

7.5.6 Restraint-Induced Injury

In a study (Reference 114) made of 810 automobile accidents in Switzerland and France, in which the occupants used three-point belts, particular attention was given as to whether the belt itself could be the cause of neck injuries during lateral collisions. In 98 of the 810 accidents there were nearside lateral impacts. In 10 of these, neck injuries were registered, but only 2 of them could be attributed to contact with the shoulder belt webbing. The corresponding incidence of neck injuries, 111 in the 712 cases of frontal, farside, and rollover impacts, was not considered significantly different. The conclusion from the study was that the number of hazardous effects of three-point belts to the neck region is insignificant.

High-velocity impacts can cause severe injury to the occupant's body, especially if the restraint permits lateral and forward movement of the midsection of the torso (Reference 115). Depending upon the acceleration profile variables, the internal organs and tissues can be distorted with varying degrees of injury resulting. To prevent this, the torso may be confined in a flexible but essentially isovolumetric restraint system, which minimizes the distortion and, in essence, allows the organs and bones to "float." Experimental verification was obtained using guinea pigs and monkeys at a 40-ft/sec velocity change. This work indicates the desirability of restraining as large an area of the occupant's torso as practicable, in order to decrease the severity of internal injury during crash impacts.

7.5.7 Dynamic Malfunction of Restraint Buckle

It is essential for the safety of the seat occupant that the restraint buckle not disengage the harness straps as happened during the crash of an Airtrainer CT4 A19-028 in Australia in 1979. Both occupants were ejected through the windshield (Reference 116). Laboratory tests to simulate "out of line" strap tensions revealed that off-axis loading on the fittings caused them to slip off the latch pins. This study suggests that static tests of the buckle which produce only strap tensions that are "in line" with the plane of the buckle are inadequate. This is recognized in MIL-S-58095, which requires that, with the buckle restrained, the two shoulder harness fittings be able to withstand a 4,000-lb static pull 45 degrees forward and 45 degrees aft out-of-plane and plus 45 degrees and minus 45 degrees in-plane and that the other harness fittings be able to withstand the same load with pull angles of 30 degre s.

8. SEAT STRENGTH AND DEFORMATION REQUIREMENTS

8.1 INTRODUCTION

Previous sections of this volume have presented background information to aid in understanding the problems involved in designing crash-resistant seats and restraint systems. This chapter presents specific design and test requirements for seat systems and litter systems. Occupant sizes and weights to be used in the design are defined, as are the required static design strength-deformation relationships. Static tests to demonstrate the adequacy of the system in all loading directions are presented. Finally, dynamic test requirements, to demonstrate that the seat systems, restraint systems, and litter systems will provide the degree of protection desired, are also defined. Successful completion of all static tests and dynamic tests are required to demonstrate acceptability of a design.

In this chapter, the direction of applied loads are referred to in terms of forward or aftward, lateral or vertical, and upward or downward. These terms, together with aircraft and occupant axes, are defined in Chapter 2 and refer to seat loading in directions consistent with the aircraft coordinate system. Thus, a forward load on a forward-facing seat is in the positive x direction with respect to both the seat and the aircraft. If the seat is a side-facing seat, the forward load would be applied to the seat in the plus-or-minus y direction, depending on whether the seat faces right or left respectively in the aircraft. For an aft-facing seat, the forward load would be applied in the negative (-x) direction (toward the back of the seat).

8.2 RECOMMENDED OCCUPANT WEIGHTS FOR SEAT DESIGN

8.2.1 Crewseats

It is recommended that the upper and lower limits of occupant weights to be considered in seat design be based on the 95th and 5th percentiles. Equipment weights including combat gear should also be considered based on data in References 117 and 118; typical male and female aviator weights are presented in Table 13.

For some applications, the design weight should be based on the typical weight of the occupant, not the extremes. Although the weight of a 95th-percentile, combat-equipped male aviator can be as high as 250 lb, the majority of the flight hours logged in Army aircraft are noncombat hours. Consequently, it is more likely that crewmembers will be lightly equipped. Severe restrictions are placed on crewseat design options, including stroke length, control access, and seat armor, if the crew seats are designed to protect male occupants over the full range of weights (140 to 250 lb).

8.2.2 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. Based on data contained in References 35, 36, 75, 100,

TABLE 13. TYPICAL AVIATOR WEIGHTS

Item	95th-Percentile Weight (lb) Male	Female	50th-Percentile Weight (lb) Male	Female	5th-Percentile Weight (lb) 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

118, and 119, the typical weights of male and female seated troops in aircraft are shown in Table 14.

8.3 STRENGTH AND DEFORMATION

8.3.1 Forward Loads

A minimum forward load factor of 35 G is recommended for crewseats and 30 G for troopseats. Deformation should be minimized to reduce the occupant's strike envelope and keep him from striking instruments and controls. Occupant weight should be the total weight of the 95th-percentile crewmember or trooper as presented in Section 8.2.

8.3.2 Aftward Loads

Large aftward loads seldom occur in fixed-wing aircraft accidents but sometimes 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 8.2.

8.3.3 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

TABLE 14. 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

order of 23 G for durations up to approximately 0.025 sec. Since most back tangent lines are oriented at a backward leaning angle of about 13 degrees from the vertical aircraft axis, tolerance to vertical impact loads should be somewhat increased over the stated criteria. In spite of this, however, the 48-G design pulse applied to seat system-to-fuselage mount points imposes the requirement for energy absorption in the vertical direction by some form of load limiting. The vertical dynamic response of seat-occupant systems and, in particular, the effect of seat behavior on the occupant deceleration excursions, has not been sufficiently investigated to allow a full explanation of the effects of this phenomenon. The factors affecting the response of the seat and occupant and thus the final design of the load-limiting system include:

- Input pulse variables.
- Orientation of the occupant and seat relative to the resultant force vector.

- Effective occupant weight.

- Occupant spring rate and damping characteristics.

- Weight of the movable part of the seat.

- Spring rate and damping characteristics of the seat.

- Spring rate and damping characteristics of the cushion.

- Available stroke distance.

- Force-deflection characteristic of the energy-absorption system.

- Any external influences such as those caused by loads transmitted through dummy legs, or binding of the seat mechanism.

The effective weight in the vertical direction of a seated 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 8.2.1). 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 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, 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 elminates 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 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 up to 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.

Crew seats 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 $\pm 2\text{-}1/2$ in. from NSRP is typically required by crew-seat 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.

The minimum of 12 in. of stroke is recommended to provide the minimum required level of protection. As illustrated later in this section, even with 12 in. of stroke, heavier occupants in more severe crashes will exhaust the available stroke distance and bottom out. The following reasons point out the need for obtaining the greatest possible energy-absorbing stroke from the seat:

- It is most weight efficient to control crash loads of the specific items of concern (e.g., occupants) rather then the entire aircraft.

- It is easier to provide energy-absorbing stroke in the seat than in the fuselage or landing gear. The distance from the floor of the helicopter to the ground is usually specified either directly or implicitly by overall dimensional requirements. Combined with the ground clearance requirement, this usually results in a rather thin fuselage floor. Thus fuselage crush distance is limited.

- Terrain irregulations (i.e., trees, rocks, etc) may eliminate the landing gear. In each case, the fuselage will somewhat control these localized penetration loads and thus permit the seats to function.

- The energy-absorption capacity of the seat is much easier to demonstrate than that of the airframe, as the energy-absorption capacity of the airframe is difficult to predict and hardware is usually not available for testing in the early design phases of a new aircraft.

- Full energy absorption assigned to landing gear can be lost in the majority of types of terrain upon which the aircraft crashes; i.e., soft versus hard, as in soft soil, marshes, or water as opposed to a landing strip. Aircraft attitude at impact may also have a significant influence; a high roll angle, for instance, could render the landing gear energy-absorbing feature virturally inoperative. The landing gear may also be retracted at the time of impact.

- Based on the above, the seat is a low-risk approach for providing energy-absorbing stroke.

Since energy-absorbing systems should be designed for dynamic loading, the static test loads should be obtained by adjusting the dynamic limit loads by an 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 reduced from 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 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. Weights for pilot/copilot, troop, and gunner are shown in Tables 13 and 14.

The following is an example of the calculations made for a seat designed to stroke under the decelerative load imposed by a 50th-percentile male crewmember. The average deceleration and stroke of the 5th- and 95th-percentile seat occupants are approximated. First, using weights from Table 13, the male 50th-percentile effective weight is calculated according to

$$Wt_{eff} = 0.80\ (Wt_{50} + Wt_c) + Wt_h \qquad (34)$$

where Wt_{eff} = effective weight of 50th-percentile occupant, lb

Wt_{50} = nude weight of 50th-percentile occupant, lb

Wt_c = weight of clothes, lb

Wt_h = weight of helmet, lb

Thus,
$$Wt_{eff} = 0.80\ (170.5 + 3.1) + 3.4$$
$$= 142.3 \text{ lb}$$

which is shown in Table 13 as the effective weight of the 50th-percentile male crewmember. The effective weights for the 95th- and 5th-percentile male aviators are 175.2 and 112.6 lb, respectively.

Assuming a 60-lb movable seat weight, the total weights that the load-limiting system must be designed for are:

5th percentile: 172.6 lb

50th percentile: 202.3 lb

95th percentile: 235.2 lb

The 50th-percentile limit load (L_L) is calculated as follows:

$$L_L = G_L\ Wt_{eff} = (14.5)\ (202.3) = 2{,}933 \text{ lb}$$

The load factors for the 95th- and 5th-percentile aviators are then

$$G_{L95th} = \frac{2{,}933}{235.2} = 12.5$$

$$G_{L5th} = \frac{2{,}933}{172.6} = 17.0$$

With seats designed to this criteria, short deceleration spikes of 23 G or more can be expected in a crash. However, decelerations of this magnitude would not be expected to cause severe injury if their total duration are approximately limited to that of the Eiband criteria. Also, in extremely severe crashes, the stroke could exceed 12 in. for a seat occupied by the heavier percentiles. This would mean that protection could not be guaranteed in the most severe vertical survivable crash corresponding to a 48-G, 50-ft/sec floor acceleration in the seat adjusted-down position. With the seat in the neutral or up position, however, protection over the entire range would be provided (see Reference 28). The probability of a 95th-percentile occupant being in the seat in the most severe crash is relatively small and the seat designer should keep in mind that the actual amount of seat stroke will be determined by the specific accident's characteristics, seat design, and occupant's size.

For comparison, the same type of calculations for a system limit load sized for the 95th-percentile crewmember yields the following:

$$L_L = (14.5)\ (235.2) = 3{,}410 \text{ lb}$$

and

$$G_{L50th} = \frac{3{,}410}{202.3} = 16.9$$

$$G_{L5th} = \frac{3{,}410}{172.6} = 19.8$$

All occupants below the 95th-percentile weight range could be expected to receive deceleration spikes in excess of Eiband criteria for spinal injury in seats in which the limit load was designed for the 95th- percentile occupant. Also, the natural distribution of occupant weights places the majority of aviator weights near the 50th percentile. It is therefore expected that more overall protection can be provided by sizing limit loads for the 50th-percentile rather than for a heavier occupant.

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 seat design 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 aviator weight. In operation, the aviator would be required to select a limit load by movement of a lever or dial upon entering the seat. An example of one such system is discussed in Reference 28. An example of a variable load limiter which selectively engages/disengages individual load limiters is shown in Figure 79.

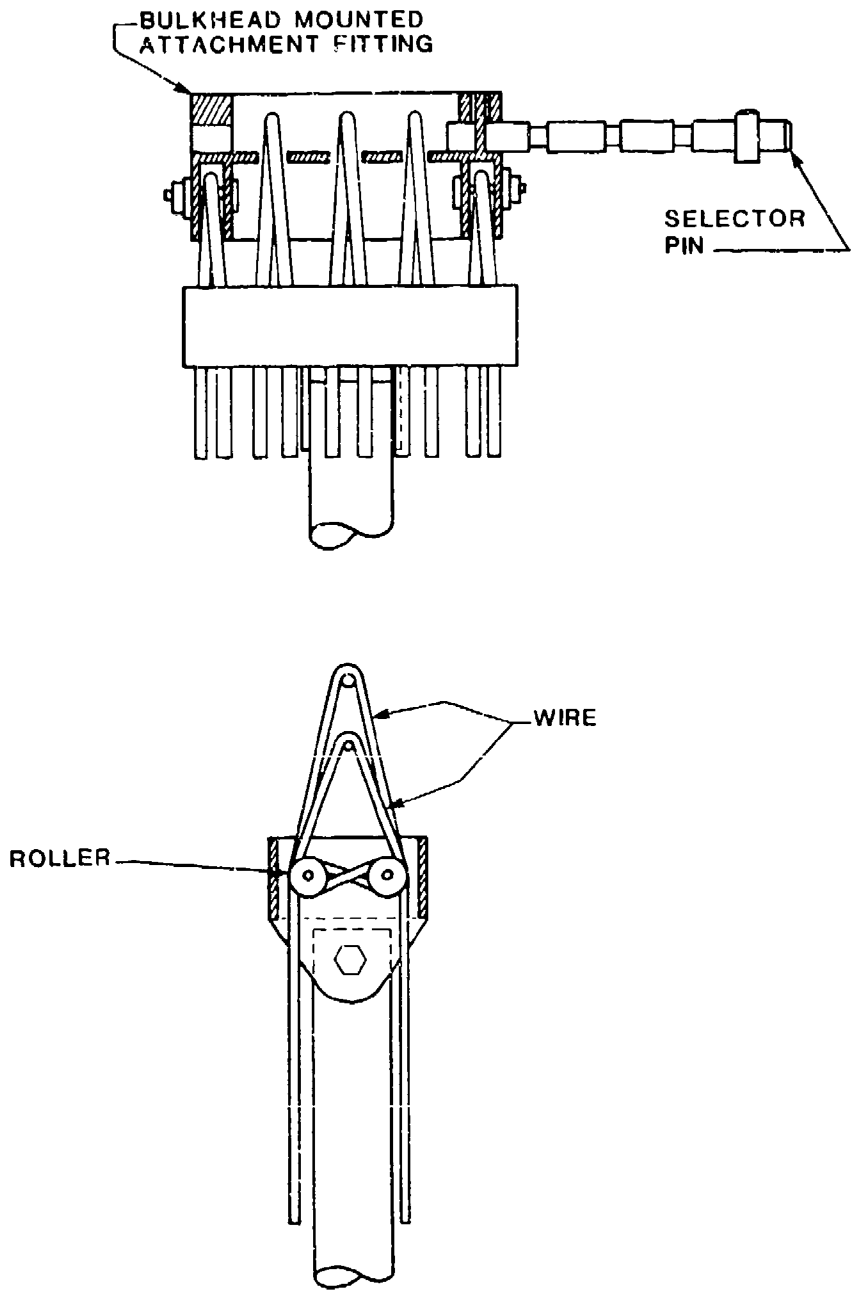


FIGURE 79. MULTILOAD ENERGY ABSORBER.

when possible, a multiple-level load limiter (preferably three or more levels) should be used to provide maximum protection over the complete occupant weight range. As an illustration, consider the limit-load factors calculated above in this section. With the limit load set for the

50th-percentile occupant weight, the calculated load factors were 12.5 for the 95th- and 17.0 for the 5th-percentile occupant weights. This produces a negative variation of 2.0 G for the heavy occupant and a positive variation of 2.5 G for the lighter occupant from the design factor of 14.5 G. If two load settings were possible, the variations could be halved. An infinitely adjustable mechanism would reduce the variation to zero.

Because troops do not have operational functions to perform and troop seats are not armored, more flexibility exists in troop seat design. 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 desirable for troop seats only if automatically adjusted since improper adjustment of such devices can increase the hazard to the occupant.

8.3.4 Upward Loads

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 8.2.

8.3.5 Lateral Loads and Deformation

A minimum lateral load factor of 20 G is recommended. Deformation should be minimized to reduce the occupant's strike envelope.

8.4 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 as noted in Chapter 7. 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 subassemblies are specified in Table 9.

Specific component tests, including operational tests, are detailed in a draft military specification (Reference 111). 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.

8.5 STRUCTURAL TEST REQUIREMENTS

In compliance with MIL-S-58095 and MIL-S-85510, both static and dynamic tests are recommended. Dynamic tests of aircraft seats have shown that individual components capable of maintaining the design loads often fail when tested in combination with other components. Therefore, it is recommended that all seat and litter systems be tested as complete units. This is not to imply that component tests are not useful. Component tests can be extremely useful and should be used 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. A significant weight increase, however, 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 or significant. The vertical position should be at least consistent with the 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).

8.5.1 Static Test Requirements

8.5.1.1 General. The purpose of the static tests is to demonstrate that the seat has the strengths and other properties required to provide the desired performance in all the principal loading directions. Static testing enables basic properties to be ascertained for known loads applied at a slow enough rate so that seat response can be observed. Successful completion of the static tests does not guarantee passing the dynamic tests, but it improves the chances. Weaknesses can be identified and corrected prior to conduct of the ultimate dynamic tests. Also, due to the loading rate sensitivity of materials, load distributions may be different in dynamic tests than they are in static tests. Certain structures, statically soft, may react as stiffer members under dynamic loading, and thus, pick up more of the load than when the system was loaded statically. Because of these reasons and because of dynamic overshoot, a margin of safety has been added to the ultimate static load factor on the design curves as compared to the peak accelerations of the dynamic design pulses. It is recommended that this margin not be sacrificed for reduced weight.

Table 15 presents the static test requirements for complete crewseat units per MIL-S-58095. The tests required include a series of unidirectional tests to determine basic seat strengths along the major axes. A combined loading

TABLE 15. COCKPIT SEAT DESIGN AND STATIC TEST REQUIREMENTS

Test Ref. No.	Loading Direction with Repect to Fuselage Floor	Minimum Load Factor[a] (G)	Body Weight 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 81).

(f) Effective weight of a 250 lb (114 kg) equipped occupant.

test is also required to evaluate the seat performance under static conditions simulating the most severe, unsymmetrical loading condition anticipated. All static tests should be conducted under simultaneous conditions of floor buckling and warping or bulkhead warping as illustrated in Figure 6 (Section 4.4.5). The warping conditions must be introduced in the static test phase to evaluate completely the performance of the seat under the most severe requirements selected for design.

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.

8.5.1.2 Unidirectional Tests. Where separate strength and deformation requirements have been specified in Table 15 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.

8.5.1.3 Combined Loads. Seats must demonstrate no significant loss of structural integrity under conditions of combined loading as shown in Table 15 and should demonstrate ability to stroke in the vertical direction with the transverse loads applied.

8.5.1.4 Load Application Method. The static test loads are to be applied at the expected center-of-gravity location of the occupant or occupants of each seat. The occupant loads should be applied through a body block (see Section 8.5.1.5) restrained in the seat with the restraint system. Figure 80 shows the location of the center of gravity that should be used as the initial static load application point for the seat occupant.

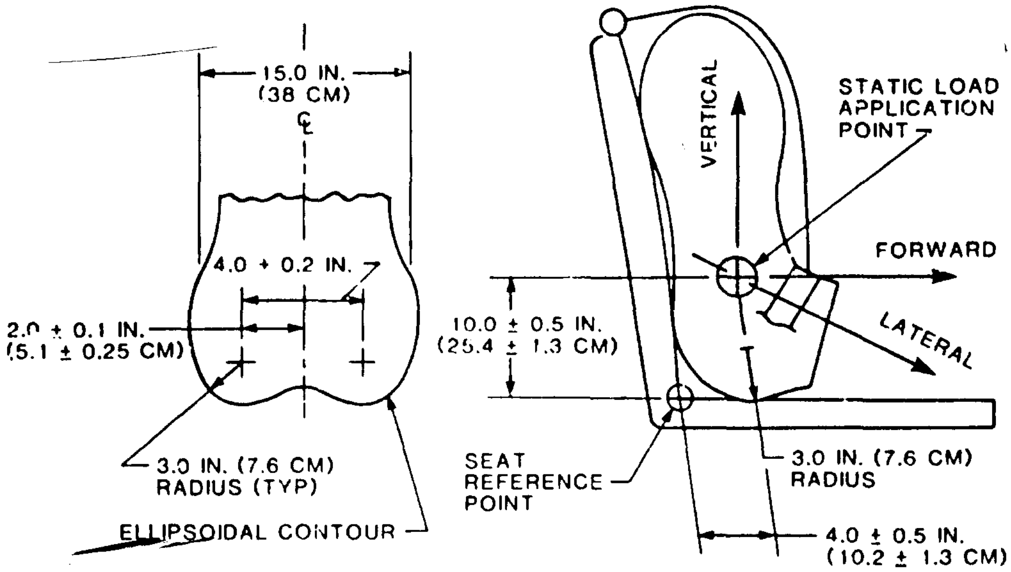


FIGURE 80. STATIC LOAD APPLICATION POINT AND CRITICAL BODY BLOCK PELVIS GEOMETRY.

For the testing, the seat should be adjusted to its aftmost horizontal adjustment position or to the most critical position if it is different from full aft. The vertical position should be determined in accordance with Section 8.5. 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. To assess compliance, maximum loads need not be held for more than 1 sec.

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 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 relatively heavy frames, 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 imposed on the body block.

8.5.1.5 <u>Static Load Body Block</u>. The static test loads must be applied through a body block contoured to approximate a 95th-percentile occupant seated in a normal flying attitude. The body block must contain shoulders, neck, and upper legs, and provide for passage of a 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 80. 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 harness while maintaining the primary contact between the ischial tuberosities and the seat pan through the cushions.

8.5.1.6 <u>Deflection Measurements</u>. Deflection should be measured as close to the seat reference point as possible to eliminate 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.

8.5.1.7 <u>Load Determination</u>. The total load required for all test directions, except downward, is determined by multiplying the required load factor from Table 15 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 81 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 and the centripetal acceleration should apply the load factors of Table 15 for at least 1 sec.

8.5.1.8 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.

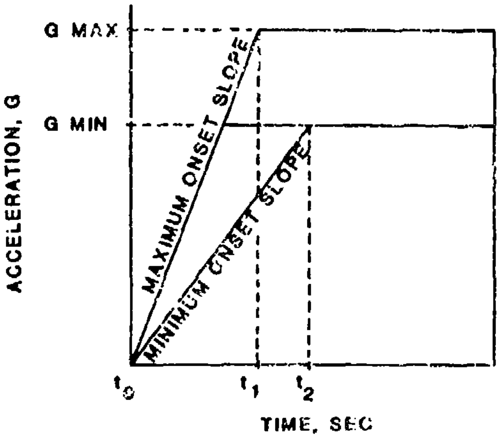
8.5.1.9 Seat Static Load Application By Centrifuge. As an alternative, load application by centrifuge is allowed. For each loading condition specified by Table 15, the appropriately sized dummy should be seated in the test seat and fastened with the restraint subsystem. The seat should be oriented relative to the centrifuge arm such that the load is applied in the required direction. The simulated aircraft floor or bulkhead should be deformed as required. The centrifuge device should be brought to a rotational speed corresponding to the required centripetal acceleration for at least one second. The seat should withstand each of the Table 15 load conditions without failure or deflections beyond limits.

8.5.2 Dynamic Test Requirements

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

Crewseats Designed for a Fixed Load. All prototype crew seats should meet the requirements of MIL-S-58095. These seats shall be dynamically tested to the conditions specified in Tests 1 and 2 of Figure 81. 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 should be performed with the inertia reel seat in the "auto-lock" mode.

String or tape sized to easily break at relatively low loads may be used to retain the dummy in the appropriate pretest position. The seat should retain the dummy within the confines of the restraint harness and should evidence no loss of structural integrity. Any failure of a restraint system load-carrying component or of a primary load-carrying structural member of the seat would 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 should be set in the mid-position for Test 1 and in the



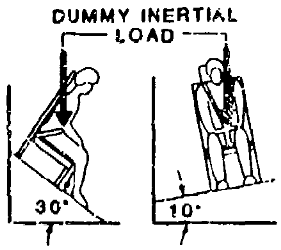
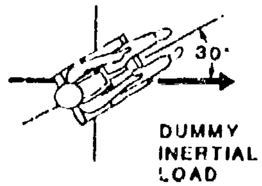
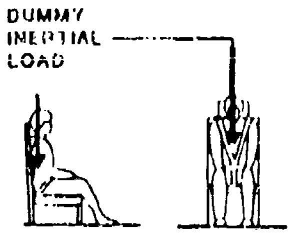
TEST	CONFIGURATION	PARAMETER	COCKPIT SEATS LIMITS	CABIN SEATS LIMITS
1		t_1 SEC	0.043	0.059
		t_2 SEC	0.061	0.087
		G MIN	46	32
		G MAX	51	37
		ΔV MIN, FT/SEC	50	50
2		t_1 SEC	0.080	0.081
		t_2 SEC	0.100	0.127
		G MIN	28	22
		G MAX	33	27
		ΔV MIN, FT/SEC	50	50
3&4		t_1 SEC	0.039	
		t_2 SEC	0.061	
		G MIN	46	
		G MAX	51	
		ΔV MIN, FT/SEC	42	

FIGURE 81. DYNAMIC TEST REQUIREMENTS FOR QUALIFICATION.

full-up position for Test 2. A clothed Hybrid III or VIP-95 95th-percentile dummy weighing 230 lb (105 kg) should be used for Tests 1 and 2. For all tests, the dummy's feet should be secured in a representative antitorque pedal position.

Crew Seats Designed with an Adjustable Load Attenuation System. These seats should be dynamically tested to the conditions specified in all four tests of Figure 81. 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-pcercentile 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 cm).

Cabin Seats. All prototype troop/passenger seats should meet the requirements of MIL-S-85510 (Reference 15), which requires dynamic testing to the conditions specified in Tests 1 and 2 of Figure 81, using a clothed 50th-percentile dummy (Reference 120) in Test 1 and a clothed 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 81, 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 8.2) 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 26 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 81:

1. Determine the maximum acceleration and construct the onset slope for the test pulse by the method explained in Section 8.5.3.

2. Compare the achieved onset and peak acceleration of the test pulse with those allowed and presented in Figure 81. 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 81 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.

8.5.2.2 <u>Special Dynamic Test Requirements for Seats Having Less Than 12 in. of Vertical Stroke</u>. In the event that the application of a system's approach permits the seat to have less than 12-in. (30.6-cm) 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 82. 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 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 81).

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 system 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.

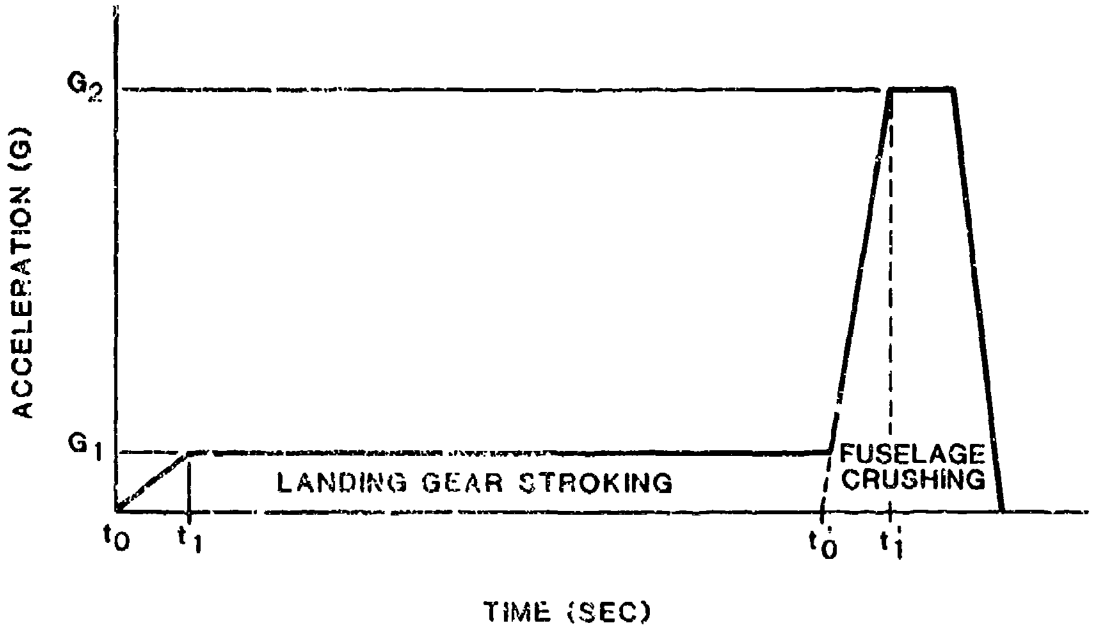


FIGURE 82. EXAMPLE OF INPUT PULSE FOR SEATS HAVING LESS THAN 12 IN. OF STROKE.

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 8.5.2.1 for establishing compliance with the required test pulse applies directly to the portion of the special test pulse following t_0'.

8.5.3 Data Acquisition and Reduction

Data acquisition and reduction should comply with the requirements of SAE J211 (Reference 121) for measurements of an anthropomorphic dummy, body accelerations, 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 16 for convenience. Data should be visually examined in the unfiltered state to assure that saturation or other distortion did not occur.

TABLE 16. 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
Test fixture and seat 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 $\pm$ 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 3 (Section 2.7). 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 8.5.2) and to determine other parameters associated with the data is similar to that presented in MIL-S-9479(USAF), see Reference 122.

Parameters such as rise time, onset slope, and acceleration plateau duration may be obtained using the following graphic approximation technique shown in Figure 83.

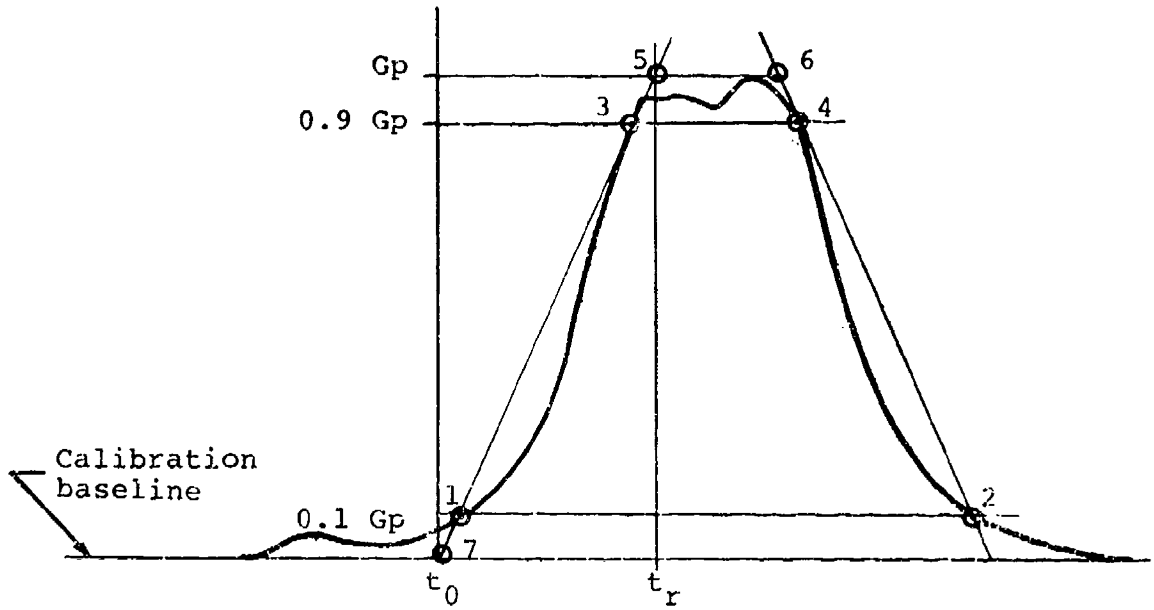


FIGURE 83. GRAPHIC APPROXIMATION EXAMPLE. (REFERENCE 122)

- 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 logic and practical judgment may be required for selection of the first and last intersections depending on the 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 (Δt).

- 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). Referring to Figure 81, the rise time should be greater than t_1 but less than t_2 when determining compliance with dynamic test requirements. Point 7 is the initial time t_0 in Figure 81.

8.5.4 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
Upward:	10 G
Forward:	35 G
Aftward:	15 G
Lateral:	25 G

These criteria may be somewhat conservative for load-limited seats; however, load limiting is mandatory in the vertical direction only. In light of the potential hazard, the strength requirements are considered justified.

9. RETROFIT FOR SEATING SYSTEMS

If a retrofit effort is initiated 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.

9.1 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 crew seats for both the SH-3 and CH-53 helicopters. For each of these aircraft, crew seats 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 84 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 85 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 18 and 19.

9.2 STRENGTH AND DEFORMATION

9.2.1 Forward Loads

In Section 4.7, it was shown that for a load-limited system there is a minimum displacement that must be achieved if the system is to remain in place during a given deceleration 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 occupants capacity to survive the loads imposed.

The basic data used in developing the seat design curves presented in Figure 85 were obtained through a computer simulation of the seat/occupant system and from the results of static and dynamic seat tests (References 35, 36, 77, and 100) using body blocks and anthropomorphic dummies, respectively.

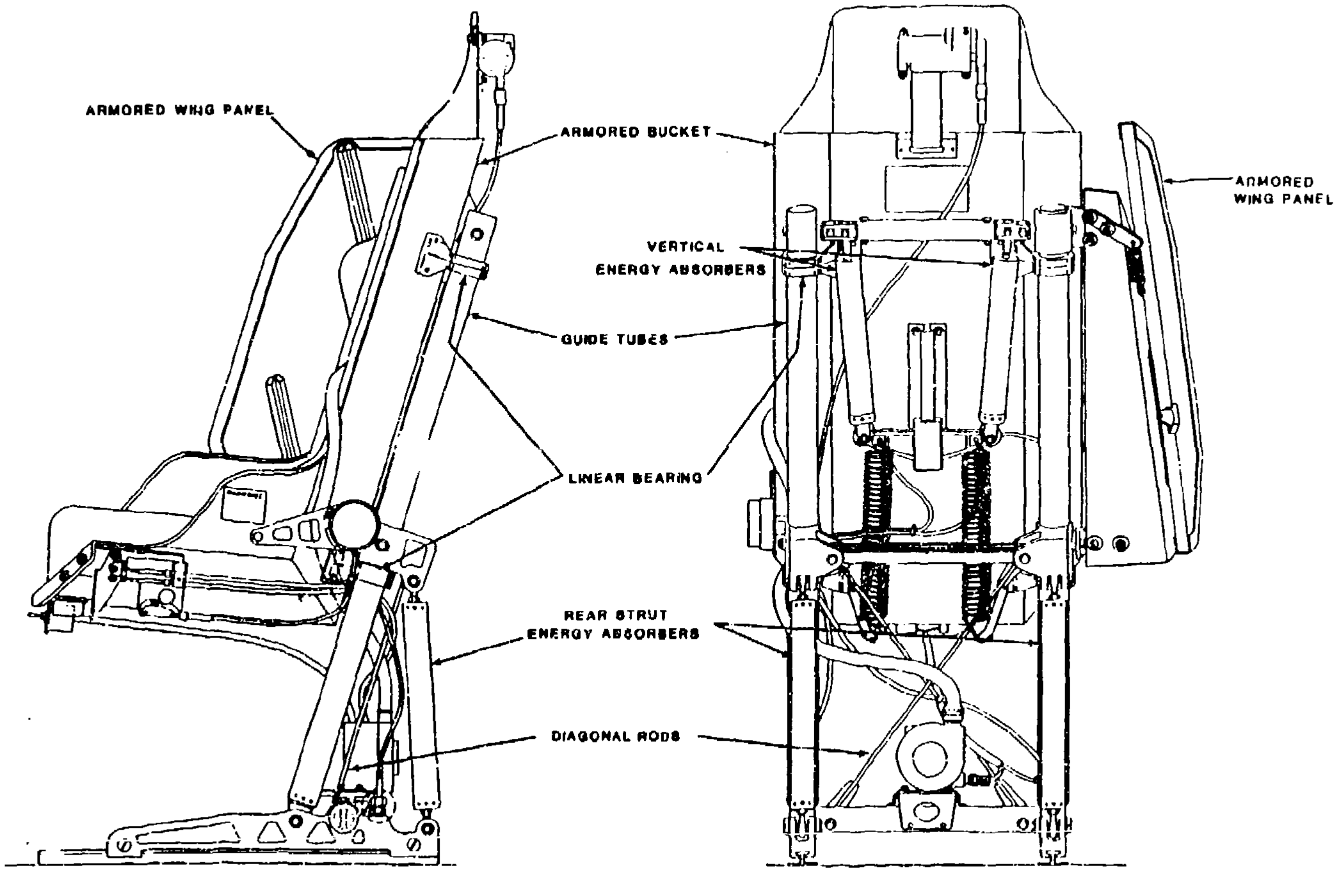


FIGURE 84. CH-53 CREWSEAT.

The computer simulation allowed the calculation of the seat displacement for given load-limiting values. The simulator included a realistic kinematic behavior of the occupant and the nonlinear effects of the restraint system. It is estimated that the requirements given in Figure 85 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 85 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 8.2.1).

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

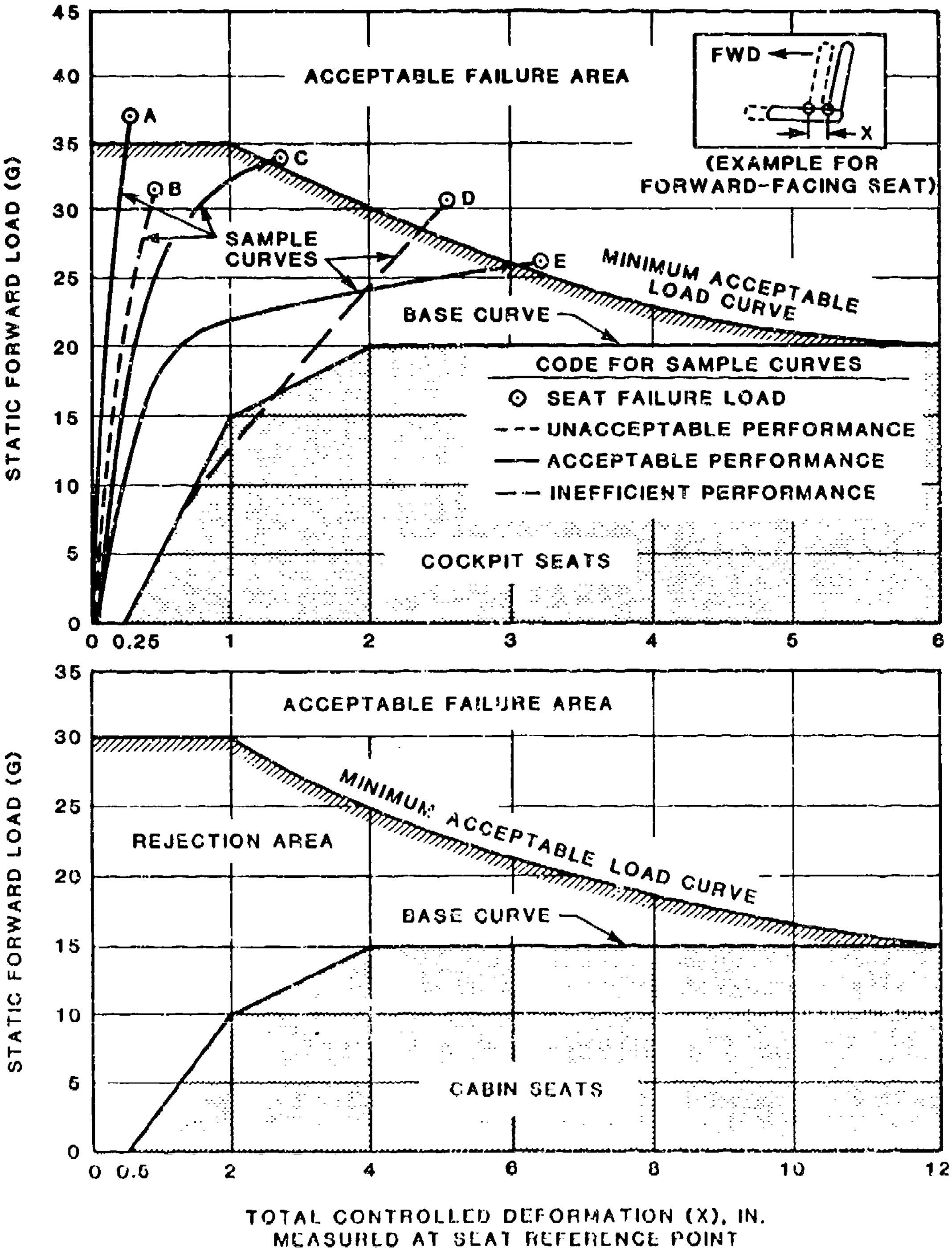


FIGURE 85. SEAT FORWARD LOAD AND DEFLECTION REQUIREMENTS FOR ALL TYPES OF ARMY AIRCRAFT (FORWARD DESIGN PULSE).

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 a seat weight and increase the level of protection offered over a wider occupant weight range.

In viewing Figure 85, 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 85 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 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 cabin and cockpit locations, and practical limitations of seat weight and excessive airframe loading.

9.2.2 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 85 and extends into the region beyond the upper curve. This discussion also applies to the lateral strength and deformation requirements discussed in Section 9.2.4. In Figure 85 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 it could.

9.2.3 Downward Loads

See Section 8.3.3 for a discussion of downward loads, in which a minimum seat stroke of 12 in. (30.5 cm) is recommended. If it is absolutely impossible to obtain a minimum of 12 in. of stroke, a lesser amount can be used, but 7 in. (17.8 cm) is a practical minimum. The reduced stroke should only be used for a retrofit application or for use in small aircraft in which it is simply impossible to find the space for a 12-in. stroke. In such cases a systems analysis should be used; the analysis should show the occupant protection level achieved. The design goal is to approach the 12-in.-stroke occupant protection level; however, retrofit of some stroking capability is superior to no retrofit. The resulting retrofit capability will be limited to those accidents with less severe impact conditions.

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 8.5.2.2 of this document.

9.2.4 Lateral Loads and Deformation

The lateral load and deformation requirements for forward- and aft-facing seats are presented in Figure 86. Two curves are presented. One is for light fixed-wing aircraft and attack and cargo helicopters, while the other is for other rotary-wing aircraft. The deflections of the seat are to be measured by recording the motions of the seat reference point. Occupant weight should be as stated in Section 8.2 and should be that of the 95th-percentile aircrew member or troop.

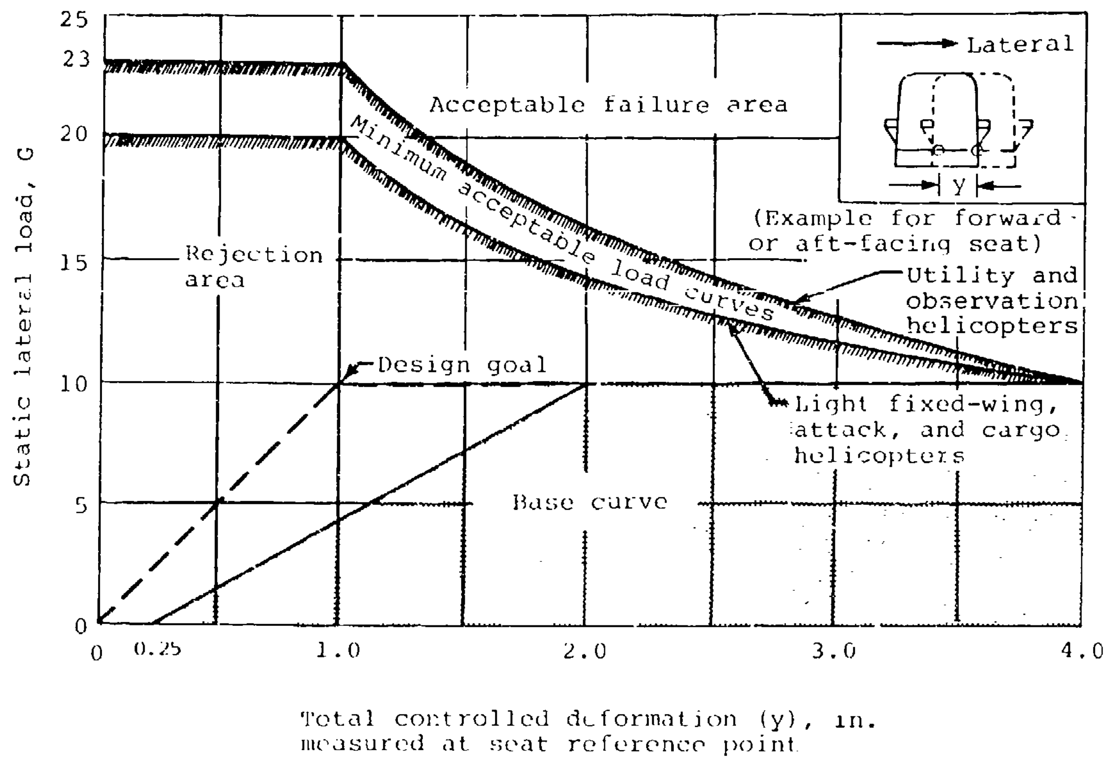


FIGURE 86. LATERAL SEAT LOAD AND DEFORMATION REQUIREMENTS FOR ALL TYPES OF ARMY AIRCRAFT.

Lateral loading in the forward direction (aircraft reference system) on side-facing seats should be the same as for forward-loading (Figure 85) except load limiting should be employed.

For crew seats, the lateral deflection should be minimized; however, it is doubtful if any great stiffness can be achieved in lightweight hardware. As a matter of interest, many new armored buckets are made from Kevlar, a very tough and strong material in tension. Its resin-starved condition (required for good ballistic protection properties) leaves it with a rather low flexural modulus, particularly after the seat has had other loads imposed. The material is also rather rate sensitive (stiff under high loading rates, soft under low rates). For this reason, 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 considered acceptable to demonstrate compliance by analysis of test data. This analysis might include adjustment of the 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 may allow the seat to realign itself with the well prior to entry after the lateral and longitudinal loads are relieved, as explained in Chapter 4.

9.2.5 Other Observations

The requirements presented for crewseats or 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.

It should be noted that forward and lateral energy-absorbing characteristics in a seat increase the chances of flailing injury while protecting the occupant from seat/aircraft separation. Extensive deformation of the seat might also trap the occupant. Therefore, the technique of energy-absorber limiting of airframe loads should only be used when no other techniques are possible. Also, energy-absorber loads should be as high as possible to minimize deformation.

9.3 ENERGY ABSORBERS IN RESTRAINT SYSTEMS

As mentioned in Section 7.5.5, incorporation of energy absorbers into the seat occupant restraint system can reduce restraint loads and alter the relationship between load and aircraft deceleration.

9.3.1 Test Run Equipment For Energy Absorbers Retrofitted in the Diagonal Shoulder Strap

Sled tests (Reference 123) using an Alderson VIP50 anthropomorphic 77-kg (170-lb) dummy representing a 50th-percentile male were made both with and without an energy absorber inserted in the diagonal shoulder strap at a point between the back of the seat and the frame. Two types of energy absorbers were used (Figures 87 and 88). Type A was a commercial unit which dissipated energy by twisting a torsion bar. Extra webbing on the end of the shoulder strap was stored on a reel, the rotation of which was controlled by the torsion bar. When the torque from the tension in the strap exceeded the torsional strength of the bar, the reel rotated and allowed the shoulder strap to extend. Type B was a unit that dissipated energy by plastic bending of two mild steel strips that was folded in a V-shape and fitted into a case. One

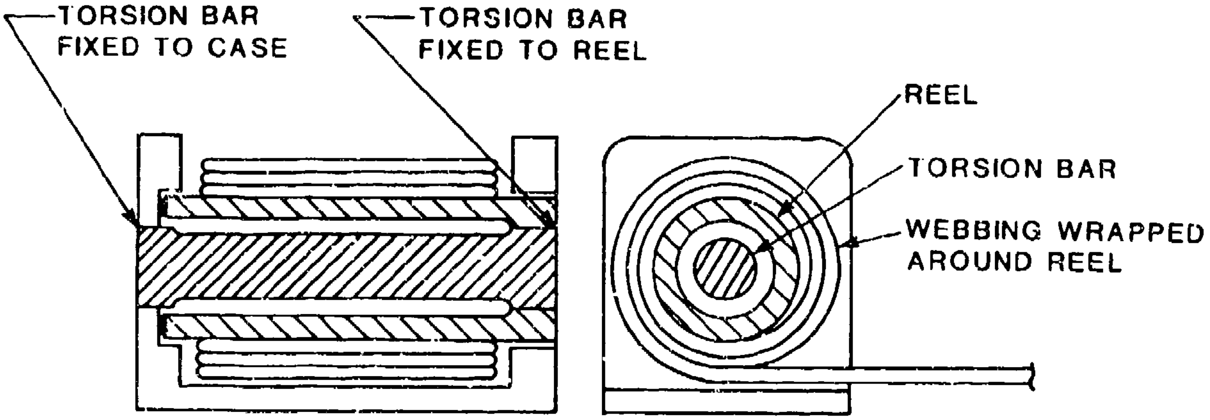


FIGURE 87. CONSTRUCTION OF TYPE 'A' ENERGY ABSORBER. (FROM REFERENCE 123)

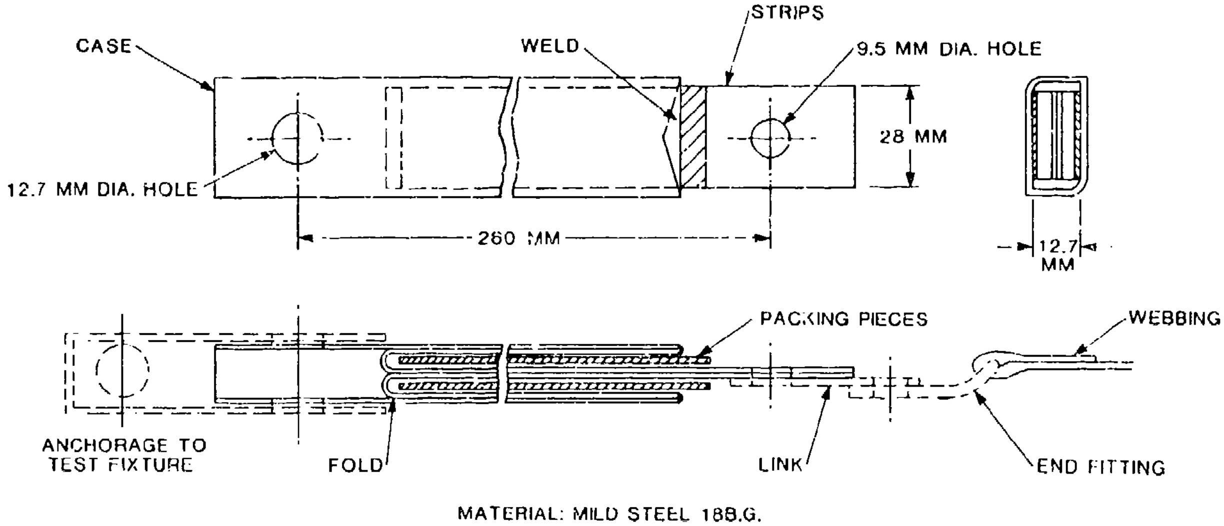


FIGURE 88. CONSTRUCTION OF TYPE 'B' ENERGY ABSORBER. (REFERENCE 123)

end of each strip was welded to the case. Load was applied to the case and the other end of the strips. When the load overcame the bending strength of the strips, the fold rolled along the case allowing the unit to extend.

9.3.2 The Effect of Energy Absorbers in the Diagonal Shoulder Strap

The development of the loads in diagonal shoulder straps with and without an energy absorber at a sled peak acceleration of 28.5 G showed that incorporation of an energy absorber into the shoulder strap of a restraint system reduced the load in that strap by 50 percent and maintained an almost uniform load. However, there is a trade-off with shoulder displacement of an additional 130 mm (5.1 in.), thus increasing the occupant strike envelope. An energy absorber could also be used in the lap strap to decrease pelvic loads; however, the problem of slack in the strap would have to be resolved.

Tests without an energy absorber in the restraint system indicated that forces in the restraint could reach the typical design ultimate loads for light aircraft at a cabin peak deceleration of only 8 G. An energy absorber in the restraint would allow the system to withstand cabin decelerations of greater severity without an increase in the restraint forces, and may have to be used in some retrofit applciations where insufficient strength is available in the structure to carry the unlimited loads.

9.3.3 Energy-Absorbing Restraint Tests

The Aeronautical Research Laboratories in Australia reported (Reference 124) the results of a comparison of conventional and energy-absorbing restraint systems. In each test an Alderson VIP50 dummy was seated in a simulated light aircraft seat with an automotive-type lap/shoulder seat belt and subjected to longitudinal accelerations from 12 G to 30 G. Tests were made with a load-limited shoulder strap. The study recorded relative body displacements for the various restraint conditions.

9.4 RETROFITTING OF ENERGY-ABSORBING INERTIA REEL

Energy absorption through restraint webbing elongation may allow severe occupant injury due to flailing. The webbing absorbs the impact energy elastically, similar to stretching a rubber band. It will reduce impact loads, but the energy is stored rather than absorbed, and will be returned to the system after impact. The timing of this load return can be significant. A more efficient system would allow loading to build to a tolerably high level and then deform or deflect an energy absorber at an essentially constant load (Reference 125).

Figure 89 depicts performance test data of a typical restraint system component modified to incorporate energy absorption. A modified MIL-R-8236, MA-6 inertia reel, used as the energy absorber, is shown in Figure 90. A set of relatively soft metal rollers are press fit between the shaft and the ratchet wheel of the reel. Loads exceeding a predetermined value of 2,000 lb deform the rollers as the shaft rotates inside the ratchet wheel, thus providing a large amount of energy-absorbing capability within a very small envelope. Forward travel was 3.6 in. compared to a typical lap belt travel of 1.8 in. without insertion of an energy absorber, thus contributing an additional 1.8 in. to the overall flail envelope.

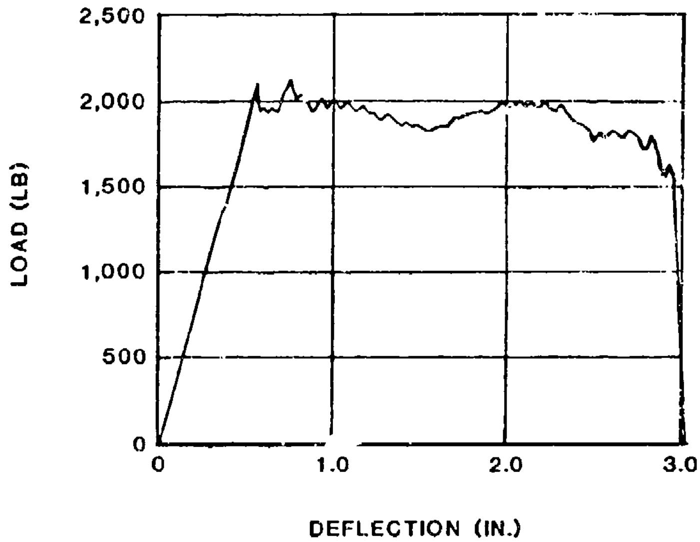


FIGURE 89. LOAD-VERSUS-DEFLECTION CURVE, ENERGY ABSORBER INERTIA REEL. (REFERENCE 125)

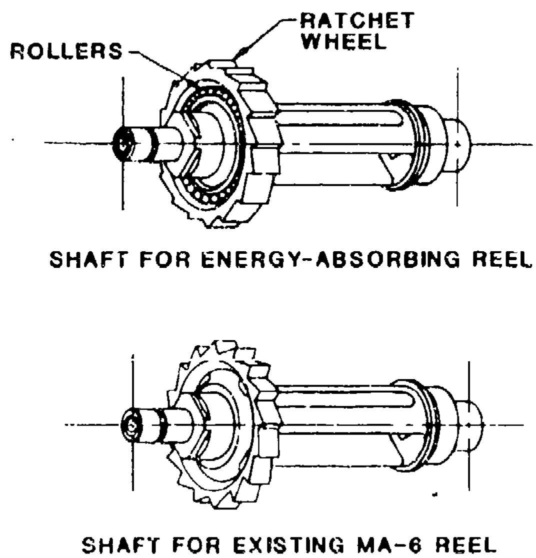


FIGURE 90. MODIFICATION OF INERTIA REEL TO SERVE AS ENERGY ABSORBER. (FROM REFERENCE 125)

9.5 USE OF RIP STITCH TO LIMIT SHOULDER HARNESS LOADS

The principle of using rip stitches to absorb energy is mentioned in Section 7.4.4. In Reference 126 the authors report that new design features for the Cessna Caravan 1 crewseat/restraint system were tested at the Protection and Survival Laboratory dynamic impact test track facility of the FAA Civil Aero Medical Institute. The work included fabrication of the shoulder harness with a rip stitch to reduce harness loads, submarining, and pelvic/lumbar loading. The military flying population would not require the load limiting on the body, and the Cessna uses a ceiling-attached shoulder restraint so that limiting floor-seat loads is not a major concern. However, the same rip stitch concept could be used in the same way, but with the shoulder restraint attached to the seat to reduce floor loads in a retrofit application.

It is possible to design webbing so that it will absorb some energy itself without depending upon the ripping of stitching. This is done by blending fibers of different stiffness when the webbing is woven. When the material is loaded, the stiffest fibers break first, and the progressive tensile failure of the stiffer fibers provides a load-limited, energy-absorbing region. Eventually, higher-strength, higher-elongation fibers support the load and the webbing reacts similarly to conventional webbing following the energy-absorbing process. Figure 91, from Reference 127, shows the performance of a sample of such webbing compared to all nylon MIL-W-4088 cargo tiedown webbing. The energy-absorbing webbing for this test used a mix of nylon, polyester, and polyvinyl alcohol fiber.

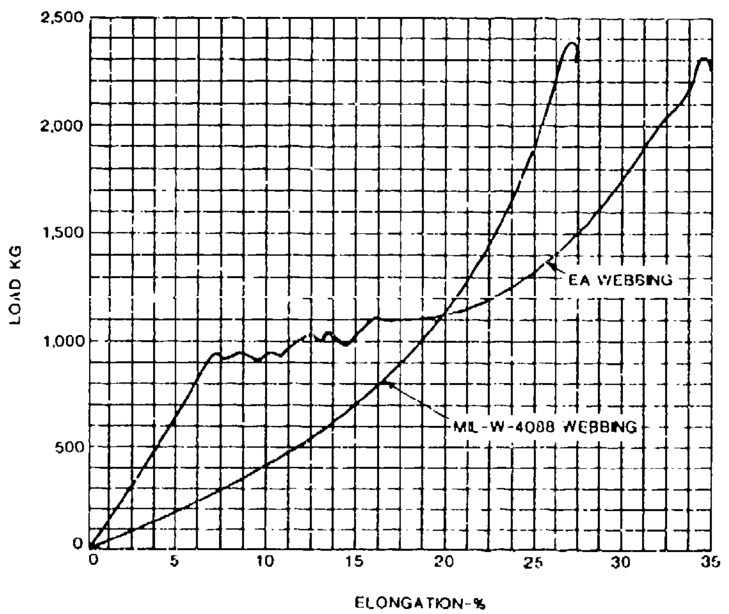


FIGURE 91. LOAD ELONGATION OF ENERGY-ABSORBING WEBBING AND MIL-W-4088 NYLON CARGO TIEDOWN WEBBING. (REFERENCE 127)

10. LITTER STRENGTH AND DEFORMATION REQUIREMENTS

10.1 INTRODUCTION

This chapter presents strength and deformation requirements for litter systems. Aircraft systems are rather difficult to design because of limitations including that of the strength of existing litters and width of utility aircraft as compared to the length of standard litters. The ultimate vertical strength of existing litters with a 200-lb occupant and a total system weight of 250 lb (see Section 10.2) 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. A new litter should be developed having the required strength to support loads in excess of 13 G, preferably 17 G, as presented as a minimum in this chapter.

The other problem is associated with the length of the litter. The standard litter is 90 in. long from handle end to handle end and 20.5 in. wide from pole center to pole center; the poles have a 1.5-in. outside diameter, making the overall width 22.0 in., exclusive of cover canvas thickness (Reference 128). The width of the new Army utility helicopter does not allow litters to be placed in the preferred lateral direction. The lateral orientation is preferred because of the characteristics of existing restraint systems used on litters which provide more support when loaded laterally than when loaded longitudinally. Since higher loads are more frequently seen in the forward direction than in the lateral, it would be desirable to orient the litters laterally in the aircraft. This is not possible because the helicopter is not wide enough, so special devices have been developed to permit loading the litters in a lateral direction and then rotating the litters into a fore-and-aft orientation inside the aircraft. Improved litter restraint systems are needed to provide the desired support to the supine occupant on litters orientated in the fore-and-aft direction in these aircraft. An example of a potentially improved litter restraint is individual thigh straps and a chest strap for a litter with feet forward orientation.

This chapter presents the design strength/deformation relationships and testing requirements for aircraft litters and their supports.

10.2 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 129).

10.3 VERTICAL LOADS

10.3.1 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 (see Volume II). The use of ceiling-supported litters is limited by the strength of the overhead fuselage structure. The inefficiency of structural deformation of the ceiling of older aircraft requires additional energy-absorbing stroke to provide the protection desired. 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 92. This curve is read in the identical manner as the seat load/deflection curve shown in Figure 85. 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 10.2. The curve of Figure 92 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 larger 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.

The additional problem associated with inadequate litter strength must be dealt with in the design of litter systems. The curve of Figure 92 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 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 mechanism, then the stroke can be extended to 12 in. at a 17-G limit-load factor. The load/deformation curve of Figure 92 would be extended at 17 G to 12 in. of stroke.

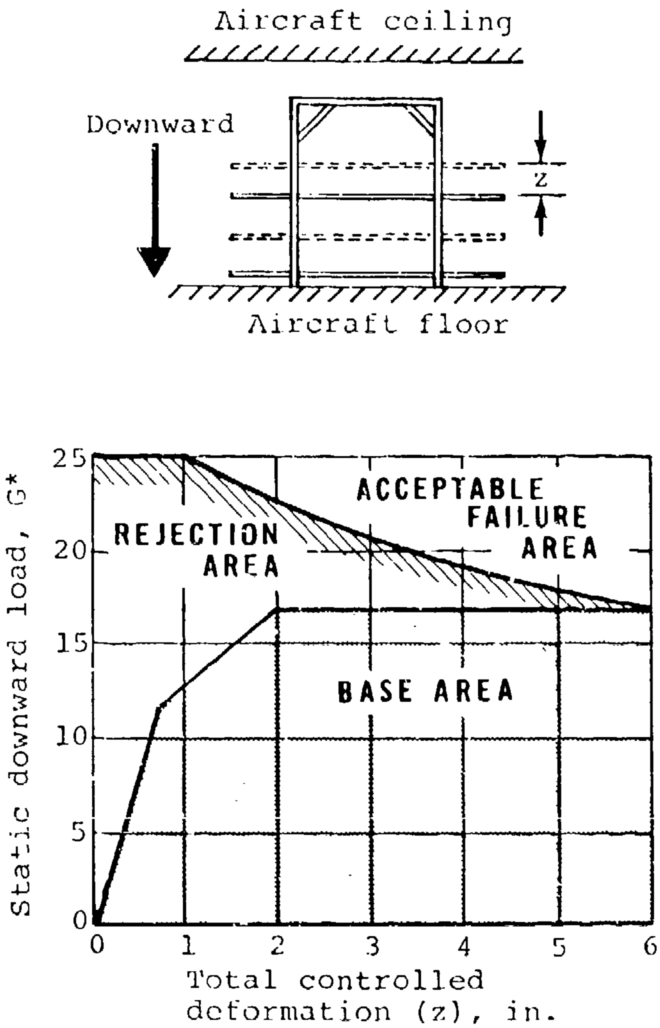
Further background information on analysis and testing of helicopter litter systems can be found in Reference 26.

10.3.2 Upward Loads

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

10.4 LATERAL AND LONGITUDINAL LOADS

Litter systems for all aircraft should be designed to withstand the load and deformation requirements indicated in Figure 93 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.

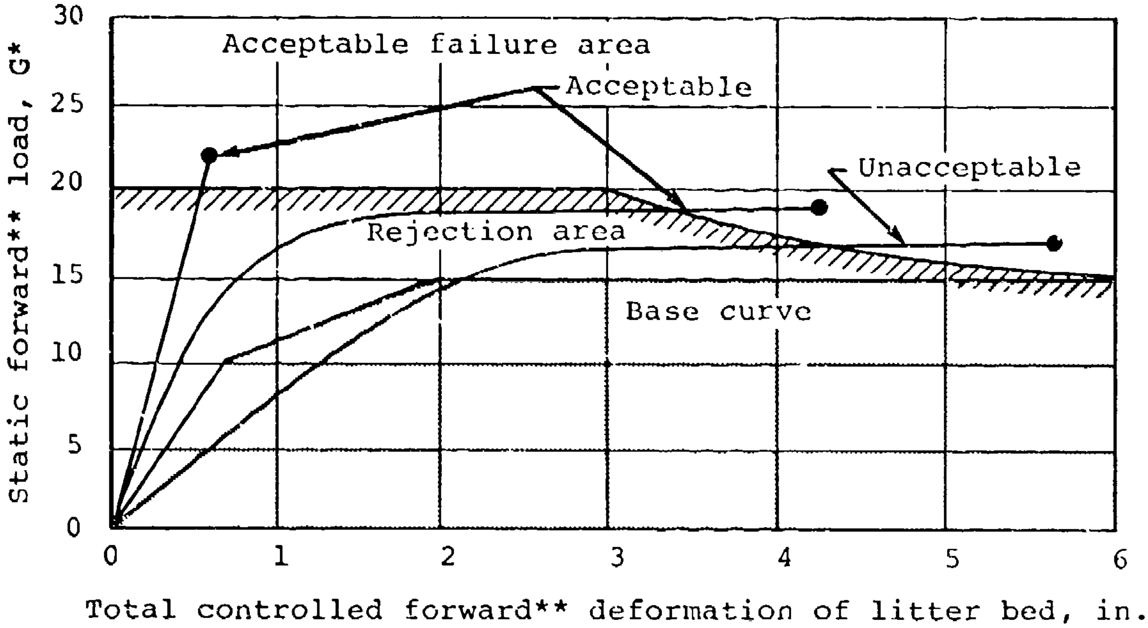


*G value based on 250-lb per litter position.

FIGURE 92. LITTER DOWNWARD LOAD AND DEFLECTION REQUIREMENTS.

The 20-G acceptable load level indicated in Figure 93 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 crashworthiness, the 20-G load should be increased to 25 G.

Acceptable or nonacceptable load/deformation characteristics are read from Figure 93 in the identical manner as the readings from Figures 85 and 86 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.



*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 93. LITTER FORWARD OR LATERAL LOAD AND DEFLECTION REQUIREMENTS FOR ALL TYPES OF ARMY AIRCRAFT.

10.5 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.

10.6 LITTER SYSTEM TEST REQUIREMENTS

10.6.1 Static Test Requirements

10.6.1.1 General. Table 17 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

TABLE 17. LITTER SYSTEM STATIC TEST REQUIREMENTS

Test Ref. No.	Loading Direction With Respect to Fuselage Floor	Load Required	Deformation Requirements
1	Forward	See Figure 93	See Figure 93
2	Lateral	See Figure 93	See Figure 93
3	Downward	See Figure 92	See Figure 92
4	Upward	8 G	No requirement
5	Combined loading		
	Downward plus transverse load along any radial in the x, y plane of the aircraft	See Figure 92 See Figure 93	See Figure 92 See Figure 93

to implementing these recommendations. The tests required include a series of unidirectional tests to determine basic litter and attachment strengths in the major axes. Also, a combined loading test is required to evaluate the litter system performance under static conditions simulating a severe crash loading situation with loading components in multiple directions. Since the litter orientation can be either lateral or longitudinal, a single requirement is made for transverse loading in the horizontal plane (Test 5).

10.6.1.2 __Unidirectional Tests__. The test loads for forward, lateral, and downward loading of litter systems as presented in Table 17 should be applied separately.

10.6.1.3 __Combined Loads__. Litter systems must demonstrate no loss of system integrity under conditions of combined loads as specified in Table 17.

10.6.1.4 __Point of Load Application__. The loads should be applied through a body block that simulates a supine occupant.

10.6.1.4.1 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 has adequate strength to take the loads.

10.6.1.4.2 **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 is adequate, then the load should be applied at the center of gravity of the body block.

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

10.6.1.6 **Load Determination**. The test load should be determined by multiplying the required load factor (G) as specified in Table 17 by 250 lb.

10.6.2 Litter System Dynamic Test Requirements

A single test to evaluate the vertical load-limiting system is required. Litter systems with 95th-percentile anthropomorphic dummies and 30 lb (250 lb total) of additional weight 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 8.5 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 should also be measured. It is advisable to use redundant accelerometers to sense the input pulse to assure acquisition of the needed impact environment data.

11. DELETHALIZATION OF COCKPIT AND CABIN INTERIORS

11.1 INTRODUCTION

The kinematics of body action associated with aircraft crash impacts are quite violent, even in accidents of moderate severity. The flailing of body parts is much more pronounced when the aircraft occupant is restrained in a seat with only a lap belt. However, even with a lap belt and a shoulder harness that are drawn up tightly, multidirectional flailing of the head, arms, and legs, and to a lesser extent, the lateral displacement of the upper torso within its restraint harnessing, is extensive. If it were possible to provide adequate space within the occupant's immediate environment, this flailing action of a fully restrained occupant would not be a particular problem. Since space for occupants is usually at a premium in aircraft, especially in cockpit areas, it is not feasible to remove structural parts of the aircraft sufficiently to keep the occupant from striking them. The only alternative is to design the occupant's immediate environment so that, when the body parts do flail and contact rigid and semirigid structures, injury potential is minimized.

An occupant who is even momentarily debilitated by having his head strike a sharp, unyielding structural object or by a leg injury can easily be prevented from rapidly evacuating the aircraft and may not survive a postcrash fire or a water landing. The importance of occupant environment designed for injury prevention, therefore, should be emphasized if optimum crash protection is to be ensured.

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.

11.2 OCCUPANT STRIKE ENVELOPES

11.2.1 Full Restraint

Body extremity strike envelopes are presented in Figures 94 through 96 for a 95th-percentile Army aviator wearing a restraint system that meets the requirements of MIL-S-58095 (Reference 14). The restraint system consists of a lap belt, lap belt tiedown strap, and two shoulder straps. The forward motion shown in Figures 94 and 95 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.

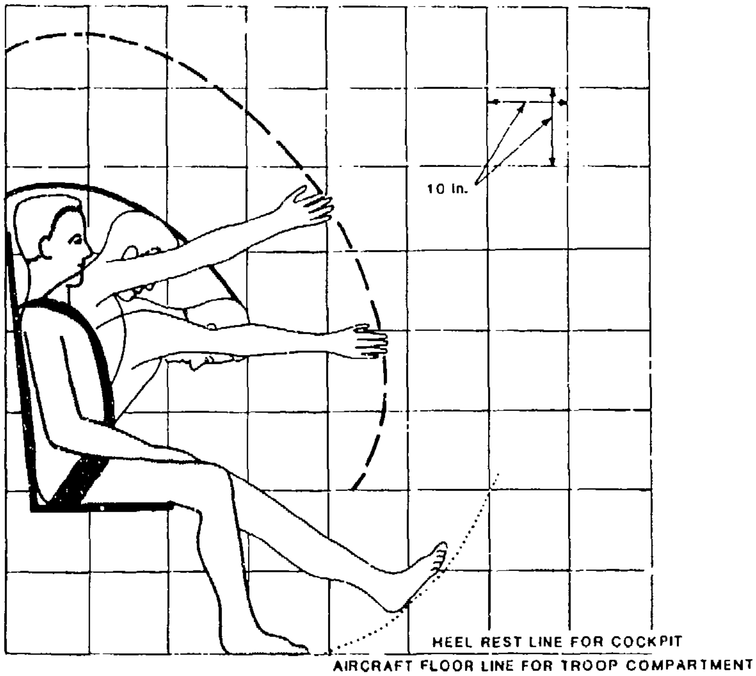


FIGURE 94. FULL-RESTRAINT EXTREMITY STRIKE ENVELOPE - SIDE VIEW.

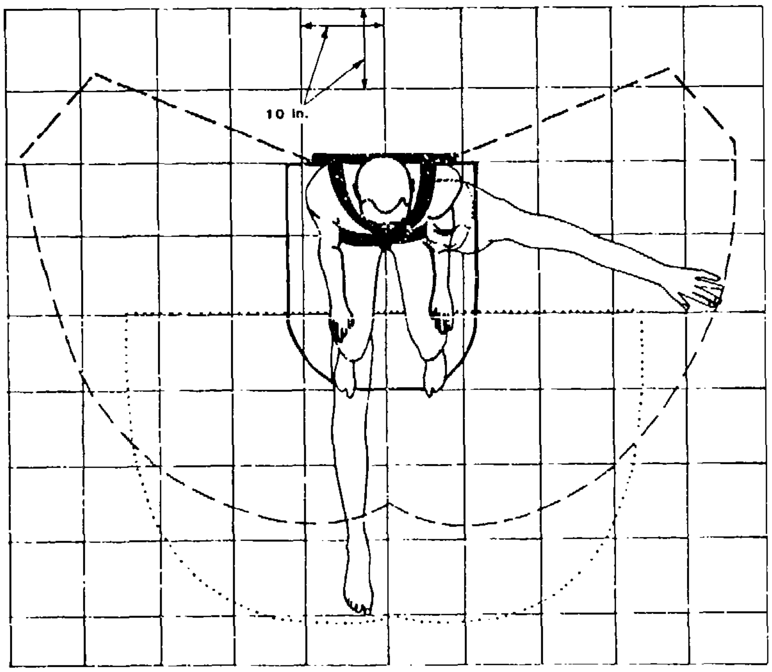


FIGURE 95. FULL-RESTRAINT EXTREMITY STRIKE ENVELOPE - TOP VIEW.

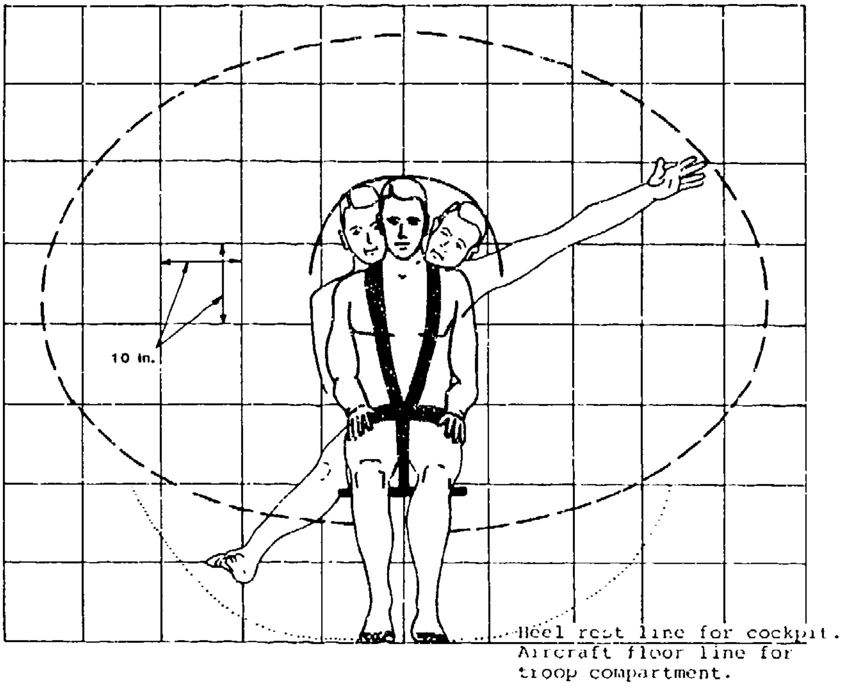


FIGURE 96. FULL-RESTRAINT EXTREMITY STRIKE ENVELOPE - FRONT VIEW.

11.2.2 Lap-Belt-Only Restraint

Although upper torso restraint is required in new Army aircraft, strike envelopes for a 95th-percentile aviator wearing lap belt-only restraint are presented in Figures 97 through 99 for general information. They are based on 4-G accelerations and 4 in. of torso movement away from the seat laterally and in a forward direction. In positions where an occupant is expected to wear a helmet, the helmet dimensions must be added to the envelope of head motion.

11.2.3 Seat Orientation

The strike envelopes of Figures 94 through 99 apply to all seat orientations.

11.2.4 Comparison of Strike Envelope Using Various Restraint Types

Crash impact sled tests were performed on various restraint types at the Federal Aviation Administration Civil Aeromedical Institute (CAMI), using an Alderson Model VIP-95 95th-percentile adult male anthropomorphic dummy (Reference 103). Runs were made at peak input accelerations of 5.4, 16, and 30 G.

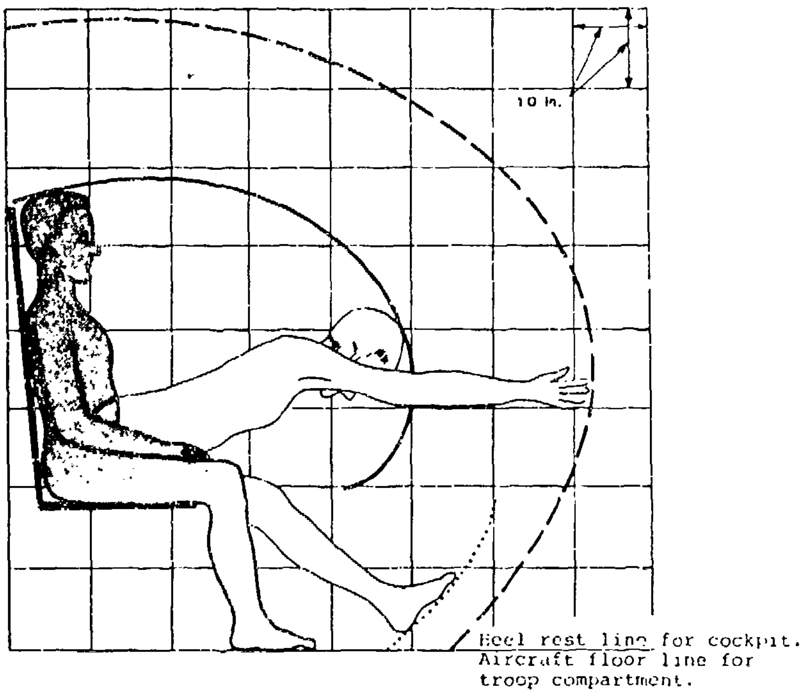


FIGURE 97. LAP-BELT-ONLY EXTREMITY STRIKE ENVELOPE - SIDE VIEW.

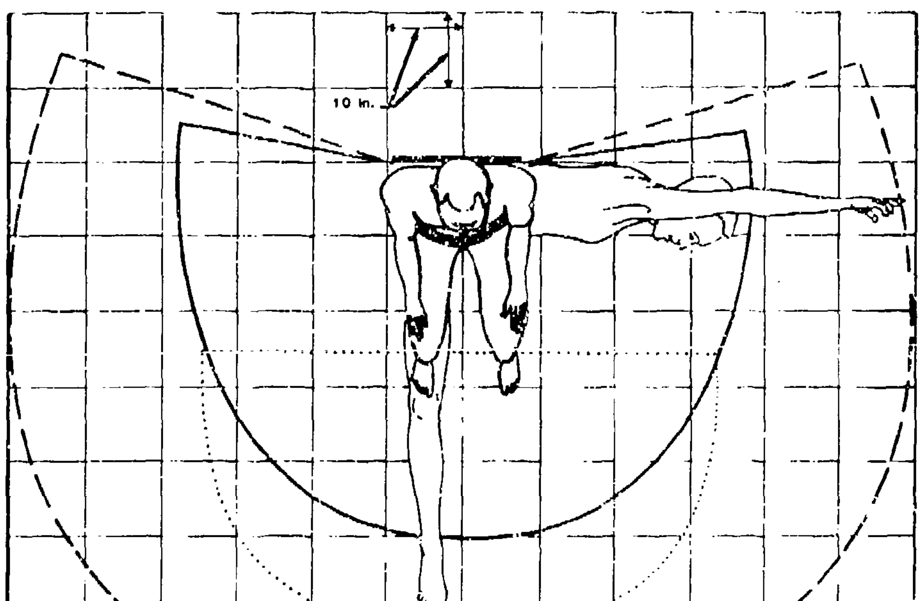


FIGURE 98. LAP-BELT-ONLY EXTREMITY STRIKE ENVELOPE - TOP VIEW.

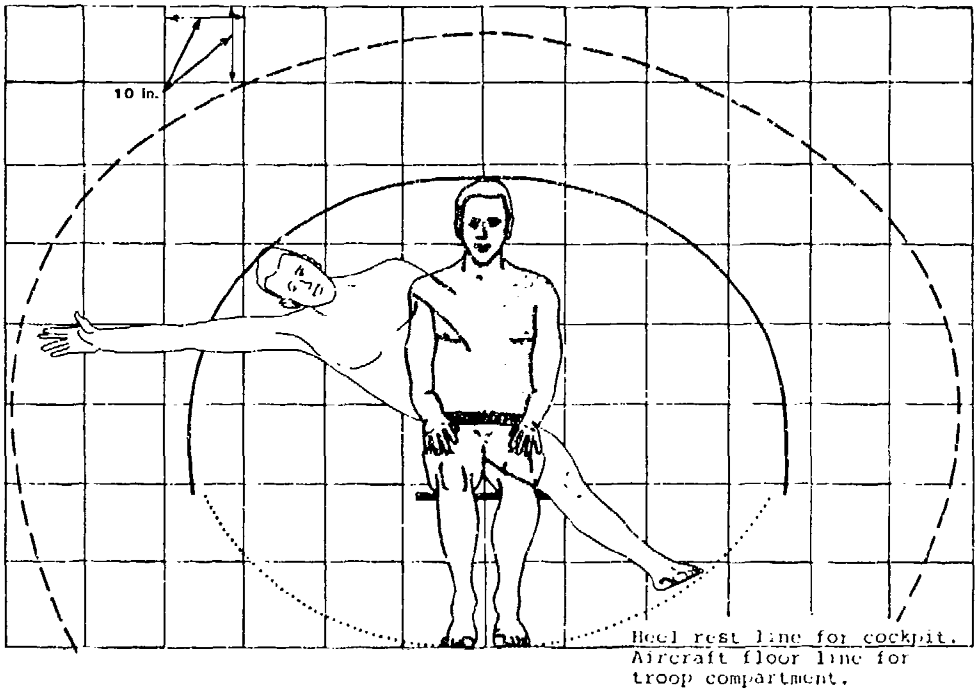


FIGURE 99. LAP-BELT-ONLY EXTREMITY STRIKE
ENVELOPE - FRONT VIEW.

In all tests the experimental prototype inflatable body and head restraint system (IBAHRS) shown in Figure 66 produced the best occupant head strike envelope (least forward motion of head, neck, and upper torso). However, it was observed that the advantage was diminished as the severity of the test pulse increased. The IBAHRS contains inflatable bags sewn on the underside of the shoulder straps which are inflated within 0.06 sec. by the action of a crash impact sensor. The inflated bags force the seat occupant against the seat back, thus reducing the strike envelope, dynamic overshoot, concentration of strap load on the body, and rotation and whiplash-induced trauma. Since the bags deflate immediately after inflation, they are effective for only a single pulse; however, the occupant is then restrained by the base restraint system.

Figure 100 illustrates the strike envelope for an occupant wearing the IBAHRS relative to one wearing the standard MIL-S-58095 restraint system for two different crash pulses.

11.2.5 Head Strike Envelope in Stroking Seats

The head strike envelope for a stroking energy-absorbing seat is obviously exaggerated relative to the above diagrams since the downward seat bucket

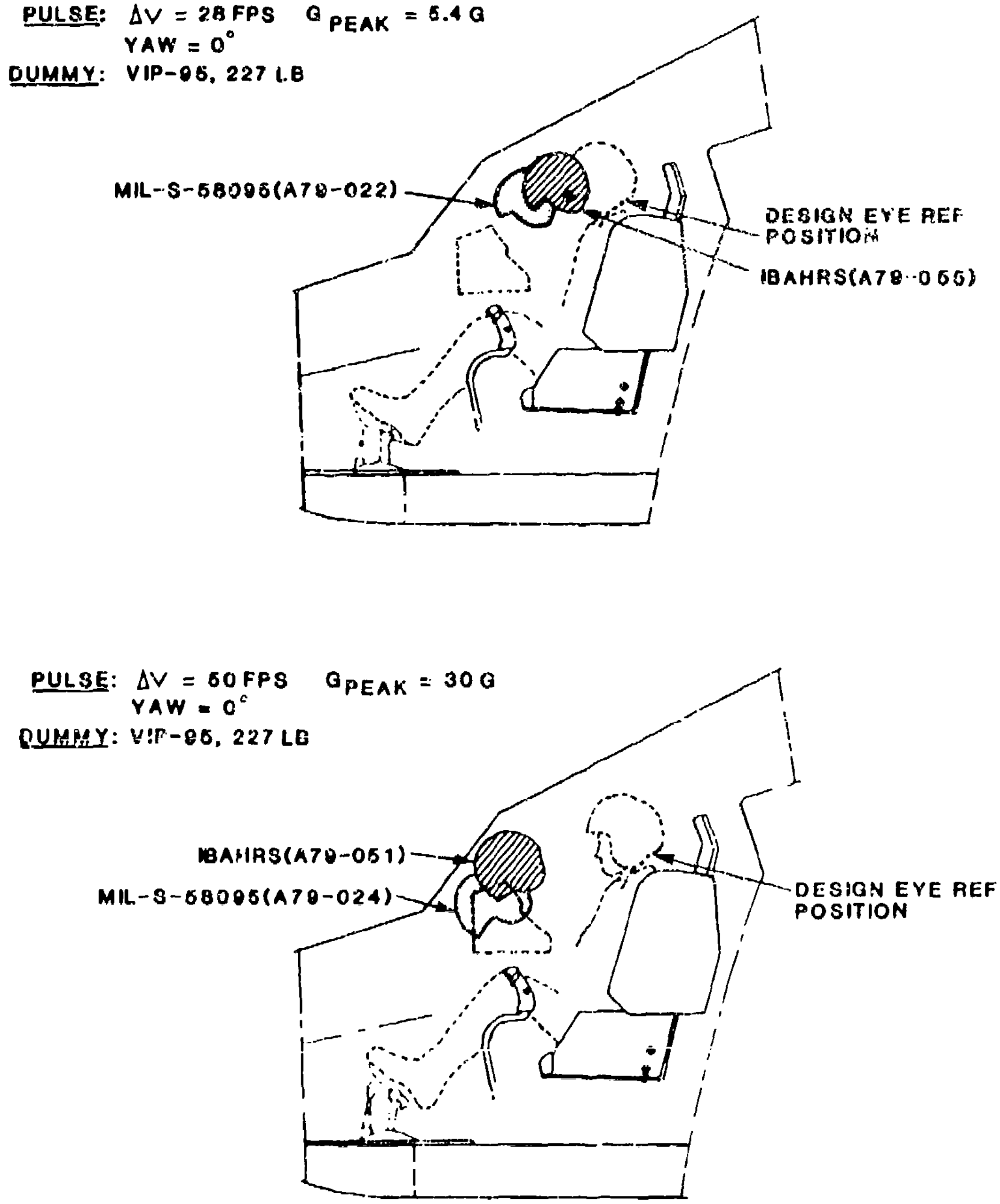


FIGURE 100. COPILOT/GUNNER STRIKE ENVELOPE COMPARISON. (REDRAWN FROM REFERENCE 103)

motion contributes to extended head motion. Reference 130 describes some simulations which were performed to evaluate the head strike envelope in this situation.

Computer program SOM-LA was used for computer simulations of both the 50th- and 95th-percentile crewmembers. For this simulation a 48-G vertical drop with 30-degree forward pitch angle and 50-ft/sec velocity change was used. This pulse is the same as the vertical dynamic test pulse of Section 6, except that the 10-degree roll was not included in order to limit the simulation to two dimensions. The occupants were restrained with a five-point restraint harness. They were assumed to be seated in crash-resistant crewseats of the type used in the UH-60A, and the program accounted for the stroking of the seat. The results are illustrated in Figure 101.

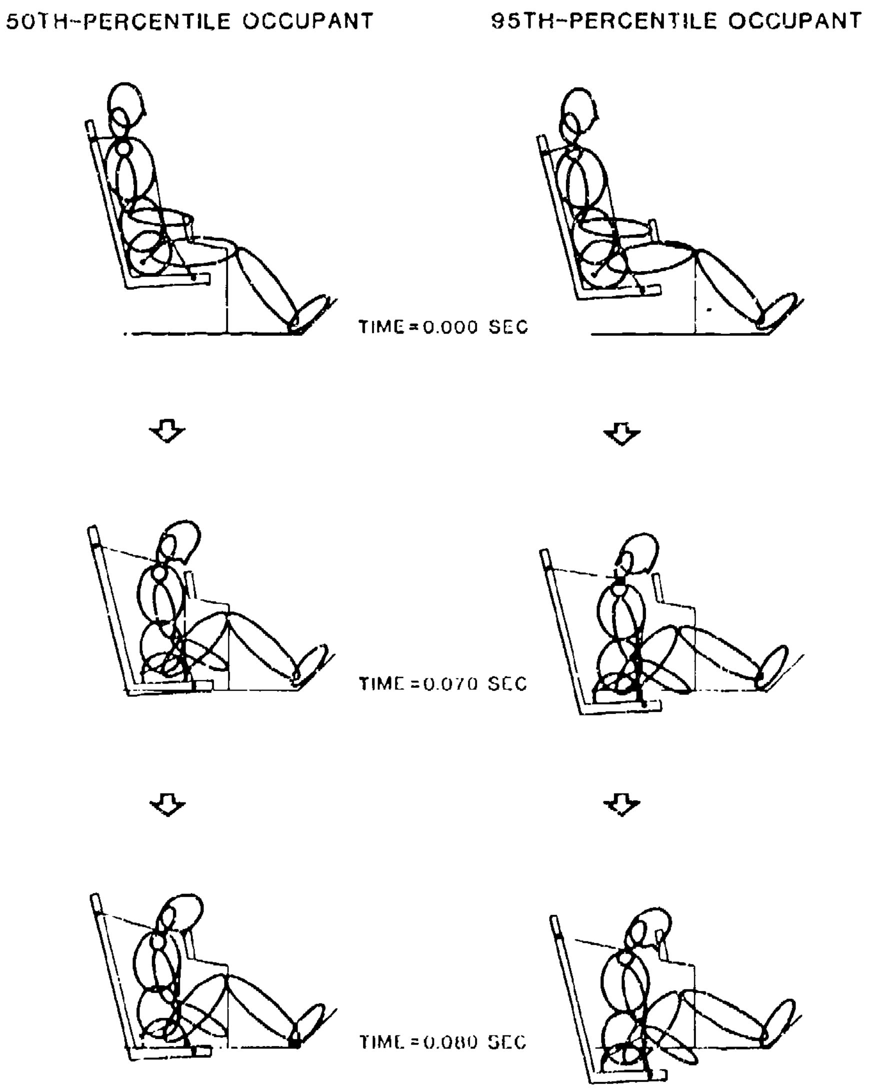


FIGURE 101. SOM-LA OCCUPANT MODEL: UH-60A CREWSEAT, 50-FT/SEC, 48-G VERTICAL DROP WITH A 30-DEGREE FORWARD PITCH (CYCLIC CONTROL FULL AFT). (REFERENCE 130)

Plots of the path of the center of gravity of the head for the 50th- and 95th-percentile occupant are shown relative to the neutral seat reference point (Figure 102). The paths shown are maximum excursions since they represent uninhibited movement. Secondary impacts between seat or occupant and the aircraft were neglected in the simulation.

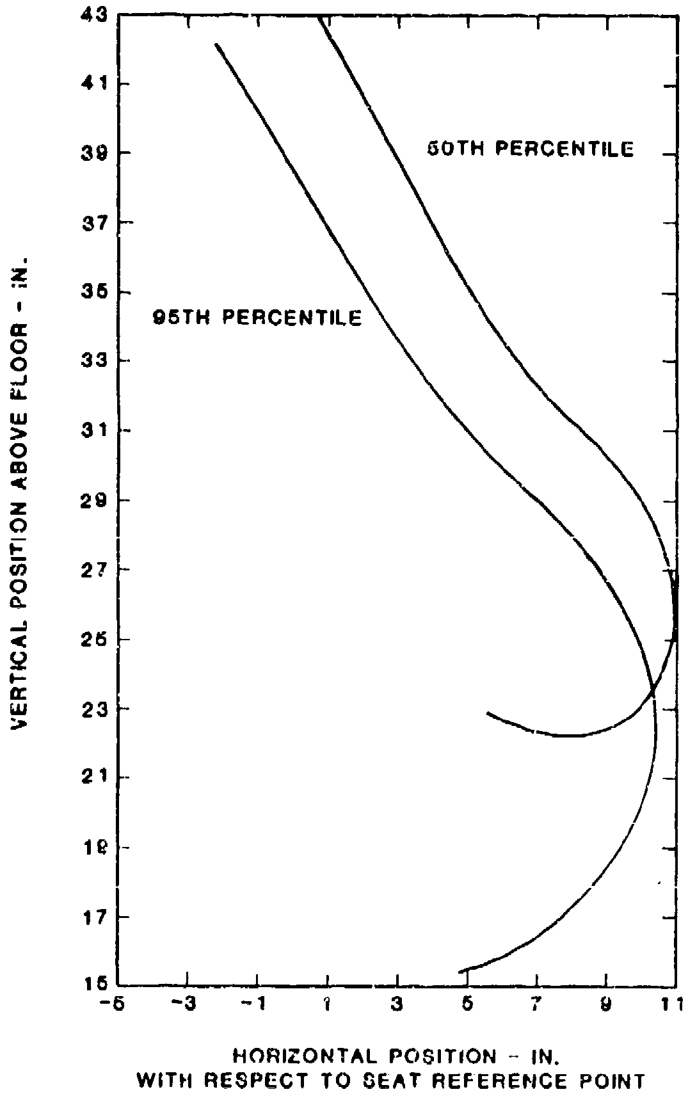


FIGURE 102. 50TH- AND 95TH-PERCENTILE OCCUPANT HEAD C.G. PATH DURING SOM-LA CRASH SIMULATION. (REFERENCE 130)

Numerous dynamic drop tests have confirmed this extensive head motion even with a five-point restraint. It is not unusual for the dummy head to strike the knees. Therefore, delethalization is essential even with upper body restraint.

11.3 ENVIRONMENTAL HAZARDS

11.3.1 Primary Hazards

The primary environmental hazards are those rigid or semirigid structural members within the extremity envelope of the head and chest. It can be seen in Figures 94 through 99 that the strike envelopes allow considerabl^ upper torso movement for various seating and restraint configurations. 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.

11.3.2 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. The movement of unrestrained lower extremities in a crash impact is not significantly influenced by method of body restraint. Consequently, even with an optimized body restraint system, those areas within the lower extremity stroke envelope must include ample protective design.

11.3.3 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.

11.4 HEAD IMPACT HAZARDS

11.4.1 Geometry of Probable Head Impact Surfaces

Aircraft in the U.S. Army inventory in 1965 were examined to determine the kinds of contact hazards most commonly found (Reference 131). Typical hazards in the cockpit area included window and door frames, consoles, control columns, seat backs, electrical junction boxes, and instrument panels. Reference 131 presents further details of these impact hazards and a statistical analysis of head injuries in both civilian and military aircraft accidents. 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 will reduce the injury potential of occupied areas.

11.4.2 Tolerance to Head Impacts

Protection of the head in the form of protective helmets and energy-absorbing structure and padding in the occupant's immediate environment is considered to be essential since, under certain circumstances, even the force incurred in minor crash impacts could cause unacceptably high head impact velocities.

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 103. These data, resulting from impact tests conducted on animals and human cadavers at Wayne State University, demonstrate the contribution of both acceleration and pulse duration to the tolerance criterion (Reference 132).

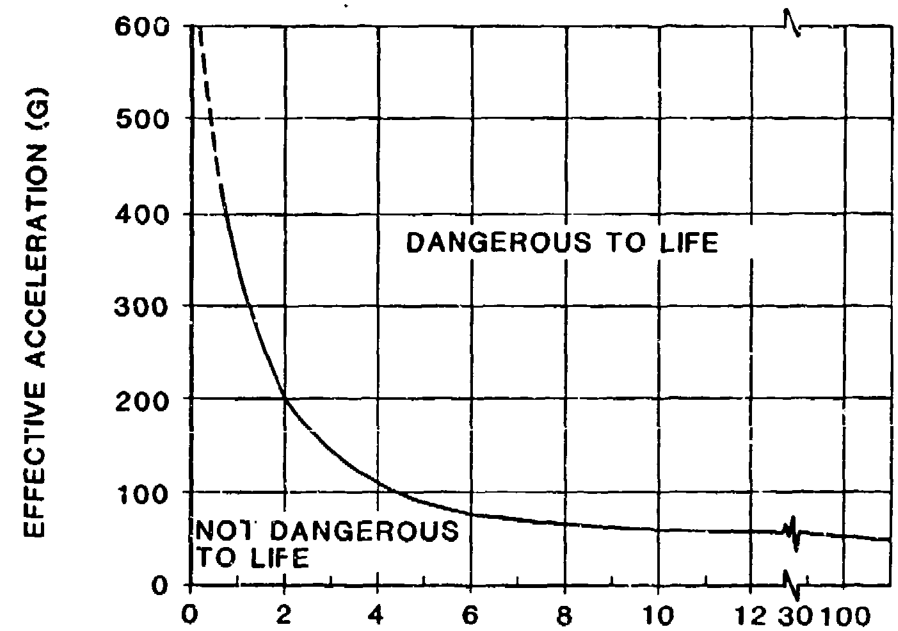


FIGURE 103. WAYNE STATE TOLERANCE CURVE FOR THE HUMAN BRAIN IN FOREHEAD IMPACTS AGAINST PLANE, UNYIELDING SURFACES. (REFERENCE 132)

While the majority of test data is centered around the skull, the entire facial structure has less strength than the forehead, and other facial components are just as likely to impact instruments, controls or other structure in a primarily forward and/or vertical impact. Reference 130 contains a compilation of data taken from the literature and pertaining to the strengths of facial bones. Unfortunately, it is in terms of force rather than acceleration with inadequate definition of durations. Nevertheless, it provides an indication of how much weaker the facial bones are than the forehead. Figure 104 (Reference 133) depicts the mean limits of impact loading on the various facial bones and neck cartilages. These impacts were inflicted using a 1-1/8-in.-diameter impactor with varying degrees of padding. These are a good approximation to objects, such as the top of the cyclic control grip, which could be struck by a crewmember.

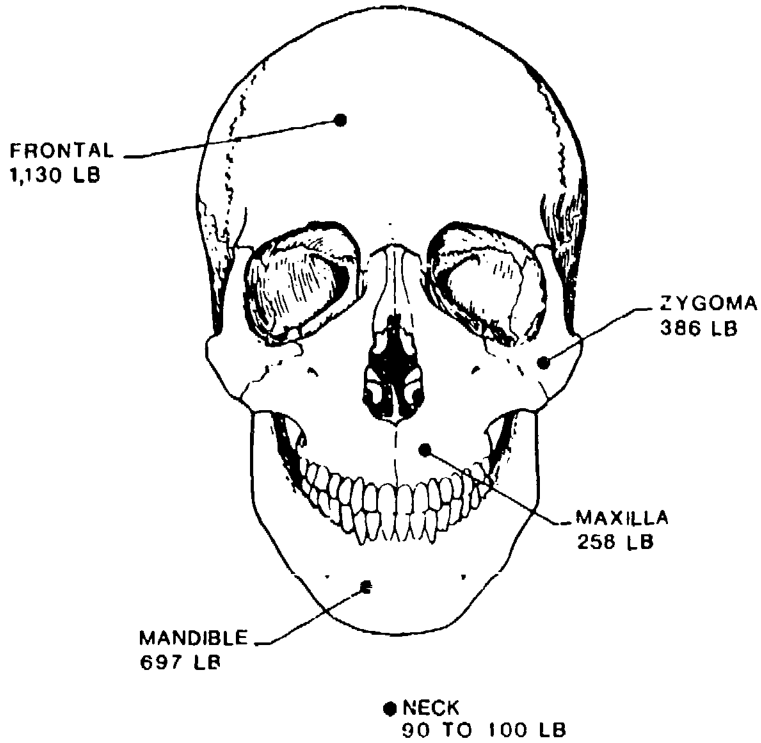


FIGURE 104. FACIAL BONE IMPACT TOLERANCE. (REFERENCE 133)

The frontal bone values are from data obtained with fresh and embalmed cadavers. Impacts to the forehead with impactors under 2 in.^{2} inflict a depressed (cave-in) fracture rather than a linear fracture, which can cause mechanical impingement on the brain and allow entry of foreign bodies into the skull. A fracture of this type is considered an extremely serious injury.

The cheekbone (zygoma) forces cited caused fracture of the bone from a frontal blow near the joint with the upper jaw bone, an area called the maxillary suture. The severity of the fractures were judged to be "clinically significant." The literature noted that the thickness of the overlying tissue played an important role in the actual fracture load. Paired tests were performed with the 1-1/8-in.-diameter impactor on one side and a 2-9/16-in.-diameter impactor on the other. Average fracture loads were 283 lb and 573 lb, respectively, demonstrating that the zygoma is also susceptible to concentrated loading.

The maxilla, the weakest of the facial bones, produced depressed and comminuted (small-pieced) fractures under the concentrated load.

The shape and size of the mandible presents a wide range of impact possibilities. The mean value of 697 lb shown in Figure 104 is for a center frontal impact. Resulting fractures occurred at any of three locations: the cartilage joint with the skull, the rounded projection of the bone to this joint, or on the body of the bone itself.

The neck is an especially vulnerable area to a concentrated load. The fracture forces of Figure 104 were obtained using unembalmed cadavers. Dynamic loads of 90 to 100 lb produced marginal fractures of the thyroid or cricoid cartilage (Adam's apple cartilage and the cartilage ring immediately below, respectively). These fractures could be fatal, due to total collapse of the larynx and subsequent obstruction of the airway.

11.4.3 Energy-Absorbing Earcups

The Army flight helmet, the Sound Protective Helmet Number Four (SPH-4), meeting the requirements of MIL-H-43925 (Reference 134), provides hearing protection, voice communication, and head protection against impact. Work done by the U.S Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama, during the past 16 years (References 135 through 137) to evaluate the impact performance of aviator flight helmets retrieved from aviation accidents has made it clear that the SPH-4 is relatively deficient in its ability to protect wearers against impacts to the lateral portions of the helmet. This was considered due to there essentially being no energy-absorbing material interposed between the helmet shell and the hard plastic circumaural housing for the communication headphones. There is a foam liner incorporated into the superior portions of the helmet, but it does not generally extend below the "hatband" region of the head at the sides of the helmet. Consequently, the force of an impact directed at the earcup region of the helmet is transmitted to the head of the wearer with relatively little attenuation other than that provided by the bending deformation effect of the helmet shell itself.

Accident statistics indicate that 26 percent of all impacts to the SPH-4 have occurred in the earcup region, and impacts in this area are known to result in substantially more severe injury than impacts to other areas of the helmet. To provide increased impact protection to the earcup region of the helmet, a crushable energy-absorbing earcup was developed to be a direct replacement for the standard plastic cup. The initial development work is reported in Reference 138.

The modified earcup is constructed of 1-mm-thick convoluted aluminum and is designed to provide 25 mm of crush at a maximum load of 4,500 N, whereas peak loads for the standard earcup are five times this level. The crush distance was selected based on available space within the current helmet so modification of the helmet shell would not be required. The load limit of 4,500 N is close to the fracture threshold for localized impacts in the temporo-parietal area. However, the size of the earcup allows loads to be spread over a large surface area (7,900 mm^2). Because of the limited stroke distance available, a relatively high load limit had to be used.

A pressure relief mechanism was needed to vent the contracting earcup internal volume during crushing, because a pressure rise of no more than 4 psi can be tolerated. An orifice area of at least 1 sq. cm was required to provide sufficient pressure release. Slots of 0.25-mm width and 28-mm length were machined into the sides of the earcup shell to improve the crushing performance of the earcup shell and to provide a pressure venting mechanism. The slots were sealed with enamel paint to maintain an acoustically sealed enclosure. Pressure relief would occur when the slots open during crushing. A metal cap with four tangs was bonded adhesively to the top of the earcup to provide a method of attaching the earcup to the helmet harness. Testing showed that the pressure vents opened 0.007 sec after the headform touched the earcup. This was too late to prevent the internal pressure from exceeding the limit at which the normal human eardrum will rupture. Nevertheless, the vent did shorten the time duration and the peak pressure when crushing was carried out without venting; thus the venting is deemed desirable, and further work is necessary to provide an improved venting system.

The extensive static and dynamic testing carried out led to the conclusion that an energy-absorbing crushable earcup can be built with existing technology and within the limitations imposed by the existing helmet and acoustic protection requirements, and the USAARL recommended that:

1. All impact-protective helmets containing large-volume (circumaural type) earcups be provided with an integral energy-absorbing mechanism in the earcup structure.

2. Energy-absorbing earcups be procured for retrofit to all inventory flight helmets and for inclusion in all future flight helmets.

11.4.4 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. The recommended procedure is described in SAE J921 (Reference 139). 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 Volume II.

Figure 105 shows typical head velocities relative to the seat as measured on anthropomorphic dummies, cadavers, and live human subjects in dynamic seat tests. Various combinations of occupant restraint were used and are so indicated on each curve.

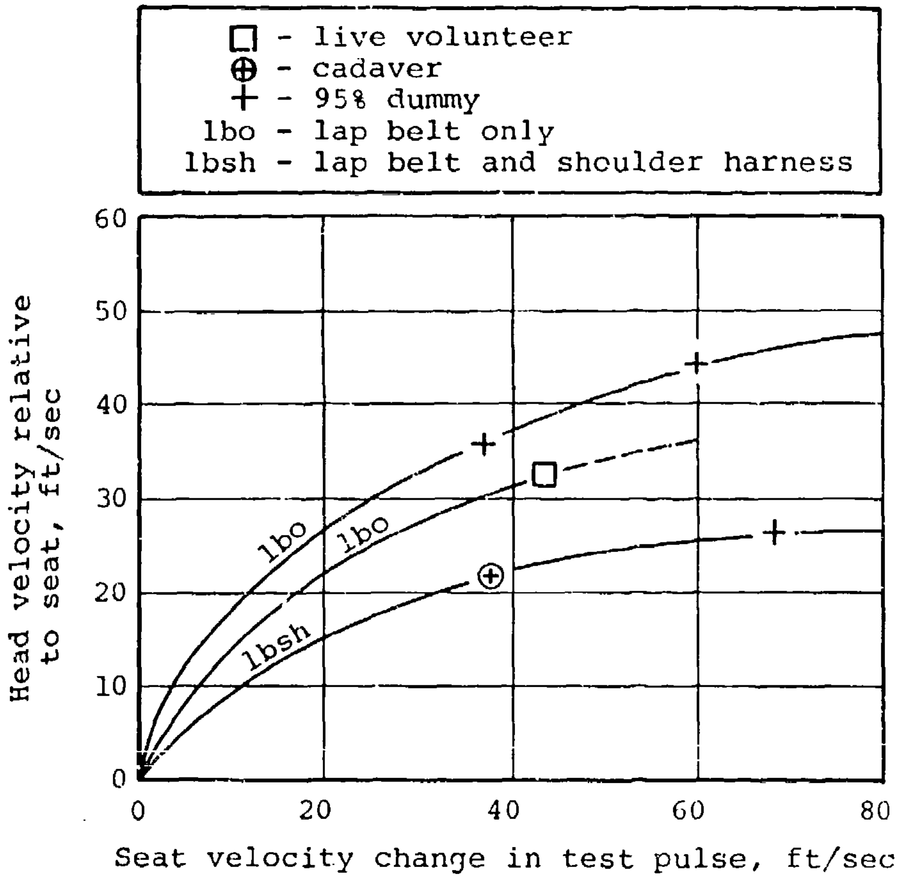


FIGURE 105. MEASURED HEAD VELOCITIES IN SLED TESTS WITH ANTHROPOMORPHIC DUMMIES AND CADAVERS.

11.4.5 Simulation

Simulations of the occupant seat system can be used to support the design and test of delethalized components. For example, as described in Section 11.2.5, Program SOM-LA was used to simulate the dynamics repsone of the body in a stroking seat in a vertical impact. From Figure 101, it can be seen that the simulation predicts head impact with the cyclic stick between 70 and 80 miliseconds. Therefore, from Figure 106, which was also generated by the simulation, it can be seen that the vertical head velocity at impact will be approximately 20 ft/sec in a severe, survivable crash.

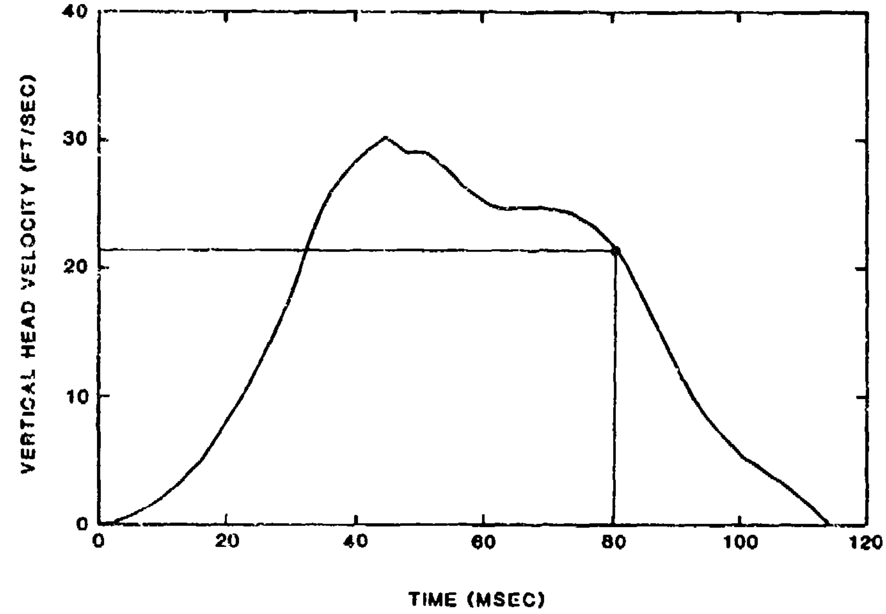


FIGURE 106. HEAD VELOCITY - VERTICAL COMPONENT.
(REFERENCE 133)

11.5 INSTRUMENT PANEL STRUCTURE PROXIMITY

Most aircraft cockpits are, of necessity, very compact. It is necessary, for instance, for a pilot to be able to reach various controls on the instrument panel by leaning forward no more than 18 in. (the extent of unlocked inertia reel extension). Consequently, instrument panels must be close enough to be reached and seen easily. Unfortunately, this usually requires that the instrument panel and its supporting structure be placed directly above the pilot's lower legs as they rest normally on the rudder pedals. When a seated pilot is exposed to $-G_x$ (eyeballs-out) accelerations in a crash, the lower limbs are abruptly extended longitudinally with some upward velocity. In this process, the lower leg usually impacts on the lower edge of the instrument panel. Depending on the particular aircraft configuration, this contact can take place from the kneecap down to the ankle. In view of the high velocities associated with such flailing, disabling lower leg injuries are common in accidents where high $-G_x$ forces are present. Designers should consider using suitable energy-absorbing padding materials, frangible breakaway panels, or ductile panel materials for structure within the lower leg strike envelope.

11.5.1 Delethalizing Glare Shield

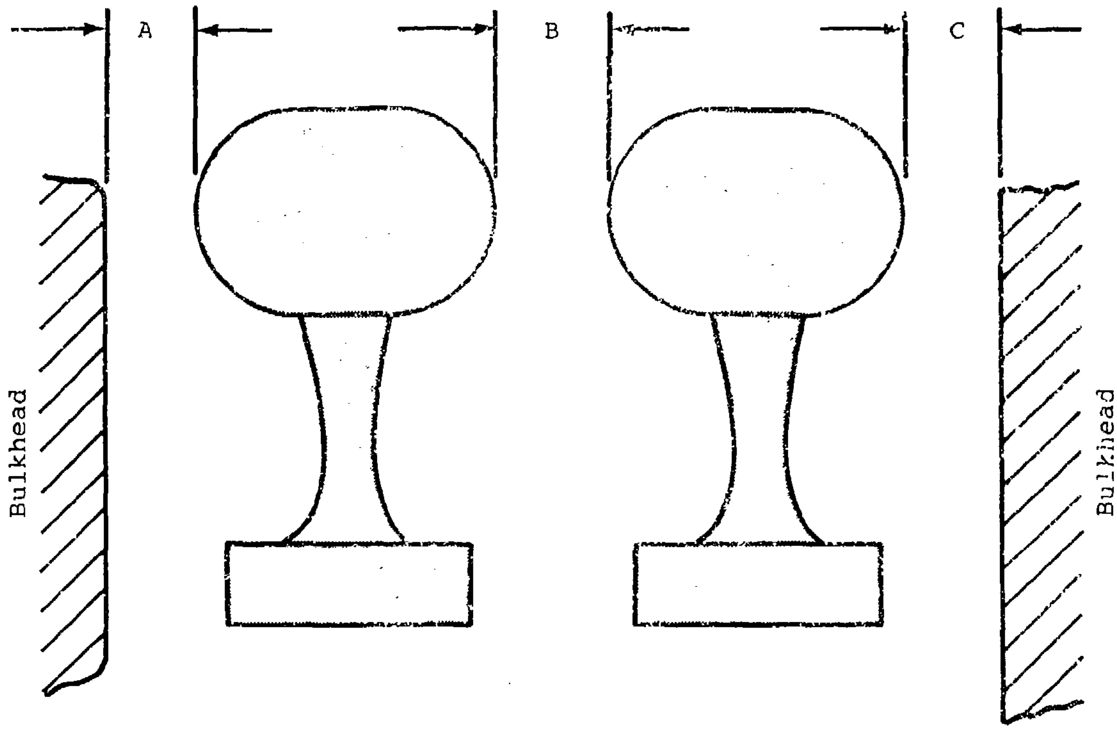
While the instrument panel can be padded to help reduce the severity of head and face impacts during a crash, the use of a fiber glass instrument glare shield has been evaluated (Reference 140) as an alternative to padding or to provide additional protection from protruding instruments. The glare shield consisted of a basic structure of a thin fiber glass layer covered with a 1/4-in.-thick layer of Ensolite and a thin layer of plastic vinyl. The shield extended 9-1/2 in. from the instrument panel toward the pilot and was elevated about 13 degrees above the horizontal. The protruding edge nearest the pilot was rolled down and under with an inside radius of curvature of about 1/4 in. In a 30-ft/sec head impact the shield reportedly provided significant improvement in head injury protection compared to using no shield. On impact, the shield folded down over the heavy instruments and sharp knobs and edges and produced a maximum deceleration force on the head of only 60 G while distributing the load over large facial areas, as compared to 300-G forces produced on small areas of the head in similar impact tests of conventional light aircraft instrument panels without the glare shield. (The forehead can tolerate a force of 80 G on one square inch without bone fracture, and the average head weight, without helmet, is approximately 9.5 lb.)

11.6 RUDDER PEDAL CONFIGURATION

In certain types of aircraft accidents, the pilot's feet remain on the rudder pedals instead of flailing upward and outward. If the rudder pedal is a simple, bar type of arrangement, the heel may be forced under the pedal. When the body is exposed to a combination of vertical (G_z eyeballs-down) and longitudinal ($-G_x$ eyeballs-out) forces, pelvic rotation around the lap belt will almost invariably occur unless a lap belt tie-down strap is used. This pelvic rotation, which forces the feet hard against the rudder pedals, can occur even though the lap belt is drawn up tightly. A loose or slack lap belt aggravates the tendency toward pelvic rotation. If the forces are great enough, a badly injured or trapped foot can result. Therefore, it is desirable to design the rudder pedals and surrounding structure to prevent this from occurring. This is usually done by providing a pedal capable of supporting both the ball of the foot and the heel, and by providing 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 107.

11.7 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. Such a failure often leaves a torn, jagged stump that can inflict serious injury to a crewman should he be thrown against it during impact, move into it as an energy-absorbing seat strokes, or come in contact with it during egress after impact. 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.



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

FIGURE 107. 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 in the cockpit. As the seat strokes, the crewmember's head comes closer to the stick. Both tests and analysis have shown that the upper body restraint system will not prevent this head-stick impact.

References 130, 133, and 141, describe development work which has been conducted in an attempt to develop means for delethalizing the cyclic control stick. Many options were investigated, and it was determined that a stick with a separating joint as shown in Figure 108 would be the preferred approach. For a retrofit application, it was determined that separation initiated by occupant impact would be most practical. For newly designed aircraft, it may be preferable to initiate stick separation prior to crewmember impact. This could be done with seat stroke, belly crush, or G sensor, for example.

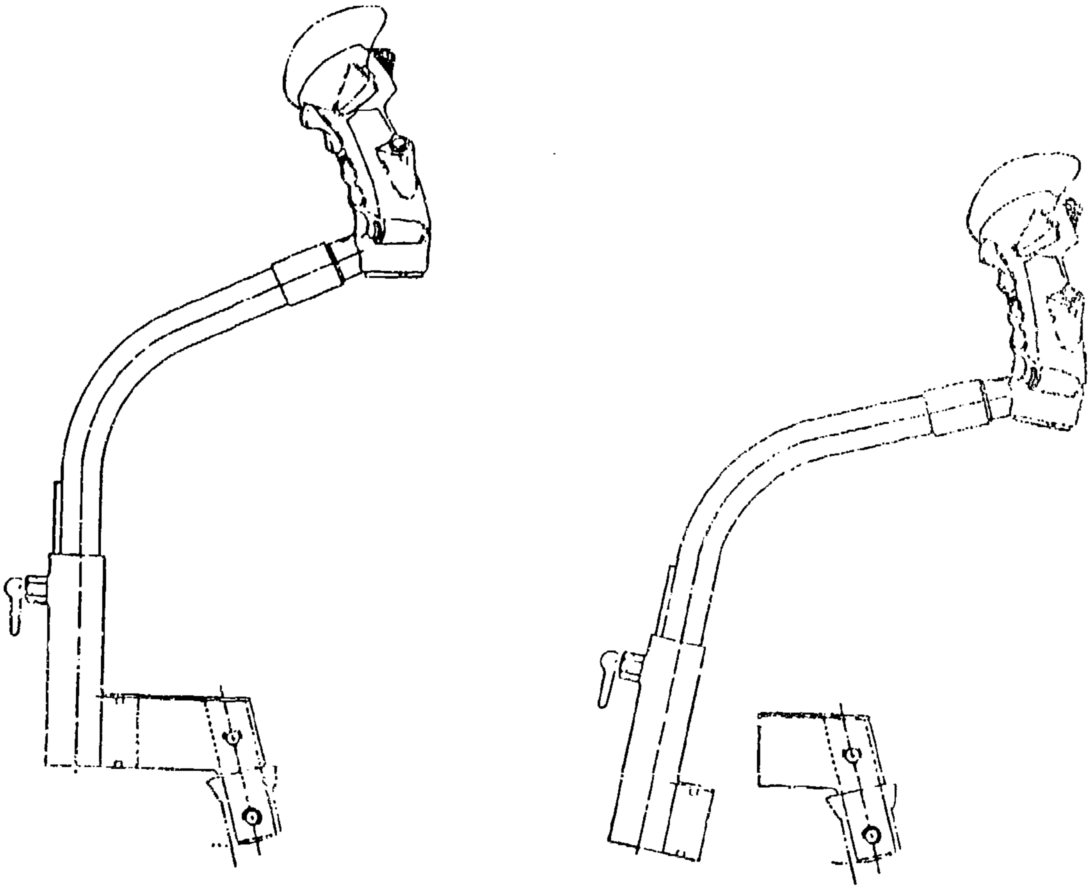


FIGURE 108. DELETHALIZED CYCLIC CONTROL STICK. (REFERENCE 132)

When occupant impact causes separation, the design process is limited by the fact that the required emergency operating loads for the stroke are close to the threshold of human tolerance. Nevertheless, the referenced work showed that a considerable reduction in stick lethality could be made. It was found that the likely area of impact was the head or neck. To minimize injury, three changes were made to the stick and grip assembly. The stick was equipped with the previously illustrated separating joint, the mass of the stick was minimized, and a crushable pad was placed on top of the grip. This combination of techniques reduced the lethality to what is probably a minimum for a contact-activated system. An energy-absorbing mechanism in the joint precluded a non-crash separation.

The resulting design was tested with a UH-60 crewseat and a Hybrid III dummy and compared with test results from an unmodified UH-60 stick. The forces acting on the stick mount for two of the four tests are shown in Figure 109. Head and neck injury indices, as described in the cited reference, were used to evaluate injury potential. Both the Head Index Criteria (HIC) and the neck injury severity index were reduced by approximately one-half.

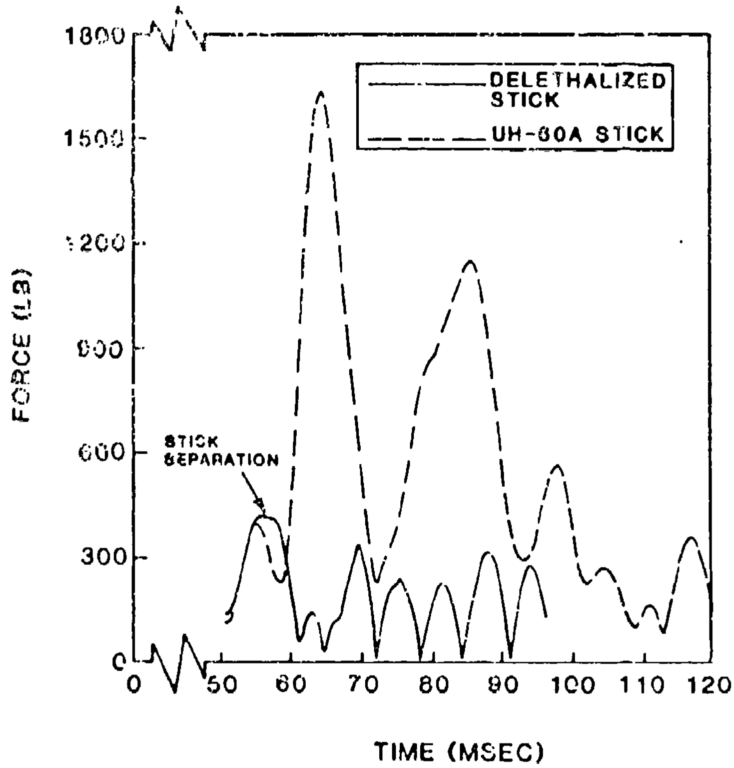


FIGURE 109. STICK LOAD. (REFERENCE 141)

11.8 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 copilot/gunner crewstation activities demand that the CPG will be either in contact with the ORT eyepiece during hazardous nap-of-the earth (NOE) flight or close to the eyepiece when sitting in the full upright, erect position. Operational location of the CPG head, when not looking in the ORT, may be as little as 8.5 in. from the eyepiece. Therefore, it can be expected that the CPG, when restrained by a MIL-S-58095 restraint system, will contact the ORT eyepiece under nearly all impacts over 4 G (see Figure 110). Any deformation of the bulkhead which would cause the ORT to move rearward will only further ensure head contact. Forward motion of the upper torso after head contact with the ORT could cause spinal injury.

Under NOE conditions with the CPG looking through the ORT, it can be expected that no warning of impending impact will occur. Regardless, any courses of action taken by the CPG to hold himself erect will probably not help in keeping his head from striking the ORT due to head flailing and body stretch. Another factor that further decreases the distance between the head and the ORT eyepiece is the travel of the seat as it strokes under crash loads.

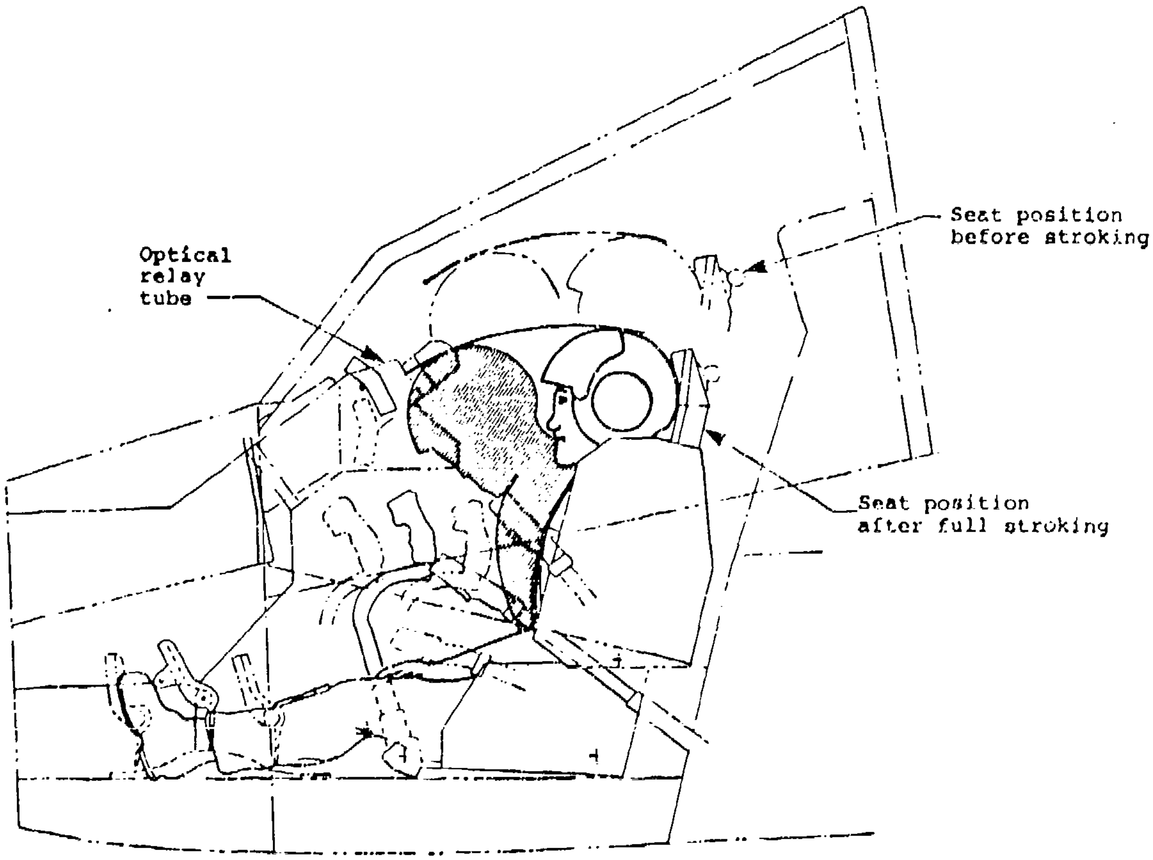


FIGURE 110. PILOT/GUNNER STATION OCCUPANT STRIKE IN-BOARD PROFILE 4-G IMPACT.

Possible ORT hazards to the lower extremities and the torso consist of the sharp unyielding lower structure of the ORT. In addition, the rudder pedals may be located adjacent to the ORT. During a crash, the potential displacement of the ORT may cause the CPG's legs to become entrapped. A summary of typical ORT crash hazards is presented in Table 18.

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:

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

TABLE 18. POTENTIAL OPTICAL RELAY TUBE CRASH HAZARDS

Hazard	Location Of Injury	Type Of Injury	Cause
1	Head	Laceration, Fracture, Concussion	Head strikes ORT due to flailing forward and downward on impact
2	Head/Chest	Crushing, Avulsion, Fracture	Head/Chest strikes ORT due to ORT dis-placing rearward
3	Head/Chest	Laceration, Crushing, Fracture	CPG seat displaces downward and forward during energy-absorbing stroke. Contact of the head/chest with sharp edges of franged ORT.
4	Arm	Laceration, Fracture	CPG arms flail forward on longitudinal impact
5	Lower Torso	Avulsion, Laceration, Crushing, Fracture	ORT displaces rearward on longitudinal impact
6	Leg	Laceration, Fracture	CPG leg flails forward on longitudinal impact
7	Leg	Crushing	CPG leg trapped between aircraft structure and displacing ORT

- Restraint System - The restraint system of Figure 62 would offer improved upper torso restraint, particularly when combined with the power-haulback inertia reel.

- Inflatable Restraint - Consideration should be given to an inflatable restraint system (see Section 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 and increasing the surface area of the body over which the harness reacts.

- Frangible/Breakaway Features - 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.

- Collapsible Features - 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 111 illustrates one crushable sight eyepiece concept (from Reference 142). 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.

- Power-Haulback Inertia Reel (PHBIR) - On the basis of Air Force testing accomplished for the development of PHBIRs, 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 say 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 head-down CPG position.

11.9 ENERGY-ABSORBING REQUIREMENTS FOR COCKPIT AND CABIN INTERIORS

11.9.1 General

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

As an example of the need for an energy-absorbing system to possess both these characteristics, consider the case of head impact. Head injuries sustained from impact may be grouped in two general categories. The first is skull fracture with its inherent brain damage and danger to life. The second is injury to facial tissue and bone structure with a lesser probability of brain damage.

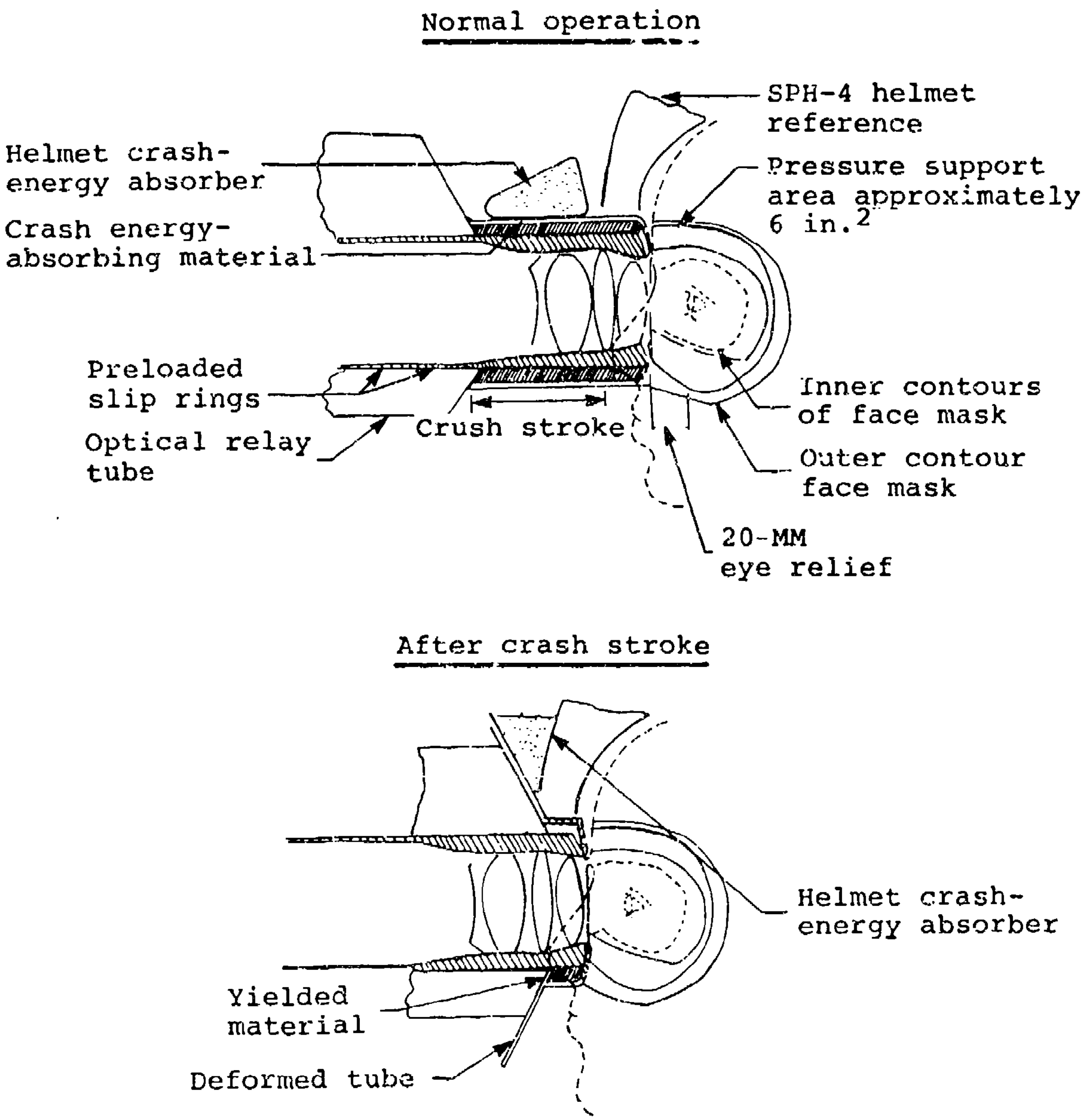


FIGURE 111. CRUSHABLE EYEPIECE CONCEPT. (REFERENCE 142)

A system that is to absorb the energy of an impacting head should cushion the head to prevent skull fracture or penetration from protruding objects as a result of decelerative forces. It should also distribute the forces to minimize injury to tissue and bone structure. The cushioning material used must effect low peak deceleration and low average stress. Figures 112 and 113, taken from Reference 143, indicate the impact behavior of three plastic foams. The foam sample specimens used to obtain these data were 6 in. thick to minimize any bottoming-out effect. Although the semirigid urethane

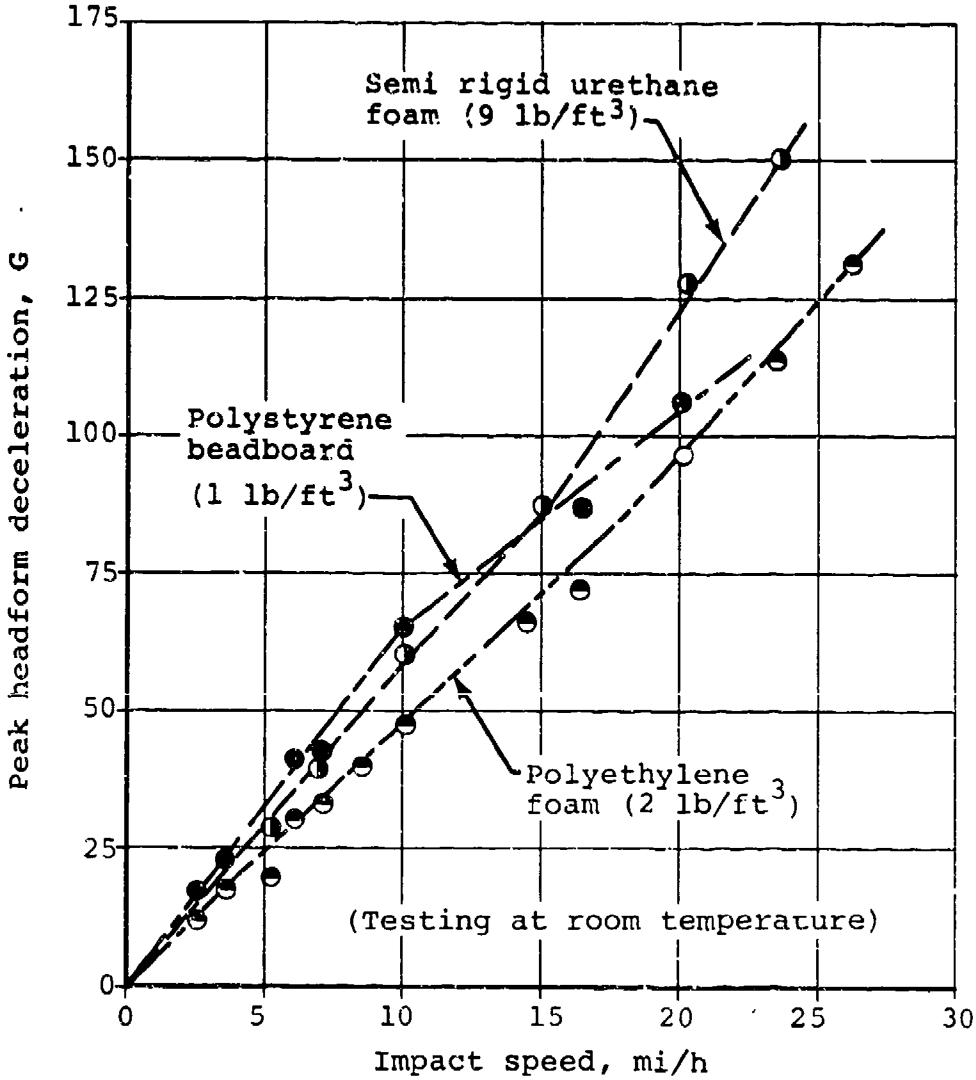


FIGURE 112. IMPACT BEHAVIOR (HEADFORM DECELERATION VERSUS SPEED) OF THREE PADDING MATERIALS.

appears to be a fair cushioning material, it does not distribute the load as well as the materials with which it is compared. A fair cushioning material is not necessarily an effective load distributor. Both criteria must be considered in the selection of a material that is to provide impact protection for the head.

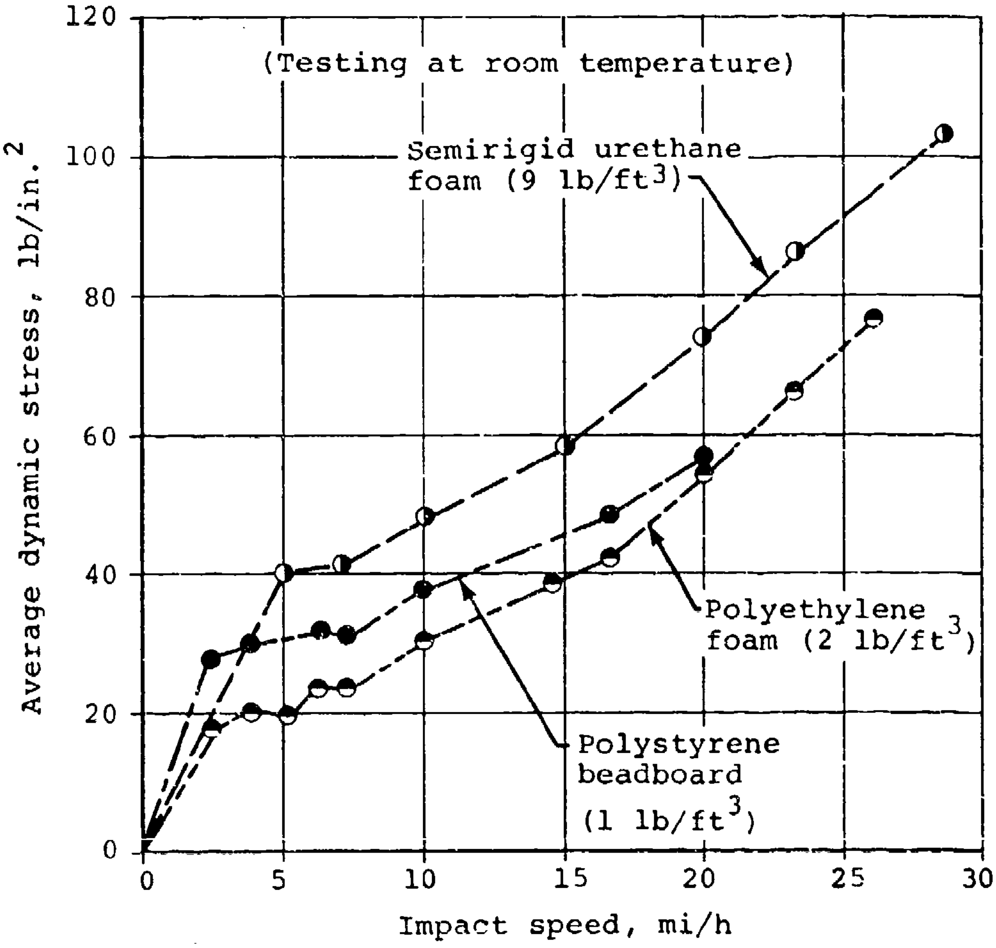


FIGURE 113. IMPACT BEHAVIOR (AVERAGE DYNAMIC STRESS VERSUS SPEED) OF THREE PADDING MATERIALS.

In addition to protecting bone structure and facial tissue, the energy-absorbing system must also afford protection against intercranial lesions. Cerebral concussion, and the loss of consciousness which often accompanies it, may occur if the head is subjected to excessive decelerative forces. Mattingly, et al. (Reference 144), in discussing possible intercranial lesions and cerebral trauma including concussion, swelling, contusion, laceration, and hematoma, conclude that 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.

11.9.2 Types of Padding Materials and Properties

The most useful types of materials for energy-absorbing padding are plastic foams. A foamed plastic is usually totally unlike the same plastic in the solid: unlike in properties, in processing, and usually in applications. Three steps are involved in producing a cellular structure in a polymer: (1) preparation of polymeric material into a viscous liquid state, (2) introduction of fine bubbles of gas to produce expansion, and (3) solidification of the foamed plastic to stabilize the foamed structure. The particular process used in manufacturing foam materials has a direct effect on their properties and can result in products of the same chemical composition being very different in performance.

11.9.2.1 Material Form. The form in which the foam material is commercially available influences its adaptability to vehicle applications. Slab and molded foams are often used in the construction of instrument panels and seat systems. Differences in properties due to varying the form should be considered in the selection of a material. For example, Figure 114 shows the variation of minimum tensile strength versus product density for polyethylene foam in sheet and plank forms.

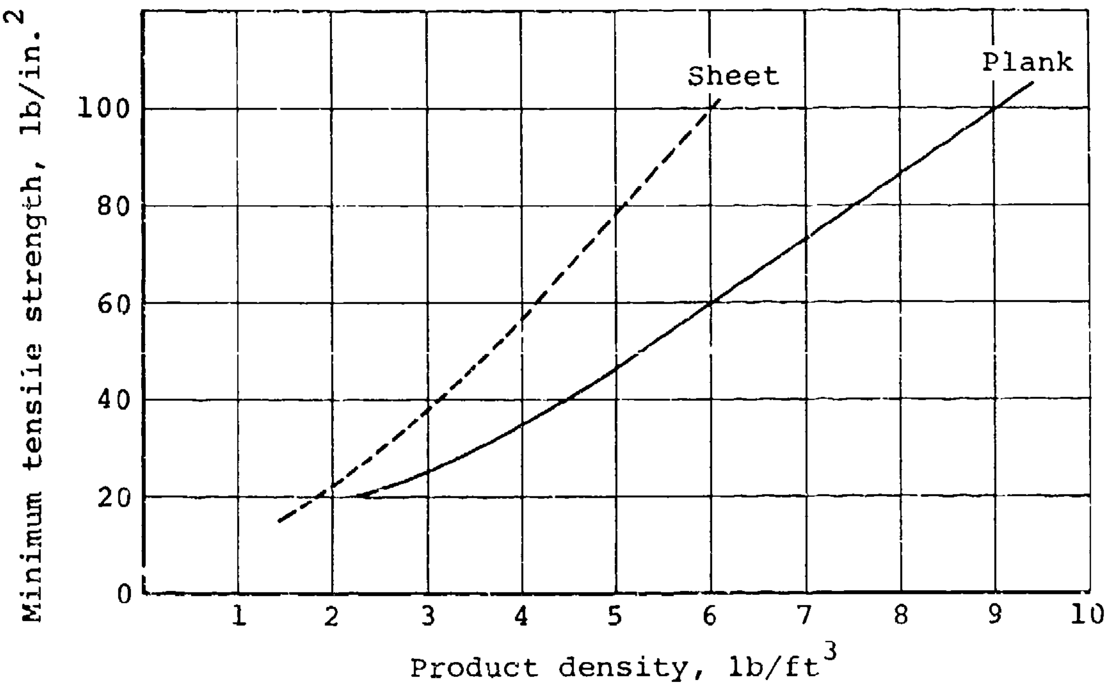


FIGURE 114. MINIMUM TENSILE STRENGTH VERSUS PRODUCT DENSITY FOR POLYETHYLENE SHEET AND PLANK. (REFERENCE 146)

11.9.2.2 Classification of Foams. Foams can be described as flexible or rigid. A flexible foam recovers when deformed, whereas a rigid foam cannot sustain multiple impacts. Flexible foams are most widely used in situations where energy absorption is important.

Another method of classifying foams is open-cell or closed-cell. An open-cell foam contains individual cells that interconnect with the others, while in a closed-cell foam individual cells are completely enclosed by a wall of plastic.

Plastic foam materials also can be classified according to their chemical composition. Several energy-absorbing plastic foams and some of their typical applications are listed in Table 19.

TABLE 19. ENERGY-ABSORBING PLASTIC FOAMS AND SOME TYPICAL APPLICATIONS

1. Semirigid and flexible urethane foam

   Aircraft, automobile, and furniture seat cushions, safety padding, arm rests, sun visors, horn buttons, bedding, carpet underlay, packaging delicate products.

2. Polyvinylchloride foam

   Crash padding in automobile head liners and sun visors, flooring, shoe soles and heels, automobile door panels, seating upholstery sealants, gaskets, bumperstock.

3. Polystyrene foam

   Insulation, packaging.

4. Expanded rubber

   Bus and subway seat cushions, truck and ship mattresses, gaskets, hose insulation.

5. Polyester foam

   Short-run, custom-type seat cushioning.

6. Polyolefin foam

   Packaging, gasketing, water sports equipment, rug underlay, athletic padding, antivibration padding.

11.9.2.3. **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
- Low rebound
- Temperature insensitivity
- Low water absorption
- Resistance to chemicals, oil, ultraviolet radiation, and sunlight
- Nontoxic, fume generation
- Favorable flammability rating
- Minimal smoke generation
- Durability and long life
- Cost competitive
- Aesthetic

Foam materials are most often characterized by the mechanical properties listed below, where it may be noted that several of the properties apply only to rigid or flexible foams. For example, compressive strength is not relevant in considering flexible foams. The compression-set test, on the other hand, applies only to flexible materials.

- Density
- Tensile strength
- Tensile modulus
- Compressive strength
- Tear strength
- Compression set
- Compression deflection
- Elongation
- Compressive modulus
- Flexural strength
- Flexural modulus
- Rebound
- Hardness
- Impact

Properties of possible interest in selection of a material for energy-absorbing applications are presented in Table 20 for several applicable materials (data taken from References 145 through 148).

Tables 21, 22, and 23 list static padding evaluation results, including Safety Research Lab (SRL) derived crush properties of different size samples and SRL derived stiffness for headform static tests (Reference 149). Tables 21 and 22 are for loading with a flat 2.5-in. square plate and a 2.5- x 12-in. plate, respectively, while Table 23 is for a Hybrid III headform loaded into the foam (face forward). Dynamic tests were also conducted with the Hybrid III headform and selected foams.

TABLE 20. PROPERTIES OF SELECTED FLEXIBLE CELLULAR POLYMERS

Property	Polyvinyl Chloride with Nitrile Rubber (Uniroyal "Ensolite")	Urethane (Edmont-Wilson "Temperfoam")	Polystyrene	Urethane (Mobay Chemical Co. "Cold-Cure Foam")	Low-Density Polyethylene (Dow Chemical Co. "Ethafoam" and Furakawa Electric Co., Ltd. "Foamace")
Density (lb/ft^3)	2.5 - 12.0	5.0	1.01 - 10.1	2.5 - 4.5	1.7 - 9.0
Tensile strength (psi)	30 - 150	19 - 51	20 - 250	10 -14	20 - 100
Elongation (percent)	60 - 150	75 - 225		90 - 110	
Shrinkage (percent)	2.0 - 3.0			0.3 - 3.0	
Water absorption	0.1 lb/ft^2		0 - 2.0% by volume		0.1 - 0.5% by volume
Thermal conductivity (Btu/hr ft °F)	0.25 - 0.30		0.18 - 0.28		0.3 - 0.4
25% ILD (lb/50 $in.^2$)		47 - 500		7 - 50[a]	
65% ILD (lb/50 $in.^2$)		92 - 1,070		25 - 160	
Rebound (percent)		5 - 10[b]		50 - 60	

(a) @ 20% ILD (indentation load deflection).
(b) Ball weight = 286 g, drop height = 20 in.

TABLE 21. STATIC PADDING EVALUATION RESULTS - 2.5 X 2.5 X 3-IN. SAMPLES

Material	Manufacturer	Density (pcf)	25% Compres. Mfg. Spec. (psi)	Static Crush Properties (SRL Derived) 25% Crush (in.)	25% Crush Strength (psi)	50% Crush (in.)	50% Crush Strength (psi)	75% Crush (in.)	75% Crush Strength (psi)	75% C.S./ 25% C.S.
Ethafoam 600	Dow Chemical	6	20	0.62	36	1.23	50	1.85	78	2.17
Ethafoam 900	Dow chemical	9	54	0.62	88	1.23	112	1.85	176	2.00
Lokcell #1143	Airtex, Inc.	10-14	9-13	0.68	4.5	1.37	10.5	2.05	22	4.89
Durafoam C311A	Monmouth Rubber	8	9-20	0.66	16	1.32	23	1.98	41	2.56
R-497-T	Rubatex Corp.	18-28	9-15	0.61	10	1.21	20	1.82	48	4.80
R-8407-S	Rubatex Corp.	10-20	9-17	0.69	24	1.38	32	2.06	62	2.58
Ensolite VHC	Uniroyal, Inc.	5-7	9-12	0.63	11	1.25	19	1.88	35	3.18
Ensolite HH	Uniroyal, Inc.	9-12	22-35	0.61	64	1.22	96	1.83	168	2.63
Ensolite HCR	Uniroyal, Inc.	6.5-8.5	6.5-9.5	0.61	8	1.22	16	1.83	34	4.25
Ensolite AH	Uniroyal, Inc.	6.5-8.5	7-9	0.60	12	1.20	20	1.80	39	3.25
Dytherm 2.1	ARCO Chemical	2.1	45	0.66	38	1.33	48	1.99	68	1.79
Dytherm 4.2	ARCO Chemical	4.2	135	0.69	120	1.38	136	2.07	176	1.47
Dytherm 6.0	ARCO Chemical	6.0	225	0.61	174	1.23	222	1.84	303	1.74
Dytherm 8.0	ARCO Chemical	8.0	315	0.59	390	1.19	470	1.78	600	1.54
Dytherm 12	ARCO Chemical	12.0	490	0.41	660	0.82	780	1.23	960	1.45
GTR 3.2	General Tire & Rubber	3.2	---	0.63	19	1.25	22	1.88	32	1.68
Sorbothane 30	Sorbo, Inc.	83	---	0.58	12.5	1.15	32.5	1.73	95	7.60
Sorbothane 50	Sorbo, Inc.	83	---	0.57	20	1.15	60	1.72	190	9.50
Sorbothane 70	Sorbo, Inc.	83	---	0.60	40	1.19	100	1.79	260	6.50

TABLE 22. STATIC PADDING EVALUATION RESULTS - 2.5 X 12 X 3-In. SAMPLES

Material	Manufacturer	Density (pcf)	25% Compres. Mfg. Spec. (psi)	Static Crush Properties (SRL Derived)						
				25% Crush (in.)	25% Crush Strength (psi)	50% Crush (in.)	50% Crush Strength (psi)	75% Crush (in.)	75% Crush Strength (psi)	75% C.S./ 25% C.S.
Ethafoam 600	Dow Chemical	6	20	0.72	72	1.44	93	2.16	156	2.17
Ethafoam 900	Dow chemical	9	54	0.67	93	1.34	133	2.00	250	2.69
Lokcell #1143	Airtex, Inc.	10-14	9-13	0.57	33	1.14	7	1.70	13	3.34
Durafoam C311A	Monmouth Rubber	8	9-20	0.66	23	1.31	33	1.97	58	2.52
R-497-T	Rubatex Corp.	18-28	9-15	0.62	18	1.25	31	1.87	58	3.78
R-8407-S	Rubatex Corp.	10-20	9-17	0.65	36	1.30	50	1.95	86	2.39
Ensolite HH	Uniroyal, Inc.	9-12	22-35	0.63	42	1.26	59	1.89	114	2.71
Dytherm 4.2	ARCO Chemical	4.2	135	0.61	163	1.23	213	1.84	273	1.67
Dytherm 6.0	ARCO Chemical	6.0	225	0.62	295	1.23	360	1.85	485	1.64
Dytherm 8.0	ARCO Chemical	8.0	315	0.60	455	1.20	556	1.79	691	1.52

TABLE 23. HEADFORM STATIC TEST RESULTS
2.5 X 12 X 3-IN. SAMPLES

Material	Manufacturer	Density (pcf)	SRL Derived Stiffness (lb/in.)
Ethafoam 600	Dow Chemical	6	398
Ethafoam 900	Dow Chemical	9	450
Lokcell 1143	Airtex, Inc.	10-14	57
Durafoam C331A	Monmouth Rubber	8	185
R-497-T	Rubtex Corp.	18-28	100
R-8407-S	Rubtex Corp.	10-20	238
Ensolite HH	Uniroyal, Inc.	9-12	323
Dytherm 4.2	ARCO Chemical	4.2	1,208
Dytherm 6.0	ARCO Chemical	6.0	1,846
Dytherm 8.0	ARCO Chemical	8.0	4,000

11.9.3 Standard Test Methods

ASTM standard test procedures are widely used by manufacturers to specify various properties of a particular type of material. Table 24 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 150). Among other tests, there are compression-set and load-deflection tests. In the compression-set test, the method consists of deflecting the foam specimen under specified conditions of time and temperature and noting the reduction of specimen thickness after removal of the load. The compression device consists of two flat plates larger than the specimen.

TABLE 24. SUMMARY OF ASTM TEST METHODS AND SPECIFICATIONS FOR FLEXIBLE CELLULAR PLASTICS (REFERENCES 149 AND 151)

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.

In the load deflection test, one method consists of measuring the Indentation Load Deflection (ILD) value, which is the load necessary to produce a specified 25-percent or 65-percent indentation in the specimen under a 50-in.^{2} circular indenter foot. Acceptable deflection rates range from 1.0 to 15.0 in./min. A second method, which uses the same indenter, obtains the deflections under specified loads of 4.45, 111, and 222 N (1, 25, and 50 lb) during loading and 111 N during unloading. These deflections are reported as Indentation Residual Gage Load (IRGL) values. The latter method, which involves indentation to specified loads, is intended for use with seat cushion materials.

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 150), more closely simulates actual impact conditions. An acceleration-time curve is obtained by mounting a transducer on the dropping head. The parameters evaluated are peak deceleration and the dynamic set of the specimen. This method allows the test parameters to vary and yet is simple enough to ensure repeatability among different test facilities. In a drop test, the test parameters are the drop height that determines the impact velocity, the weight and surface area of the impactor, and the foam thickness.

Other standard test procedures include SAE J815, "Load Deflection Testing of Urethane Foams for Automotive Seating," as described in Reference 151. This test 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. SAE J815 determines load versus deflection by measuring the thickness of the padding under fixed loads of 1 lb, 25 lb, and 50 lb with a circular indentor foot (see Reference 152).

Also, SAE J388, "Dynamic Flex Fatigue Test for Slab Urethane Foam" (Reference 153), describes procedures for evaluating the loss of thickness and the amount of structural breakdown of slab urethane foam seating materials. A test specimen is measured for thickness under a specified load and, subsequently, subjected simultaneously to compressive and shear deformation under a constant load for a specified number of cycles. In the constant load height measuring test, a flat, circular indenter foot of 50 in.^{2} with loads from 1.0 to 75.0 lb is deflected at rates from 2 to 8 in./min. The constant load dynamic fatigue apparatus uses rollers in a more complicated setup.

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 139). An SAE J984 headform with an effective weight of 15.1 lb is impacted at specified positions. The parameters evaluated are the impact velocity, the acceleration-time history of the headform, and the start of impact, with optional measurement of the rebound velocity and the headform dynamic displacement.

11.9.4 Research on Materials for Energy-Absorbing Applications

Static tests that deviate from ASTM test procedures and simple dynamic tests that are intended to grossly simulate crash conditions have been performed by manufacturers and users with different types of materials. Several of their approaches and their energy-absorption criteria are discussed below.

11.9.4.1 Acceptable Stress-Strain Characteristics. Haley, et al., have investigated design criteria for padding materials, as described in Reference 131. According to their conclusions, energy-absorbing materials with stress values between 40 and 80 $lb/in.^2$ at 50 percent strain would offer reasonable survival potential for head impacts on flat surfaces at velocities of up to 20 ft/sec with a padding thickness of 1.5 in. More recent unpublished data gathered by the Army's Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, indicates that the above stress values are too high because the values were based on the compressive strength alone while it is probable that tensile stresses and shear stresses around the periphery of the compressed areas play a large role in the total force resisting compression. Regardless of the stress distribution in the padding material, the USAARL research has shown that the stress level should fall between 30 and 45 $lb/in.^2$ for padding less than 1 in. thick and 20 to 30 $lb/in.^2$ for padding greater than 1 in. thick in order to prevent peak G pulses from exceeding the tolerance values stated in Volume II of this Design Guide. These crush strength values, as illustrated in Figure 115, are recommended and are expected to prevent unconsciousness (within the limits of the crush depth). The lower stress level for the thicker padding is based on: (1) the average design decelerative level must be reduced as the depth of the padding and concomitant time duration are increased to meet the known tolerance limits stated in Volume II, and (2) a larger area of foam is crushed as the head sinks into the thicker pad.

Use of a padding, as proposed in Figure 115, is intended to limit head peak G values to 160 for the thin pads and 120 G for the thicker padding.

The criteria of Figure 115 are to be satisfied by the padding material over the entire anticipated operating temperature range if the potential for survival is to be maintained. Practical considerations and risk analysis, however, may reduce the temperature range requirements. Figure 116, taken from Reference 154, indicates the temperature dependency of the stress-strain properties of a particular foam material. It illustrates the variation experienced by many padding materials and indicates that temperature sensitivity must be considered as a padding material selection criterion.

Stress-strain curves for a polyurethane-foamed plastic used in U.S. Air Force helmets are shown in Figure 117 (Reference 155). The curves indicate that a 1-in. thickness of the foam with a density of 4 lb/ft^3 will nearly satisfy the criteria of Figure 115 (superimposed as a crosshatched area). The lowest impact velocity used to obtain the data of Figure 117 was 50 ft/sec. A weight of 295 lb impacting at this velocity requires the absorption of over 11,000 ft-lb of energy by the padding material. This requirement is obviously considerably more demanding than that of 90 ft-lb of energy at an impact velocity of 20 ft/sec, as described above.

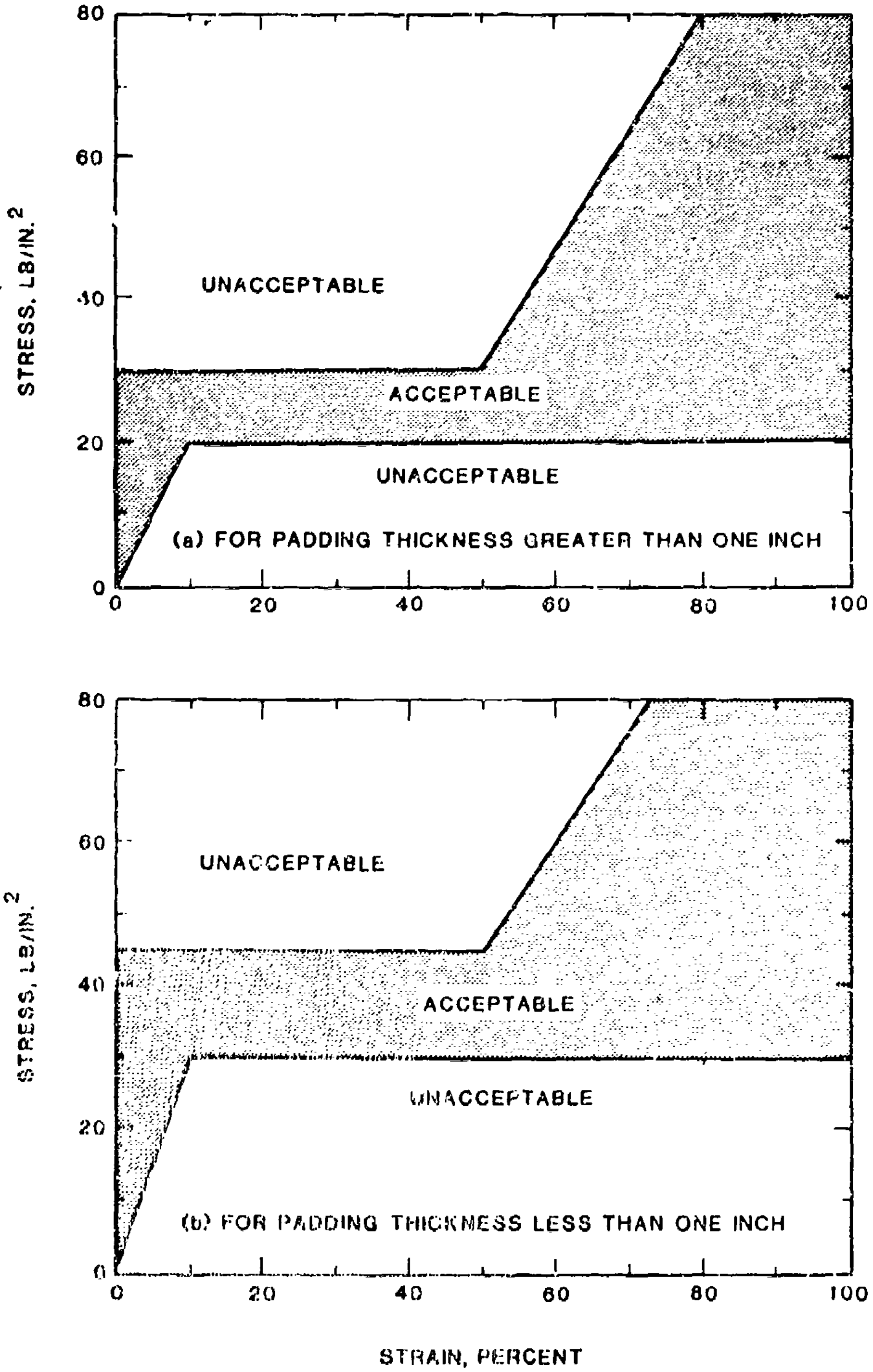


FIGURE 115. RECOMMENDED STRESS-STRAIN PROPERTIES FOR PADDING MATERIAL FOR HEAD CONTACT. (REFERENCE 131)

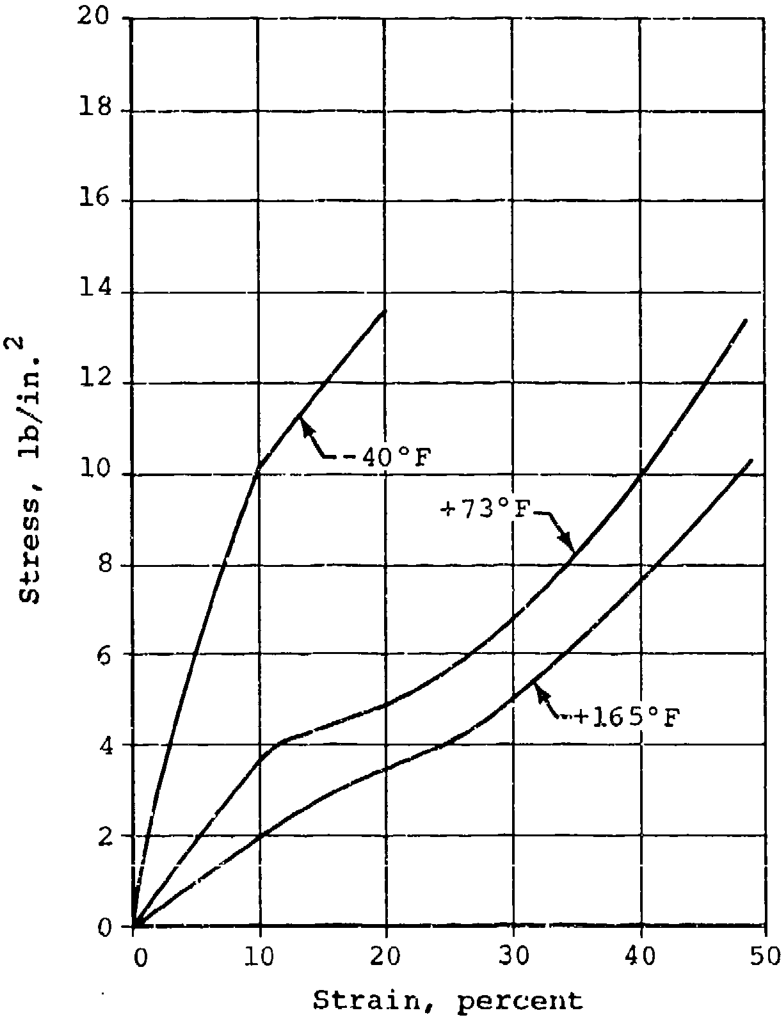
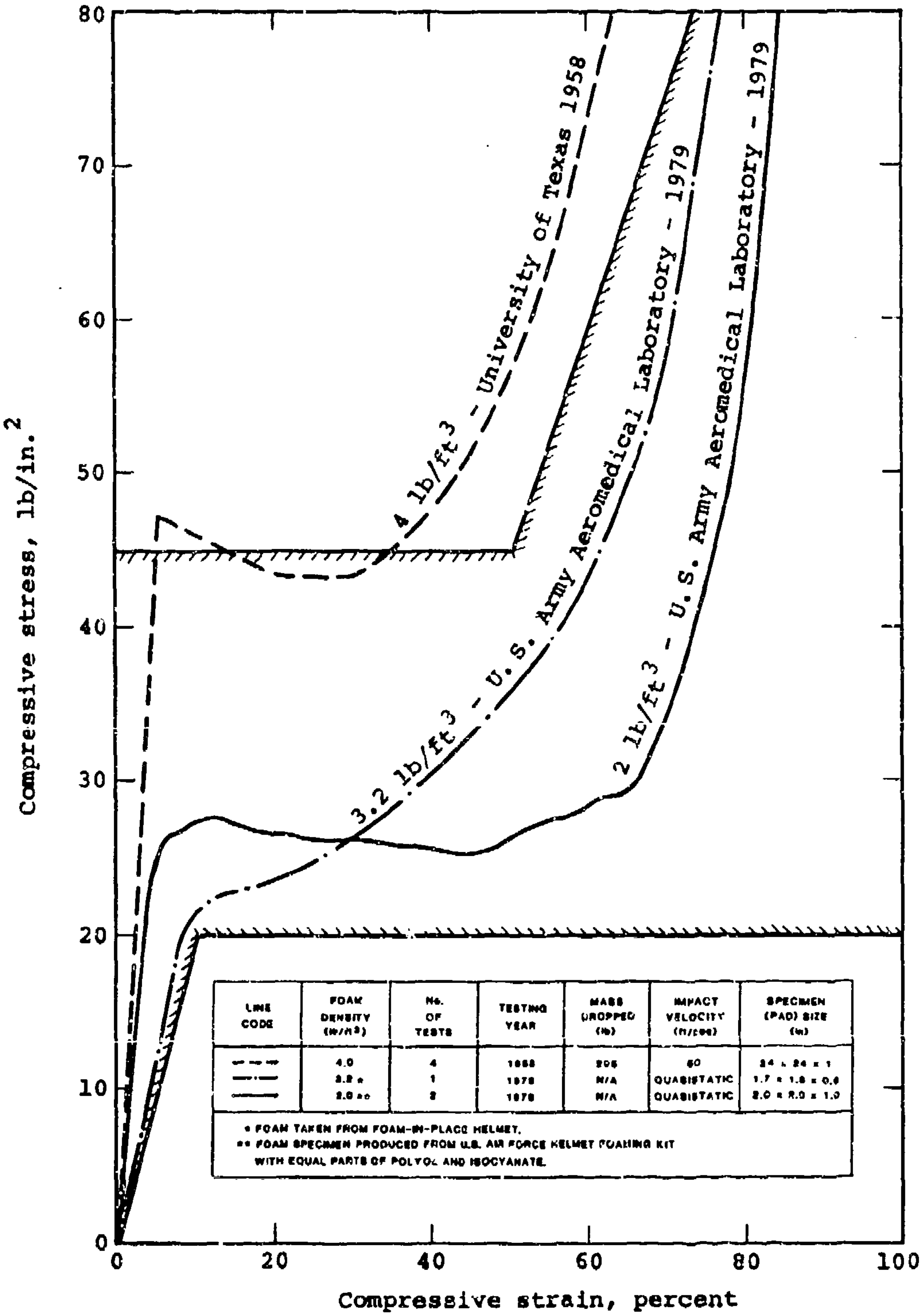


FIGURE 116. STRESS-STRAIN CURVES FOR POLYETHYLENE FOAM. (REFERENCE 154)

11.9.4.2 Bioengineering Approach to Material Evaluation. Daniel investigated the injury-reducing functions of crash padding, considering strength of skull segments (as described in Reference 156). He concluded that because the cranial vault (above the eyebrows) is strong under localized impact, padding used for protection of this region has the primary function of energy absorption to reduce the possibility of brain damage.

On the other hand, padding for facial protection should distribute the impact load over the weaker facial bones, and required energy absorption would be provided by the supporting structure. His suggested evaluation criterion for energy-absorbing materials, based on a program of 91 impact tests, is illustrated in Figure 118. For any given material, plotting on these curves the results of a test conducted according to the given parameters would enable the determination of a material "efficiency," where a 100-percent efficiency would correspond to the deceleration achieved by an ideal square-wave energy



LINE CODE	FOAM DENSITY (lb/ft^3)	No. OF TESTS	TESTING YEAR	MASS DROPPED (lb)	IMPACT VELOCITY (ft/sec)	SPECIMEN (PAD) SIZE (in)
— — —	4.0	4	1958	205	60	24 x 24 x 1
—·—	3.2 *	1	1979	N/A	QUASISTATIC	1.7 x 1.8 x 0.6
——	2.0 **	2	1979	N/A	QUASISTATIC	2.0 x 2.0 x 1.0

* FOAM TAKEN FROM FOAM-IN-PLACE HELMET.
** FOAM SPECIMEN PRODUCED FROM U.S. AIR FORCE HELMET FOAMING KIT WITH EQUAL PARTS OF POLYOL AND ISOCYANATE.

FIGURE 117. EFFECT OF DENSITY ON STRESS-STRAIN CURVES FOR POLYURETHANE-FOAMED PLASTIC. (REFERENCE 155)

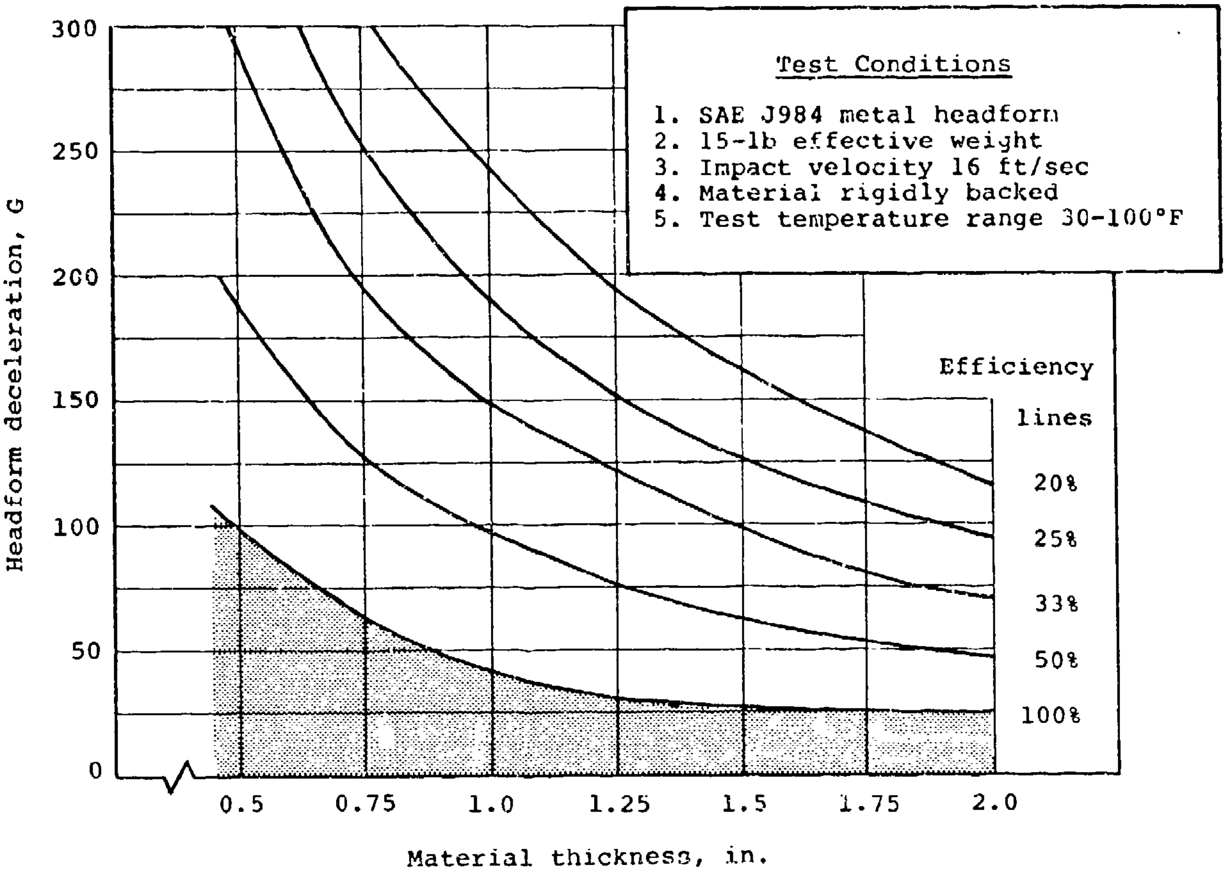


FIGURE 118. EVALUATION CRITERIA FOR ENERGY-ABSORBING MATERIAL. (REFERENCE 156)

absorber of the given thickness. According to Daniel, energy-absorbing materials might be selected on the basis of maximum efficiency.

Evaluation criteria for load-distributing applications, which are illustrated in Figure 119, are based on the following assumptions:

- A load-distributing pad should permit the face to penetrate its surface relatively easily and then maintain a cushioning layer of foam between the base and the underlying structure during collapse of the understructure.

- The understructure should deform at close to the 80-G (1200 lb) face tolerance level expressed in both SAE J885 and Federal Motor Vehicle Safety Standard 201 (References 157 and 158, respectively).

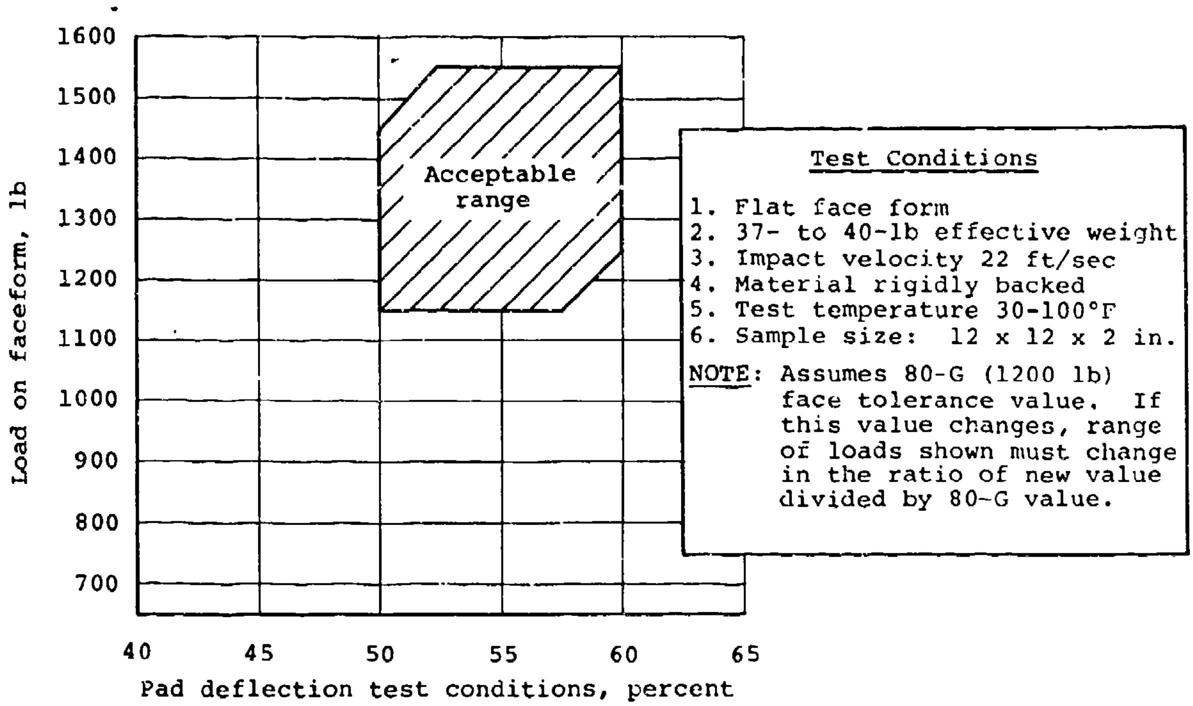


FIGURE 119. LOAD-DISTRIBUTING MATERIAL EVALUATION CRITERIA. (REFERENCE 156)

11.9.4.3 Energy-Absorbing Efficiency Calculations. The energy-absorbing characteristics of foamed polymers were mathematically calculated by Rusch from low-speed experimental data for compressive strain and modulus (Reference 159). Materials were characterized by three parameters: energy-absorbing efficiency, impact energy per unit volume divided by foam modulus, and the maximum decelerating force per unit area divided by foam modulus.

An ideal energy absorber would provide a constant deceleration from an initial speed, v_i, for 100 percent of its thickness, h. The maximum deceleration for an ideal absorber is then given by

$$d_{m_i} = v_i^2/2h \tag{35}$$

The energy-absorbing efficiency, K, is defined as the inverse ratio of the maximum deceleration exhibited by a real material, d_m, to that for an ideal material of equivalent thickness, d_{mi},

$$K = v_i^2/2hd_m \tag{36}$$

Generally, K is expressed as a function of the impact velocity. At low v_i, the impact energy is small relative to the stiffness of the foam, the degree of penetration is small, and K is low. At high v_i, the impact energy is large relative to the stiffness, the impacting body "bottoms" on the understructure, and K is low. At some intermediate v_i, K exhibits a maximum. The optimum material is one for which: (1) the K versus v_i curve is as broad as possible, (2) K_{max} is close to unity, and (3) K_{max} occurs at the most probable v_i for the particular application.

On the basis of his calculations, Rusch stated the following conclusions: (1) the energy-absorbing characteristics of a brittle foam are superior to those of a ductile foam; (2) the optimum energy-absorbing foam has a large cell size, a narrow cell size distribution, and a minimum number of reinforcing membranes between the cells; and (3) foam composites offer no significant advantage over a single foam.

11.9.4.4 Composite Foam System. Brooks and Rey (Reference 160) found that a composite could be formed combining the high energy dissipation of polystyrene beaded foam with the load-distributing effects of semi-rigid urethane. Simple dynamic tests consisted of dropping a 6-1/2-in.-diameter aluminum hemispherical headform weighing 15 lb at impact velocities up to 30 mi/h (44 ft/sec). As shown in Figure 120a, the urethane exhibits the lowest level of headform acceleration during impact. On the other hand, the polystyrene exhibits the lowest level of penetration, as shown in Figure 120b. The urethane can be said to absorb the least amount of energy, as indicated by the highest rebound value in Figure 120c.

In small-scale static tests, 2-in. cubes were compressed to 70-percent deflection and then relaxed with an Instron testing machine at 2.0-in./min crosshead speed. Figure 120d shows the relative energy absorption of the three materials tested, indicating the composite foam as a compromise between polystyrene and semirigid urethane foam.

11.9.4.5 Specific Energy and Relative Energy-Absorption Ratio. Reference 161 discusses performance parameters of Dow composite foam in energy-absorbing applications. It was concluded that, on the typical response curve for a compression test, where the area contained within the hysteresis loop shown in Figure 121 is directly related to the energy absorbed, three performance parameters can be defined: the specific energy absorbed at maximum strain, the relative energy-absorption ratio, and the maximum stress. The total energy absorbed at maximum strain is the sum of areas A and B. When this total energy is expressed in terms of a unit volume (or unit weight), the quantity becomes the specific energy absorption at maximum strain. The ratio of area A to the sum is the relative energy-absorption ratio, which is a measure of the amount of energy actually dissipated during compression. In effect, it corrects the performance parameter for the energy that is momentarily stored. The maximum stress is usually the stress at maximum strain. Exceptions to this occur when some rigid cellular materials are compressed and a spike is observed during the initial stage of compression. Maximum stress levels are directly related to the deceleration that the impacting object sustains.

Melvin and Roberts (Reference 162) measured the specific energy absorbed and the relative energy-absorption ratio for the materials listed in Table 25 using three speeds: 20, 2,000, and 13,000 in./min. Their results are summarized in Table 26 and Figure 122, from which they concluded that the

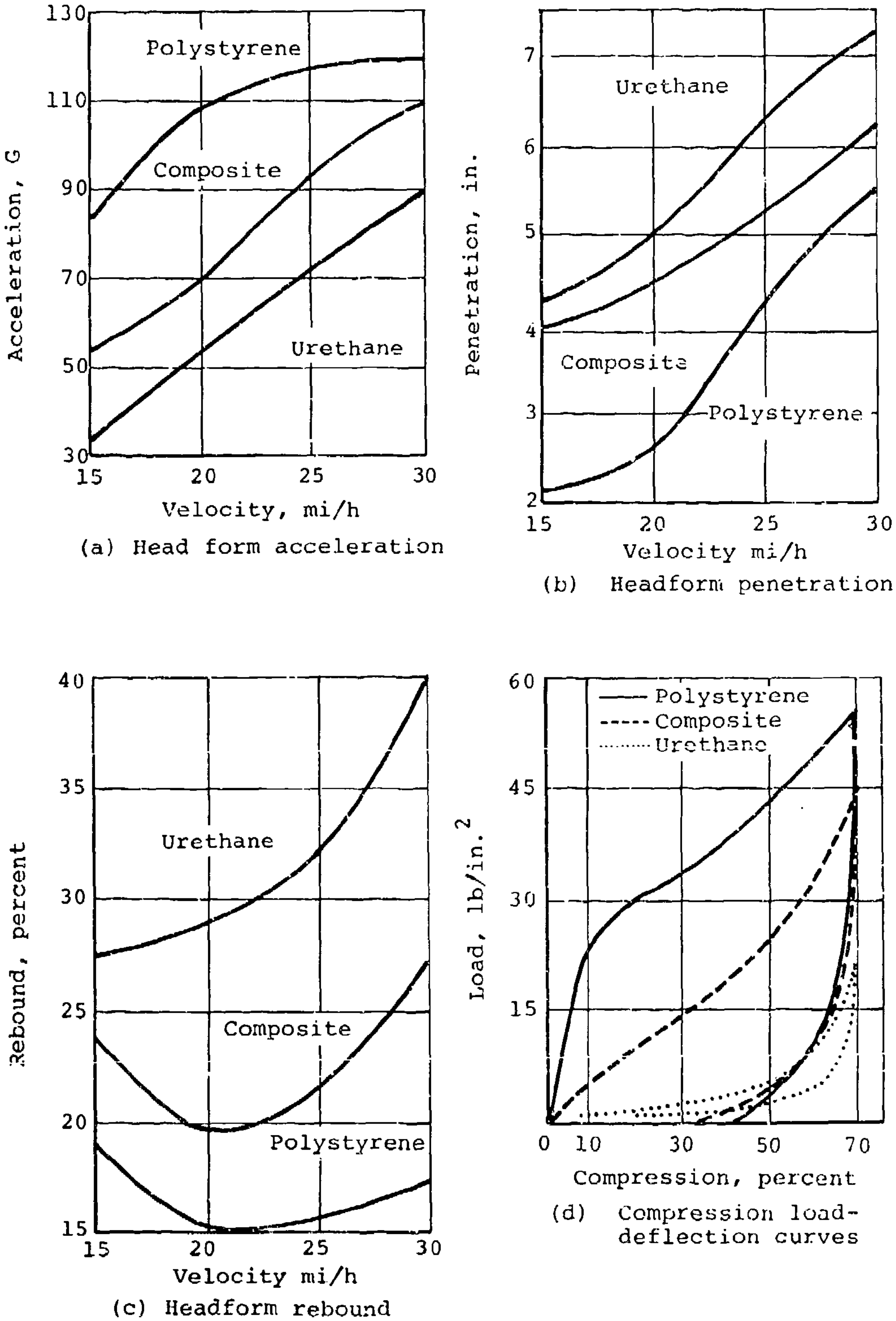


FIGURE 120. RESPONSE OF COMPOSITE FOAM, COMPARED WITH URETHANE AND POLYSTYRENE. (REFERENCE 160)

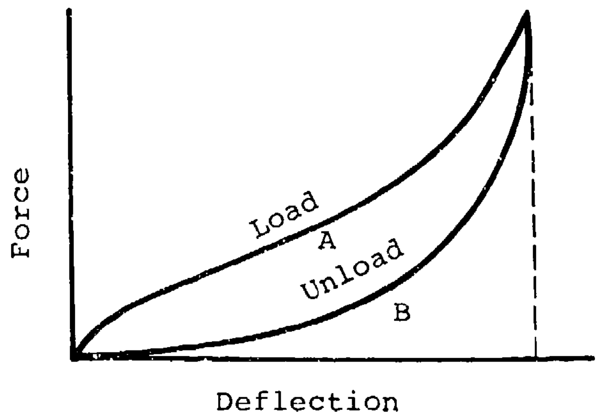


FIGURE 121. TYPICAL RESPONSE OF PLASTIC FOAM TO COMPRESSION TEST.

TABLE 25. MATERIAL SUMMARY

Material and Code Number	Density (lb/ft^3)	Specimen Height (in.)	Initial Strain Rate (sec^{-1}) Speed 1	Speed 2	Speed 3
Polyethylene E-1	2.34	2	0.17	17	100
Polyethylene E-2	6.65	1.5	0.22	22	150
Polyethylene E-3	9.05	2	0.17	17	100
Polystyrene S-1	1.09	2	0.17	17	100
Polystyrene S-2	3.35	2	0.17	17	100
Polystyrene S-3 (pelletized)	1.21	2	0.17	17	100
Polyurethane U-1 (rigid)	1.53	2	0.17	17	100
Vinyl V-1	7.35	1	0.33	33	220
Vinyl V-2	7.25	1	0.33	33	220
Vinyl V-3	5.04	1	0 33	33	220
Cork C-1	11.5	1.5	0.22	22	150

TABLE 26. TEST RESULTS SUMMARY

Material	Curve Type	Average Maximum Stress lb/in.^{2} Speed 1	Speed 2	Speed 3	Average Specific Energy Absorbed to Maximum Strain, in.-lb/in.^{3} Speed 1	Speed 2	Speed 3	Average Relative Energy-Absorption Ratio Speed 1	Speed 2
E-1	II	15.8	20.2	21.8	4.42	6.4	7.0	0.48	0.69
E-2	II	59.8	60.5	77.7	20.9	19.9	29.2	0.76	0.87
E-3	II	86.2	107.1	132.0	28.9	37.6	45.2	0.82	0.90
S-1	I	47.2	48.5	49.7	19.8	20.7	21.2	0.86	0.87
S-2	I	141.1	177.5	175.4	57.1	71.0	72.7	0.93	0.95
S-3	I	34.7	37.0	37.7	11.6	12.1	12.2	0.82	0.85
U-1	I*	36.8	41.2	42.0	13.2	13.0	14.0	0.97	0.98
V-1	II	18.7	34.0	49.0	4.2	9.6	14.0	0.39	0.56
V-2	II	22.9	43.5	60.3	5.9	13.6	18.3	0.50	0.70
V-3	II	24.6	44.2	55.9	7.2	16.3	20.4	0.62	0.75
C-1	I	364.5	382.8	445.3	124.3	152.6	171.2	0.87	0.87

NOTE: Speed 1 = 20 in./min, Speed 2 = 2000 in./min, and Speed 3 = 13,000 in./min.

*Exhibited initial load spike.

majority of foams do not exhibit marked increases in properties with increasing test speed. The vinyl foams, which exhibit dramatic increases, are the exceptions.

11.9.4.6 Dynamic Property Index. Fan (Reference 163) developed techniques for simulating the force-penetration properties of viscoelastic materials based on results of pendulum impact tests on polyurethane foam. The dynamic force-penetration relationship of polyurethane can be approximated by a function of three variables: penetration-thickness ratio, sample thickness, and impact velocity. Fan suggested a criterion for energy absorption expressed as the dynamic-property index:

$$I = E_d/G_m \tag{37}$$

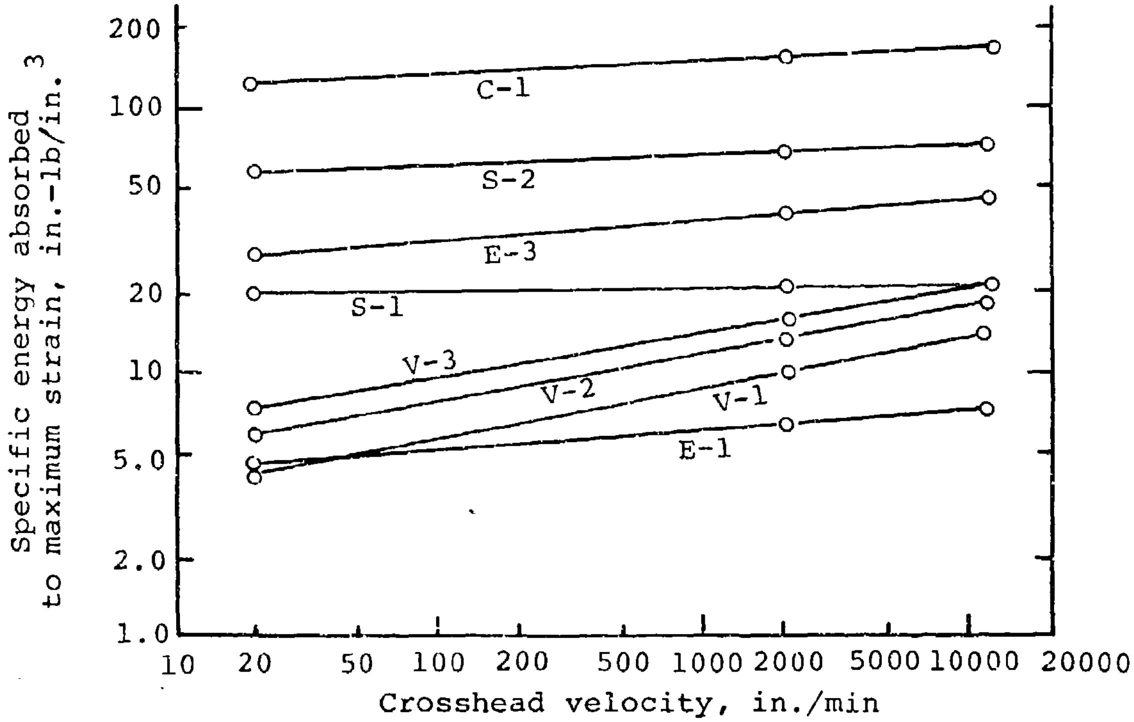


FIGURE 122. SPECIFIC ENERGY ABSORBED TO MAXIMUM STRAIN VERSUS CROSSHEAD VELOCITY.

where I = dynamic-property index of the material.

E_d = the amount of energy dissipation by the foam material during impact.

G_m = the maximum deceleration measured at the impactor during impact.

A high index value implies a high degree of effectiveness. The dynamic-property index of a material varies with the test conditions. The material rated as the most effective in a certain case is not necessarily the most effective material in other cases.

11.9.4.7 Dynamic Crushing Pressure. Furio and Gilbert (Reference 164) conducted a series of drop tests with low density (2 lb/ft^3) urethane foam using a flat impactor weighing 729 lb at a drop height of 45 ft.

The dynamic crushing pressure, P_{cr}, which is the product of the weight of the impact mass and the acceleration divided by the impact area, is shown in Figure 123 as a function of temperature and velocity for two samples of identical dimensions. The increase in pressure with velocity is attributed to

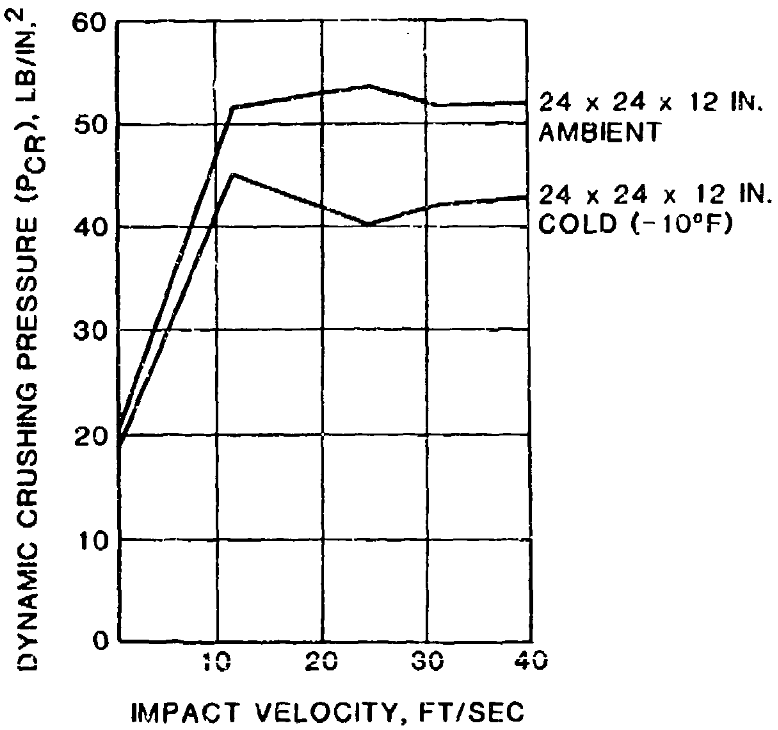


FIGURE 123. DYNAMIC CRUSHING PRESSURE VERSUS IMPACT VELOCITY FOR TESTS AT TWO TEMPERATURES.

the fact that the entrapped gas must escape in order for the foam to collapse. Under dynamic loading, the gas cannot escape fast enough, and a higher pressure results.

11.9.5 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.

11.9.6 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 bones, etc., should be designed with large radii (1 in. or more) rather than with sharp edges and corners.

Swearingen concluded in Reference 165 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 the head may impact during the crash sequence.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1990 - 727-075/00621