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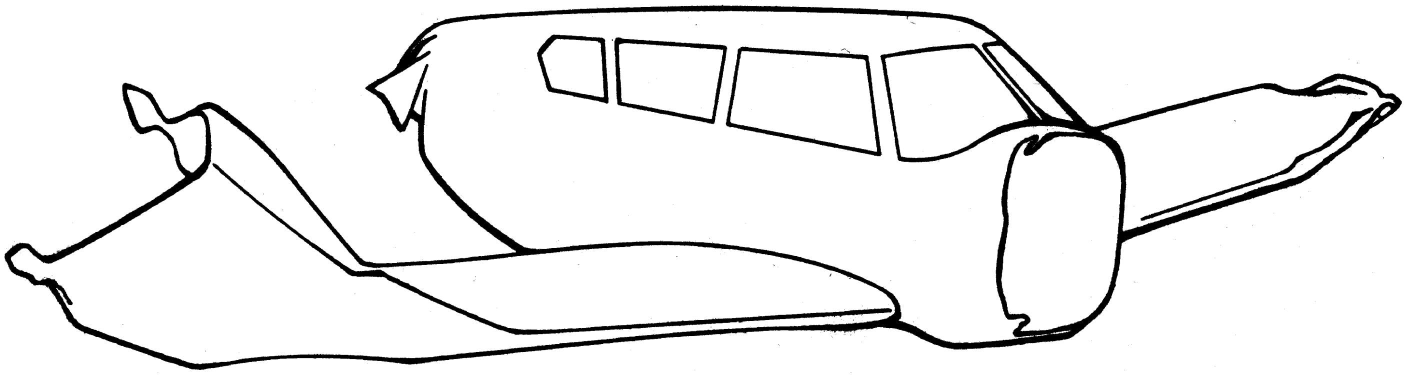
GENERAL AVIATION AIRCRAFT CRASHWORTHINESS

An Evaluation of FAA Safety Standards for Protection of Occupants in Crashes



prepared for
The Aircraft Owners and Pilots Association
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Washington, D.C. 20014

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Final Report UM-HSRI-81-10
15 May, 1981

Technical Report Documentation Page

1. Report No. UM-HSRI-81-10	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle GENERAL AVIATION AIRCRAFT CRASHWORTHINESS: An Evaluation of FAA Safety Standards		5. Report Date 15 May 1981 6. Performing Organization Code
7. Author(s) Richard G. Snyder, Ph.D.		8. Performing Organization Report No. UM-HSRI-81-10
9. Performing Organization Name and Address The Highway Safety Research Institute Institute of Science and Technology The University of Michigan Ann Arbor, Michigan 48109		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DRDA-81-243-C1
12. Sponsoring Agency Name and Address The Aircraft Owners and Pilots Association 7315 Wisconsin Avenue Washington, D.C. 20014		13. Type of Report and Period Covered 1 Sept. 1980 - 15 May 1981 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A study was conducted to review sections of the Federal Aviation Regulations (14CFR23) related to general aviation safety standards and crashworthiness requirements to evaluate how effective the present requirements are within the state-of-the-art. Particular attention has been focused in Part 23 on sections 561, "emergency landing conditions"; 785, "seats, berths, safety belts, harnesses"; Part 34.132 (TSO-C22f) "safety belts," and TSO-C39a "aircraft seats and belts," as well as proposed TSO C-100 "child restraints." Background review includes documentation and citations going back to 1910 relative to criteria and need for improved crashworthiness design, with some 750 references cited. Changes in regulations have been traced back as far as possible to the original Bureau of Air Commerce requirements of 1926. Analysis of the state-of-the-art in these areas has considered experimental research, aircraft accident statistics, human impact tolerance, and comparison with pertinent regulations, standards, specifications, recommended practices, and guidelines of other technical, military, and civil federal organizations. Conclusions and specific recommendations for up-dating the current regulations in the area of crashworthiness and occupant crash protection are provided.

17. Key Words Crashworthiness, Aircraft Accident Data, Restraint, History of Regulations, Seats, Human Impact Tolerance, Safety Standards, General Aviation, Child Restraint		18. Distribution Statement	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 299	22. Price

EXECUTIVE SUMMARY

The number of general aviation aircraft in operation has increased faster than any other form of transportation, with more passengers reportedly carried annually than by the commercial airlines. In the ten-year period 1970-1979 over 100,000 occupants of general aviation aircraft have been involved in 43,557 accidents, of which 16.1 percent were fatal accidents with some 14,194 fatalities. Yet many accident studies, dating back over 40 years, have concluded that from 50-93 percent of these fatalities would not have occurred if adequate crashworthiness design (such as stronger cabin structures, restraints and attachments, shoulder harnesses, and energy-absorbing seats) had been utilized.

Crashworthiness refers to the ability of an aircraft to withstand crash impact forces and to protect its occupants from injury during a survivable accident. A survivable accident is defined as one in which the forces transmitted to the occupant through the seat and restraint system do not exceed human tolerance limits and prevent ejection or contact with injurious structure, and in which the cabin structure in the occupants' immediate area remains substantially intact without intrusion throughout the crash sequence. It may still be classed as survivable even though a system element (the seat, restraint) fails, as long as the other two requirements are satisfied. While the term crashworthiness itself does not appear in the present Federal Aviation Regulations (FARS, 14CFR23), it is a concept that has been recognized as analogous to airworthiness. A basic philosophy of crashworthiness is that since some crash impacts will continue to occur despite all efforts of prevention, the occupants should receive adequate protection and chance for survival when a crash does occur.

There has been mounting concern that the Federal Aviation Administration has not given adequate attention to crashworthiness requirements in the FAR's. A basis for such concern includes findings that: (1) the probability that at least 60 percent (ranging to 150%) of the aircraft manufactured will be involved in an accident during a 20-year service life; (2) the general aviation fatality rate per passenger mile is 6 to

13 times that of passenger cars, and 216 to 432 times that of U.S. air carriers; (3) the chances of being killed in a general aviation aircraft accident are about 2 in 3, as compared to receiving more than minor injury, and one's chances of receiving a disabling injury are over 25 times that of being fatally injured in an automotive accident; and (4) most general aviation aircraft certified today are actually grandfathered in under CAR 3 requirements of the 1950's, rather than under the current requirements of FAR 23.

The purpose of this study has been to review sections of Part 23 (Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes) of the Federal Aviation Regulations (14CFR23) related to crashworthiness requirements, and evaluate how effective the present requirements are within the state-of-the-art. Particular attention has been focused in Part 23 on sections 561, "emergency landing conditions"; 785, "seats, berths, safety belts, harnesses"; 625, "fitting factors"; 1413, "safety belts and harnesses"; and Part 34.132 (TSO-C22f) "safety belts," and TSO-C39a "aircraft seats and belts," as well as proposed TSO C-100 "child restraints." Analysis took the state-of-the-art in these areas into consideration, including human tolerance, with comparison to pertinent regulations, standards, specifications, recommended practices, and guidelines of other technical, military, and civil federal organizations. Background review includes documentation and citations going back to 1910 relative to criteria and need for improved crashworthiness design, with some 750 technical references cited. Changes in the pertinent FARs have been traced back as far as possible to the original Bureau of Air Commerce requirements of 1926.

It is concluded that the FAA has given little attention to, and has in the past resisted, updating regulations in the area of crashworthiness which would effectively reduce fatalities and serious injuries in general aviation crashes. The Flight Standards Division or Administration of FAA has consistently taken no positive action on findings and recommendations of the FAA's own medical and engineering research, as well as reports of other agencies and organizations such as the NTSB.

Critical terms such as "moderate descent velocity" and "minor crash landing" remain undefined. Seat belt strength has been addressed only once since 1934 when in 1950 (31 years ago) today's single-belt standard of 1500 lbs. was specified as an exception to the National Aircraft Standards Specification 802 requiring 3000 lb. minimum strength. Metal-to-webbing type restraint buckles have had a long history of failure, reported in accident studies of the 1940's, with a warning reporting test data, issued by Crash Injury Research in 1955. A decade ago the NTSB recommended a requirement for metal-to-metal type buckles. An FAA requirement will become effective 4 December 1981. The FAA requirement for a shoulder harness in the front seats, in "newly certified" aircraft after 18 July 1978, was found 40 years ago to be the single most effective means of protection. In 1981 an estimated 50 percent of general aviation aircraft do not have this protection.

Since general aviation is the most rapidly growing form of transportation, with a 44.1 percent increase to 315,000 aircraft estimated by 1992, it is concluded that it is urgent that increased attention be given to updating the FAR's related to crashworthiness.

RECOMMENDATIONS

Part 23.561 Emergency Landing Conditions:

1. It is recommended that the term "survivable accident," or "survivable crash," be substituted in this requirement for the present undefined term "minor crash landing" [23.561(b)].

2. Eliminate the subjective terms altogether, and consider rewording to "the structure must be designed so that each occupant will escape serious injury in a survivable crash"...rather than the current "the structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing..." [23.561(b)].

3. Human impact tolerance levels for injury are far above those presently required in "ultimate inertia forces" [23.561(b)(2)]. This fact should be taken into consideration in updating and increasing seating, restraint, and attachment design criteria to more realistic levels.

4. Part #23.561 should be amended to include downward (vertical) and rearward design values. At present there are no requirements. A confusion in technical meaning of terms exists in #23.561(b) and (b)(2) in use of forces and accelerations. A solution to clarify this point is simply to add a definition (or reference in glossary) together with a simple coordinate system figure illustrating exactly what is meant relative to direction of loading on the occupant.

5. An objective and meaningful definition is needed to clarify specifically what the present requirement "moderate descent velocity" [23.561(c)] means. Part #23.561(c)(2) needs to be upgraded to better reflect the state-of-the-art for vertical impact protection and the multitude of structural means to accomplish improved energy-absorption and reduce loads on the seated occupant in a crash.

6. In view of the apparent incidence of overturns, attention should be given to upgrading #23.561(d)(1) to require stronger cabin rollover protection than the present "upward ultimate inertia force of 3g."

7. In view of the number of places needing updating in this section, it would make better sense to modify 23.561, by starting all over and developing a totally new section on occupant protection. Such a new section should reflect the emphasis on crashworthiness by retitling it from "emergency landing conditions" (of 1945) to something like "emergency crash landing conditions," "crashworthiness protection," or "occupant crash protection." Further, additional guidelines should be incorporated to provide more meaningful information to the designer.

Part 23.785 Seats, Berths, Safety Belts, and Harnesses:

8. Part 23.785(a) should be amended to increase the occupant weight requirement from the present 170 lbs. to 224 lbs., and the Army's practice of using both 5th-percentile and 95th-percentile occupant weights should be adopted. (A U.S. 5th-percentile women weighs 104 lbs. A 95th-percentile male weighs 224 lbs.).

9. Part 23.785(e) and (e)(3) should be amended to require dynamic test criteria (already developed and used by the FAA), rather than static tests. FAA tests have concluded that static testing cannot be related to crash environments.

Part 23.1413 Safety Belts and Harnesses:

10. Part 23.1413 should be modified to realistically increase webbing strength requirements to take into consideration the state-of-the-art and present (5500-6000 lb.) belt availability. This would also serve to greatly strengthen and upgrade one important link in the occupant crash restraint chain.

Part 23.625 Fitting Factors:

11. Since this requirement has an important bearing on seat and safety belt attachment strength, it deserves further engineering review.

Consolidation of Seat, Belt, Berth, and Belt Attachment Factors:

12. Consolidate all seat, berth, and belt attachment factor requirements into a single section.

Child and Infant Restraint:

13. (1) Pilots should be educated concerning adequate protection of their younger passengers. (2) Until further rulemaking action is taken on proposed TSO-C100, interim action should allow certain automotive infant/restraint systems to be used on aircraft seats (not blocking emergency egress). This would offer considerably greater impact protection to children than is presently the case (where an infant must be held in the parent's lap without restraint or children are improperly and inadequately placed in adult restraints).

Technical Standard Orders (TSO's):

14. All TSO's should be immediately reviewed relative to state-of-the-art and amended to reflect the updating necessary. Priority attention should be given to TSO-C39a (formerly Part 37.136) for seats (also TSO-C25a for air carrier seats), and TSO-C22f (formerly Part 37.132) for safety belts.

Safety Belts TSO-C22f (formerly Part 37.132):

15. In view of the accident crash test data over the past 30 years documenting the need for stronger restraint systems, and especially FAA's recent studies, TSO-C22f should be upgraded to be at least comparable to the webbing strength protection provided in automobiles. The restraint-seat system must be considered as a whole, since restraint is no stronger than its weakest link--in this case the hardware and attachments which should be upgraded as well. It is recommended that restraint systems in general aviation aircraft should be designed for a forward dynamic load of 25 G's applied 20 degrees to either side of the airplane's longitudinal axis; an upward load of 16 G; a downward load of 15 G; and an aft load of 5 G.

Seat Strength (TSO-39a):

16. General aviation seat strength requirements specified in TSO-C39a should receive priority attention to upgrade. As an interim measure the new FAA TSO completed in 1978 should replace the present TSO.

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1.0 INTRODUCTION

The importance of aircraft crashworthiness and occupant protection when an accident does occur has been known and documented in the literature for the past 70 years through medical and engineering research and accident investigation studies. Yet little attention has been given to this knowledge in the federal standards under which general aviation aircraft* are manufactured, licensed, or operated. The prevailing notion that all, or most, accidents can be prevented through emphasis upon airworthiness and accident prevention programs, rather than crashworthiness and protecting the occupant when a crash does occur, is a premise not supported by the annual accident statistics and data indicating that at least 60% of all aircraft manufactured will be involved in an accident during their service life. In the past the emphasis on aircraft airworthiness performance and styling in the marketing of aircraft has been to the detriment of development of safety features. The assumption has been that "safety doesn't sell" aircraft. As a result, few general aviation pilots or aircraft owners are familiar with the details of sections of the Federal Aviation Regulations (FAR's) dealing with design requirements for the protection of their passengers and themselves--that is, such considerations as the strength of the cabin, seats, restraint systems and tie-down anchorages, fire and rollover protection, emergency egress, and safety equipment. Such things "come with the airplane" and "must conform to federal regulations." With a staff of over 56,000 persons (excluding military personnel) at the end of 1979, a pilot would assume that the Federal Aviation Administration (FAA) must be constantly upgrading requirements within the technical state-of-the-art to bring out the safest aircraft product possible (FAA Handbook, 1979). The intent of the following report is to evaluate the current status of crashworthiness requirements for general aviation aircraft, primarily by evaluation of the current Part 23 FAR's (14CFR23).

* General aviation aircraft are defined as airplanes certified under 14CFR23 and preceding regulations, with a gross weight of 12,500 lbs. or less.

1.1 Objectives and Scope

Federal Aviation Regulations (FAR's) applicable to general aviation aircraft are found in Part 23 of the Code of Federal Regulations (14CFR23) and are entitled "Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes." The primary purpose of this study is to review those sections of Part 23 applicable to crashworthiness and provide an evaluation of how well they actually provide meaningful occupant protection within today's technical knowledge. Where experience and supporting documentation indicate areas or specific places where omission or confusion is found to exist, or data may be outdated, the intent is to point toward recommended modifications and additions that would bring those portions of the FAR's to a higher level of crashworthiness protection.

The scope, within the limits of time and budget, is to take a broad look at all of Part 23 under which general aviation aircraft are manufactured, licensed, and operated, but to focus on the several key sections. To provide the reader with further background, additional sections pull together previous aircraft crashworthiness research studies and also outline the development of the pertinent federal requirements. This material is also supplemented by comparable standards, recommendations, and requirements from civil and military technical organizations relative to seat and restraint systems, human tolerance forces, and occupant protection. Post-crash factors of fire protection and emergency exits have not been evaluated within the scope of this study, but should be considered in overall crashworthiness requirements.

1.2 Definition of Crashworthiness

Crashworthiness in simplest terms refers to the ability of an aircraft to withstand crash impact forces and to protect its occupants from injury during a survivable accident. Many studies have shown that when the aircraft structure remains relatively intact, without significant intrusion, the occupant is adequately restrained in an energy-absorbing seat system, the interior structures are designed to distribute loads and absorb energy, and the impact forces imposed on the occupant are within human tolerance* limits, the occupant can survive without serious injury even when the aircraft itself is destroyed.

Most researchers in crashworthiness use a definition that encompasses most of the above conditions. It should be pointed out that a survivable crash may be defined in two different ways. The Army's definition of a survivable accident reflects the field investigator's post-crash evaluation of an existing crash. Other definitions additionally require that the seat and restraint system provide energy-absorbing protection and restrain the occupant from ejection and contact with injurious structure. These additional elements are basic conditions which the designer should strive for. However, a crash can be classified as survivable even though a system (the belt, the seat) fails, _if_ the two primary requirements in the Army's definition (livable cabin volume and impact within human tolerance) are satisfied.

Undoubtedly the basic principle of general aviation crashworthiness design originated with DeHaven. In a 1952 Society of Automotive Engineers symposium on "Packaging the Passenger," DeHaven simply stated four basic protection concepts in terms of packaging to protect goods in transit:

1. "...the package should not open up and spill its contents and should not collapse under reasonable or expected conditions of force and thereby expose objects inside it to damage."
2. "...packaging structures which shield the inner container must not be made of brittle or frail materials; they should resist force by yielding and absorbing energy applied to the outer container so as to cushion and distribute impact and thereby protect the inner container."
3. "...articles contained in the package should be held and immobilized inside the outer structure....This interior packaging is an extremely important part of the overall design, for it prevents movement and resultant damage from impact against the inside of the package itself."

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* See Section III for discussion of human tolerance levels.

4. "...the means for holding an object inside a shipping container must transmit forces to the strongest parts of the contained objects." (DeHaven, pp. 3-4, 1952).

Comparing the human to an egg, DeHaven effectively demonstrated his point by dropping an egg on the floor, which would smash; then dropping an egg 150 feet onto 1-1/2 inches of energy-absorbing padding, unbroken.

In reviewing crash-impact engineering progress of the 1940's, Hasbrook reported that:

- "By 1950, as a result of this progressive interest in an increasing number of engineers and safety people in the aviation field, a number of aircraft contained numerous features originally advocated by DeHaven's group. Forty-G cockpits in fighter aircraft, lightweight, frangible (delethalized) instrument panels, control wheels and tilting seatbacks--the last to protect the heads of persons in passenger cabins--were becoming standard equipment. The shoulder harness, which had proved itself of value during the latter part of World War II, also was being considered for light planes. Such terms and phrases as "crashworthiness," "survivable" and "nonsurvivable" accidents, and the word "deceleration" became routine jargon of the industry" (Hasbrook, pp. 271-272, 1956).

The following selected excerpts from various authors over the past 40 years illustrates a similarity in concept of crashworthiness definitions.

- "The term "crashworthiness" which has been taken from the British, does not mean, and must not be considered to imply, crashproof airplanes. It does mean providing the maximum practicable degree of occupant protection in those crashes in which aircraft damage is such that the accident may be considered survivable." (Stieglitz, p. 1, 1950).
- "To prevent injury by inward crushing of structure, the fuselage and cabin structure should be designed as a <u>crashworthy</u> container

in that the inhabitable areas of the fuselage will remain relatively intact under survivable crash conditions." (Hasbrook, p. 1, 1956).

- "To ensure the occupants impact survival, three requirements must be met:
  1. The occupants' environment must remain reasonably intact in order to provide living space;
  2. The occupant should not receive dangerous or fatal injury as a result of forcible contact with environmental structure, and
  3. The crash force transmitted to the occupant must not exceed the survivable limits "of human G tolerance." ("....implies the acceptance of non-dangerous-to-life injuries") (Bruggink, AvCIR, 1961).
- "Crashworthiness is the ability of a vehicle to attenuate impact effects so as to protect the vehicle contents." (Hegenwald, p. 5, 1962).

The Federal Aviation Administration Flight Standards Technical Division has described crashworthiness as follows:

> "The purpose of crashworthiness is to protect lives and prevent injuries in airplane accidents." ..."to produce a practical design which would recognize the limitations of a "totally safe" design. This approach would combine present levels of performance and operating economy with crashworthy design features which accident studies show can substantially reduce the number of accident casualties. It would require that the structure be able to absorb the maximum amount possible of the crash impact energy. Then, as much of the remaining energy as possible would be absorbed by the seat and restraint systems. This would provide the most practicably attainable deceleration environment. Further protection would be provided though the use of energy absorbing interiors. This approach appears to be most practical." (Federal Aviation Administration, A Survey of Crashworthiness Information for Small Airplanes, 1973; see also Crashworthiness Design Handbook (Proposed), circulated to Industry in 1971).

Currently, the U.S. Army's Aircraft Crash Survival Design Guide defines crashworthiness in terms of a "survival envelope" and a "survivable accident." The latter is "an accident in which the forces transmitted to the occupant through his seat and restraint system do not exceed the limits of human tolerance to abrupt decelerations 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." (1980 Edition, Vol. II. p. 17).

There have been several revisions to the Army's guide, first published in 1967. In earlier editions an objective was to require occupant protection in crashes up to and including the severity of the 95th-percentile survivable crash pulse. Since acquiring operational aircraft designed to these crash safety specifications and development/issue of Military Specifications, this requirement has been dropped and presently the recommended design crash environment is simply presented as the design pulse. (The reason it is a design pulse is that Mil Specs (MIL-S-58095(AV) and MIL-STD-1290(AV) have been adopted, so the "requirement" is provided by the Mil Spec instead of the Crash Survival Design Guide.)

While the term "crashworthiness" itself does not appear in the Federal Air Regulations, it is a concept that has been recognized as analogous to airworthiness. Throughout U.S. federal regulation history the main focus in civil aircraft safety design has been upon airworthiness requirements, or "safety of the airplane relative to its environment." The concept of crashworthiness, or "safety of the occupants relative to the airplane" (Federal Aviation Administration, "Crashworthiness Design Handbook (Proposed) July 1971; A Summary of Crashworthiness Information for Small Airplanes, February 1973) has played a secondary role which has received little recognition in the FAA until fairly recently. This appears to reflect the marketing influence which for many years hid behind the conundrum "safety doesn't sell," and "planes are built to fly, not crash." (Bruce and Draper, 1970). Such marketing platitudes completely ignore the fact that despite the most earnest efforts at pilot education and training, combined with an emphasis upon airworthiness, each year a fairly predictable proportion of the manufacturers' products do in fact become an accident statistic.

A basic philosophy of crashworthiness is that since some crash impacts will continue to occur despite all efforts at prevention, the occupants should receive adequate protection and chance for survival when a crash does occur.

1.3 Need For This Study

General aviation aircraft are a vital link in the nation's transportation system. The U.S. general aviation aircraft fleet has increased during the past five years (1976-1980) at a rate of 3.4 to 7.3% per year (FAA Forcast Table 6, p. 44, 1980), and presently numbers about 208,000 active* aircraft, with an estimated 250,000 total aircraft (FAA, Dec. 1980). While preferential emphasis is often given to requirements of the commercial airlines, the U.S. air carrier fleet currently includes only 2745 aircraft (1980).

During the decade between 1969 and 1978, as shown in Table I, the number of U.S. automobiles increased 33%, and buses 37%, while general aviation aircraft increased by 52%, in contrast to a decrease in the number of rail passenger cars (-1%), and commercial air carrier (-5%) units. The Federal Aviation Administration (FAA) forecasts air carriers to reach 3202 aircraft by 1992, a 14.3% increase over 1980 (FAA Forecasts Table 3, p. 41, 1980), yet general aviation aircraft are expected to number 315,500, a 44.1% increase, in the same period. It has been estimated that the 100 million people traveling intercity each year in general aviation aircraft equals the combined total of passengers carried by 26 of the nation's certified airlines (Washington Post, 27 November 1977), while other sources estimate more passenger travel by general aviation aircraft each year then by all U.S. civil air carriers combined (NTSB, 1980). It is apparent that general aviation is the most rapidly growing form of transportation.

Yet with this growth there is increasing urgency to deal with findings of reports that general aviation crashworthiness safety is deficient. The following statistics show some major areas pointing to this conclusion.

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* An active aircraft must have a current registration and it must have flown during the previous calendar year.

TABLE I

CHANGE BETWEEN 1969 and 1978
ACCORDING TO MODE OF TRAVEL
(number of vehicles)

	1969	1978	1969-1978 PERCENT CHANGE
Automobiles[1]	87,153,381	115,826,496	+32.9
Buses[1]	364,340	500,362	+37.3
Rail Vehicles[2] (Passenger)	10,665	10,554	- 1.0
General Aviation Aircraft[3]	130,806	198,778	+52.0
U.S. Air Carrier Aircraft[4]	2,690	2,545	- 5.4

[1] Number of Vehicles registered. Source: Ward's Automotive Yearbook, 1980

[2] Number of Passenger rail vehicles owned or leased in the U.S. Source: APTA, '78-'79 Transit Fact Book.

[3] Active (1969) or Eligible (1978) Aircraft. Annual Review of Aircraft Accident Data, NTSB, 1973-1978.

[4] Number of aircraft used in the fourth quarter, excludes "aircraft operated by air taxi operators who hold authority to operate aircraft over 12,500 pounds, turbo jet aircraft under blanket authority, or aircraft operated by air travel clubs." (p. 40, FAA Statistical Handbook of Aviation - Calendar Year 1978.

1.3.1. Probability of an Accident. During the past decade (1978-1969) over 100,000 occupants have been involved in 43,744 general aviation accidents. Of these, 6,972 were fatal (that is, one or more occupants were fatally injured) and during this period 14,123 fatalities occurred (NTSB, 1980; FAA Av. News, 1975). Statistics show that this number of accidents was equivalent to 38% of the total U.S. non-carrier aircraft production during this period. Between 1968 and 1977 there were 44,747 accidents, and 124,912 new aircraft manufactured. This number of accidents is equivalent to 35.8% of the total aircraft production during that period. For at least one model, 73% of total production will have been involved in an accident within ten years at current rates (Snyder, 1978). Since the mean life of a general aviation aircraft is about 20 years, (Aviation Safety Digest, 1977; NTSB, 1980) it has been estimated that 60-70% of all aircraft manufactured will be involved in an accident during their lifespan (Bruce and Draper, 1970; Swearingen, 1971; Snyder, 1975, 1978; NTSB, 1980).

Currently the number of general aviation accidents each year is equivalent to one out of each four aircraft manufactured annually. However, in 1970 this had reached 64.6% of the annual production, and over the past 19 years it has averaged about 40%. If the number of annual accidents is compared to the total active general aviation fleet, accidents presently only occur to about 2% of the total operational aircraft each year, with an average of about 4% the past 19 years. However, since the service life expectancy is estimated to be about 20 years, it can be stated with statistical certainty that a large proportion of the aircraft rolling off the assembly lines today will be involved in an accident during their lifetime. Table II provides data relative to annual fixed-wing production, total annual active aircraft, and annual accident data.

A decade ago it was reported that "allowing for the event of one plane being involved in more than one accident, it might be confidently predicted that at least 70% of the aircraft in production today will eventually have an accident" (Bruce and Draper, 1970, p. 4). In responding to the FAA NPRM 73-1 Crashworthiness for Small Airplanes in 1973, the Australian Department of Civil Aviation calculated that "an airplane can be expected on average to experience 1.5 accidents (150%) of any severity

TABLE II
A Comparison of General Aviation shipments, total active aircraft, and annual accidents. (1959-1979)

Year	Total G.A. fixed-wing aircraft manufactured (1,2,3,8)	Total no. active G.A. aircraft (3,4,7)	accidents	No. of General Aviation fatal accidents	fatalities	No. of occupants in accidents (7)	% accidents/ Total active aircraft	% accidents/ annual shipments
1959	7,802 (1)	70,747	4,576	450	823		6.5	58.7
1960	7,726	78,760	4,793	429	787		6.1	62.0
1961	6,943	82,853	4,625	426	761		5.6	66.7
1962	6,797	86,287	4,840	430	857		5.6	71.2
1963	7,628	87,267	4,690	482	893		5.4	61.5
1964	9,459 (2,3)	90,935	5,070	504	1056		5.6	53.6
1965	(12,053)* 11,852 (2,3)	97,741	5,196	538	1029		5.3	43.8
1966	(15,723) 15,747	107,085	5,712	573	1149		5.3	36.2
1967	(13,536) 13,577	116,781	6,115	603	1228	12,515	5.2	45.0
1968	(13,749) 13,698	127,164	4,968[a]	692	1399	10,518	3.9	36.3
1969	(12,581) 12,457	133,814	4,767	647	1495	10,231	3.6	38.2
1970	7,283	134,539	4,712[b]	641	1310	10,043	3.5	64.6
1971	7,466	133,869	4,648	661	1355	9,739	3.5	62.3
1972	9,774	147,695	4,256[b]	695	1426[c]	9,026	2.9	43.5
1973	13,645	156,207	4,255[b]	723	1412	8,691	2.7	31.8
1974	14,165	164,160	4,425[b]	729	1438	9,317	2.7	31.2
1975	14,057	171,156	4,237[b]	675	1345	8,773	2.5	30.1
1976	15,447	180,854	4,193[b]	695	1320	8,358	2.3	27.1
1977	16,920	184,300	4,286[b]	702	1436	8,625[d]	2.3	25.3
1978	16,920 (8)	198,778	4,494[b]	793	1770[c]	9,288[d]		
1979			4,051[p]	682[p]	1382			
1980p	(9)		3,799[p]	677[p]	1375[p]			
Totals	(212,443)	-	98,909	12,809	25,647	(97,211)	average 4.2	average 46.8

*data from Manufacturing sources (1) differs from that of FAA (2,3). Both are given.

[a]Commencing January 1, 1968 the definition of "substantial damage" was changed; therefore fewer accidents were reported. Care should be used in comparing with similar data for prior years.

[b]Suicide/sabotage accidents included (1970-1; 1972-3, 1973-2, 1974-2, 1975-2, 1976-4, 1977-1, 1978-2)

[c]Includes air carrier fatalities (1972-5, 1978-142) when in collision with general aviation aircraft

[d]While NTSB lists 8625 total occupants aboard in 1977 accidents, they list an injury index for 8672 individuals. Since the injury index includes persons aboard any aircraft involved in a collision with general aviation aircraft involved. In 1978 NTSB lists 9,288 total aboard, and an injury index for 9,544 individuals, or 256 additional individuals. However, the NTSB data for injuries has not excluded the later nor provided a means to know which injuries should be excluded.

[p]Preliminary data.

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1. Institute for Aviation Safety 1974 Aviation Almanac "Shipments of General Aviation Fixed-Wing Aircraft: 1958-69 Table 9.7 p. 415 1973.

2. Aerospace Facts & Figures 1978/79 "General Aviation Aircraft Shipments" p. 35
1980/81 (excludes transports, helicopters)

3. FAA Statistical Handbook of Aviation. Calendar Year 1977 "General Aviation Fixed-Wing Shipments. Calendar Years 1968 through 1977" Table 9.5. p. 132.

4. FAA Statistical Handbook of Aviation. 1970 Edition "Eligible U.S. Civil Aircraft and Airports on Record with FAA as of December 31, 1959-1969. Table 8.2 p. 180.

5. NTSB Annual Report to Congress 1979 "Accidents, Fatalities, Rates, U.S. General Aviation 1970-1979" Appendix K. p. 64.

6. NTSB Annual Report to Congress 1970 "Accidents, Fatalities, Rates, U.S. General Aviation 1960-1970" Appendix G. p. 53.

7. NTSB Annual Review of Aircraft Accidents "Overview, U.S. General Aviation 1977 through 1978", Table 1. 1978.

8. FAA Statistical Handbook of Aviation. Calendar Year 1978 "Fixed Wing General Aviation Aircraft Production, Weight and Cost. Calendar Years 1969-1978." Table 9.5, p.114.

9. Revised 1979 accident data from preliminary report of 4,238 accidents, 658 fatal accidents, 1311 fatalities.

10. NTSB preliminary accident data for 1980. Revised from 638 fatal accidents, 1375 fatalities of earlier preliminary data obtained in personal communication, NTSB.

in its lifetime; one airplane in three will experience an injury producing accident and one in eight a fatal accident" (Docket No. 10162 F.R. 38120: 2985, 31 Jan. 1973).

Several studies have pointed out the disproportionate accident rates, especially those aircraft models popular as trainers (Aviation Consumer, 1 June, 15 Aug. 1979; Snyder, 1978, p. 86; NTSB Special Study AAS-79-1, 31 May 1979). A study of Cessna aircraft accidents found that approximately 5% of all Cessna aircraft in any given year would be involved either in a crash or reportable accident (Sterns, p. 16-17, 1977). Further, over a 20-year life span, this report estimated that a Cessna had "approximately a 60% to 70% chance of being involved in the sort of mishap which could produce serious injury or death" (p. 17). Another report found that of 459 American Aviation AA-1 American Yankees manufactured between 1969 and 1972, 133 (29%) had been involved in an accident within an 8-year period (1969-1976) and at that rate of attrition about 73% of the total number produced may be expected to have an accident during its 20-year lifetime (Snyder, 1978, p. 86).

In 1979 the National Transportation Safety Board (NTSB) published a special study of 17,312 single-engine fixed-wing general aviation accidents for the period 1972-1976. This included 81% of the general aviation accidents, 76% of the fatal accidents, and 69.2% of the fatalities for this period. During this period there were 7,051 Cessna, 4,482 Piper, and 962 Beech aircraft accidents, including 2,111 Cessna 150 and 1,800 Piper PA-28 aircraft. Engine failure in 4,069 cases was the most common type of accident, followed by collisions with obstacles (2,582), ground loops (2,519), stalls (1,993), collisions with ground/water (1,278), and hard landings (1,240). The NTSB found that the mean fatal accident rate varied significantly between makes and models of aircraft. Overall, Cessna aircraft included in this study had a significantly lower mean fatal accident rate per 100,000 hours (1.65) than that of the other five manufacturers still producing aircraft: Beech (2.54), Bellanca (4.84), Grumman (4.13), Mooney (2.50), and Piper (2.48).

These data have been further analyzed by the Aviation Consumer, and problems with estimating exposures to danger and unreliability of hours flown* pointed out. (Av. Cons., 1 June 79). Looking at crash survivability (not done in the NTSB report), Aviation Consumer found "some surprising numbers about the survivability of light plane crashes. In general, "light single-engine aircraft crashes are fatal about 10 to 20 percent of the time" (June 1, 1979, p. 13). Yet cropdusters (Cessna C-188, Grumman G-164, and Piper PA-25), while having an accident rate more than twice that of non-agricultural aircraft, had a fatal accident rate (1.5) only about 7% of the time, or two to three times better than non-agricultural single-engine general aviation aircraft. They concluded, "what that says to us is that designed-in crashworthiness can make a significant difference in the fatality rate of an aircraft. Cropdusters are the only aircraft designed to be crashworthy (they have roll cages, energy-absorbing material in front of and below the pilot, and many other safety features)" (Aviation Consumer, June 1979, p. 13).

Since the FAA collects and analyzes its accident data annually, it has had available statistics in-house which show the high probability of accidents and fatality.

1.3.2. Probability of Fatality When Accident Occurs. A decade ago an FAA study concluded "In fact, of all vehicles designed for human transportation, the so-called general aviation aircraft offer the least protection from, and chances of survival in, crash decelerations" (Swearingen,

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* Prior to 1977 the FAA requested exposure data on the same form used anually by all aircraft owners to revalidate their aircraft registration. In 1977 a new sampling procedure was initiated by the FAA, involving a General Aviation Activity and Avionics survey questionnaire mailed to a random sample of 30,643 (about 15%) of 213,000 registered general aviation aircraft owners (FAA Handbook, 1978, p.101). But the FAA, NTSB, and others analyzing these data (Aviation Consumer, June 1979, p.9; Aug. 15, 1979) have found discrepancies between the data collected through these two methods. For example, the questionable accuracy of the FAA method is shown by the fact that the 1978 estimate of hours flown by general aviation was found to be less than the 1977, even though more aircraft were flying more hours. The FAA believe their estimates to be accurate to within 4%. NTSB estimates the figures given in this report, based upon FAA data, are within 5% accurate (Aviation Consumer, 15 Aug. 1979). Aviation Consumer calculates a ± 20% error for FAA total accident rates, and 10% error for the fatal accident rates.

1971, p. 129). This report noted that while there are some exceptions, including the special-purpose aircraft with cabins built to withstand 40 g impacts without collapsing, "most of the small general aviation aircraft built for passenger transportation are so fragile that they will open up and spill their contents or collapse inwardly in crash decelerations exceeding about 10 g." Further, "the statistics presented at the beginning of this report prove that this environment is so lethal to body impact that your chances of being killed are twice that of receiving serious injury" (Swearingen, 1971, p. 130). This study, based upon a biomedical engineering study of 27 accidents was published as a special report by the Office of Aviation Medicine, Civil Aeromedical Institute, and was conducted by Dr. John Swearingen, Chief of the Protection and Survival Laboratories. His findings presented a grim picture of the results of failure to provide adequate crashworthiness protection in general aviation accidents, confirming accident studies of the previous 30 years.

There has been no noticable change in the pattern, severity, or mechanisms of serious and fatal injuries (DeHaven found 88% had injury in 1943, and Snyder estimates about 85% in 1978). The head remains the main site of severe and fatal injury, although this pattern should change with increased use of shoulder harnesses.

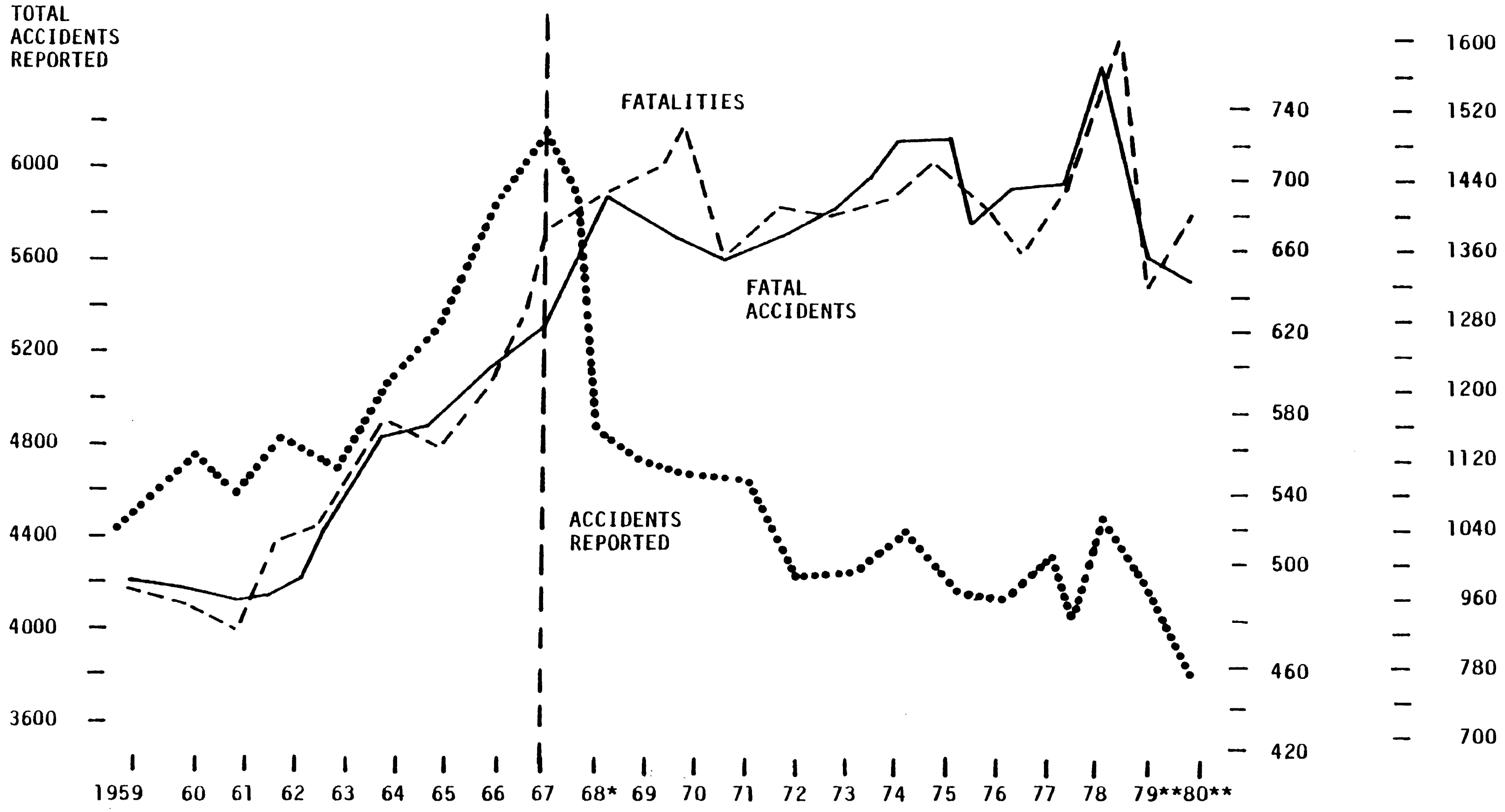
The NTSB use four categories of injury in describing trauma: "fatal," "serious," "minor," and "none." The guidelines defined for "fatal" and "serious" injuries in aircraft accidents are specified as follows:

"Fatal Injury" means any injury which results in death within 7 days of the accident.

"Serious Injury" means any injury which (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) involves lacerations which cause severe hemorrages, nerve, muscle, or tendon damage; (4) involves injury to any internal organ; or (5) involves second or third degree burns, or any burns affecting more than 5 percent of the body surface" (CFR47, NTSB Part 830.1, 1978).

FIGURE I
U.S. GENERAL AVIATION ACCIDENTS
1959-1978

Comparison of Accidents Reported, Fatal Accidents, and Fatalities



*January 1968 definition of "substantial Damage" changed
**1979, 1980 NTSB Preliminary Data

The general trend of annual increases in the number of fatal accidents and fatalities is shown by review of the data previously presented in Table II, showing general aviation accident data for the past 20 years. In 1959 there were 450 fatal accidents and 823 fatalities (with only 70,747 active aircraft); in 1979 preliminary NTSB data show 658 fatal accidents and 1311 fatalities. While the overall accident rate has been improving, the annual total number of fatal accidents and fatalities has been increasing. Utilizing the FAA forecast for 315,500 aircraft in the general aviation fleet (FAA Aviation Forecasts, 1980, p. 44), if present rates continue, one may project 1,050 annual fatal accidents and 2,388 fatalities by the year 1992 (Ladd, personal communication, 1980).

Figure 1 presents a general overview of U.S. general aviation accidents for the past 20 years in graphic format. An annual comparison of accidents reported, fatal accidents, and fatalities is included. This shows that while there has been an overall decline, with fluctuations, in the annual total number of accidents, the number of fatal accidents and fatalities remains high, with overall increases.

Table III presents a tabulation of occupant injury for the most recent (1967-1978) 12-year period for which NTSB data are available. The proportions of injury severity are shown for this period in the accompanying diagram. By far the largest proportion of pilots and passengers involved in accidents receive no or only minor injury (78%). However, 22% (25,451 individuals) incurred fatal, disabling, or serious injuries as a result of the accident. A total of 115,564 pilots and passengers were involved in accidents during this period.

Since the data for over a decade may not reflect more recent accident characteristics, the following illustration (Table IV) presents injury data for 1977 and for 1978, the most recent years for which NTSB data are available at this time. In 1977 74.4% (6447 individuals) and in 1978 72.5% (6916 Individuals) received either no or minor injury. In 1977 16.5% (1436 individuals) and in 1978 18.6% (1770 individuals) received fatal injuries in the accident. Serious injuries were in

TABLE III
OCCUPANT INJURY

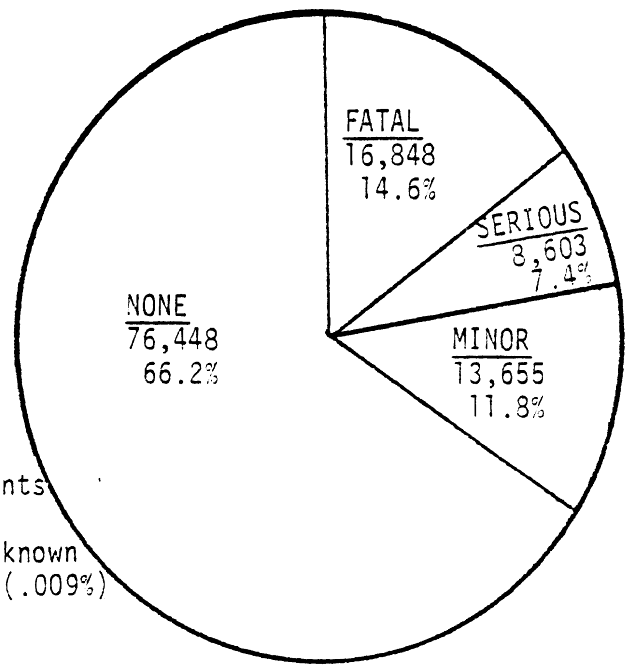
U.S. GENERAL AVIATION
1967 - 1978

INJURY INDEX					
Year	Fatal	Serious	Minor	None	Unk
1978	1770	858	1,317	5,599	0
1977	1436	789	1,132	5,315	0
1976	1320	737	1,016	5,329	1
1975	1345	761	1,162	5,525	2
1974	1438	719	1,075	6,136	1
1973	1412	646	1,051	5,590	1
1972	1421[a]	675	1,124	5,833	1
1971	1355	730	1,177	6,479	0
1970	1310	695	1,172	6,886	0
1969	1413[a]	698	1,111	7,007	1
1968	1399	678	1,169	7,260	0
1967	1229	617	1,149	9,489	3
TOTALS	16,848	8,603	13,655	76,448	10

[a]Excludes air carrier fatalities (1966-2, 1967-104, 1969-82, 1972-5) when in collision with general aviation aircraft.

Sources: 65, 68, 72

INJURIES[b]



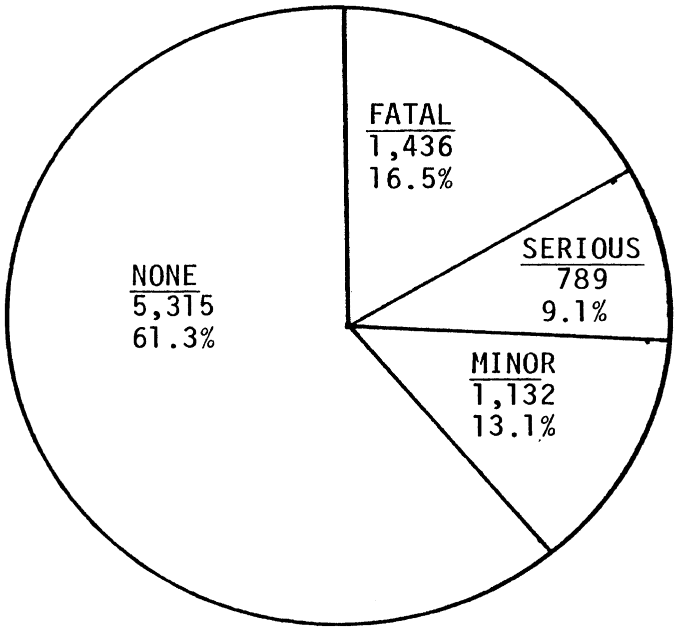
Total 115,564 Occupants

[b]Degree of injury unknown for 10 individuals (.009%)

TABLE IV

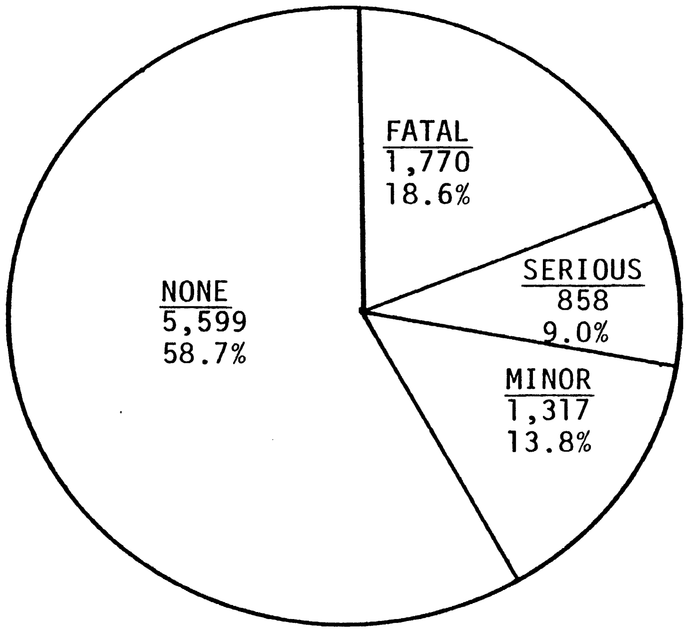
OCCUPANT INJURY
GENERAL AVIATION ACCIDENTS 1977, 1978*

1977



Total 8,672 Injury Indices

1978



Total 9,544 Injury Indices

* See foot note d, Table II. Injury data shown are based upon NTSB injury indexes for <u>all</u> individuals injured in general aviation accidents during 1977 and 1978.

9.1% (789 individuals) in 1978. Many of the serious injuries also include disabling non-reversible paraplegic types of trauma, but no breakdown on these is yet possible from either the NTSB or FAA files due to the information retrieval systems utilized, and often such details are not provided in the individual accident reports.

In examining these injury data one fact seems fairly consistent: Annually there are about twice the incidence of fatal injuries when compared to serious injuries. The chances of being killed in a general aviation accident appear to be about 2 in 3, as compared to receiving more than minor injury. This has been previously recognized in an FAA study which reported ..."this environment is so lethal to body impact that your chances of being killed are twice that of receiving serious injury" (Swearingen, p. 130).

In comparison, in 1978 there were 51,500 deaths from motor vehicle accidents and 2,000,000 disabling injuries (National Safety Council, Accident Facts, 1979, p. 3). One's chances of receiving disabling (serious) injury were 25.8 times that of being fatally injured in an automotive accident, given that the accident is severe enough to cause at least serious injuries. This significant injury/fatality discrepancy between aircraft and motor vehicle accidents is a clear indication that occupants of general aviation aircraft are not receiving crash protection comparable to that provided in the automotive crash environment, even allowing for the low impact velocities in many automotive crashes.

1.3.3. General Aviation Fatality Rate. The fatality rates provide another means by which the crash safety record of general aviation aircraft can be judged, relative to other forms of transportation. Published figures to date consistently indicate that no other form of transportation except motorcycles are more dangerous when a crash occurs. A current editorial in Business and Commercial Aviation stated that "the fatality rate for all general aviation aircraft is about seven times that for private automobiles and more than 100 times higher than the scheduled airlines record." If automobiles were as unsafe as general aviation aircraft, it was pointed out, "over 1.3 million people would perish each year and highway safety would be a national disgrace" (Olcutt, 1980, p. 11).*

Fatality rates have been pointed out by a number of authors previously (Bruce and Draper, 1970; Swearingen, 1971; Snyder, 1975, 1978, 1980; Lane, 1977; Olcott, 1980). A decade ago Bruce and Draper had concluded that "there are forty-eight times more deaths per passenger mile in small, single-engine aircraft than in travel by passenger car," and "there are more than fifty times as many deaths per passenger mile in small, single-engine aircraft than in the scheduled air carriers" (Bruce and Draper, 1970, p. 4).** While the 1980 assessment included all general aviation aircraft and the 1970 analysis appeared to consider only single-engine general aviation aircraft, the magnitude of the difference when compared to automotive transportation is obvious.

An Australian government report analyzed the problem of general aviation fatality rates in 1977, finding that "the Australian rate of 16.5 fatalities per 10^8 occupant miles in 1969-70 is very similar to that for the U.S.A. While the Australian accident rate has been improving slowly (18 accidents per 10^5 hours in 1974), they found 18% belt failure in pilots' seats, and seat failure in 28% of fatal and serious injury accidents. Table V provides a comparison of various forms of transportation from this Australian study.

Note that this study reported that while the proportion of all accidents that produce non-fatal injury is similar for automobiles and aircraft (12.3% and 19.3%), the proportion of accidents producing fatal

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* Based upon comparison of about 1600 annual fatalities for some 185,000 G.A. aircraft, with 50,000 fatalities relative to 154 million automotive vehicles in the U.S.

** This ratio was derived by dividing 17.66 by .34 fatalities per 10^8 passenger-miles, which equals 52 - the ratio of rates of fatalities in small single-engine airplanes to air carrier aircraft per 10^8 passenger miles (1970, p. 91).

injuries is significantly greater for aircraft (12.3%) than for automotive vehicles (0.36%). As shown in Table V the general aviation aircraft is the least safe passenger vehicle in common use, exceeded only by the motorcycle, with a fatality rate of 35.6.

TABLE V

FATALITY RATE PER 10^8 PASSENGER OR OCCUPANT MILES
(after Lane, 1977, p. 5)

Rail	0.09	U.S., 1962-1964
Airplane	0.1	Australia, 1968-72 U.S., 1968-72
Bus	0.17	U.S., 1962-64
Tram	0.39	Melbourne, 1963-68
Urban Bus	0.53	Melbourne, 1963-68
Passenger Car	2.9	Australia, 1963-68
Horsedrawn Transport	10.20	California, 1909
General Aviation	16.5	Australia, 1969-70
Motorcycles	35.6	Australia, 1971

A 1971 FAA study bluntly reported "crash safety design in light aircraft has fallen so far behind that for the automotive that death rates per 100,000,000 passenger miles in light aircraft are at least seven times those for automotive transportation"* (Swearingen, 1971, p. 1). The fact that in automobile accidents the serious injury rate is 1000% greater than the death rate, but in general aviation serious injuries are only 50% of the death rate "certainly calls for some explanation" (Swearingen, 1971, p. 1). This FAA report examined 27 aircraft accidents of terms of the packaging principles of DeHaven (published in 1945) and "concluded that in most instances these well-known

*Based upon the 1967 NTSB report of 111,000 general aviation aircraft flying an estimated 21,000,000 hours, or 3.15 billion miles, assuming average flying speed of 150 mph. with 12,298 occupants reported on board 6,115 aircraft involved in accidents the average occupancy is two. Multiplying total miles flown by average occupancy gives 6.3 billion or 63 (100,000,000) passenger miles. Based on 1,100 fatalities, the rate for 100 million passenger miles is 17.5. The automotive death rate of five per 100,000,000 passenger miles is reduced to 2.4 when pedestrians, motorcycles, bicycles, buses and trucks are excluded.

principles have been so grossly ignored that serious and fatal injuries have occurred in anything more severe than a hard landing" (p. 129).

A 1975 study attempted to confirm the statistics of Swearingen's report (1971) but found that the FAA has officially not published fatality comparisons between general aviation aircraft and other forms of transportation in the 1970, 1972, 1977, and 1979 FAA Statistical Handbook of Aviation. In 1970, for example, the 1969 passenger fatality per 100,000,000 passenger miles was tabulated for comparison between passenger automobiles (2.3), buses (.22), railroad passenger trains (.07), and domestic scheduled air carriers (.13) (1970, p. 247). --but general aviation (estimated by reference JJ5, 1971 to be 16.1), was omitted.

In 1972 the fatality rate was calculated to be 14.3 per 10^8 miles of travel (excluding 3 suicides) (personal communication, FAA Statistics Division, 1975). In 1973 the NTSB Annual Report to Congress reported accident rates per 100,000 aircraft hours flown, rather than on a basis of passenger miles (NTSB, 1973, Appendix G, p. 82). However, for 1973 the general aviation fatal accident rate was estimated as 15.1 per 10^8 miles of travel (compared to 4.27 for the automobile , NSC, 1973, p. 40). This was 154 times greater than that for scheduled domestic air carriers (15.1 compared to 0.098, NTSB, 1973, p. 81).

The FAA Statistical Handbook of Aviation for 1977 again reveals passenger fatalities per 100 million passenger-miles for autos, taxis, buses, railroad passenger trains, and domestic air transport planes (1977 Table 10.11, p. 148) but similar data for comparison is completely omitted for general aviation. These data are reproduced in Table VI below.

The FAA does provide a table for U.S. general aviation (see Table VIII) listing fatal accident rates per 100,000 aircraft hours and by 1,000,000 aircraft miles (FAA, 1977, Table 10.10, p. 147) for years 1968 through 1976. No listing for passenger fatality rate per 100 million passenger-miles is provided, even though such data are listed in the preceding tables comparing other forms of transportation.

TABLE VI

COMPARATIVE ACCIDENT DATA: 1968 THROUGH 1977

(PASSENGER FATALITIES PER 100 MILLION PASSENGER-MILES)

Year	Passenger Automobiles and Taxis	Buses	Railroad Passenger Trains	Domestic Scheduled Air Transport Planes
1968	2.40	.21	.20	.28
1969	2.30	.19	.07	.13
1970	2.10	.19	.09	.00
1971	1.90	.19	.24	.15
1972	1.90	.19	.53	.13
1973	1.70	.14	.07	.10
1974	1.30	.21	.07	.12
1975	1.40	.15	.08	.08
1976	1.50	.01	.05	.003
1977	1.33	.13	.05	.04

Source: Motor vehicle (automobiles, taxis, and buses) and railroad passenger train data from the National Safety Council. Domestic scheduled air transport data from the National Transportation Safety Board. FAA Statistical Handbook of Aviation, Calendar Year, 1977, p. 148. Table 10.11.

Since previous estimates of general aviation fatal accident rates have been significantly higher than for commercial air carriers (50 to 150 times) and many other forms of transportation, an attempt has been made to put this in perspective as the FAA has not published such comparisons. Some tables (see Table V, after Lane, 1977) have not differentiated between "passenger" and "occupant" because this information has not been made available by the FAA. A change in the estimate of miles flown, hours flown, average airspeed, and load factors, as well as other variables can change the results. Thus three separate approaches were utilized: using the FAA's own high and low load factor estimates; and a University of Michigan computer analysis of FAA accident data for the number of pilots and passengers actually in each fatal general aviation accident for the past 15 years. This latter approach allowed a fairly precise annual tabulation of passenger/pilot breakdowns.

TABLE VII

GENERAL AVIATION OCCUPANT AND PASSENGER FATALITIES
PER 100 MILLION OCCUPANT AND PASSENGER-MILES

YEAR	HUNDRED MILLION MILES FLOWN		FATALITIES			OCCUPANT* FATALITIES PER 100 MILLION PASS.MILE		PASSENGER** FATALITIES PER 100 MILLION PASS.MILE	
	A(1.0 Pass.)	B(1.5 Pass.)	Total	Pilots	Passengers	(A)	(B)	1.0 Pass.	1.5 Pass.
1970	32.071	48.1065	1,310	588	553	40.8	27.2	17.24	11.50
1971	31.432	47.148	1,355	602	621	43.1	28.7	19.76	13.17
1972	33.171	49.7565	1,426	618	632	43.0	28.7	19.05	12.70
1973	36.868	55.302	1,412	657	589	38.1	25.5	15.98	10.65
1974	38.638	57.957	1,438	653	613	37.2	24.8	15.87	10.58
1975	39.390	59.085	1,345	608	607	34.1	22.8	15.41	10.27
1976	41.724	62.586	1,320	615	557	31.6	21.1	13.35	8.90
1977	44.021	66.0315	1,436	626	672	32.6	21.7	15.27	10.18
1978	49.644	74.466	1,770	696	753	35.7	23.8	15.17	10.11
1979	50.528	75.792	1,315	616	617	25.9	17.3	12.21	8.14

(A) Assuming an average load factor of 2.0. (This factor is very close to that reported for 1977 by the National Transportation Safety Board (NTSB-ARG-80-1)).

(B) Assuming an average load factor of 2.5, as was used by the FAA for the early 1970's. (Ref. - Letter from Mr. Dalbow).

* GAA rates are for total occupants per 100 million passenger miles. One might assume on the basis of (A) and (B) that passenger fatalities would be at least 50% of total fatalities. At that level, passenger fatality rates per 100 million passenger miles would be estimated at one-half the rates shown in (A) and (B).

** Based upon University of Michigan computer analysis of NTSB Data Tapes of pilot/passenger occupancy in each fatal crash.

TABLE VIII

AIRCRAFT ACCIDENTS, FATALITIES, AND ACCIDENT RATES--U.S. GENERAL AVIATION FLYING: 1968-1977

Year	Accidents		Fatalities	Aircraft Hours Flown (000)[1]	Aircraft-Miles Flown (000)[1]	Accident Rates			
						100,000 Aircraft Hours		Million Aircraft Miles	
	Total	Fatal				Total	Fatal	Total	Fatal
1968	4,968[2]	692[2]	1,399	24,053	3,700,864	20.6	2.86	1.34	0.186
1969	4,767	647	1,495[3]	25,351	3,926,461	18.8	2.55	1.21	0.164
1970	4,712[2]	641[2]	1,310	26,030	3,207,127[4]	18.1	2.46	1.47	0.200
1971	4,648	661	1,355	25,512	3,143,181	18.2	2.59	1.48	0.211
1972	4,256[2]	695[2]	1,426[3]	26,974	3,317,100	15.8	2.57	1.28	0.209
1973	4,255[2]	723[2]	1,412	30,048	3,728,500	14.2	2.40	1.14	0.193
1974	4,425[2]	729[2]	1,438	32,475	4,042,700	13.6	2.24	1.04	0.180
1975	4,237[2]	675[2]	1,345	34,165	4,238,400	12.4	1.97	1.00	0.159
1976	4,193	695	1,320	36,128	4,476,014	11.6	1.92	0.94	0.155
1977	4,286	702	1,436	NA	NA	NA	NA	NA	NA

1 Statistics compiled by FAA.
2 Suicide/sabotage accidents are included in all computations except for rates (1968-3, 1970-1, 1972-3, 1973-2, 1974-2, 1975-2, 1976-4, 1977-1).
3 Includes air carrier fatalities (1967-104, 1969-82, 1972-5) when in collision with general aviation aircraft.
4 Beginning in 1970, the decrease in aircraft-miles flown is the result of a change in the FAA standard for estimating miles flown.

Source: National Transportation Safety Board Annual Report, 1977. In, FAA Statistical Handbook of Aviation. Calendar Year 1977. Table 10.10, p. 147.

A. 1970 FAA study estimated that there were 2.5 (weighted average) persons on the average general aviation flight during the period 1964 to 1968 (FAA, 1970), although the 1.5 (passenger) figure is generally used by FAA in computations. Using NTSB estimated general aviation aircraft miles flown (FAA Aviation News 1975, p. 14), $\frac{3.73 \times 10^9}{10^8} \times 2.5$ (occupants) = 93.2 occupants per 10^8 miles. In 1973 there were 1,411 fatalities reported for pilots and passengers (but excluding 2 suicides, for 1409 total), (FAA Av. News, 1975, p. 14) thus a fatal accident rate of 15.1 per 10^8 miles of travel.

The results are presented in Table VII in terms of both occupant fatalities per 10^8 million miles, and passenger fatalities per 100 million passenger-miles. The latter column can be compared to Table VI to show the significant difference in fatality rates between passenger cars, buses, trains, air carriers, and general aviation. Assuming an average load factor of 2.0, in 1979 there were 25.9 occupant fatalities per 10^8 million miles, with a load factor of 2.5 this changes to 17.3. Even the lower figure is 432 times that of air carriers, and 13 times the rate for automobiles. To be conservative, assuming passenger fatalities are 50% of total fatalities, and reducing the 1979 general aviation occupant fatality rate from 17.3 to 8.7, the general aviation aircraft fatality rate is still 216 times that for the airlines (.04), and 6.5 times that of the automobile.

The latest available NTSB Annual Report to Congress continues to omit providing this information by listing. FAA data on fatal accident rates are presented only on a basis of per 100,000 aircraft hours flown, and per million aircraft miles flown, rather than 10^8 passenger miles comparison (NTSB, 1979, Appendix K, p. 64).

The actual number of fatalities occurring in general aviation accidents are higher than reported, since fatalities occurring after seven days are not reported.

Table IX, below, provides the most current available published tabulation of U.S. General Aviation accident fatality rates. This is taken from the 1979 NTSB annual report to Congress, and overlaps the preceding table and updates it for 1977 through 1979 (preliminary) data. However, the entire table is presented for comparison with the preceding FAA Table VIII. Note, that the statistics for accident rates per 100,000 aircraft hours have now been revised from 1974-1977, and for rates per million aircraft miles for 1973-1977. Again, this NTSB table omits data on passenger fatalities per 10^8 passenger miles. Review of the past decade of NTSB annual reports indicates that it is not unusual to revise the rates for preceding years.

TABLE IX

ACCIDENTS, FATALITIES, RATES
U.S. GENERAL AVIATION
1970-1979

	Accidents					Accident Rates			
				Aircraft-Hours Flown	Aircraft-Miles Flown	Per 100,000 Aircraft-Hours Flown		Per Million Aircraft Miles Flown	
	Total	Fatal	Fatalities	(000) c/	(000) c/	Total	Fatal	Total	Fatal
1970	4,712[a]	641[a]	1,310	26,030	3,207,127[d]	18.1	2.46	1.47	0.200
1971	4,648	661	1,355	25,512	3,143,181	18.2	2.59	1.48	0.211
1972	4,256[a]	695[a]	1,426[b]	26,974	3,317,100	15.8	2.57	1.28	0.209
1973	4,255[a]	723[a]	1,412	29,974[f]	3,666,802[e]	14.2	2.41	1.15	0.196
1974	4,425[a]	729[a]	1,438	31,413[f]	3,863,799[e]	14.1	2.31	1.14	0.188
1975	4,237[a]	675[a]	1,345	32,024[f]	3,938,952[e]	13.2	2.10	1.08	0.171
1976	4,193[a]	695[a]	1,320	33,922[f]	4,172,406[e]	12.3	2.04	1.00	0.166
1977	4,286[a]	702[a]	1,436	35,792[f]	4,402,126[e]	12.0	1.96	0.97	0.159
1978	4,494[a]	793[a]	1,770[b]	39,400	4,964,400[e]	11.4	2.01	0.90	0.159
1979	4,051	682	1,382	39,900	5,052,800[e]	10.6	1.65	1.71	0.135
Total	43,557	6,996	14,194						

[a] Suicide/sabotage accidents included in all computations except rates (1970-1, 1972-3, 1973-2, 1974-2, 1975-2, 1976-4, 1977-1, 1978-2).
[b] Includes air carrier fatalities (1972-5, 1978-142) when in collision with general aviation aircraft.
[c] Source: FAA
[d] Beginning in 1970, the decrease in aircraft-miles flown is the result of a change in the standard for estimating miles flown.
[e] Estimated by NTSB
[f] Revised by FAA.

[p] Preliminary.

Source: NTSB 1979 Annual Report to Congress. Appendix K, p. 64.

One must wonder why both the FAA and NTSB avoid making a meaningful comparison of general aviation accident fatality rates, unless they do not wish to acknowledge and bring attention to general aviations' poor crash safety record. In this regard, Aviation Consumer has noted discrepancies of the NTSB in reporting accident rates by boosting estimates of hours flown by some aircraft by 25 to 40% (which reduced the accident rates for each type correspondingly) (Aviation Consumer, 15 Aug. 1979, p. 4). There are frequently discrepancies between FAA and NTSB raw data, although they should be based upon the same data base.

1.3.4. Aircraft Damage and Occupant Injury Relationships. The severity of structural damage in an aircraft accident is categorized by the NTSB in four classifications: "destroyed," "substantial damage," "minor," or "no damage."

Contrary to popular opinion, accident investigation studies have reported a lack of direct relationship between the degree of structural damage to the aircraft involved in a crash, and the resulting degree of injury to the occupants. Previous studies have documented that an aircraft may be "destroyed" yet perfectly survivable to the occupants; similarly, pilots and passengers may incur serious or fatal injury in accidents in which the damage to the aircraft is only "minor." Before discussing the reasons for this, it is important to understand the FAA and NTSB definitions involved.

The NTSB defines an "Aircraft Accident" as "an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, and in which any person suffers death or serious injury as a result of being in or upon the aircraft or by direct contact with the aircraft or anything attached thereto, or in which the aircraft receives substantial damage" (Part 830.1 Code of Federal Regulations, 1978). The key determinants of whether a reportable accident has occurred, therefore, are whether a death or serious injury or substantial damage has occurred. Changing the definitions for any of these three terms will also change the accident statistics. In the majority of cases where it is determined that no "serious" injury to any occupants has occurred, the determinant hinges about a judgment as to what constitutes "substantial" damage.

Until January 1, 1968, the NTSB definition of "substantial damage" was:

"(1) Except as provided in subparagraph (ii) of this paragraph:

(i) Substantial damage in aircraft of 12,500 pounds maximum certified takeoff weight or less means damage or structural failure reasonably estimated to cost $300 or more to repair.

(ii) Substantial damage in aircraft of more than 12,500 pounds maximum certified takeoff weight means damage or structural failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which would normally require major repairs or replacement of the affected component.

(2) Engine failure, damage limited to an engine bent fairings, or cowling, dented skin, small puncture holes in the skin or fabric, taxiing damage to propeller blades, damage to tires, engine accessories, brakes or wingtips are not considered "substantial damage" for the purpose of this part (CFR 47 NTSB Part 830.1, 1978).

In 1968 the definition of "substantial damage" was changed to more realistically reflect economic realities, and this current definition is as follows:

"(1) Except as provided in subparagraph (2) of this paragraph, substantial damage means damage or structural failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which would normally require major repair or replacement of the affected component.

(2) Engine failure, damage limited to an engine, bent fairings or cowling, dented skin, small puncture holes in the skin or fabric, ground damage to rotor or propeller blades, damage to landing gear, wheels, tires, flaps, engine accessories, brakes or wingtips are not considered "substantial damage" for the purpose of this part" (CFR 14, Part 830.2 32 FR 20771, 23 Dec. 1967, as amended 34 FR 15749, Oct. 11, 1969).

One result was that the total number of accidents for general aviation (excluding air carrier) for 1968 dropped nearly 20%, to 4,968, from the 6,115 reported in 1967. Thus when comparing accident statistics, care should be used when total number of annual accidents involve pre- and post- 1968 data. (If the pre- 1968 definition of an accident were used today, there would have been nearly 5,400 accidents listed for 1978, rather than 4,494). (Table X).

In practice the classification of damage may be somewhat arbitrary where a clear distinction between "substantial" (reportable) and "minor" (need not be reported if any injury incurred is less than "serious") damage occurs, since this may initially be an owner or pilot decision. Similarly it is not always readily apparent whether damage is severe enough to be classified as destroyed. As a result the majority (74.7% 1968-1976) of the U.S. general aviation aircraft accidents are classified as incurring substantial damage. 98.2% of accidents are classified as

TABLE X

DAMAGE INDEX
U.S. GENERAL AVIATION ACCIDENTS
1967-1979

Year	No. of Accidents	Aircraft Damage[c] Destroyed	Substantial	Minor	None	Unk
1967	6115	1052	5171	30	27	2
1968	4968[a]	1179	3923	32	15	2
1969	4767	1090	3783	57	31	2
1970	4712[b]	1034	3712	61	20	1
1971	4648	1065	3604	30	29	0
1972	4256[b]	1035	3245	76	20	0
1973	4255[b]	1107	3176	60	21	0
1974	4425[b]	1120	3294	69	22	0
1975	4237[b]	1087	3164	62	21	0
1976	4193[b]	1075	3122	40	23	0
1977	4286[b]	1129	3157	28	23	0
1978	4494[b]	1227	3284	29	17	0
1979	4238P	1012	2927	27	24	0
Totals:		9792	31023	487	202	5
1967-1976		23.5	74.7	1.2	.5	

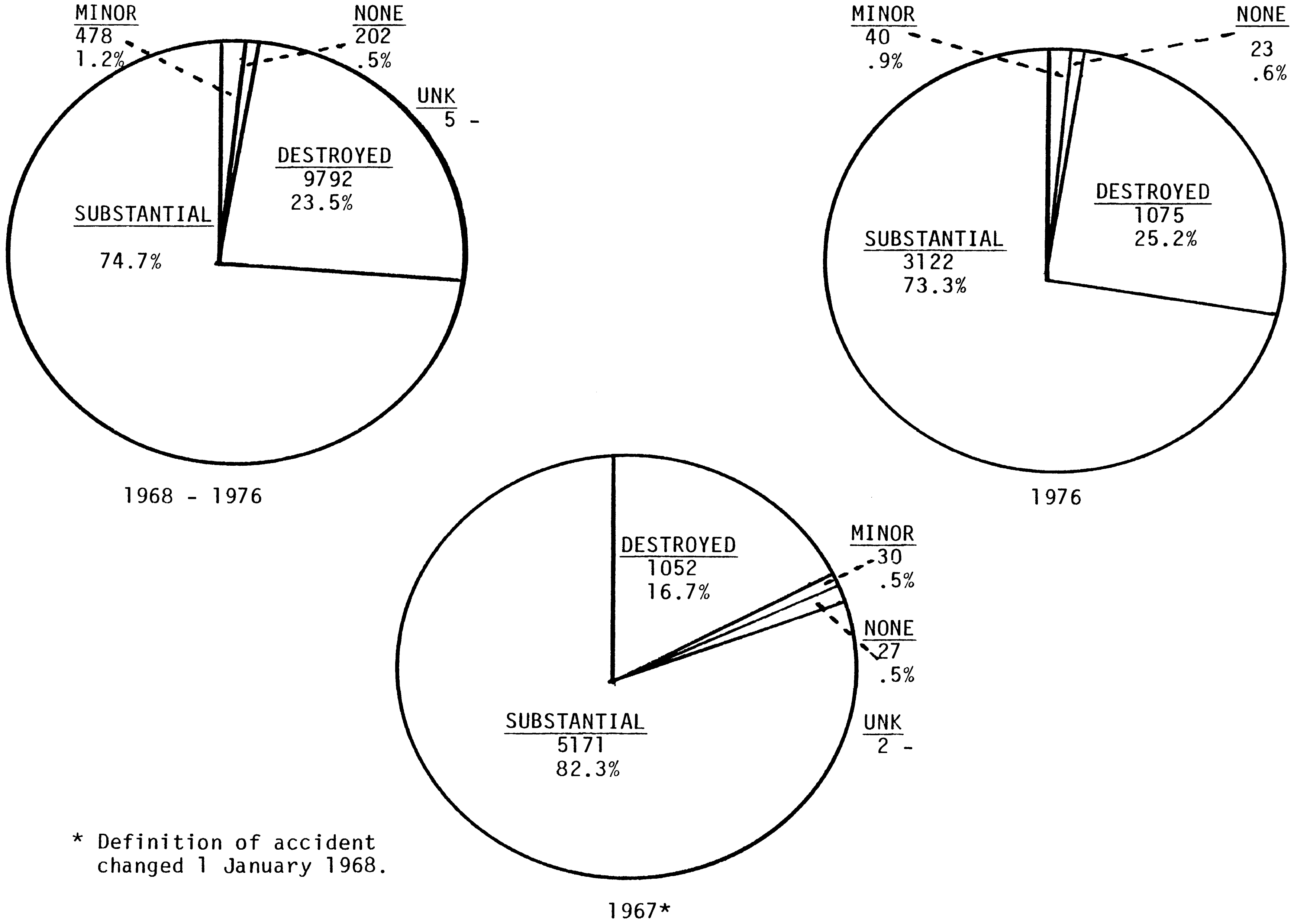
a. the definition of "substantial damage" was changed 1 January, 1968. 1967 data not included in totals.

b. Suicide/sabotage accidents included (1970-1, 1972-3, 1973-2, 1974-2, 1975-2, 1976-4, 1977-1, 1978-2).

c. The FAA totals of annual damage categories do not equal the total number of accidents they list. For example, in 1967 the FAA lists 6115 accidents but 6282 separate damage indexes, in 1971 4648 accidents and 4728 damage indexes, and in 1976 4193 accidents, but 4260 damage indexes, etc. No reason for this discrepancy is provided by FAA but it is assumed to be FAA computer errors.

FIGURE 2

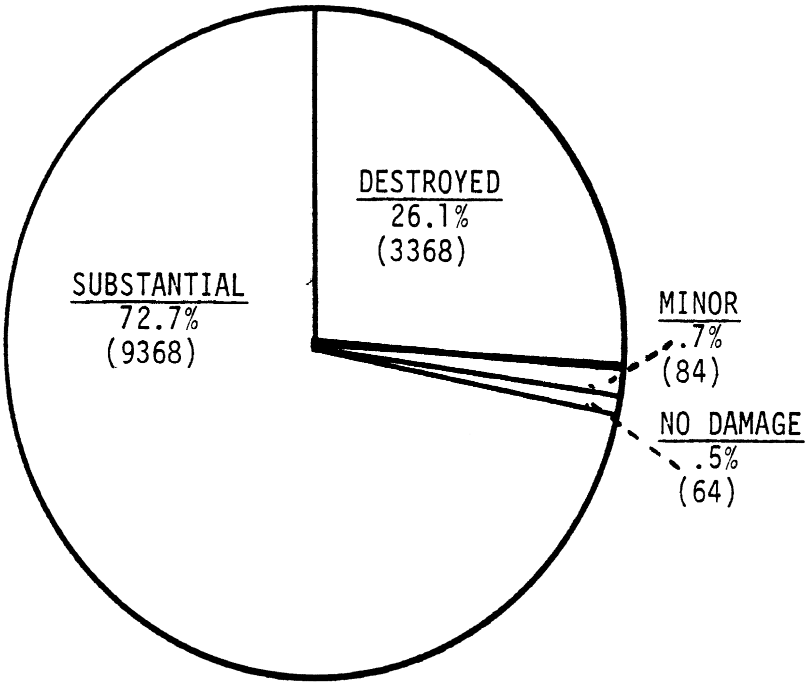
PROPORTION OF DAMAGE
U.S. GENERAL AVIATION ACCIDENTS



* Definition of accident changed 1 January 1968.

FIGURE 3

PROPORTION OF DAMAGE
U.S. GENERAL AVIATION ACCIDENTS
1977-1979 COMBINED



Based on preliminary data, courtesy NTSB, December 31, 1980.

either destroyed or having substantial damage, with only 1.2% minor damage and 0.5% as having received no damage in the accident.

Figure 2 illustrates these proportions for the years 1968-1976, and also shows the difference between 1967 (before the definition of "substantial damage" changed) and 1976.

With 180,854 active general aviation aircraft registered in 1976, the 1,075 aircraft "destroyed" represented only 0.6% of the entire fleet or 7% (6.959) of the 15,447 aircraft manufactured that year. However, if planes receiving substantial damage are also included, over 2.3% of the total fleet was involved, and over 27% of all aircraft manufactured that year were either destroyed or received substantial damage. However, this represents an improvement over damage recorded in aircraft accidents of some 40 years ago. In 1941, for example, of 20,000 U.S. civil aircraft registered, 3,286 aircraft, or 16.4% of the entire fleet, was either destroyed or "required major repair" in accidents that year (DeHaven, 1944). Figure 3 shows the damage index for the most recent three year period 1977-1979 data are presently available.

The relationship between aircraft damage and occupant injury is shown in the following Table XI, which lumps data for the preceding three years (1977-1979). While 18.8% of fatalities occur in accidents with no damage, many such cases involve being struck by the propeller and other non-crash environments. On the other hand 26.4% of accidents in which the aircraft is destroyed only involve minor or no injury. These data do not show any straight-line relationship between the damage and injury indices.

Survival from catastrophic accidents in which the aircraft is totally destroyed, such as mid-air collisions, high-angle high-velocity dives into the ground, or in-flight structural failure (Snyder, 1972) is rare, since the occupants' cabin area is usually crushed and impact may be beyond survival limits. While one would expect certain other types of severe crashes (such as flying into a mountainside in a snowstorm, or crashing into a forest) to be associated with occupant fatality, there are a number of factors influencing occupant injury causation and severity, or prevention and occupant survival. For example, a recent survivable accident has included in-flight structural

TABLE XI

COMPARISON OF GENERAL AVIATION
DAMAGE/INJURY INDICES FOR ACCIDENTS
1977-1979*

A. DAMAGE INDEX

DAMAGE INDEX	INJURY INDEX							
	FATAL		SERIOUS		MINOR		NONE	
	(No.)	(%)	(No.)	(%)	(No.)	(%)	(No.)	(%)
3368 Destroyed	1935	57.4	567	16.8	417	12.4	475	14.1
9368 Substantial	249	2.7	654	7.0	1486	15.9	7032	75.1
84 Minor	18	2.1	23	27.4	3	3.6	40	47.6
64 No Damage	12	18.8	48	75.0	0	-	4	6.2

B. INJURY INDEX

INJURY INDEX	DAMAGE INDEX							
	FATAL		SERIOUS		MINOR		NONE	
	(No.)	(%)	(No.)	(%)	(No.)	(%)	(No.)	(%)
3159 Fatal	1935	89.6	245	11.3	18	.8	12	.6
1281 Serious	567	44.3	654	51.1	23	1.8	48	3.7
1801 Minor	419	23.3	1486	82.5	3	.2	0	-
7483 None	479	6.4	7032	94.0	40	.5	4	-

* Preliminary data, courtesy NTSB, December 1980.

- Totals do not match number of aircraft as include some collisions with 2 aircraft. These data are not corrected for the number of collisions. Also the percentages will not add up to 100% due to rounding.
- To use these charts, for classification on left side, read the number of times of occurrance on right. For example in A., of the 3368 destroyed, 1935 involved a fatal injury index, 567 a serious injury index, etc.

failure in an Aero Commander 690 and subsequent fall over 14,000 feet into wooded terrain. In another case a Cessna 172 crashed into a tree on a hilltop at cruise velocity in fog without injury, except a minor cut, to one of the two lapped-belted occupants. Whether a particular accident is survivable or not must be individually evaluated on a basis of the crashworthiness design and packaging criteria previously discussed, rather than the damage index.

1.3.5. FAA Certification. An important point often overlooked in considering state-of-the-art with respect to FAA certification requirements is that a newly manufactured 1981 aircraft may have been certified under earlier Part 3 requirements. It is probable that most of today's general aviation fleet was certified under earlier CAR requirements effective prior to Part 23 (1964). A "new model" aircraft brought out by the manufacturer in 1981, for example, does not have to be certified under FAR Part 23 under some conditions if the manufacturer considers it to to be a modification of an earlier model. Some five years may go by prior to introduction of a "new" airplane, requiring a new certificate. In 1970, for example, Beechcraft had not introduced a "new" model since 1966 (Rembleske, quoted p. 45, Bruce and Draper, 1970).

Some examples of popular aircraft in today's fleet which were certified under earlier regulations include the Beech 18 (Type approval, 4 March 1937), Piper PA-18 Super Cub (FAA type approval, 18 Nov. 1949; PA-18-150, 1 Oct. 1954), Piper PA-24B-260 Commander B (Oct. 1957), Piper PA-25 Pawnee (August 1959); Piper PA-28-140 (FAA type certified Feb. 14, 1964), PA032 Cherokee Six (FAA type approved 4 Mar. 1965), PA-28-235C Cherokee (FAA type approved 15 June 1963), Beechcraft Musketeer (FAA Certified 20 Feb. 1962), Cessna 150 (FAA type approval 10 July 1968), Cessna 337 (FAA type approval, 22 May 1962), 401 & 402 (20 Sept. 1966) 421 (1 May 1967), Mooney M-20 (FAA type approval 7 Nov. 1971).

Examples of aircraft certified under Part 23 include the Beechcraft Baron Model 58P (FAA certified May 1974), Super King Air 200 (14 Dec. 1973), Cessna 303, and Piper PA-38112 Tomahawk (20 Dec. 1977).

Illustrations of new models of general aviation aircraft brought out since 1964 (when FAR Part 23 became effective), but certified under older CAR requirements, include: Piper PA-32 Cherokee Six (FAA type approval, 4 March 1965); PA-32 RT-300T Turbo Lance II (FAA certification 20 April 1978); Piper Aerostar 600 (March 1968), 601 (November 1968); and Piper PA-31 Navajo.

The following genealogy illustrates how a current model aircraft can still be certified under CAR rules of 16 years ago.

Piper Cherokee 180 (1967) → Cherokee Challenger (Oct. 1972) → Cherokee Archer (1974) → redesignated PA-28-181 Archer II (1976)→ Warrior II (1978) → PA-28-236 Dakota (1978) → PA-28-201T Turbo Dakota (1979).

If FAR Part 23 requirements represent "minimum" requirements (FAA Order 2100.1, 1962), do the preceding CAR requirements represent less than minimum standards for current operation?

The developmental linage of an aircraft is indicated on the Type Certificate Data Sheet, although it may take several data sheets to trace the entire evolution. For example, the Model 35 Beechcraft Bonanza was first approved in 1947, continuing on one type certificate until 1956, when the Bonanza H35 received a new certification which has carried through to the current A36TC. A discussion of the Type Certificate Data Sheet and detailed data on year certified for a number of general aviation aircraft has appeared in the April 1981 issue of Aviation Consumer (pp. 10-15).

One especially important crashworthiness area where the problem of "newly certified" aircraft is apparent is in the FAA's amended shoulder harness rule. With a compliance date of 18 July 1978, this amendment added requirements concerning shoulder harnesses and compartment interior design for the type certification of small airplanes and an operating rule requiring a shoulder harness for each front seat in certain newly manufactured small airplanes (Part 23.785 (g) (F.R. 32(116):30601-30603 16 June 1977). Thus only "certain newly manufactured" aircraft are actually required by the FAA to meet this amended standard.

Yet in publishing this amendment the FAA stated that "over the next 25 years, it is estimated that approximately 1,875 lives may be saved by this amendment at an average cost of less than $5.5 million per year" (F.R. 42(116): 30603, 16 June 1977). When the FAA's own data show that shoulder harnesses (even just in the front seats) represent such a major step in occupant crash protection, why has the FAA chosen to limit this requirement to the relatively few "newly certified" aircraft?

1.4 Review of FAA Regulatory Changes

Prior to 31 December 1926, neither pilots nor airplanes required a license, pilot schools were unlicensed, and passengers and goods could be flown with no regulations. There were no rules whatever. A pilot could take off or land wherever he pleased, and build and fly his own plane without conforming to any mandatory engineering requirements. One study showed that 20% of fatal accidents involved students on solo flights (Komons, 1978, p. 119).

The Contract Air Mail Act of 1925 was a major step towards growing sentiment in Congress to take government out of business, by providing a plan of competitive bidding to establish airmail service through private enterprize instead of the Post Office. This was followed by the Air Commerce Act of 1926, signed by President Coolidge on 20 May (exactly one year before Lindberg's famous flight). The Air Commerce Regulations of the Aeronautics Branch, Department of Commerce, became effective 31 December 1926, and represented the first U.S. civil aviation requirements. The 1926 Act, besides directing Secretary of Commerce Herbert Hoover to license pilots and aircraft, conduct research, establish airways and organize air navigation, also included the task of promoting safety by investigating causes of accidents.

After 10 months of experience with the requirements as first published, it was evident that modifications were needed. In December 1927 a conference was held at the Department of Commerce with a committee of engineering representatives of the aircraft manufacturers. At this time it was decided that a set of rules providing the requirements for structurally airworthy airplanes should be issued to provide the industry with a guide as to what would be required on new designs. The proposed changes were circulated throughout the industry for comment, and Bulletin 7A Airworthiness Requirements of Air Commerce Regulations resulted, first issued in 1929. Aeronautics Bulletin 7A was further amended 1 October 1934.

The Air Commerce Regulations included elementary structural strength requirements, strength of fittings and landing gear, protection to pilot and passengers (against possible propeller breakage), the earliest civil requirement for "safety belts," and emergency exits. The first seat-anchor requirement appeared in a June 1928 revision. A number of subsequent amendments added requirements for fire protection, safety belt specifications (including being capable of withstanding 1000 lb. loads), seat or chair strength, turn-over protection, and seat and safety belt anchorages, which will be outlined in greater detail in the following discussions of specific changes. The Aeroneutics Branch (later Division) of the U.S. Department of Commerce regulated civil aviation from 1926 to 1938.

The Civil Aeronautics Act of 1938 transferred the responsibility for regulating civil aviation to the Civil Aeronautics Board (CAB). Between 1938 and 1945 regulations pertinent to crashworthiness underwent still further revision and additions, through supplements. The Civil Aeronautics Manual (CAM) provided the requirements of Parts 03, 04, and 15 of the Civil Air Regulations, (Bureau of Air Commerce, U.S. Department of Commerce) and the CAA interpretations. It notes, however, that the CAM "is not mandatory, and is intended only to explain and to share acceptable methods of complying with the pertinent requirement" (Dept. of Commerce, CAM 04, revised 1 July 1944).

In 1945 the Civil Aeronautics Board published new general aviation aircraft airworthiness requirements, which broadened previous regulations and specified occupant protection design criteria during minor crashes. Additional modifications occurred in 1946 (14CFR3) and the term "moderate descent velocity" originated. An important change at that time was upgrading the 0 to 6 g forward protection to 9 g, establishing the present 3 g upward criteria (previously 2 g) and eliminating the 4.5 g downward criteria entirely. A CAA interpretation (3.386-1) was added in 1950 (Supplement No. 5. CAM 3. 8 March 1950) providing CAA interpretations to crash protection (3.386 previously 3.3811), seat belts (4a.565), and seat belt loads (4a.193). These interpretations for crash protection remained in effect for 19 years until they were dropped when the present Part 23 regulations came into effect in 1964. It stated that "cockpit arrangement and collapse of cabin structure had been found to cause excessive injuries in crashes," and further the "close study of crash results shows that the human body, when properly supported, can tolerate crash forces which exceed those necessary to demolish comtemporary aircraft structure" (3.386-1, 8 March 1950).

This was followed by discussion of a number of major points of general significance to the general aircraft designer.

The Federal Aviation Agency (FAA) was established by the Federal Aviation Act of 1958, 23 August 1958 under the Civil Aeronautics Board (Titles VI and VII). However, no changes in the occupant protection requirements occurred until 1964, when Part 3 was recodified to Part 23. Codification into a single body of rules, the Federal Aviation Regulations (FAR's) begun in 1961, was completed in December 1964.

In turn, the Department of Transportation Act (Public Law 89-670, approved 15 Oct. 1966; 80 Stat. 931) effective 1 April 1967, transferred all functions, powers, and duties of the Federal Aviation Agency to the Secretary of Transportation (sections 6(d) and 3(e) (1) 1958 act). In 1969 further amendments to Part 23 occupant protection requirements occurred, and a Notice of Proposed Rulemaking was published to require shoulder harnesses in front seats or require several alternate means of occupant protection.

The Independent Safety Board Act of 1974 (Public Law 95-633, approved January 3, 1975; 88 Stat. 2166) transferred the National Transportation Safety Board (NTSB) from the Department of Transportation to the status of an independent agency as of 1 April 1975.

An important amendment to #23.785 (seats, berth, safety belt and harnesses) was published by the FAA (FR42(116)30601, 16 June 1977) effective 18 July 1977, requiring compliance as an operating rule by 18 July 1978. This stated that each occupant of a front seat must be protected from serious head injury by installing a safety belt and eliminating injurious objects within striking distance of the occupants' head or torso in the cabin area, or by installing safety belts and energy absorbing designs or devices. However, these requirements were applicable to the front seat only of newly certified aircraft. This had no effect upon the current aircraft fleet, and in fact would not be legally applicable to many future aircraft manufactured and certified under existing Part 3 regulations (See 1.3.5 Certification, p. 34).

In summary, to provide a historical overview, the following table notes in chronological order the major changes that have occurred in civil aviation safety administration.

TABLE XII
Historical Overview - Civil Aviation Safety Administration

Date	Legislation/Regulation	Regulation Title	Responsibility
1978*†	•Shoulder Harness Amendment to 23.785		
1975 (1 April 1975)	(Independent Safety Board Act of 1974) •Transferred NTSB from DOT to Independent Agency		
1969	•Further Amendments		
1967 (1 April 1967)	The Department of Transportation Act. Transferred FAA from CAB to DOT.		(Federal Aviation Admin.) Department of Transportation
1964*	Recodified Part 3 to Part 23.	Federal Aviation Regulations, FAR.	
1958 (23 Aug.1958)	The Federal Aviation Act of 1958. Est. Federal Aviation Agency under CAB		(Federal Aviation Agency)
1950*	•CAB publishes CAA Interpretations (3.386-1 and 3.390-1)		
1946	•Further modifications, Part 23		
1945*	•CAB publishes new requirements, recodifies Part 3.	Civil Aviation Regulations, CAR.	
1940		Civil Aeronautics Manual, CAM, 1940.	
1938 (eff.30June1940)	The Civil Aeronautics Act of 1938 Transferred responsibility to CAB	Civil Aeronautics Authority Manual, CAAM.	(Civil Aeronautics Admin.) Civil Aeronautics Board
1934		Airworthiness Reqs for Aircraft, Aeronautics Bull. no.7-A. Oct 1934	Bureau of Air Commerce, U.S. Dept. of Commerce
1929		Airworthiness Reqs of Air Commerce Regulations, Aeronautics Bull.no.7A	U.S. Department of Commerce
1926* (signed 20 May) (eff.31 Dec)	The Air Commerce Act of 1926 Established first federal regulations	Air Commerce Regulations	(Aeronautics Branch) U.S. Dept. of Commerce

*Key changes in occupant protection requirements.
† NPRM, 1969; Published 16 June 1977; effective 18 July 1977; compliance 18 July 1978.

2.0 ANALYSIS OF 14 CFR PART 23 FEDERAL AVIATION REGULATIONS RELATIVE TO CRASHWORTHINESS ASPECTS

The term "crashworthiness " does not appear in the Federal Aviation Regulations. However, several key sections provide standards for occupant protection, seats, safety belts and harnesses, structural loading, emergency exits, fire protection, and other aspects of crash and post-crash survival. Each will be reviewed in terms of its present requirements, development, effectiveness, comparison with other standards and state-of-the-art, and assessment of needs for improvement. Since there is some overlap cross-referencing is necessary.

2.1 Emergency Landing Conditions (#23.561)

2.1.1 Contents. The primary occupant protection standard is stated in section 561 of Part 23. This section provides the current FAA requirements relative to occupant protection in an "emergency landing" including the ultimate inertia forces for structural design. It is cross-referenced by #23.625 (Fitting Factors), #23.785 (Seats, Berths, Safety Belts, and Harnesses), #23.1413 (Safety Belts and Harnesses).

"#23.561. Emergency Landing Conditions

(a) The airplane, although it may be damaged in emergency landing conditions, must be designed as prescribed in this section to protect each occupant under those conditions.

(b) The structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when -

(1) Proper use is made of belts or harnesses provided for in the design; and

(2) The occupant experiences the ultimate inertia forces shown in the following table:

ULTIMATE INERTIA FORCES

	Normal and Utility Categories	Acrobatic Category
Upward...........	3.0g	4.5g
Forward..........	9.0g	9.0g
Sideward.........	1.5g	1.5g

(c) Each airplane with retractable landing gear must be designed to protect each occupant in a landing -

(1) With the wheels retracted;

(2) With moderate descent velocity; and

(3) Assuming, in the absence of a more rational analysis -

(i) A downward ultimate inertia force and 3g; and

(ii) A coeficient of friction of 0.5 at the ground.

(d) If a turnover is reasonably probable, the structure must be designed to protect the occupants in a complete turnover, assuming, in the absence of a more rational analysis -

(1) An upward ultimate inertia force of 3g; and

(2) A coeficient of friction of 0.5 at the ground.

(e) Except as provided in #23.787 the supporting structure must be designed to restrain, under loads up to those specified in paragraph (b)(2) of this section, each item of mass that could injure an occupant if it came loose in a minor crash landing.

[Docket No. 4080, 29FR 17955, Dec. 18, 1964, as amended by Amdt. No. 23-7, 34 FR 13090, Aug. 13, 1969]"*

2.1.2 Discussion and Analysis

2.1.2.1 Development of the FAA Requirement. The present FAR #23.561 ("Emergency Landing Conditions") (1964) has had several important changes in its development from CAR 3.386 (1950) ("Emergency Provisions, Protection"), CAR 03.3811 (1945) ("Protection"), and its origin in CAM 04.460 (1944) ("Provision for Turn-Over"). The following modifications have been identified in review of the Code of Federal Regulations, Federal Register, and various CAA, FAA, CAB, and Department of Commerce Documents, and have been brought together in the following chronological outline to provide an overview of the regulatory development and historical changes that have occurred.

Modification/Data	Reference/Comment
• FAR #23.561 (13 August, 1969)	Ref: (Amended by Amdt. No. 23-7, 34FR13090) (Notice 67-14) (a) amended #25.561(c)(3): to provide for a more rational analysis than the prescribed assumption and to describe the inertia force associated with the descent as "downward" instead of "upward"; and (b) to amend #25.561(d) to also provide for the more rational analysis.

* 14 CFR23, p. 138, 1980.

Note: Notice 67-14 explains that the note in #3.386(c) (from which #23.561(c) and (d) were recodified) "was intended to refer to inertia forces that are downward in the wheels - retracted emergency landing condition." As noted below, recodification of #3.386 referred to accelerations and specified the corresponding directions. The substitution of force for acceleration in the recodification of the rule without reversing the directions of the acting forces was an error which has not been fully corrected by Amt. 23-7 because #23.561(b) and (c) still show the wrong force directions (but the correct acceleration directions).

- FAR #23.561 (new) Ref: (Notice 64-17) recodified #3.386 to #23.561
  (18 December 1964)
  (23 September 1964)

  Note: #3.386 requirements are specified in terms of "acceleration" and Notice 64-17 retained the concept. But #23.561 substituted the word force for acceleration without reversing the directions stated in #3.386(a), viz., upward and forward. Furthermore, whereas a note in #3.386(c) states the requirement in terms of vertical acceleration, #23.561(c) and changed it to "downward ultimate inertia force" and (d) to "upward ultimate inertia force."

  In recodifying from #3.386 to #23.561 a major change included dropping 3.386-1 CRASH PROTECTION. (CAA Interpretations which apply to section 3.386, previously 3.3811). This section was important as it provided guidelines for crashworthy ("crash protection") design of general aviation aircraft, although was not in itself a rule. Omitting the CAA interpretations greatly weakened the usefulness of this regulation.

- CAR 3.386 Ref: (Notice 3-13) adopted 20 July 1955, added
  (20 July 1955) #3.386(d) to requirement items of mass that might come loose and injure occupants to withstand loads prescribed for minor crash landing.

- CAR 3.386-1 Ref: (14 April 1951) 16FR3290, Supplement 10 adds Section #3.386-1 to #3.386.

- CAR 4.60 Ref:
  (1 January 1951)

  It should be noted that Civil Aeronautics Manual 8, Appendix A,"Pilot Safety Items" provided general design recommendations for restricted category aircraft also pertinent to general aviation design. This type of federal interpretive information was provided for the manufacturers' guidance in the 1950's as a result of studies conducted in the 1950's showing that design modifications could offer improved occupant protection. However, in recodifying to FAR 23.561 in 1964 design guidelines were dropped and no longer provided. These recommendations also appear to define the "minor crash conditions" as one imposing a load of 6g forward on a 170 lb. occupant, and 2g upward, 1.5g sidward, 4.5g downward.

"4.0 GENERAL

Restricted category aircraft operations are inherently hazardous; hence pilot safety is of paramount importance... crash protection also is of paramount importance. Accident records and service experience definitely show the importance of the aforementioned items and these will now be discussed in detail.

"4.1 Visibility

...The seat structure should have sufficient strength to withstand the following loads anticipated in minor crash conditions:

Forward = 6 x 170 = 1020#
Upward = 2 x 170 = 340#
Sideward = 1.5 x 170 = 255#
Downward = 4.5 x 170 = 765#

The values of 6, 2, 1.5 and 4.5 are the design load factors anticipated for a so-called minor crash in the forward, upward, sideward and downward directions."

"4.60 Cockpit Design. The cockpit should be the "strong point" of the structure. The forward portion of the fuselage, wing panels and tail should have decreasing structural strength away from the cockpit. Cockpit tubing or other structure should be arranged to buckle outwardly instead of inwardly. Special consideration should be given to the design of all structure within range of the head, and instruments, sharp objects, etc., should be moved beyond range of the head. Sharp edges should be avoided and rubber padding should be used where necessary. It should be noted that parts and structure can be crushed in upon the pilot as well as pilot striking parts and structure due to his motion during a crash. Rudder pedals should be strong enough to support the feet and the control column should be strong enough to resist buckling anchored to longitudinal members of the primary structure. Floor structure should afford maximum protection for the feet.

"4.6.1 Over-all Design. A strong keel or skid or similar additional structure under the fuselage permits the craft to slide instead of plowing into the ground in low-angle accidents; otherwise the bottom portions of the fuselage may gouge into the ground, causing extremely abrupt decelerations. To prevent the engine from driving into the cockpit, a heavy fire-wall may be advisable. Fuel tanks should preferably be placed in the wing. A strong turnover structure should be provided. Landing gear should be designed to fail prior to failure of structure to which it is attached and the landing gear travel should be as large as possible for maximum energy absorption during hard landings. If possible, concentrated items such as hoppers, batteries, generators, and pumps should be located so they will not strike the pilot if they break loose. Also, their supports should be able to stand loads to be expected in minor crashes.

If the weight of an object is "X" then the loads that may be expected on the object in a minor crash are:

Forward 6 times X
Sideward 1.5 times X
Downward 4.5 times X
Upward 2.0 times X

(The values of 6, 1.5, 4.5 and 2.0 are the design load factors anticipated in a so-called minor crash in the forward, sideward, downward and upward directions, respectively.)

For example, calculation of loads likely to act on a battery in a minor crash is as follows:

Battery weight = 20#
Forward Load = 20 x 6 = 120#
Sideward Load = 20 x 1.5 = 30#
Downward Load = 20 x 4.5 = 90#
Upward Load = 20 x 2.0 + 40#

"4.6 Crash Protection.

Service records of both agricultural and personal type aircraft show that relatively minor crashes often result in serious or fatal injuries due to inadequate crash protection. Installation of extra-strong safety belts and/or safety harness alone is not sufficient. Typical special precautions that may be advisable are as follows.

• CAR 3.386-1 (8 March 1950)

Ref: Supplement No.5. Civil Aeronautics Manual 3. U.S. Dept. of Commerce.

"Emergency Provisions" from Civil Aeronautics Manual 3 (CAM 3) (3.386 and 3.386-1 "Crash protection (CAA Interpretations which apply to section 3.386, previously 3.3811); and 4a.565 (seat belts) and 4a.193 (safety belt loads).

"CAR 3.386 Protection. The fuselage shall be designed to give reasonable assurance that each occupant, if he makes proper use of belts or harness for which provisions are made inthe design, will not suffer serious injury during minor crash conditions as a result of contact of any vulnerable part of his body with any penetrating or relatively solid object, although it is accepted that parts of the airplane may be damaged.

"(a) The utlimate accelerations to which occupants are assumed to be subjected shall be as follows:

	N,U	A
Upward............	3.0g	4.5g
Forward...........	9.0g	9.0g
Sideward..........	1.5g	1.5g

"(b) For airplanes having retractable landing gear, the fuselage in combination with other portions of the structure shall be designed to afford protection of the occupants in a wheels-up landing with moderate descent velocity.

"(c) If the characteristics of an airplane are such as to make a turn-over reasonably probable, the fuselage of such an airplane in combination with other portions of the structure shall be designed to afford protection of the occupants in a complete turn-over.

"Note: In section 3.386(b) and (c), a vertical ultimate acceleration of 3g and a friction coefficient of 0.5 at the ground may be assumed."

3.386-1 CRASH PROTECTION. (CAA interpretations which apply to section 3.386, previously 3.3811).

(a) Cockpit arrangement and collapse of cabin structures have been found to cause excessive injuries in crashes. Close study of crash results shows that the human body, when properly supported, can tolerate crash forces which exceed those necessary to demolish contempory aircraft structure.

(b) The following points are of general significance:

(1) Many survivable accidents are "fatal" because of insufficient design consideration when mocking up the cabin and its installation.

(2) The torso is rarely exposed to dangerous injury when the safety belts hold and control wheels provide reasonable support for the chest.

(3) Fractures of the extremities occur in severe crashes but are not normally regarded as dangerous injuries

(4) Head injuries are the principal cause of crash fatalities. Increased protection for the head can be provided by elimination, shielding, or redesigning of

elements of the cabin which permit solid head blows in a crack-up, such as turn-overs during a bad landing.

(c) In view of the fact that injuries and fatalities in many moderate and severe accidents are purely mechanical results of poor cockpit design, the following guide rules for design are suggested:

(1) Typical injurious objects, from the standpoint of crash injury, are listed as follows:

(i) Those which present a hard surface and are so attached or have sufficient mass to produce a severe impact when struck by the head or other vulnerable part of the body as it swings forward under the specified inertia forces.

(ii) Those which present corners, knobs, or similar projections which are likely to penetrate a vulnerable part of the body, even when the impact forces are not as high as in case (a).

(2) A flat or curved sheet metal panel which will dent upon impact by the head is not considered dangerous, whereas a magnetic compass case having appreciable mass and a rigid mounting might cause fatal head injuries.

(3) Heavy transverse braces or other structures immediately behind a light instrument panel have changed many accident reports from "Instrument panel depressed six inches by pilot's head" to "Fatal head injury; depressed fracture of the skull." Pilot's chances can be greatly improved by spacing solid braces several inches behind the ductile skirt of an instrument panel.

(4) The solid tubing used as a backrest of the front seats of tandem aircraft is a set-up for excessive head injury. The suggestion has been made that backs of forward seats be allowed to pivot forward so that the head of the occupant of the rearward seat would not contact the solid members when the body pivots about the belt.

(5) Panels should be smooth, with top edge curved in a substantial radius.

(6) Apertures for instruments should preferably have bevelled instead of sharp edges.

(7) In personal aircraft, every consideration should be given to holding the body by adequate safety belt installations, and by the support which can be provided in control wheels and instrument panels. The present "1000 pound" safety belts have failed in a high percentage of accidents without causing internal injuries or bruising of the hips. In failing, they have exposed the pilot to excessive injuries.

(8) Control wheels should be designed to provide broad areas of support for the chest. Wheels which break under heavy loads from the hands or deform to permit contact between the chest and a small hub, localize force and set up chances of unnecessary chest injury."

- CAM 3.386 (16 July 1949)

FR 14/136, renumbered #3.3811 to #3.386.

- CAR 03.3811 (29 May 1946)

Dept. of Commerce memo to CAA Regional Administrators, First, Third, Fifth, Sixth Regions.

03.3811 Protection Changed the first paragraph to read:

"The fuselage shall be designed to give every reasonable probability that all the occupants, if they make proper use of belts or harness for which provisions are made in the design, will not suffer serious injuries in the following minor crash conditions as a result of contact of a vulnerable part of his body with any penetrating or relatively solid object, although it is accepted that parts of the airplane may be damaged.

Changed (a) to read as follows:

"(a) Conditions in which the occupants experience the following ultimate acceleration forces:

Category	N.U.	A.
upward	3.0 g	4.5 g
forward	9.0 g	9.0 g
sideward	1.5 g	1.5 g

- Part 03 #03.381 Emergency Provisions (1946)

14CFR3 - Civil Aviation. Civil Aeronautics Board Rules and Regulations published in the Federal Register in 1946 (p.2089).

In 1946 recodification occurred and #04.26 "Emergency Landing Provisions" became #03.81 "Emergency Provisions". Several important modifications were added at this time. Related to fuselage design to escape serious injury, where it had specified "every reasonable probability" in 1945, it now read to give "reasonable assurance". The "ultimate inertia forces" became "ultimate accelerations", substituting accelerations for forces. At this time two modifications to the human tolerance figures occurred: "0 to 6.0 g" (all combinations) became "9.0 g" in the "forward" direction, and an upward "ultimate acceleration" of 3.0 g was established for normal and utility aircraft, replacing the earlier vertical distinctions of "0 to 4.5 g (down)" and "0 to 2.0 g (up)". An exception was also noted that allowed "a lesser value" under conditions including an "ultimate descent velocity of 5 fps" in

1945, which was changed in 1946 to the term (presently used in #23.561) "moderate descent velocity" without definition.

The occupant protection values established at this time have not been modified in 34 years by the FAA.

#03.3811 Protection. The fuselage shall be designed to give reasonable assurance that each occupant, if he makes proper use of belts or harness for which provisions are made in the design, will not suffer serious injury during minor crash conditions, as a result of contact of any vulnerable part of his body with any penetrating or relatively solid object, although it is accepted that parts of the airplane may be damaged.

(a) The ultimate accelerations to which occupants are assumed to be subjected shall be as follows:

	N.U.	A
Upward	3.0 g	4.5 g
Forward	9.0 g	9.0 g
Sideward	1.5 g	1.5 g

(b) For airplanes having retractable landing gear, the fuselage in combination with other portions of the structure shall be designed to afford protection of the occupants in a wheels-up landing with moderate descent velocity.

(c) If the characteristics of an airplane are such as to make a turnover reasonably probable, the fuselage of such an airplane in combination with other portions of the structure shall be designed to afford protection to the occupants in a complete turnover.

"NOTE: In paragraphs (b) and (c) of #03.3811, a vertical ultimate acceleration of 3 g and a friction coefficient of 0.5 at the ground may be assumed."

- #04.260 Emergency Landing Conditions (13 November 1945)

14 CFR3 - Civil Aviation. Civil Aeronautics Board Documents issued by Federal Register in 1945.

In these new regulations issued by the CAB in 1945 the basic occupant protection requirements for general aviation aircraft were established. This is the basis for todays #23.461, with changes noted in the preceding and subsequent applicable regulations through the present.

• "#04.26 Emergency Landing Conditions

#04.260 General. The following requirements deal with emergency conditions of landing on land or water in which the safety of the occupants shall be considered, although it is accepted that parts of the airplane may be damaged.

The structure shall be designed to give every reasonable probability that all the occupants, if they make proper use of the seats, belts, and other provisions made in the design (see #04.382) will escape serious injury in the event of a minor crash landing (with wheels up if the airplane is equipped with retractable landing gear) in which the occupants experience all combinations of the following ultimate inertia forces relative to the surrounding structure.

Forward..................0 to 6.0 g
Sideward.................0 to 1.5 g
Vertical.................0 to 4.5 g (down)
0 to 3.0 g (up)

A lesser value of the downward inertia force may be used if it is shown that the airplane structure could absorb the landing shock corresponding to the design landing weight and an ultimate descent velocity of 5 fps without exceeding the value chosen. The specified inertia forces shall also be applied to all items of mass which would be liable to injury the passengers or crew if they came adrift under such conditions, and the supporting structure shall be designed to restrain these items."

These "emergency landing conditions" contained several provisions which have been subjected to modifications in succeeding regulations. The use of the terms "every reasonable probability" in relation to occupants escaping injury through structural design; the use of the term "minor crash landing"; and the provision of combinations of "ultimate inertia forces" relative to structure were basic points established. The ultimate inertia forces were specified as 0 to 6 g forward, 0 to 1.5 g sideward, and vertical forces of 0 to 4.5 g down and 0 to 2 g up.

Another important point is that a specific "ultimate descent velocity" of 5 fps was provided, apparently the first and only time in the history of the occupant protection rules that an objective definition has been given for this. Further requirements, most similar to preceding regulations, were provided for seats, safety belts, emergency exits, and anchorages, and will be discussed in detail in other sections of this report.

- CAM 04.460 1938-1944

Ref: Title 14-Civil Aviation-Bureau of Air Commerce, (1938); 30 Title 14-Civil Aviation p. 62 (1944).

The form of today's 23.561 probably began with this brief two-sentence statement. While the first states the intent of the regulation, the second sentence appears to have provided a loop-hole definition of the term "remote", allowing for arbitrary subjective judgement. Nevertheless, it was a start.

"04.46 Fuselage and Cabins

04.460 Provision for Turn-over. The fuselage and and cabins shall be designed to protect the passengers and crew in the event of a complete turn-over and adequate provision shall be made to permit egress of passengers and crew in such event. This requirement may be suitably modified when the possibility of a complete turn-over in landing is remote."

This section was cross-referenced to #04.247 which provided loading requirements.

- Bureau of Air Commerce #04.460 (1938) cross referenced #04.247 complete turn-over, which provided the following requirement:

"04.247 Complete turn-over. The ultimate load factor for this condition shall be 4.5. The airplane shall be assumed to be inverted and the cabane structure (or its equivalent) shall be assumed to carry the entire load acting normal to the thrust line (or equivalent reference line). In cases where a wing is above the fuselage and braced by more than one cabane left truss, at least one truss shall be designed for the entire load. The superstructure shall be designed for the entire load. The superstructure shall also be capable of resisting a total ultimate load of at least three-fourths the weight of the airplane, acting either forwardly or rearwardly parallel to the thrust line or wing cord and suitably divided between the uppermost points of the side trusses of the cabane or equivalent structure. Partial failure of the structure under these conditions is permissible provided that the specified ultimate loads can be resisted without endangering the occupants, assuming safety belts to be fastened (See also #04.460)."

- ACR Section 12; 13 (effective 31 Dec.1926)

Ref: Department of Commerce, Aeronautics Branch, Air Commerce Regulations Section 12 structural strength requirements for airworthiness. pp. 8-10 1926.

The original Air Commerce Regulations had no precedence to be based upon and requirements were briefly stated. However, section 12, which dealt with structural strength requirements for airworthiness, in "(E) Fuselage Strength" provided design load factors for five conditions which included, for three-point and level landings" a load factor of 5.0; for "nosing over" a load factor of 4.5. Section 13 provided requirements for "construction of cockpit, cabins, and controls", which was concerned with cockpit construction to afford "suitable ventilation", "adequate vision", and "reasonable protection to pilot and passengers against possible propeller breakage." So although it can be said that from the beginning of federal regulations protection of occupants has been a stated concern, the emphasis and direction has remained secondary in relation to the development of other airworthiness regulations.

2.1.3 Discussion and Analysis

The current FAR #23.561 contains problems for the user in interpretation, confusion in terminology, and, perhaps most importantly, completely outdated and unrealistic requirements for occupant protection in today's world. Thus rather than forming a set of core requirements for improved design, it confuses the designer and encourages second-rate (minimum) crash protection to aircraft occupants.

2.1.3.1 "Minor Crash Landing." #23.561(b) Paragraph (b) states that "the structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when -" (14 CFR 23, p. 138, 1980). The term "minor crash landing" is undefined except for the two conditions stated (proper use of restraints provided, and that the ultimate inertia forces on the occupant do not exceed 9.0 g forward, 3.0 g upward, and 1.5 g sideward). These conditions were set forth in 1946 although they were not state-of-the-art at that time. The FAA is apparently unable to provide the designer with a more objective definition of a minor crash landing.

If a "minor crash landing" is considered to imply that the resulting damage to the aircraft is "minor" or less, this is completely unrealistic when compared to accident data showing that approximately 98.2% of general aviation accidents actually involve damage determined to be classified as "substantial" or greater. Only 1.2% of accidents reported between 1968 and 1976 were assessed as resulting in minor damage.

The concept of the survivable crash was developed in the 1940's by DeHaven, and resulted from the subsequent accident findings in innumerable Aviation Crash Injury Research (AvCIR, later AvSER and Dynamic Sciences) investigations to study the problem of occupant survival in aircraft crashes. This work resulted in the Army's comprehensive Crash Survival Design Guide of 1967 (1967), followed by three revisions (1970; 1971; 1980, a, b, c, d).

The U.S. Army currently considers a survivable accident to be one "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 occupants' immediate environment remains substantially intact, to the extent that a livable volume is provided for the occupants throughout the crash sequence" (Vol. IV, 1980, p. 30). They also recognize a "survival envelope" of environmental conditions in providing design guidance for the aircraft engineer. The design elements of a survivable crash require that the aircraft cabin structure remains relatively intact in the area of the occupant, without significant intrusion, the occupant is adequately restrained in an energy-absorbing seat system, the interior structures are designed to distribute loads and absorb energy, and the impact forces imposed on the occupant are within human tolerance limits.

In 1975 the General Aviation Cockpit Safety Provisions Committee (A-33) of the Society of Automotive Engineers (SAE), in developing and proposing new restraint (Snyder, SAE, 1977; SAE Transactions) and seating (Snyder, SAE, 1978; SAE Transactions) standards for general aviation aircraft, based guidelines upon "a survivable crash."

Summary: At present there is no objective description for the term "minor crash landing" in requirement #23.561(b). It is recommended that the term "survivable accident," for which environmental criteria have been recognized for 35 years, be substituted in this requirement.

2.1.3.2 "Every Reasonable Chance." #23.561(b) Paragraph (b) currently reads "the structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when -." While the phrase "every reasonable chance" is one which few could disagree with at initial reading, the term specifies nothing except general intent and actually has been considerably watered down from previous language. The following list shows the way this expression has been modified since 1945.

Phrase	Reference	Date
"every reasonable probability"	14CFR3; 04.260	1945
"reasonable assurance"	03.3811	1946
"every reasonable probability"	03.3811 (Dept.Com.Memo)	1946
"reasonable assurance"	3.386	1950
"every reasonable chance"	23.561	1964

Changing "every reasonable probability" to "reasonable assurance" considerably weakened this requirement in 1946 and 1950, and modifying it to "every reasonable chance" in 1964 did little to strengthen it. Who is to say what the terms reasonable or chance or assurance mean? What objective criteria apply? There is a considerable difference, on the other hand, between the word "chance" and "probability." This distinction is especially recognized in a legal sense.

Summary: One can only conclude that the original wording of 35 years ago was much stronger than that of today, and that today's requirement, changing "probability" to "chance," is considerably weakened by this modification, particularly in combination with the undefined term "minor crash landing."

2.1.3.3 "Ultimate Inertia Forces." #23.571(b)(2). The preceding section has documented modifications that have occurred since 1945 in this requirement, and there are two major problems presented. First, the load factors criteria for occupant protection has not changed in 34 years, despite enormous advances in research on human tolerances; and secondly, terminology changes have produced some apparent technical errors which remain unclarified at this date.

2.1.3.3.1 Review of origins and Development. Of basic importance in the whole concept of crashworthiness are the values for human impact tolerance. In 1945 14CFR3 established requirements for (minimum) forward ultimate inertia forces of 0 to 6.0 g, which was changed to ultimate accelerations of 9.0 g in 1946 (#03.3811, FR 1946). The sideward 1.5 g requirement of 1945 has remained unchanged for 35 years. In 1946, vertical loading requirements, originally established as 0 to 4.5 g (down) and 0 to 2.0 g (up) in 1945, were changed to the present Part 23 upward requirement of 3.0 g for normal and utility category aircraft (4.5 g for acrobatic category), dropping a downward requirement.

Where then did the CAB (CAA) come up with requirements for only 6.0 g (later 9 g) forward, 1.5 g sideward, 2.0 g (upward) 4.5 g downward (later 3.0 g upward), which are 1980's general aviation design standard?

In a comprehensive review of publications, reports, and studies of the 1940's available to this author, no source could be found to document the CAB's Civil Air Regulations on this point. Rather than take into consideration estimates of human body impact tolerances available at the time, it appears that the ultimate inertia forces originally specified in 1945 originated from, and were related more to, the airframe structure than that of the human occupant. The basic structural load factors of fuselage strength dating back to 1926 required load factors (sec. E, 1-5) of 4.5 to 6.5, while structural strength of landing gear in the 1926 requirements called for a side load of 1.5 times the (airplane) weight (Sec. F). Is it simply coincidence that 54 years later the FAA standard still requires only 1.5 g for side loads on the occupant? A comparison of FAR 23.561 occupant protection design requirements with other standards is shown in Table XIII.

2.1.3.3.2 Human impact tolerance design limits. The published data relative to human tolerances to crash impact landings is extensive. A decade ago, by 1970, it had been estimated that within the past 25 years there had been over 220 research studies and over 6,000 references on impact in the literature (including 5,000 tests on the AF Daisy Simulator done) (Snyder, 1970; Chandler, 1967). The following references provide comprehensive state-of-the-art human tolerance data. Previous work by

TABLE XIII

COMPARISON OF OCCUPANT PROTECTION DESIGN REQUIREMENTS IN GENERAL AVIATION (FAR 23.561) WITH OTHER STANDARDS

DIRECTION (of forces on occupant)	FAR 23.561		SAE ARP 1318 (Proposed) General Aviation Aircraft	USAF Design Handbook July 1974	U.S. ARMY MIL-STD-1290(1974)* Velocity Change(ft/sec)	FMVSS 208 (Automobiles)
	Normal & Utility	Acrobatic				
Forward $-G_x$	9.0g	9.0g	25.0g (applied 20 degrees to either side of longitudinal axis)	45.0g for 0.1 sec 25.0g for 0.2 sec	50 ft/sec	20g
Sideward $\pm G_y$	1.5g	1.5g		9.0g for 0.1 sec lap belt only	25 ft/sec	
Upward $+G_z$	3.0g	4.5g	16.0g	11.5g for 0.1 sec lap belt & shoulder harness 25.0g for 0.1 sec	30 ft/sec, rotorcraft	
Downward $-G_z$	None	None	15.0g	15.0g for 0.1 sec	42 ft/sec	
Rearward $+G_x$	None	None	5.0g	from 45.0g for 0.1 sec to 83.0g for 0.004 sec	None	

*Design impact velocity changes for the 95th percentile potentially survivable accident.

Snyder available through NASA (1973), and Society of Automotive Engineers (1970; 1972) contain 446 impact study citations together with detailed data tables for conditions and results of all published tests to 1972. Earlier compendiums resulting from joint FAA and USAF research were published by the FAA and NASA in 1963 (Snyder, et al., 1963) and 1966 (Ice, et al.), containing some 4,905 pages. Other comprehensive studies which should be referred to include Stapp (1964; 1971; Snyder, 1966; King, 1975; and Hess et al., 1980). Occupant Impact Injury Tolerances for General Aviation Aircraft Crashworthiness design have also been published by the SAE (Snyder, 1971). Other current key documents include the U.S. Army's Aircraft Crash Survival Design Guide (1967, 1970, 1971, 1980a, b, c, d, e), the SAE document Human Tolerance to Impact Conditions, SAE J885, April 80 (1980); 1964 (rev. 1966), and Air Force Systems Command Design Handbook (Human Acceleration Tolerance, 3Q2-2.3 revised 1975).

During the 1940's little objective crash impact data were known, since it wasn't until the Air Force conducted controlled human deceleration tests by Stapp between 1947 and 1953 that human tolerance levels were extensively studied. Nevertheless, the occupant crash protection standards published by the CAB in 1945 (03.3811, followed by 3.386, 1946; 1950) were outdated from the start.

DeHaven had shown in 1942 that the human could survive 200 G's* in free fall. German studies reported by Ruff in 1941 documented that decelerations of 26 g* in the seated forward-facing body orientation (with lap restraint only) "produced not the slightest injury" (Ruff, 1941). Seated upward (vertical) impacts at 13 g were reported not to affect test subjects, and, while impacts to 18.4 g produced no more than headache, sternal or lumbar pains, 20 g was established as the subjective tolerance "limit of endurance," below non-reversible injury (Ruff, 1941).

* Both g and G units are used in the literature, and the original author's designation applies here. Although g is the physicist's symbol for a specific physical quantity (32.2 ft/sec^2), the acceleration of gravity, it is often indiscriminately used in place of G. G, a physiological measure, refers to whole body impact, rather than response. For a complete discussion of the difference see (Snyder, NASA, 1973, p. 226).

Transactions, German Academy of Aviation Development, 31 October 1941). Similarly, there was sufficient amount of crash investigation documentation in the engineering and medical literature by 1945 to support the conclusion that airplane occupants could survive impact loads estimated as "above 40 G in the forward-facing position" (DuBois, 1945; 1946; see detailed references, Section III).

In 1944 the National Research Council Committee on Aviation Medicine had recommended that shoulder harness, seat belt, seat and structures should be designed "to remain intact with a force of 50's applied anteroposteriorly or vertically" (Hass, 1944, p. 5). This committee included representatives of the Civil Aeronautics Administration Engineering and Safety Bureau of the CAB.

DuBois believed "that pilots with seat belts and shoulder harness can tolerate impacts of 40 g and probably much more," and asks "If a man with proper harness will tolerate 40 g, why not make full use of this tolerance? (1946, p. 627). Why are there so many cockpit structures that collapse completely at 10 to 15 g, so many seats and belts that give way at 8 or 10 g?" (p. 627).

Between 1947 -1951, Air Force studies conducted on the "long track" at Edwards AFB and, from 1953 to the late 1960's at the Daisy Track and at "Long Track" Holloman AFB, by Stapp and others provided much of the basic knowledge concerning subjective human tolerance.

By 1959 over 256 impact studies had been published providing guidelines for whole body impact tolerances (summarized in Eiband, 1959). For the past 25 years the U.S. automotive industry has conducted or sponsored much work relative to animal, cadaver, and modeling tests, with emphasis upon regional body impact tolerances to the head, neck, thorax, and other body areas. In 1964 SAE Information Report J885 "Human Tolerance to Impact Conditions as Related to Motor Vehicle Design" was issued, which also provided a summary of tolerances related to impact to different regions of the body. This report has subsequently been revised twice, with J885 April 80 completed in 1980.

It is important, in attempting to utilize human impact tolerance data, to understand what it means. In most instances the "limits" derived from human subject tests do not refer to fatal, or even severe (non-reversible) injury levels, but have resulted from voluntary "whole body" tests up to a subjective pain or discomfort level. The deceleration referred to is "whole body" impact; contact with the chest, legs, or head on interior structure is localized "regional" impact. There are three levels of whole body "tolerance": subjective pain limits (using human voluntary subjects), an irreversible or serious injury level (but not life-threatening), and a fatal level. Higher than subjective levels involve human subjects only where the experiments have accidently proceeded beyond the intended end-point, or in free-falls. Different parts of the body also have levels of injury independent of an individual's whole body tolerance. There are also a large number of variables in an impact environment which influence the outcome and level tolerable. Physical factors include tightness and configuration of the restraint and seat, body orientation (sideward or forward facing), the magnitude, direction, distribution, duration, and pulse shape of the force resulting from the impact. In addition, biological factors such as sex, age, and physical condition have been identified as influencing tolerable impact levels. Most data are known from young healthy male subjects; there have been no controlled impact tests with children, and only limited tests to date utilizing female volunteer subjects (Airman, Nov. 1978). Individual variability must be considered, for tolerance under identical test conditions will vary in the same individual as well as from person to person. Tolerance have been variously defined in the literature and different researchers have established difference end-points. For example, Bierman (1974) defined tolerance as "that value of impact of load which produces a painful reaction"; while Stapp ultimately defined tolerance as the limit beyond which either the subject or the experimenter fears to go lest there be serious injury. More detailed discussions of criteria are found in references (J885b, Snyder NASA 1973; SAE 1970; King, 1975 or Stapp, 1961; 1969).

In contrast to the current FAR requirements discussed in regard to forces on the restrained general aviation aircraft occupant (#23.561) or air transport passenger (Part 25.561), field data from aircraft crash investigations and research data related to human impact testing have long documented that current requirements provide considerably less occupant protection than has been the state-of-the-art. In this respect the following briefly summarizes and discusses restrained human tolerances.

(1) Subjects restrained by lap belt only. In the forward-facing ($-G_x$) seated position, protected only by the lap belt restraint, human subjects have been voluntarily tested to 32 G (at a velocity of 4.69 m/sec (10.5mph) with a duration of 0.001 sec. with an onset rate of 1600 g/sec) with no significant injury (Test No. 5, p. 141), Stapp, 1971; Von Gierke and Brinkley, 1975). In a further series of tests (Lewis and Stapp, 1957) concluded that minimum contusions would result when decelerative force exceeded 10 G, at 300 G/sec rate of onset, for 0.002 sec duration. By 13 G, at the same onset rate and time duration, soreness and muscle strain would be expected. At the highest level studied--26 G (at 850 G/sec for 0.02 sec)--although the subject complained of severe epigastric pain lasting for 30 sec post-impact, and thoracic back strain for two days, no lasting injury was reported. In this case, a 7.6-cm (3-in) nylon military lap belt was used; impingement pressure was calculated to be 6.3 kg/sq cm (89.5 psi), and belt loads were measured at 1,946 kg (4,290 lb). Up to 15 G, these levels of time duration and onset rate have subsequently been considered safe for human volunteer subjects (for subjective pain threshold and transient injury only). These data are summarized in Table XIV.

In human deceleration tests conducted by Ryan in 1957 at the University of Minnesota, a subject restrained by a lap belt only received no injury in a forward impact of 23 G's and seat belt force of 2800 lbs (at 25 mph impact velocity). It was concluded that a seat-belt force of 7000 lbs. and deceleration force of 60 G's could be sustained with "no permanent injuries" (Ryan 1962, p. 172).

For the forward-facing position, with lap belt restraint only, Stapp (1970) concluded that "rates of onset between 250-1600 G/sec and 11.4-32.0

TABLE XIV

HUMAN SUBJECT TESTS, RESTRAINED BY 3" WIDE LAP BELT

Force, lb	Peak G	Onset rate, G/sec.	Time Duration sec.	Response	Data Source
• Forward-facing ($-G_x$):					
	15	300	0.002	Subjective pain threshold limit with no significant injury highest voluntary level tested; transient injury, minor reversible injury.	Lewis & Stapp 1957
4290	11.4-32.0	280-1,600	0.002		Stapp 1970 (721); 1971 (p.140)
	26	850	0.002		Lewis & Stapp 1957
	-30	-1,500			Stapp 1970
• Rearward-facing ($+G_x$):					
	30	1,065	0.110	No injury.	Stapp 1949
	40	2,000		Severe but transient response.	Stapp 1949
	82.6(chest) 40.4(sled)	3,800	0.040	Highest voluntary measured test, transient injury.	Beeding & Mosely 1960
	>45		0.100	Estimated injury threshold Air Force design limit.	HIAD
• Lateral ($\pm G_y$):					
	9 (average)		0.100	Subjective pain threshold.	Zaborowski 1966; Zaborowski et al. 1965
	14.1	600	0.122	Maximum voluntary pain level.	Sonntag 1968

peak G can be sustained against a lap belt restraint up to approximately 90 psi (6.3 kg/sq cm) average load, with no significant injuries resulting." Effects of higher loads have been investigated with animal subjects, but even in tests where the lap belt was purposely positioned high and loose, 30 G peak impact (22.6 m/sec [74.2 ft/sec] entrance velocity, 3,000 G/sec onset rate, 20 deg. seat pan pitch, 0.055 sec plateau time, 0.094 sec total impact duration) produced no significant injury (Snyder et al., 1967). It has been found that seated human occupants restrained by a 7.6 cm (3 in) lap belt only and subjected to aircraft crash forces can survive 30 peak G at rates of onset below 1,500 G/sec with only minor reversible injurious effects. When this is increased to more than 38 G at 1,300 G/sec, the immediate effects of deceleration are greater than at 45 G peak at 500 G/sec.

However, as has been pointed out by Swearingen et al. (1962), the arcing trajectory as the body goes forward to the limits of the belt and then jackknifes over the lap belt is sufficiently great, so that if the torso is not also restrained, the lap-belted occupant will almost certainly strike any forward structure. And even though whole-body loads of a 32 G deceleration are survivable with no more than minor injury, fatal injuries at far lower levels can result from the head striking the sharp forward structure. Thus, upper torso body restraint is necessary for most effective crash protection of the seated forward-facing aircraft occupant.

(2) Subjects restrained by lap belt and shoulder harness. Use of upper torso restraint increases whole-body human tolerance limits to approximately 50 G peak (at 500 G/sec rate of onset for 0.25 sec duration) (Stapp, 1951): "Abrupt decelerations of 50 G's can be sustained without loss of consciousness or injury and impact of more than 100 G's can be survived" (Stapp, p. 127, 1971).

Changes in the rate of onset have been found to have direct effects upon human response for various impulse durations (Snyder, 1971). Peak acceleration of approximately 45 G (0.09 sec at 500 G/sec) resulted in no sign of human voluntary shock, yet 38 G for 0.16 sec above 1,300 G/sec produced severe delayed effects (run 215) (Stapp, 1951). Air Force design recommendations have been given as 45 G for a duration of 0.1 sec or 25 G for a duration of 0.2 sec. Restraint in the experiments establishing these limits was by means of a double shoulder harness of 7.6-cm (3-in) width, a seat belt with thigh straps, and chest belt. Even greater tolerance has been found in tests with more optimum protection. Chimpanzee tests collaborate findings from human free-falls that forward-facing whole-body tolerance with optimum full-body restraint may be about 237 G (at 11,250 G/sec for 0.35 sec), and about 247 G (at 16,800 G/sec over 0.35 sec) (Stapp 1961). Persistent injury was found above 135 G (at 5,000 G/sec for 0.35 sec), although transient injury effects were observed at 60 G (at greater than 5,000 G/sec)(Stapp, 1955). It is clear that there is a considerable range between the region of human voluntary exposure tested and the known region of injury.

Rearward-facing ($+G_x$) tolerances are considerably higher than for either forward- or side-facing positions, primarily due to the greater distribution of loading throughout the entire back area of the seated occupant, and thus the lower N/sq cm (psi) per unit area. This results in greater stress on the seat back which must be constructed to fail at higher levels than a forward-facing seat. While human tolerance for rearward-facing body orientation has not been clearly established, the occupant so protected can be expected to withstand 40 G peaks at 30 G for 0.11 sec duration when calculated rate of onset is 1,065 G/sec (Stapp, 1949), and 40 G peaks at 2,000 G/sec with severe but transient responses (Stapp, 1961). To date, a level of 83 G (chest acceleration), at 3,800 G/sec for 0.04 sec duration, has been tolerated with only transient injuries reported (Beeding and Mosely, 1960). The current Air Force design limit falls between this and 45 G for 0.1 sec endpoint (AFSC, 1969; 1974).

Knowledge of human response to lateral deceleration forces ($\pm G_y$) is very limited, but tests to date strongly indicate that tolerances are lower for this position than for either forward- or rearward-facing body orientations. This is reflected in a change in SAE Aeronautical Recommended Practice 767, omitting side-facing seated recommendations. Human subjects have found the subjective pain threshold to be only 9 G (average) for a duration of approximately 0.1 sec (Zaborowski, 1965; 1966). Even when body restraint consisting of both lap belt and upper torso harness is worn, Sonntag (1968) found the maximum voluntary subjective tolerance to be 14.1 peak sled G at 600 G/sec for 0.122 sec duration. In lateral impact, subjects with lap belt and upper torso restraint have been exposed to 40 G, and 35 G for durations up to 0.1 seconds duration is the estimated exposure limit to prevent injury (Stapp, 1971).

Human tolerances for voluntary deceleration have been measured on humans to the values shown in Table XV with no injury (except in the case of the 82.6 G rearward test; with no irreversible injury). While such maximum peak values may be high for some segments of the population such as children, elderly, or females, these voluntary subjects did not reach the injury level, and a serious injury limit, or survival level (non-reversible injury) would have been considerably higher.

2.1.3.3.3 Comparison with other standards. Table XVI lists the Emergency Landing Conditions required for general aviation (23.561), air transport (25.561), rotorcraft (27.561), and transport category rotorcraft (29.561) relative to minimum ultimate inertial forces for design requirements.

TABLE XV

SUMMARY OF HUMAN TOLERANCE
RESTRAINED BY LAP BELT AND SHOULDER HARNESS

Direction	Peak G	Time Duration (sec)	Velocity Change (m/s/mph)	Onset Rate (g/sec)	Reference
Sideward ($\pm G_y$)	40.4	0.04	14.8	2140	Stapp, 1971
	35-40	0.03		4000-5000 (2)	Stapp, 1971
	35	70.1			Von Gierke, 1975
Upward ($+G_z$)	220	0.12			
Forward ($-G_x$)	32.7-45.4	.22-.28		215-413 (3)	Stapp, 1971 (p.134)
	45	0.09		413	Stapp, 1971
					Von Gierke, (p.223)
Rearward (_G_x)	82.6	0.052			
Downward ($-G_z$)	69.5	0.01			

(1) symptoms of shock, loss of consciousness

(2) complaints of pelvic pain, changes in blood pressure recorded

(3) transient discomfort of strap impingement areas, minimal shock signs

TABLE XVI

SUMMARY TABLE OF FAR EMERGENCY
LANDING CONDITIONS

Comparison of Parts 23 (Normal, Ultility, and Acrobatic Category - General Aviation), 25 (Transport Category), 27 (Normal Category Rotorcraft), and 29 (Transport Category Rotorcraft) for Ultimate Inertia Forces Design Requirements

	23.561		25.561 (1)	27.571 (2)	29.561 (3)
Direction	Normal & Utility	Acrobatic	Transport	Normal Rotorcraft	Transport Rotorcraft
Forward	9.0 g	9.0 g	9.0 g	4.0 g	4.0 g
Sideward	1.5 g	1.5 g	1.5 g	2.0 g	2.0 g
Upward	3.0 g	4.5 g	2.0 g	1.5 g	1.5 g
Downward	None	None	4.5 g (4)	4.0 g (5)	4.0 g (5)
Rearward	None	None	None	None	None

(1) 14 CFR24, 1980. (Docket No. 5066, 29 FR 18291, Dec. 24, 1964, as Amended by Amdt. 25-23, 35FR 5673, April 8, 1970)

(2) 14CFR27, 1980

(3) 14CFR29, 1980

(4) "or any lower force that will not be exceeded when the rotorcraft absorbs the landing loads resulting from impact with an ultimate descent velocity of five f.p.s. at design maximum weight."

(5) "or any lesser force that will not be exceeded when the airplane absorbs the loadings resulting from impact with an ultimate descent velocity of five f.p.s. at design landing weight."

Note that while both normal and transport rotorcraft require 2.0 g instead of 1.5 g sideward protection, they require only 4.0 g instead of 9.0 g for forward protection. General aviation aircraft have no design standards, in contrast to all other categories, for downward forces. A downward value of 0 to 4.5 g was required for general aviation design in 1945, but was dropped in 1946 (03.3811) without explanation. There is no rearward force requirement for either civil fixed wing or rotorcraft. These standards do not appear to be based on any human tolerance data, but rather originated with the earliest design criteria in 1926.

In contrast, military aircraft design standards have directly utilized results of human tolerance tests and have reflected the state-of-the-art fairly closely for the past 30 years. The Air Force Systems Command Handbook (5th Ed., 1978), for example, provides a section on crash protection and escape survival systems for designers. This handbook is a successor to the earlier HIAD (Handbook of Instruction for Aircraft Designers) of the 1960's. Air Force tolerance criteria are for the most part based upon the human deceleration studies of Col. (then Capt.) John Paul Stapp (refs, 1951; 1949; 1955; 1954; 1961), conducted between 1947 and 1954. Rearward impact data resulted from Daisy Decelerator studies of Beeding (1949), and lateral impact tolerances from work of Zaborowski (ref: 1965; 1966), and Sonntag (1966). The current Air Force aircraft design standards are listed on Table XVI. Note that these standards are from 5 (forward) to 7-1/2 times (sideward) higher than the minimum FAA standards for the same orientation.

Similarly the U.S. Army has conducted research to improve crashworthiness of fixed-wing aircraft and helicopters since the late 1950's, and have issued and updated various design requirements periodically. The human tolerance requirements have been generally based upon Air Force studies but in turn the Army has generated most of the crash design data, most recently published in Aircraft Crash Survival Design Guide (Vol. II. Aircraft Crash Environment and Human Tolerance, Laananen, 1980).

An attempt to up-grade general aviation occupant protection occurred in 1975, when the SAE General Aviation Cockpit/Cabin Standardization Committee for General Aviation Aircraft (A23), after several years discussion and study, approved Aerospace Recommended Practice 1318 "General Aviation Seat Design." Although this caused such a reaction among the manufacturers that the SAE disbanded the committee without further action, the ARP 1318 was published as part of another SAE paper on crashworthiness (Snyder, 1978). This document recommended dynamic ultimate load factors for "a forward load of twenty-five (25) g's applied twenty (20) degrees to either side of the longitudinal axis, on aft load of 5 g's, an upward load of 16 g's and a downward load of 15 g's.

Reviewing human tolerance data available in 1967 and 1968, an FAA Office of Aviation Medicine staff study, concluded that Part 25.561 should be upgraded for air transports and provided the 1965 table of recommended design loads proposed by Turnbow et al. (1965). Their emphasis was on air transports rather than general aviation aircraft. This document concluded "There are no standards dealing with occupant protection in moderate to severe survivable accidents. It is concluded that human tolerance to acceleration forces is much greater than the forces generated during some of today's "nonsurvivable" accidents. We have 40 g people riding in 20 g airplanes, and sitting in 9 g seats and restraint systems" (Mohler, 1968).

The Federal Motor Vehicle Safety Standards (FMVSS) of the National Highway Traffic Safety Administration (NHTSA) apply to a number of occupant protection design criteria for requirements for car seating systems and specified in FMVSS No. 207, which concerns attachment assemblies and their installation to minimize the possibility of their failure by forces acting upon them as a result of vehicle impact. Under this standard each occupant seat shall withstand 20 g in both forward and rearward directions, in any position to which it can be adjusted (35 F.R. 15290, October 1, 1970). In addition, occupant crash protection is specified in FMVSS No. 208, which provides various injury criteria that must be met in a 30 mph frontal and 30 mph lateral barrier crash test, rollover (decelerated from 30 mph at least 20 g for minimum of 0.04 secs), under three options of passive or combination lap and shoulder restraint system in the front seats (36 F.R. 17430, August 31, 1971). FMVSS No. 209 specifies seat belt assembly strength, belt elongation, buckle and retraction, and other performance requests (44 F.R. 72131, December 13, 1969). Other automotive requirements for passenger protection are found in FMVSS No. 210 (seat belt assembly anchorages - 5,000 lb. force, or 3,000 lb. force with type 2 belt anchorage), 213 (child seating system), 214 (side door strength), 215 (exterior protection, 216 (roof crash resistance), 220 schoolbus rollover protection). A lap belt and shoulder harness have been required in all outboard front seat positions of all new cars manufactured for sale in the U.S. since 1 January 1968. The 20 g motor vehicle requirement is compared to the 9 g aircraft requirement in Table XVI.

Review of Table XVI indicates that occupants of general aviation aircraft designed in compliance with the ultimate inertia forces of #23.561 are provided only limited protection as compared with the military design requirements. Various recommendations have been proposed to increase the design criteria.

2.1.3.3.4 Confusion in terms. A technical problem that has not apparently received further attention was expressed in an internal FAA analysis which questioned the substitution of the term "force" for "acceleration" without reversing the directions (unpublished data, 1980). In 1946 the term "ultimate accelerations" was used (and retained in the revision adding #3.386 in 1950). However, the present #23.561(b)(2) has used the term "ultimate inertia forces" since 1964. (The original expression in 1945 also used "ultimate inertia forces" in "all combinations"). The question was whether the upward and forward force is not actually in the opposite direction of upward and forward acceleration.

Whether or not this assessment is technically correct*, it may be analogous to the distinction made between acceleration and deceleration (impact) in the forward-facing body orientation: in acceleration the

* The author queried several engineers experienced in the fields of biomechanics, mechanical engineering, mathematics, aerospace engineering, and physics, and did not find agreement on this point.

the expression +Gx is used, but in impact it becomes -Gx, as the direction of force acting on the body is opposite to that which occurs in acceleration, even though the direction of motion is the same (NASA Bioastronautics Data Book, 1973, p. 221). Similarly, in Part 23.561(b) (2) is "upward ultimate inertia forces" the same thing as "upward ultimate accelerations" (CAR 3.386)?

In any case, a solution to clarify this point is simply to add a definition (or reference in glossary) together with a simple coordinate system figure illustrating exactly what is meant relative to direction of loading on the occupant.

2.1.3.4 "moderate descent velocity". This phrase, cited in #23.561(c) (2) provides that "Each airplane with retractable landing gear must be designed to protect each occupant in a landing - (1) with wheels retracted; (2) with moderate descent velocity..". The original #04.260 (14CFR3, 1945) requirement specified an "ultimate descent velocity of 5 fps," but this was modified the following year to the present "moderate descent velocity." Other than the 5 fps original requirement, no further definition has been found in the FAR's or amendments.

Work on an energy-absorbing seat design for light aircraft was reported by Piper Aircraft Corp. in 1972 in which vertical descent velocity was an important consideration (Underhill and McCullough, 1972). The design criteria established in this work, which included dynamic impact tests conducted by the FAA's Civil Aeromedical Institute, was for vertical velocity components of 1500 ft/min (7.62 m/s)... "without exceeding acceptable g loads," or 25 ft/sec. This may be assumed to represent a higher value than present FAA requirements and a higher value than most previous general aviation aircraft have been designed to. Thus a practical interpretation of the present meaning of "moderate descent velocity" is above 5 fps and below 25 fps, with about 15 fps estimated as the norm (note that gust load requirements (#23.425) are currently for positive and negative gusts of 25 fps - Amdt 23-7 34FR 13089 August 13, 1969 (Docket No. 4080 20 FR 17955. Dec. 18, 1964) Notice 67.14 was amended to base gust loads on aircraft mass instead of wing loading). "Moderate" undoubtably is more than "minor" and less than "severe," but this phrase is subject to subjective interpretation (currently by the region certifying the aircraft, as well as the designer (manufacturer). An objective meaningful definition is needed to clarify specifically what this requirement means.

But more importantly, this needs to be upgraded to better reflect the state-of-the-art for vertical impact protection and the multitude of structural means to accomplish improved energy-absorption and reduce loads on the seated crash occupant. The military standards, for example, have offered considerably greater protection. The Air Force Design Guide specified 25.0 G (for 0.1 sec) for design of upward tolerance (USAF Design 1975). The Army Aircraft Crash Survival Design Guide specifies protection in the vertical impact direction for a velocity change of 42 ft/sec (Vol. IV, 1980, p. 44). The FAA requirements for vertical descent velocity protection is presently on the order of only 1/3 to 1/8 that of Army aircraft. In view of technology which has produced the UTTAS crashworthy military helicopter, there is no doubt that the state-of-the-art and technology is considerably beyond the FAA requirement of over a decade ago. "Moderate descent velocity" is an unclear and essentially meaningless term that must be better defined and upgraded to provide the improved protection available with today's technology.

2.1.3.5 "turnover..upward ultimate inertia force of 3 g." Part #23.561 (d)(1) states "If a turnover is reasonably probable, the structure must be designed to protect the occupants in a complete turnover, assuming in the absence of a more rational analysis - (1) an upward inertia force of 3 g; and (2) a coefficient of friction of 0.5 at the ground." The origins of the present turnover requirement have roots back to at least 1938. Part #04.247 required an ultimate load factor of 4.5, and allowed partial failure of the structure provided the safety belted occupants were not endangered. Part #04.460 stated that the fuselage and cabins shall be designed to protect the passengers and crew in a complete turnover, although this requirement could be "suitably modified" when a turn-over in landing is "remote." Although in 1945 the CAB said nothing about a turn-over in the new Part #4.26 requirements for emergency landing conditions (14CFR3), a requirement for vertical loading of 0 to 2.0 g (up) and 0 to 4.5 g (down) was incorporated. In 1946 Part 03.381(c) specified that if the characteristics of an airplane are such as to make a turnover reasonably probable the fuselage shall be designed to afford protection to the occupants in a complete turnover. An attached note specified the 3 g vertical acceleration, incorporated in subsequent modifications.

Aside from the fact that in a turnover the occupant may be subjected to both rotational acceleration and lineal deceleration, there is again confusion in use of the term upward. Since 1946, when the distinction between up and down vertical forces was abandoned, it has not been clear what the present "upward" force referred to in 23.561(b) (2) and (d)(1) means. In aircraft crashes there may be a large vertical loading on the occupants through the seat, but this loading will be in the opposite direction from that of a turnover. That is, in a crash landing in which the occupant is loaded from the seat to the head, the occupant will be moving in a downward direction; but when he is loaded at the conclusion of a complete turnover in a roof (head) toward seat vector, the occupant's direction of motion is seat toward roof. (Actually it is more complex than that, since rotational acceleration may play a major role. The complex crash environment in a fatal turnover general aviation accident is detailed in Snyder et al., 1981). However, the point is that the vertical direction of force on seats and occupants in a crash is the opposite of that in a turnover, although Part 23.561 fails to make this distinction in protection.

Turnovers are not uncommon. In one study of ELT effectiveness in crashes, 38% of the high-wing general aviation accidents studied ended up inverted, and 24% of the low-wings overturned (Hall, SAFE, 1980; Av.Cons. 15 Aug. 1980, p. 5). In northern states such as Michigan in the winter, 3 out of 5 aircraft accidents in winter months may involve overturns, some with fatal results (Snyder and Armstrong, 1979).

The requirement for 3 g protection was established some 34 years ago. Both aircraft performance and structures have changed since that time, but there is no evidence that any attempt to improve this requirement has occurred by the FAA. In the meantime military helicopter requirements call for beefed-up cabin rollover structures and a roof capable of protecting against 8 to 12 g impacts on helicopter transmissions. The Sikorsky YUH-60A, for example, designed to improve crashworthiness levels in Army helicopters, is capable of protecting against 10 g downward inertial loads (Cornell, 1975, p. 57). In view of the apparent incidence of overturns, attention should be given to upgrading this section of #23.561.

2.1.3.6 Title and Content Revision. The present #23.561 as the primary occupant protection standard, has a number of weaknesses, inconsistencies, and many outdated requirements discussed previously. In many ways it is not even as useful as the earlier CAR 3.386-1 (crash protection), which between 1951 and 1964 provided a series of guidelines for crashworthy design. This section has developed from the Part 03 (of 1945), which is in turn based on structural standards rather than human standards. While this is consistent with much earlier structural requirements for landing gear, fuselage, seating and restraint, and fitting strength, no evidence has been found to suggest that human injury and protection tolerances were ever considered as a basis.

In the past, modifications have been made piecemeal by adding or dropping words or patching-in phrases. In view of the number of places needing updating in this section, it would make better sense to modify 23.561, by starting all over and developing a totally new section on occupant protection. Such a new section should reflect the emphasis on crashworthiness by retitling it from "emergency landing conditions" (of 1945) to something like "emergency crash landing conditions," "crashworthiness protection," or "occupant crash protection." Further, additional guidelines should be incorporated to provide more meaningful information to the designer.

2.2 Seats, Berths, Safety Belts, Harnesses (23.785)

Part 23.785 provides requirements for seats, berths, safety belts, and harnesses. It references emergency landing conditions in #23.561, flight control reactions in part #23.395, and fitting factors in #23.625.

2.2.1 Development of the FAA Requirements. The original 1926 Air Commerce Regulations addressed the issue of safety belts in 12(A)3, by stating:

> "13 (Construction of Cockpit, Cabins, and Controls):(A) The cockpit must be constructed to afford:
> ...3. Safety belts or equivalent apparatus for pilots and passengers in open cockpit airplanes carrying passengers for hire or reward;" (p.12)

This appears to have excluded any requirement for safety belts in closed cabin aircraft. While it allowed an alternative to safety belts in open cockpit airplanes, it is unknown as to what "equivalent apparatus" qualified and were allowed. Nothing was mentioned about seats.

By 1929 the expanded Airworthiness Requirements of Air Commerce Regulations No. 7A required for the first time safety belts (or equivalent) in all airplanes, and first specified that safety belts and their attachments must withstand 1000 lb crash loads. In addition a general statement of intent concerning chair or seat strength was made, although no strength requirements specified at this time. These requirements are found in:

> "11. Equipment and Instruments (A) Equipment...III. Safety Belts or equivalent for pilots and passengers in all airplanes. Seats or chairs in cabin planes shall be firmly secured in place. Safety belts and their attachments shall be capable of withstanding a load of 1,000 pounds applied in the same manner as a passenger's weight would be applied in a crash. The attachment shall be such as to be capable of carrying this load through to the main structure" (p.10).

In 1934 Aeronautics Bulletin No. 7-A Airworthiness Requirements for Aircraft, amended the 1929 requirements, and changed seat and safety belt requirements to a new section 60. The method of applying the design load at 45° angle with the floor line was first specified at this time.

"Sec. 60. Special Requirements. (A) Seats and Safety Belts - All seats shall be provided with approved safety belts. Safety belts and their attachments shall be capable of withstanding a design load of 1,000 pounds per person applied upwardly and forwardly at an angle of approximately 45° with the floor line. This load shall be carried through to the main structure. Seats or chairs, even though adjustable, in open or closed airplanes, shall be securely fastened in place whether or not the safety belt load is transmitted through the seat" (1934, p.43).

Safety belts were subsequently addressed in Part 15.30 of the Bureau of Air Commerce regulations. Belt requirements were further expanded to provide for two persons (2,000 lbs), a belt release mechanism requirement was first specified, static test report compliance specified, at least a 2 inch belt width, and labeling and certification requirements listed.

15.30 Safety belts.

15.300 Safety belts will be certificated for general aircraft use or for glider use dependent upon the strength of the belt.

15.3000 Certification of a safety belt does not include certification of its anchorages to the aircraft.

15.3001 The installation of safety belts in certificated aircraft shall be in accordance with the pertinent provisions of Part 04.

15.301 Safety belts shall be so designed as to be easily adjustable. Each belt shall be equipped with a quick-release mechanism so designed that it cannot be released inadvertently. The width of a certificated safety belt shall be at least 2 inches.

15.302 The strength of a safety belt shall be determined by static test.

15.303 Safety belts for general aircraft use will be certificated for one person or two adjacent persons dependent upon the strength of the belt.

15.3030 A safety belt for one person shall be capable of withstanding a load of 1,000 pounds applied in the same manner as a person's weight would be applied in a crash. The quick-release mechanism shall be capable of withstanding this load without undue distortion, so that when the load is relieved to 400 pounds, the mechanism shall be capable of being operated by hand.

15.3031 A safety belt for two persons shall be capable of withstanding a load of 2,000 pounds applied in the same manner as the weight of two persons would be applied in a crash. The quick-release mechanism shall be capable of withstanding this load without undue distortion, and when the load is relieved to 800 pounds, the mechanism shall be capable of being operated by hand.

15.304 Safety belts for glider use only will be certificated as such.

15.3040 A safety belt for glider use shall be capable of withstanding a load of 850 pounds applied in the same manner as a person's weight would be applied in a crash. The quick-release mechanism shall be capable of withstanding this load without undue distortion, and when the load is relieved to 400 pounds, the mechanism shall be capable of being operated by hand.

15.305 Each unit of a certificated model safety belt shall bear the following additional identification data as prescribed in § 15.042 (e):

15.3050 Whether for one person, two persons, or for glider use only.

15.306 A request for certification of a type or model or series of models of safety belts shall be supported by the following additional data as prescribed in §15.0502:

A report of the static tests showing compliance with §§ 15.3030, 15.3031 or 15.3040, as the case may be. The report shall contain complete details of the tests, including the hand operation of the quick-release mechanism under relieved load, and shall contain photographs of the test setup. The report shall be signed by the person making the tests and shall be supported by affidavit unless the tests were witnessed by a Bureau inspector, in which case such inspector also will sign the report as a witness.

Part 04 of the Civil Air Regulations (Bureau of Air Commerce #15.31 Chapt. I, p. 207) (CAM 04) contained equipment requirements specified in 04.510 (NAC landplanes - visual-contact day flying (within 100 miles of a fixed base):) required "(i) certificated safety belts for all passengers and members of the crew" (p.65). This section cross-referenced Part 15 for belt requirements, and #04.5810 for installation requirements. Part 4a covered big and small airplanes.

"#04.5810 Safety belts. Safety belts shall be so attached that no part of the attachment will fail at a load lower than that specified in #04.2640."

The performance criteria required in the latter part was applied through the safety belt:

"04.2640 Structures to which safety belts are attached shall be capable of withstanding an ultimate load of 1000 pounds per person applied through the safety belt and directed upward and forward at an angle of 45 degrees with the floor line."

Passenger chairs and seats were also subject to federal design requirements at this time, although performance was minimal and somewhat ambiguous.

"04.646 Passenger chairs. Seats or chairs for passengers shall be securely fastened in place in both open and closed airplanes, whether or not the safety belt load is transmitted through the seat. (See Part 15 and #04.2640 for safety belt requirements)."

Seats were further addressed in #04.589 "miscellaneous equipment installation:

"04.5890 Seats. Seats or chairs, even though adjustable, in open or closed airplanes, shall be securely fastened in place whether or not the safety belt load is transmitted through the seat." (CAM 04 Revised 1 July 1944).

In 1945 these were changed to Part 03, effective November 13, 1945.

In 1949 parts 03.3822 and 3.3822 were renumbered effect July 16, 1949 (F.R. 14:136) to 3.390.

Another CAM Supplement addressed safety belts in 3.715, previously 3.543. Supplement 5 of CAM 3 issued in March, 1950 specified parts 3.390 relating to seats and berths and CAR 3.391 concerned with belt loads. In addition 3.391-1 "safety belt attachment loads" provided CAA interpretations, previously 3.38221.

"3.390 Seats and Berths (a) Passenger Seats and Berths. All seats and berths and supporting structures shall be designed for a passenger weight of 170 pounds (190 pounds with parachute for the aerobatic and utility categories/ and the maximum load factors corresponding to all specified flight and ground load conditions including the emergency conditions and section 3.386.
(b) Pilot Seats. Pilot seats shall be designed for the reactions resulting in the U and A categories under section 3.74(c)(4) shall be designed to accomodate passengers wearing parachutes.
3.390-1 Approval of seats and berths, and their installations (CAA Policies which apply to Section 3.390, previously 3.3822).
(a) Seats and berths and their installations, as well as related aircraft components, can be approved by any one of the three following procedures:

(1) Proof of compliance with the strength and deformation requirements and the regulations may be obtained on the basis of structural analysis done when the structure conforms with conventional types for which the existing methods of analysis are known to be reliable.
(2) Proof of such compliance may be obtained by a combination of analysis and load tests to limit loads.
(3) Proof of such compliance may be obtained by static load tests alone, when such tests are carried to design ultimate loads.

(b) All seats shall be designed for the weights stipulated in this section (170 pounds for normal category; 190 pounds for utility and aerobatic category). When designed for a lower weight than those referred to above, the seat should be placarded to indicate the permissible, maximum weight of the occupant"(see CAR 3.766).

"3.391 Safety Belt or Harness Provisions. Provisions shall be made at all seats and berths for the installation of belts or harnesses of sufficient strength to comply with the emergency conditions of section 3.386."

"3.391-1 Safety Belt Attachment Loads. (CAA Interpretations Which Apply to Section 3.391, previously 3.38221). All airplanes to which CAR 3.391 is applicable under CAR 3.2 should have structural provisions and attachments adequate for the safety belt loads corresponding to the requirements of CAR 3.386, even though certificated safety belts meeting these requirements may not yet be available." (Dept. of Commerce, CAM 3. Supplement 4, March 8, 1950; Supplement 10, 16 F.R. 3290, April 14, 1951).

The use of shoulder harnesses was outlined in CAM 8 in 1951; applicable to restricted category aircraft.

> 4.3 <u>Safety Belts and Harnesses</u>. Safety belts harnesses will help to prevent serious injury to the pilot in the event of a crash by restraining him relative to the surrounding structure. A complete harness which restrains the pilot's lower body and his shoulders (and head) provides more protection than a belt alone. The belt will restrain the pilot in the seat though it may allow his upper body to pivot forward or sideward in the event of a bad landing or crash. Safety belts and harnesses which have been approved by the Civil Aeronautics Administration have adequate strength to resist loads from relatively severe crashes. CAA approved safety belts and harnesses should be installed and should preferably be new. Used belts and harnesses should be carefully examined and if found glazed, with ragged edges or poor appearance they should be replaced with TSO belts. Attachment fittings and their carry-thru to the primary structure should be as strong as the belts or harnesses. Attachment fittings preferably full swiveling, should be located on the primary structure and in direct line with the expected direction of pull on the belt or harness. For example, shoulder harness upper fittings should be directly behind the wearer's shoulders and should be as strong as the harness. (Civil Aeronautics Manual 8, Appendix A. January 1, 1951).

A number of amendments were subsequently added to CAR 3.390. In 1952 Amendment 3-7 (adopted January 28, 1952) required all seats and berths to be approved. In October 1952 3.390-2 added a policy regarding proof of compliance with strength and deformation requirements (Supplement 14, 17FR9066, October 11, 1952). Amendment 3-14 (adopted February 7, 1956) amended #3.390 to provide more realistic requirements for occupants in berths. In 1962 Amendment 3-7 (issued March 27, 1962) amended #3.390(d) to restrict the use of the factor 1.33.

Notice 64-17 recodified CAR 3.390 and 3.390-2 to FAR 23.785, with the reorganization to Part 23 in 1964. Amendment 23-19 (Notice 73-1) amended #23.785 to include safety belts and harnesses and added parts (h), (i), (j) and (k), while 23-2 (Notice s 75-10, -19, -23, -26, and -31) added #23.785(1) to prevent seats from sliding off their tracks. (Docket No. 4080, 29, FR 17955, December 18, 1964, as amended by Amendment No. 23-7, 34 FR 13092, August 13, 1969; 42 FR 30603, June 16, 1977; Amendment 23-23, 43 FR 50593, October 30, 1978; 43 FR 52495, November 13, 1978).

2.2.2 Current Requirement: FAR 23.785. The current regulation (14 CFR 23, 1980) is stated as follows.

#23.785 Seats, berths, safety belts, and harnesses.

(a) Each seat, berth, and its supporting structure, must be designed for occupants weighing at least 170 pounds (or 190 pounds with parachute for seats in utility and acrobatic category airplanes), and for the maximum load factors corresponding to the specified flight and ground load conditions, including the emergency landing conditions prescribed in #23.561.

(b) Each seat, berth, safety belt, and harness must be approved.

(c) Each pilot seat must be designed for the reactions resulting from the application of pilot forces to the primary flight controls, as prescribed in #23.395.

(d) Unless otherwise placarded, each seat in utility and acrobatic category airplanes must be designed to accommodate passengers wearing parachutes.

(e) Each berth installed parallel to the longitudinal axis of an airplane must be designed so that the forward part has a padded end-board, canvas diaphragm, or equivalent means that can withstand the static load reaction of the occupant when the occupant is subjected to the forward inertia forces prescribed in #23.561. In addition -

(1) The berth must have an approved safety belt and may not have corners or other parts likely to cause serious injury to a person occupying it during emergency conditions; and

(2) Safety belt attachments for the berth must be designed to withstand the critical loads resulting from relevant flight and ground load conditions and from the emergency landing conditions prescribed in #23.561, with the exception of the forward load.

(f) Proof of compliance with the strength and deformation requirements of this section for seats and berths approved as part of the type design and for seat and berth installations may be shown by -

(1) Structural analysis, if the structure conforms to conventional airplane types for which existing methods of analysis are known to be reliable;

(2) A combination of structural analysis and static load tests to limit loads; or

(3) Static load tests to ultimate loads.

The inertia forces prescribed in #23.561 must be multiplied by a factor of 1.33 (rather than by the fitting factor prescribed in #23.625) in determining the strength of the attachment of each seat or berth to the structure.

(g) Each occupant must be protected from serious head injury when he experiences the inertia forces prescribed in #23.561(b)(2) by -

(1) A safety belt and shoulder harness that is designed to prevent the head from contacting any injurious object, for each front seat; and

(2) A safety belt, or a safety belt and shoulder harness, for each seat other than a front seat.

(h) Each shoulder harness installed at a flight crewmember station must allow the crewmember, when seated and with his safety belt and shoulder harness fastened, to perform all functions necessary for flight operations.

(i) There must be a means to secure each safety belt and shoulder harness, when not in use, so as to prevent interference with the operation of the airplance and with rapid egress in an emergency.

(j) The cabin area surrounding each seat, including the structure, interior walls, instrument panel, control wheel, pedals, and seats, within striking distance of the occupant's head or torso (with the safety belt fastened), must be free of potentially injurious objects, sharp edges, protuberances, and hard surfaces. If energy absorbing designs or devices are used to meet this requirement they must protect the occupant from serious injury when the occupant experiences the ultimate inertia forces prescribed in #23.561(b)(2).

(k) For purposes of paragraph (g) of this section, a front seat is a seat located at a flight crewmember station or any seat located alongside such a seat.

(1) Each seat track must be fitted with stops to prevent the seat from sliding off the track.

(Secs. 313(a), 601, and 603, 49 U.S.C. 1354(a), 1421, and 1423; sec. 6(c) 49 U.S.C. 1655(c); and Secs. 313(a), 601, 603, 604, Federal Aviation Act of 1958 (49 U.S.C. 1354(a), 1421, 1423, 1424), sec. 6(c) Department of Transportation Act (49 U.S.C. 1655(c)))

[Docket No. 4080, 29, FR 17955, Dec. 18, 1964, as amended by Amdt. No. 23-7, 34 FR 13092, Aug. 13, 1969; 42 FR30603, June 16, 1977; Amdt 23-23, 43 FR 5093, Oct. 30, 1978; 43 FR 52495, Nov. 13, 1978] (14 CFR 23, p. 151, 1980)

2.2.3 Discussion and Analysis. While this is not intended to be a comprehensive evaluation, the points selected for analysis require updating to be within the state-of-the-art as indicated by the accompanying documentation.

2.2.3.1. Occupant Weight (#23.785(a)). The present general aviation aircraft design structural requirements for both seat and restraint strength are based upon a 170-pound occupant (1980).* This standard has not been modified since first specified in 1929, fifty-one years ago (Airworthiness Requirements of Air Commerce Regulations, #7A,

* A 190 lb. occupant is specified for utility and acrobatic category airplanes to account for the additional weight of a parachute.

p. 14, 1929). The original requirements of 1926 did not include an occupant weight specification. However, the subsequent Bulletin 7A, issued in 1929, stated that "crew and passenger weights are calculated on the basis of 170 pounds each" (p. 11). This formed the first civil* occupant weight requirement.

The importance of the occupant weight specification to crashworthiness is often overlooked. However, it forms the basis for required seat belt and seat structural strength load tests. The 1929 requirements for Part 3. - Light Aircraft first established the design loads in Part 10 "Safety belts attached to suitable anchorages shall be provided in light aircraft. The strength of the belt and its anchorage shall be sufficient to withstand a pull of 850 pounds applied to the belt in a manner simulating the loading applied by a person weighing 170 pounds with a load factor of 5" (p.43). Today's FAR 23.785(a) specified the 170 lb. occupant relative to the maximum load factors given in #23.561 (or a forward ultimate inertia force of 9 g). In compliance tests these inertial forces must be multiplied by a factor of 1.33 in determining seat attachment strength. This fitting factor of 1.33 on the restraint system attachment fittings in effect raises the inertia level to 12 g. Although there are at present no dynamic test criteria as such in the regulations, peak pelvic decelerations on the occupant of 12 g are considered by the FAA to represent the regulatory level for test purposes (Daiutolo, 1972). A basic element in such tests is the 170 lb. occupant weight factor.

That occupant weight makes a considerable difference in seat and restraint system standards can be shown by a comparison with other standards which use a higher occupant weight. For example, the NASA development of a lightweight 15 kg (35 lb) air transport seat was designed to protect a 225 lb. (102.1 kg) occupant (against 20 g vertical, 10 g lateral and 20 g forward accelerations). A 1968 staff study of the FAA's Office of Aviation Medicine recommended that the inertial

* In 1907, twenty-two years earlier, United States Army Signal Corps Specification No. 486, for the Wright Brothers first military heavier-than-air flying machine, required that it must be designed to carry two persons having a combined weight of 350 pounds, or 175 lbs. each.

loads related to a 170 lb. (77.1 kg) occupant be established at 224 lbs. (102.1 kg), since many passengers exceed 170 lbs. (77.1 kg) and therefore compromise the safety of the current seat design (Mohler, 1968).

Occupant weight standards used in military aviation design requirements are based upon anthropometric studies of the particular pilot and passenger (troop) populations and are periodically updated.*

The military standard for light-fixed-wing and rotary-wing aircraft crashworthiness specifies the 5th-percentile troop passenger as weighing 135.9 lbs. (61.7 kg) and the 95th-percentile troop passenger as 265.1 lbs. (120.5 kg) (MIL-STD-1290 (AV) 25 January 1974). Army seat requirements specify that "seats shall attenuate impact decelerations experienced in the 95th-percentile potentially survivable crash to accepted human tolerance levels for the 5th through 95th percentile occupants" (5.2.1.2.5). An additional requirement is that a 95th-percentile clothed anthropometric dummy occupant shall be used to simulate the seat system occupant for dynamic tests of seat systems (4.5.3.2 MIL-S-58095(AV) 27 August 1971). The Army defines a 95th-percentile clothed occupant as the 95th-percentile aviator, wearing 11.5 lbs. of equipment and clothing (6.3.2). The 50th-percentile clothed occupant weight is 139 lbs. (6.3.10). The U.S. Department of Defense Military Standardization Handbook utilizes the data on 1970 Army Aviators, listing 133 lbs. (60.4 kg) 5th-percentile, 170.5 lbs. (77.4 kg) 50th-percentile and 211.7 (96.0 kg) 95th-percentile (MIL-HDBK-759, 12 March 1975).

The <u>Army Crash Survival Design Guide</u> recommends that the upper and lower limits of occupant weights be considered in seat design and that 5th- and 95th-percentile occupant weights be used. "Ideally, seat stroke limits should be sized for the 95th-percentile occupant while the occupant acceleration limits should be determined by the 5th-percentile" (Desjardins, p.177, 1980). Army static test loads for cockpit and cabin seats must be applied through a body block approximating a 95th-percentile

* A 1945 Army Air Force study found that when personal equipment was considered the <u>average</u> flyers weight was 249 lbs (279 lbs in heavy bombers), instead of the 200 lbs specified. It was recommended in 1945 that design engineers utilize 249 lbs in calculating structural strength for design of seats, shoulder harness, and safety belts (AAF Memo Rept.p.24, 1945).

occupant (pilot/copilot 222.3 lbs; troop/gunner 242.2 lb.) (Desjardins, p.185 IV, 1980), and dynamic tests must be conducted under two sets of conditions, one set of tests using 95th and another 50th-percentile (pilot/copilot 181.1 lb; troop/gunner 196.6 lbs.) (Desjardins, p.191, IV, 1980).

The Society of Automotive Engineers (SAE) has various weight guidelines provided in aerospace standards (AS) or Aeronautical Recommended Practices (ARP). Requirements in SAE AS290, Flight Deck Seats for Transport Aircraft (issued 1965). are based upon a 200 lb. (90.9 kg) occupant. SAE ARP 682B, Safety Lap Belts (for Civil Transport Aircraft), issued in 1961 and revised in 1979, includes a lap belt release requirement related to a 260 lb. (113 kg) occupant. SAE ARP 750, Passenger Seat Design, issued in 1965, references NAS 809 for seat ultimate load requirements. A revised 750A, presently in preparation, defines a standard passenger weight as 170 lbs. (77.1 kg) "to be used in developing static and dynamic test loads for the seat" (1981). SAE ARP 1318, a proposed aerospace recommended practice for general aviation seat design, was also based upon a standard occupant weight of 170 pounds (190 lbs. acrobatic) for determining static and dynamic seat loads (1975). National Aircraft Standards (NAS), issued by the Aircraft Industries Association of America, 806 (1950) and 908, Aircraft Seats and Berths, are based upon the 1929 standards of a passenger weight of 170 pounds for Type I (transport) "and 190 pounds (includes parachute)" for Types II (normal-utility) and III (acrobatic).

For seat belt fit in automotive vehicles FMVSS No. 209 specifies a 102 lb. 5th-percentile adult female and a 215 lb. 95th-percentile adult male (S4.1(g)(1)(3); 49CFR #571.209, 1980). FMVSS No. 208 also specifies a 165 lb. 50th-percentile adult in other requirements. It has been standard practice to use a 50th-percentile dummy in automotive dynamic crash tests.

Crash test dummies have been used in civil aircraft dynamic testing for the past 30 years, although present seat/restraint FAR's require only static tests with representative body blocks. Swearingen, of the Civil Aeronautics Medical Research Laboratory of the Department of Commerce's Civil Aeronautics Administration, in Oklahoma City, designed and fabricated the first practical articulated U.S. crash dummy "Oscar" for explosive decompression tests in 1949.* This dummy weighed 120 lbs. In 1950 he initiated construction of a new 190 lb. dummy, "Elmer," which weighed 216 lbs. dressed and was designed for tests of 35 to 50 g's (Swearingen, 1951). This dummy was used in 21 dynamic deceleration tests to 20.3 g for development by Beech Aircraft Corporation of a new shoulder harness in 1951 (Beech, 1951). By April 1951, it had been used in over 30 tests between 15 and 20 g. "Elmer" continued to have a long and distinguished career, and was the basis for subsequent dummies built by the Air Force at Muroc AFB, the University of Minnesota, UCLA, and the Naval Air Material Center in the early 1950's. (CAMRL Activity Reports 1948-1956). Dummies used by NACA for dynamic crash tests of three Piper Cubs at Cleveland in the early 1950's were Air Force offsprings of "Elmer" (NACA, 1956; Eiband, Simpkinson, and Black, 1953).

Despite the 170 lb. criterion a variety of dummies, often larger, have been utilized in tests. A sampling of reports show, for example, that in recent FAA/NASA crash tests conducted at Langley Research Center, Virginia, anthropomorphic dummies of 194 lb. (88 kg), 180 lb. (82 kg), 145 lb. (66 kg), 141 lb. (64 kg) are described, along with "manikins," and 200 lb. (91 kg) lead weights (Alfaro-Bou and Vaughn, 1977; Vaughn and Alfaro-Bou, 1979). In other tests anthropomorphic dummies of 135 lb. (61.2 kg) and 174 lb. (79.3 kg) weights were used (Hayduk and Thomson, 1979). Still other tests did not use dummies: "in all three specimens, the third and fourth passengers were simulated with a balance distribution of lead masses, batteries, pyrotechnic programmers, and instrumentation boxes" (Vaughn and Alfaro-Bou, 1979, p.4). A major reason for this diversity was that initially NASA had to borrow whatever dummies were available to use for these tests. The most recent tests NASA has conducted at Langley have exclusively used the 50th-percentile male Hybrid II, a 167 lb. anthropometric dummy.

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* Earlier dummies had been built by the Germans in 1940 (Wiesehöfer, 1940), and a 180 lb. dummy was designed by the British in 1942 (Pekerek, 1942).

Recent FAA tests at the Civil Aeromedical Institute have used a wide range of dummies (Chandler and Trout, 1978a; 1978b; 1979), although apparently a 50th-percentile 170 lb. dummy has been most frequently used. Early FAA crash tests of a DC-7 transport used 200 lb. "95th-percentile" dummies in both pilot and co-pilot seats (Reed, 1965), while 1971 and 1972 FAA tests at NAFEC used 170 lb. and 200 lb. dummies (Daiutolo, 1972). Cessna and Lockheed crash tests of a Cessna 150 and Cessna 188 Agwagon 230 in 1971-72 used both "95th-percentile" and 50th-percentile" dummies (Wittlin and Gamon, 1976).

There appears to be no standardization of dummy weights in aircraft crash tests, and often information on what dummy is used, or its weight, is not provided in test reports, although this is a critical test condition. In general practice, dummies having weights of over 200 lbs. appear to be used extensively, although #23.785(a) specifies only the 170 lb. occupant weight.

The U.S. population of 1980 is significantly larger than that of the 1920's. To date there have been two major anthropometric studies of the U.S. general population from ages 18 to 74 years.

The HES (Health Examination Study) of the U.S. Public Health Service included data measured from October 1959 through December 1962 on 6,672 sample subjects representing the U.S. population at that time. These data found the U.S. male mean weight (50th percentile) as 168 lbs, the 5th percentile 126 lbs, and the 95th percentile 217 lbs. (Stoudt, et al., 1965). U.S. women ranged from 105 lbs (5th percentile) to 142 lbs. (50th percentile) and 199 lbs. (95th percentile). More recently the National Center for Health Statistics conducted the first Health and Nutrition Examination Survey (HANES I) between April 1971 and June 1974 on a probability sample of 13,671 persons between ages 18-74 years. This showed that the population of the 1970's was larger than that of the 1960's. Males were found to range from 129 lbs. (5th percentile) to 173 lbs. (50th percentile) to 224 lbs. (95th percentile). Females were respectively 104 lbs. (5th percentile), 137 lbs. (50th percentile) (143 lbs. mean), and 203 lbs. at the 95th percentile (Abraham, et al., 1976). Of all females 90% weigh between 104 and 199 lbs, and 90% of males between 129 and 224 lbs.

TABLE XVI

WEIGHTS OF REPRESENTATIVE U.S. POPULATIONS
COMPARED TO 170 LB FAR OCCUPANT

MALES	5th%ile	50th%ile	95th%ile
U.S. Population HANES '76	129	173	224
U.S. Population HES '62	126	168	217
Army Aviators (Churchill,et al,1971)	133	170.5	211.7
Air Force Flyers (1969)	140	172	210.8
FMVSS 208: Part 572 Dummy (1973)		164(±3)*	215
FEMALES			
U.S. Population HANES '76	104	143	203
U.S. Population HES '62	105	142	199
Army Women '77	102	132	164
Air Force Women '72	102	126	156
FMVSS 208	102		

* Includes instrumentation in head, torso and femurs.

In a study of seat design for absorbing the energy of vertical impacts, conducted by Piper Aircraft, Underhill and McCullough discussed the problem of occupant weight (1972). Since a conventional seat structure responds to force rather than acceleration, "to generate a force great enough to deform the seat structure, a 100 lb. occupant would have to undergo approximately twice the acceleration experienced by a 200 lb. occupant before the seat would begin to deflect" (p. 2). Abandoning an approach to design a seat whose energy-absorbing capacity could be adjusted to the weight of the passenger, they instead chose to use a weight of 117 lb. (53.1 kg) (22nd percentile female, 2nd percentile male)* for a design acceleration level of 25 g and a design load of 2715 lb. (1232 kg), based upon an effective mass on the seat of 80% and an acting seat weight of 15 lb. (6.8 kg). For a 25 g light aircraft seat, they found that accelerations (as well as time and velocity) would vary significantly, ranging from 36.2 g for a 75 lb (34.0 kg) occupant, 15.5 g

* Based on 1962 HES data.

for a 220 lb. (90.7 kg) occupant, and 9.7 g for a 280 lb. (127 kg) occupant. Thus occupant weight is a significant variable not only in regard to accelerations but to seat strength requirements.

Given that a 5th percentile female with a mass of 104 lbs, and a 95th percentile male (224 lbs.) are each exposed to a 9 g acceleration (F=MA), the force on the seat/restraint/anchorage system will range from 936 lbs. to 2016 lbs. - more than a two-fold difference.

From the point of view of protecting the greatest number of occupants, use of the 95th-percentile male basic weight of 224 lbs. (101.8 kg) would be current human factors design practice. That would protect the middle 90% of the population. This would be in line with current military use of the 95th percentile of the male population at risk. Continued use of the 170 lb. standard means that only 50% of the male population (and 85% of the female population) is within this range (Abraham, 1979). A 170 lb. occupant weight is close (170 vs 173 lb.) to that of the 50th percentile U.S. male. However, it is far short of todays' 95th percentile male of 224 lbs. (1976 HANES). It is also considerably less than the 225 lbs. used by NASA in transport seat design, and the Army and Air Force. For example, U.S. Air Force seat design specifies a 250 lb. (113.4 kg) design occupant weight, (MIL-S-26688); the Army 222 lbs. for pilot, 242 lbs. for troop/gunner, (Desjardins, 1980), and sets the troop/passenger 95th percentile clothed weight as 265 lbs. (MIL-STD-1290 AV 1974).

At present about 15% of U.S. females and approximately 50% of U.S. males weigh more than 170 lbs. Thus a significant portion of general aviation pilots and passengers are not protected under #23.785(a). This also appears to have been a consideration in the construction of the CAA's first articulated crash dummy by Swearingen in 1950, which weighed 215 lbs. (personal communication, J. Swearingen).

2.2.3.2 <u>Static Load Reaction. #23.785(e)</u>. Part e presently requires that the forward end of a berth installed parallel to the longitudinal axis of the aircraft be constructed to withstand the <u>static load reaction</u> of the occupant, when the occupant is subjected to forward inertia loads specified in #23.561.

A static test does not realistically simulate a crash environment and a structure designed to accomodate a static load reaction particularly at the low levels specified in #23.561, may fail when subjected to the dynamic loading of a crash impact. FAA tests comparing dynamic and static tests of aircraft seats concluded "Static testing...cannot of itself be related to crash environments, and, consequently, static test requirements do not correspond to a consistent level of crash severity" (Voyls, 1969).

2.2.3.3 Static Load Tests #23.785(e)(3). Three alternative proofs of compliance are listed for safety belt attachments to the berth under emergency landing conditions prescribed in #23.561 for lateral ultimate inertia forces of 1.5 g and upward forces of 3.0 g. No test is required for forward forces. At present compliance is allowed by structural analysis, static load tests, or a combination. There is no provision for more realistic dynamic load tests. Such tests should be considered for the reasons reported above in 2. in FAA tests.

A series of static and dynamic tests of passenger seats was conducted at the National Aviation Facilities Experimental Center (NAFEC) by the FAA which was reported in 1969 (Voyles, 1969). The static test procedures of TSO C-22 and C-39 for certifying aircraft were used, while the dynamic tests combined procedures the FAA developed with test procedures the Navy had developed in previous aircrew seat testing.

This series of tests is important because it documented basic points of comparison between static versus dynamic tests, long an issue and clearly established the requirement for dynamic seat testing. It also questioned the validity of static tests:

> "A significant difference between static and dynamic test results was found, thus warranting further investigation of the validy of utilizing static tests alone for the type certification of aircraft passenger seats for a dynamic or crash load requirement. The fact that static test results, in themselves, cannot be related to crash environments is demonstrated and cited as a definite limitation of static tests. Dynamic test results are demonstrated as having the capability of being related to crash environments and are considered to be the more meaningful in defining the behavior of seat/occupant systems when subjected to crash phenomena" (Voyls, 1969, iii).

2.2.3.4 Safety Belt (Shoulder Harness) Part 23.785(g). Section g presently requires a safety (lap) belt and shoulder harness to protect each occupant of each front seat from "serious head injury." However there is no similar requirement for rear seats. Part (2) allows either "a safety belt, or a safety belt and shoulder harness" for other than front seats. Documentation of the need for shoulder harnesses has been shown in accident studies of the 1940's, including a 1943 NRC report. In 1947 the CAA sponsored a study with Crash Injury Research of the National Research Council, which examined cases where use of the shoulder harness might have prevented head injury (483 head injuries involving 596 occupants) (CIR, 1947). It was also found that 65% of the lap belts failed in these crashes. The crashworthiness value was demonstrated in the 1952 CAA-Texas A & M AG-1 prototype aerial applicator, which reportedly utilized a 50 g seat and integral double upper torso restraint with inertial reel, designed to protect the pilot against serious injury at collision velocities up to 120.7 Km/M (65 mph) (DeHaven, 1957; Weick, 1957). Beech Aircraft Corporation pioneered the shoulder harness for light aircraft in 1948, conducting tests to 20.4 G in a series of 35 experimental dynamic tests in 1951, utilizing a 97.9 Kg (216 lb) CAA dummy "Elmer" (Beech Aircraft Corporation, 1951; n.d.; Sprinkle, 1951; Wilson, 1950). The life-saving protection in the first crash with this harness was described in a subsequent Beech publication (Miller, 1953).

Several aircraft by 1950 offered shoulder harnesses, and by 1954 the Helio Courier offered shoulder harnesses (which it still does) as standard equipment in both front and rear seats.

Upper torso restraints have been installed in light aircraft used for flight training by the Department of Aviation, the Ohio State University continuously since 1948, when double shoulder harnesses were installed in 13 Cessna 140's. Installations were with FAA field approval although, with the exception of harnesses used in Beech aircraft in 1969, no manufacturer was able to provide upper torso restraint satisfactory to the operators. In this 33 year period of use there have been two accidents in which the aircraft were destroyed, but in both cases the occupants received either no injury or only minor injuries.

Current FAA acceptable methods, techniques and practices of shoulder harness installations, effective restraint angles, and attachment methods were published in 1967 (AC 43.13-2). Following dynamic tests, additional recommendations for installation of upper torso restraint, to specific location on structures without major airframe modification, were published in an FAA report by Young in 1966. The importance of upper torso restraint in aircraft accidents (70-80% of fatalities due to head injury; 50% might have been prevented) is shown in "Restraint for Survival," a FAA documentary film of the 1964-65 aircraft cabin dynamic tests conducted at CAMI by Young upon which the recommendations were based. A functional comparison of basic restraint systems was also made by Young. He pointed out the protective advantages of a double shoulder harness system over a single diagonal upper torso belt; the importance of the seat belt anchorage (tie-down) which establishes the seat belt angle ("a greater forward location of a tie-down decreases the restraint function of a seat belt and can seriously compromise the entire restraint system"); and the significant difference in occupant kinematics at impact restrained by shoulder harness and seat (lap) belt as compared to a lap belt only.

A Beech Bonanza crash occurred in June 1961, in which the pilot received fatal head injuries and crushing injuries of the chest from hitting the control yoke, and the right front passenger received critical injuries from jackknifing into the instrument panel, attributed by the NTSB to lack of shoulder harness installation. The NTSB recommended in November 1964, to the FAA that a shoulder harness be required for each occupant on all newly certified general aviation aircraft (unless it can be demonstrated that no injurious objects are within striking radius of the head with only a seat belt). The FAA responded in March 1965, that there was not sufficient justification. In 1973 the FAA issued a Notice of Proposed Rulemaking (NPRM) "Crashworthiness for Small Airplanes," which included proposals to amend Part 23 to require the installation of shoulder harnesses.

A final rule was published 16 June 1977 (FR 30601) with an operating rule compliance date of 18 July 1978. This amends FAR Part 23 and Part 91, adding requirements for shoulder harnesses and compartment interior design for the type certification of small airplanes, and adds an operating rule requiring a shoulder harness for each front seat in certain newly manufactured small airplanes. However, this will not apply to current production aircraft and even many manufactured after that date, since the date of manufacture is the date the inspection acceptance records reflect that the airplane is complete and meets the FAA approved Type Design Data - FAR 91.33(i). In this case it required 14 years, from the original 1964 NTSB recommendation to 1978, for the FAA to require shoulder harnesses in the front seat positions of newly certified general aviation aircraft. With approximately 232,000 aircraft in the United States civil fleet, and an estimated life-time of 20 years for an aircraft, without some retroactive effort to install shoulder harnesses on operational aircraft, it may be years before the full effectiveness of such protection may be available.

2.3 Aircraft Seats and Berths #37.136 TSO-C39a (NAS 809; 1956).

Aircraft seats are subject to "minimum performance standards" which are specified in #37.136, better known as Technical Standard Order C39a, which in turn is based upon National Aircraft Standard (NAS) Specification 809 (Appendix C).

2.3.1 Development of FAA Requirements. Seat requirements were first given attention in the equipment section of the Airworthiness Requirements of Air Commerce Regulations (7A) in 1929 by the simple sentence:

> "Seats or chairs in cabin planes shall be firmly secured in place" (Part II(A)III, p.10).

The requirement then went on to describe safety belt and attachment requirements for 1000 lb loads.

In the expansion and reorganization of the Airworthiness Requirements for Aircraft (No. 7-A) effective October 1, 1934, seats were provided for in section 60 under "Special Requirements" together with safety belts:

> "(A) Seats and Safety Belts - all seats shall be provided with approved safety belts. Safety belts and their attachments shall be capable of withstanding a design load of 1000 pounds per person applied upwardly and forwardly at an angle of approximately 45° with the floor line. This load shall be carried through to the main structure. Seats or chairs, even though adjustable, in open or closed airplanes, shall be securely fastened in place whether or not the safety belt load is transmitted through the seat." (Sec. 60, 1934).

In October 1952 Section 3.390-1, published on April 14, 1951 (16FR 3291) was deleted, and a new section 3.390-1 and 3.390-2 added.

In 1953 the CAB added a supplement (-3) to Part 3 section 3.390-3 of the CAR's to provide acceptable methods for applying the prescribed loads in analysis or tests.

The Part 3 seat and berth requirements of the Civil Air Regulations (3.390, 3.390-1, 3.390-2, and 3.390-3 of some 30 years ago are reproduced in total as follows:

#3.390 Seats and berths. All seats and berths shall be of an approved type. They and their supporting structures shall be designed for an occupant weighing at least 170 pounds (190 pounds with parachute and seats intended for the acrobatic and utility categories) and for the maximum load factors corresponding with all specified flight and ground load conditions prescribed in #3.386. The provisions of paragraphs (a) through (d) of this section shall also apply:

(a) Pilot seats shall be designed for the reactions resulting from the application of pilot forces to the primary flight controls as prescribed in #3.231.

(b) All seats in the U and A categories shall be designed to accommodate passengers wearing parachutes, unless placarded in accordance with #3.74 (b).

(c) Berths shall be so designed that the forward portion is provided with a padded end-board, a canvas diaphragm, or other equivalent means, capable of withstanding the static load reaction of the occupant when subjected to the forward accelerations prescribed in #3.386. Berths shall be provided with an approved safety belt and shall be free from corners or protuberances likely to cause serious injury to a person occupying the berth during emergency conditions. Berth safety belt attachments shall withstand the critical loads resulting from all relevant flight and ground load conditions and from the emergency landing conditions of #3.386 with the exception of the forward load.

(d) In determining the strength of the attachment of the seat and berth to the structure, the accelerations prescribed in #3.386 shall be multiplied by a factor 1.33.

#3.390-1 Approved seats and berths (CAA interpretations which apply to #3.390). An approved seat or berth is one which complies with the pertinent requirements in the regulations in this subchapter as implemented by TSO-C25 "Aircraft Seats and Berths" (#514.25 of this title).
[Supp. 14, 17 F.R. 9066, Oct. 11, 1952]

#3.390-2 Proof of strength for seats and berths and their installations (CAA policies which apply to #3.390).
(a) Proof of compliance with strength and deformation requirements for seats and berths, approved as a part of the type design, and for all seat and berth installations, may be shown by one of the following methods:

(1) Structural analysis alone when the structure conforms with conventional types for which existing methods of analysis are known to be reliable.

(2) A combination of structural analysis and static load tests to limit loads.

(3) Static load tests alone when such tests are carried to ultimate loads.
[Supp. 14, 17 F.R. 9066, Oct. 11, 1952]

#3.390-3 Application of loads (CAA policies which apply to #3.390). The actual forces acting on seats, berths, and

> supporting structure in the various flight, ground and emergency landing conditions will consist of many possible combinations of forward, sideward, downward, upward, and aft loads. However, in order to simplify the structural analysis and testing of these structures, it will be permissible to assume that the critical load in each of these directions, as determined from the prescribed flight, ground, and emergency landing conditions, acts separately. If the applicant desires, selected combinations of loads may be used, provided the required strength in all specified directions is substantiated (TSO C-25, Aircraft Seats and Berths, #514.25 of this title, outlines acceptable methods for testing seats and berths). [Supp. 17, 13 F.R. 5563, Sept. 17, 1953]

During recodification in 1964 (Docket No. 4080, 29, FR 17955, December 18, 1964, as amended by Amdt. No. 23-7, 34 FR 13092, August 13, 1969) 3.390 evolved into #23.785. (This has been previously discussed in 2.2). In conjunction with the requirements of #23.785 seats (and berths) must conform to the minimum performance standards specified in the applicable Technical Standard Order (TSO).

2.3.1.1 <u>The TSO System</u>. Under section 601 of the Civil Aeronautics Act of 1938 and the delegation of authority from the Civil Aeronautics Board in #3.18, 4a.31, 4b.18, 6.18, and 7.18 of the Civil Air Regulations, the Administrator of Civil Aeronautics is authorized to adopt performance standards and specifications of materials, parts, processes, and appliances used in aircraft as he may find necessary to implement provisions of the Civil Air Regulations (subsequently the Federal Aviation Regulations). One of several methods of obtaining approval is through a Technical Standard Order (TSO).* "Since compliance with a TSO is only one method of obtaining an approval, the standards contained in the TSO are not mandatory but are only an optional way of obtaining approval for a particular article...A TSO is not a standard of general or particular applicability designed to implement or prescribe law or policy. It does not fall within the definition of "rule" contained in the Administrative Procedure Act (5 U.S.C. 551). There is no requirement that a TSO be published as a notice of proposed rule making in the <u>Federal Register</u>" (45 FR 38342, June 9, 1980).

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*Other ways are (1) under a Parts Manufacturer Approval issued under CFR 21.303; (2) in conjunction with type certification procedures for a product, including approvals granted by a Supplemental Type Certificate; and (3) in any other manner approved by the Administrator.

A new TSO Revision Program was adopted June 2, 1980, effective September 9, 1980 to facilitate the issuance of TSO's. This eliminates TSO's from the regulations (previously published as Subpart B of 14 CFR Part 37) in accordance with Exectuive Order 12044, Improving Government Regulations, to expedite TSO issuance and amendment (45 FR 38342, June 9, 1980; 44 FR 56370, October 1, 1979). Future TSO's will make use of and reference "voluntary standards" and "industry standards" as defined by the Office of Management and Budget (OMB)(45 FR 4326, January 17, 1980).

The Technical Standard Order system was originally adopted to carry out the delegated authority, established in 1938, and provided for CAA (FAA) -industry cooperation in the development of the performance standards "and a form of self-regulation by industry in demonstrating compliance with these standards." This is found in Part 514 of the Regulations of the Administrator, and all current TSO's are listed in Part 37 of 14 Code of Federal Regulations. The manufacturer obtains a TSO authorization by submitting an application and various supporting documents to the Chief, Engineering and Manufacturing Branch, Flight Standards Division, of the region in which the manufacturer is located. The procedure is described in detail in Part 37.5 of the FAR's, as well as design changes, approval for deviations, record requirements, FAA inspection, and reporting of failures, malfunctions and defects (required after January 3, 1971). At present (14 CFR 1980) there are 86 separate Technical Standard Orders.

The FAA found 47 of the 86 current TSO's obsolete in a 1971 review (Waterman, 1972, p.2).

General aviation (normal-utility, Type II) aircraft covered in Part 37.136 (TSO-C39a), for "minimum performance specifications," were covered by NAS 806 after 1950, and NAS 809 after 1956. Prior to March 5, 1952 U.S. Department of Commerce Regulations of the Administrator (Civil Aeronautics Administration) Part 514, Subpart B - Minimum Performance Standards apply to Type I air transport seats for which a type certificate application was made. Part 514.35 aircraft seats and berths (Type I transport, 6 g forward load - TSO-C25a references in addition the standards of National Aircraft Standard (NAS) specification 806 (revised January 1, 1956) effective for aircraft manufactured after January 14, 1957 (Appendix B).

NAS 806, approved April 1, 1950, included seat requirements for Type II (normal-utility) general aviation aircraft. Based upon an occupant weight of 190 lbs (170 lbs for Type I) the minimum loads were specified as follows. For comparison, the air transport requirements (which were less stringent) are also listed:

Force Direction	General Aviation (normal-utility) Type II	Air Transport Type I
Forward	1710 lbs. (9.0g)	1020 lbs. (6.0g)
Sideward	285 lbs. (1.5g)	255 lbs. (1.5g)
Upward	570 lbs. (3.0g)	340 lbs. (2.0g)
Downward	1254 lbs. (6.6g)	765 lbs. (4.5g)

The forward loads corresponded to the emergency conditions prescribed in the Civil Air Regulations. Seats intended for multiple occupancy were required to have the loads increased accordingly. Ultimate loads are 1.5 times the limit loads. (Note that at this time air transport seats were only required to meet a 6.0g forward load).

Tests required that the seats support the limit loads without permanent deformation, the deformation not interfere with safe operation of the aircraft, and that the structure be capable of supporting the ultimate loads specified without failure for at least 3 seconds. Testing in compliance allowed use of a block, or frame, or dummy, restrained in the seat by belts attached to fittings.

2.3.2 Current Requirement (TSO-C39a/NAS 809). The minimum performance standards for seats and berths to be installed in certified general aviation aircraft is currently provided in TSO-C39a for Type II - normal and utility category.

#37.136 Aircraft seats and berths - TSO-C39a.

(a) Applicability - (1) Minimum performance standards. (i) This technical standard order prescribes the minimum performance standards that aircraft seats and berths of the following types must meet in order to be identified with the applicable TSO marking:

Type I - Transport (9g forward load).
Type II - Normal and Utility.
Type III - Acrobatic.
Type IV - Rotorcraft.

(ii) New models of seats and berths that are to be so identified, and that are manufactured on or after May 1, 1972, must meet the standards set forth in National Aircraft Standard (NAS) Specification 809, dated January 1, 1956, with the exceptions covered in subparagraph (2) of this paragraph. NAS 809 is incorporated by reference herein in accordance with 5 U.S.C. 552(a)(1) and #37.23 and is available as indicated in #37.23. Additionally, NAS 809 may be examined at any FAA regional office of the Chief, Engineering and Manufacturing Branch (or in the case of the Western Region, the Chief, Aircraft Engineering Division), and may be obtained from the National Standards Association, 1321 14th Street NW., Washington, DC 20005, at a cost of three (3) dollars.

(2) Exceptions. (i) The sideward loads as specified in 4.1.2. Table I need not exceed the requirements of the applicable Federal Aviation Regulations.

(ii) In lieu of compliance with paragraphs 2.1, 3.12, and 4.32 of NAS 809, materials in Type I seats and berths must comply with the fire protection provisions of #25.853(b) of this chapter.

(b) Marking. The weight required in #37.7 need not be included.

(c) Previous approval. Seats and berths approved prior to May 1, 1972, may continue to be manufactured under the provisions of their original approval.
[Amdt. 37-32, 37 F.R. 3973, Feb. 24, 1972](14CFR23, 1980).

In turn C39a refers to National Aircraft Standards Specification 809 for definition of minimum performance and safety standards for seats and berths. Current applicable requirements for design strength (Type II is general aviation-normal/utility):

4.1.2 Strength: All seats and berths intended for single occupancy shall be designed for the ultimate loads specified in Table I. The loads shall be considered as acting separately and shall be based on a passenger weight of 170 pounds for Types I and IV seats and 190 pounds (includes parachute) for Types II and III seats. The weight of the seat or berth times the approximate "g" value shall be added to the ultimate loads specified in Table I. For seats intended for multiple occupancy the loads must be increased accordingly. Ultimate loads are 1.5 times the limit loads.

Table I(1)

Load Direction	Type I	Type II**	Type III	Type IV
Forward	1530 lbs.(9.0g)	1710 lbs.(9.0g)	1710 lbs.(9.0g)	680 lbs.(4.0g)
Sideward***	510 lbs.(3.0g)	570 lbs.(3.0g)	570 lbs.(3.0g)	340 lbs.(2.0g)
Upward	340 lbs.(3.0g)	570 lbs.(3.0g)	855 lbs.(4.5g)	255 lbs.(1.5g)
Downward	1020 lbs.(6.0g)*	1330 lbs.(7.0g)*	1710 lbs.(9.0g)	680 lbs.(4.0g)

* The reason for the down loads exceeding those prescribed in the emergency landing conditions of the applicable Civil Air Regulations is to provide for the reduced weight gust-load-factor or special landing requirements which, in some cases, may be greater than the emergency landing loads.

** Civil Air Regulations require use of parachute in Utility Category Aircraft operated in acrobatic flight.

There are additional requirements related to pilot seats and back rest loads.

4.1.2.1 Pilot and Co-Pilot Seat Loads: In addition to the loads specified in Table I above, pilot and co-pilot seats shall be designed to withstand the following rearward loads applied 8 inches above the intersection of the seat back and seat bottom to provide for the application of pilot forces to the flight controls:

Type I seats	450 pounds
Type II and III seats	300 pounds for aircraft weighing 5000 pounds or under, and 450 pounds for aircraft weighing over 5000 pounds.
Type IV seats	195 pounds

4.1.2.2 Back Rest Loads: The back rest of rearward facing seats, when in the most vertical position, shall withstand the following airplane forward loads applied separately:

Type I Seats - 1530 pounds distributed over the seat back with the load C.G. located 10.5 inches up from the base of the seat back as described in the note in Section 4.3.1.

Type II and III Seats - 1710 pounds distributed over the seat back with the load C.G. located 10.5 inches up from the base of the seat back as described in the note in Section 4.3.1.

(1) Type I refers to air carrier aircraft. Type II refers to normal-utility (general aviation) aircraft. Type III is acrobatic and Type IV is rotorcraft.

Other requirements for castings, strength, attachments, and qualification testing are as follows:

4.1.2.3 Casting Factors: If castings are used in the construction of the seat the castings shall have a factor of safety of 2.0 where only visual inspection is employed except that it need not exceed 1.25 with respect to bearing stresses. A safety factor of 1.25 is satisfactory if the casting is substantiated by testing at least three samples and if visual and radiographic inspection is employed on all production castings to assure that they are at least equivalent to the test specimens. The samples shall withstand the ultimate loads multiplied by the 1.25 factor and the limit loads multiplied by the factor of 1.15. These loads should be applied separately. Die castings shall not be used in the primary structure of the seat without 100% radiographic inspection. Castings factors other than those specified above shall be acceptable if they are found to be appropriately related to tests and to inspection procedures.

4.1.2.4 Ultimate Load Strength: The seat or berth in any of its adjustable positions, when installed facing in a specified direction or directions and when occupied by maximum number of occupants, shall be capable of withstanding ultimate loads without failure for at least three (3) seconds.

4.1.2.5 Limit Load Strength: The seat or berth in any of its adjustable positions, when installed facing in a specified direction or directions and when occupied by maximum number of occupants, shall be capable of withstanding ultimate loads without failure for at least three (3) seconds.

4.1.3 Attachments: For Types I, II and III seats and berths the strength of the seat or berth attachments to the structure and safety belt or shoulder harness attachments to seat or structure, shall be 1.33 times the ultimate loads specified in Table I except that the down load need not be considered for the safety belt or shoulder harness attachments. When anchorages for safety belts are provided, they should be of a type which will permit self-aligning of the belt or fitting. For berth belt attachments, the factor shall be 1.15.

4.1.4 Projections: The surfaces of the seat shall be free from sharp edges or projections which may chafe the safety belt or shoulder harness webbing. Projections, sharp corners, and other hazardous features, against which the seat occupant may be thrown during a crash, shall be avoided insofar as possible. Any unavoidable features of this nature shall be padded to prevent serious head, neck or chest injury to the occupants.

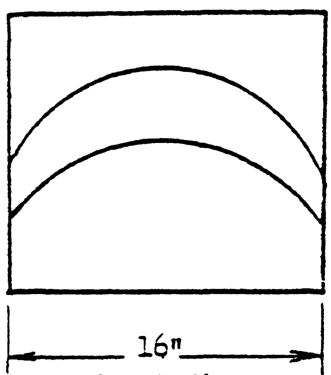
4.2 Marking: Each seat or berth shall be legibly and permanently marked with the following information:

Manufacturer's Name
Model Number or Name
Seat and Facing Direction (e.g., forward, aft, sideward, swivel)
Serial Number or Date of Manufacture
National Aircraft Standard Number (NAS_____)

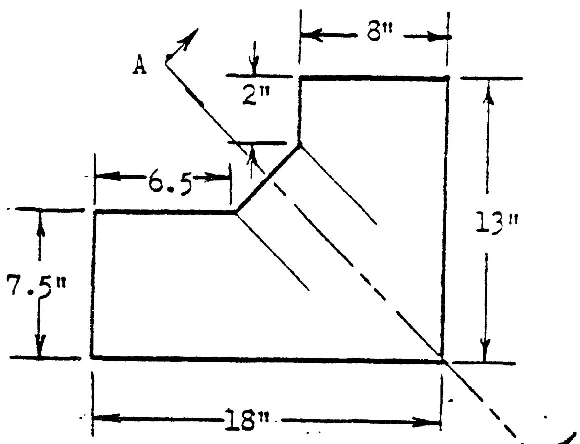
	Forward Facing Seat	Sideward Facing Seat	Rearward Facing Seat
Down Load	Evenly over seat bottom	Evenly over seat bottom	Evenly over seat bottom
Side* Load	10.5" up from base of block & about 8.5" forward from back of block.	10.5" up from base of block & about 8.5" forward from back of block.	10.5" up from base of block & about 8.5" forward from back of block.
Up* Load	"	"	"
Forward Load	"	"	Applied as specified in 4.1.2.2

*Note: These dimensions for the location of load application assume that the seat and back cushion are in place and that the seat cushion is compressed 2 inches. If the cushions are removed for the test or if the seat cushion compression varies from 2 inches, the location for applying the loads shall be changed accordingly.

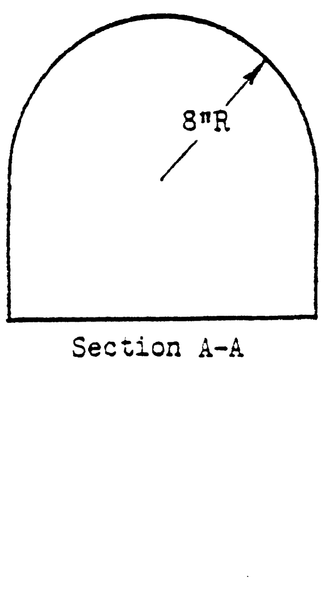
This simplified body block is satisfactory for test purposes. It may be refined or modified if desired; however, the application of all test loads should be modified accordingly if necessary.



Front View



Side View



Section A-A

4.3 Qualification Tests: Tests shall be conducted as necessary to demonstrate:

(a) that the seats or berths are capable of supporting the limit loads without detrimental permanent deformation;

(b) that, at all loads up to limit loads, the deformation shall be such as not to interfere with the safe operation of the aircraft:

(c) that the structure is capable of supporting, without failure for at least 3 seconds, the ultimate loads specified herein when applied separately.

If it can be shown that failure of an arm rest on a seat assembly does not reduce the degree of safety afforded the occupant, such failure will not be cause for rejection.

4.3.1 Detail Qualification Test Requirements: The seat or berth shall be loaded in tests such that the loads imposed on the seat or berth by the occupant(s) in conjunction with the safety belt or belts and their attachments are accurately simulated by means of a block or frame or dummy which is restrained in the seat or berth by the belt or belts attached to their fittings. The tests may be conducted in a jig simulating installation conditions. The ultimate loads, when applied separately, will serve to simulate the loads imposed by the occupant.

4.3.1.1 When a seat or berth is to be installed or adjusts to face in other than the forward direction, sufficient tests shall be made to sûbstantiate the seat strength for all intended positions.

4.3.1.2 When testing for a particular load condition of a vertically or horizontally adjustable seat, the most critical seat position associated with that load shall be used for the test.

4.3.1.3 Where the safety belt or belts or harness are not attached to the seat or berth structure, the seat or berth shall be tested for the loads which would be imposed on such installation.

4.3.2 Flame-Resistance Test of Seat Covers: Specimens of the seat covering and upholstery shall meet the applicable tests specified in 3.1.2.

(Specification - Aircraft Seats and Berths, NAS 809, approved 1 January 1956) (Appendix C).

2.3.3 Discussion and Analysis. The present FAA requirements for seats and seat tests were last revised in 1956 (when NAS 809 replaced NAS 806, dating from 1950) as referenced in TSO-C39a. Considering the progress of the state-of-the-art in the generation that has elapsed since then, Congressman Goldwater's statement in recent congressional hearings on aircraft (airline) passenger seat structural design seems pertinent: "You would think in 28 years we would know more about it. You would think that the state-of-the-art would have advanced and that knowledge would have been acquired in those years to dictate superior design to what was created in the 1950's"(House of Representatives, June 5, 1980, p.433).

On August 12, 1969 FAA published a Notice of Proposed Rulemaking which included a proposal to increase certain aircraft seat strength requirements. In 1970 FAA initiated research to develop stronger, more energy-absorbing aircraft seats. In June 1970 the FAA initiated development of standards for a new seat TSO. Originally the internal studies were focused on the need for energy-absorbing seat design criteria for transport category airplanes (FAR 25). In April 1976 the work was "revalidated," and in February 1977 the scope was revised to include a seat TSO for all categories of aircraft including general aviation (normal/utility). By August 1978 draft standards for a new seat TSO were completed, after 8 years of effort (Ross, 1978). This work reviewed previous seat testing and criteria, accident injury data, and recommended procedures. Since "there was no evidence that the current standards are inadequate" (GAO, 1980), this statement is in conflict with earlier FAA test reports which reported a number of inadequacies and need to update the standards. Some of these will be noted in the following brief discussion.

The adequacy of minimum strength requirements for seats, obtained by direct comparison to the serviceable accident loading, was found to be "inadequate for 17% of accidents" in the forward direction (23.561; TSO-C39,9g), "inadequate for 36% to 58% of accidents" in the downward direction (FAR 23 has no requirement), or using TSO-C39 requirement for 7.0g, "inadequate for 34% of accidents." For sideward impacts (FAR 23, 1.5g; TSO-C39, 3.0g) and for upward impacts (FAR 23, 3.0g; TSO-C39, 3.9g) insufficient crash test data was located to provide an estimate (Ross, 1967, p.14).

A side load requirement of only 1.5 g offers relatively little protection. In 1967 an FAA transmittal stated "it is felt that the 1.5 g side load requirement is inadequate to protect the pilot and passengers in modern aircraft" (Letter, Chief, Engineering and Manufacturing Division, to Chief, Flight Standards Division, 2/8/67; attachment 1, Congressional Hearings, 1980, p.121).

The side load requirements had been reviewed as a result of "a number of accidents involving Piper PA-28 and PA-32 series aircraft wherein the pilot and/or passengers have been seriously or fatally injured as a result of failure of the seats or seat belt fittings in a sideward direction" (Congressional Hearings, September 1980, p.121). The FAA retested similar seats in 1966 to the requirements of CAR 3.390 (under which they were certified), presently #23.785, following the test procedures of TSO-C39. No evidence of failure was found in any of the static tests.

In 1967 an FAA engineering study resulted in the recommendation that 23.561 be revised to require that the seat be subjected to a sideward ultimate inertia load factor of 3.0g. It also recommended revising 23.561 and 23.785 to require that loads be "considered in all practical combinations" as well as separately (Ross, 1967).

An FAA study completed in February 1969 included the conclusion that with improved test design requirements the probability for seat failure in small airplane accidents could be decreased from about 97 percent to about 80 percent (the severity of some impact conditions preclude a 100% seat survival). For FAR 23 general aviation aircraft this report concluded that the following seat design load factors should be applied:

Seat Design Load Factors for 17% Improved Survival	
Forward	9.0 g
Sideward	3.0 g
Downward	7.5 g
Upward	5.5 g

(Ross, 1969)

This study conducted a survey of maximum test (static) loads applied to seats by various seat manufacturers and reviewed data from 34 small airplane seats. These data from the manufacturers suggested approximate ultimate seat capabilities for general aviation in the following ranges at that time.

Forward	7.9 g - 12.7 g
Sideward	1.8 g - 4.2 g
Downward	6.1 g - 10.6 g
Upward	2.6 g - 4.5 g

Test criteria developed and used by FAA over the past decade in some dynamic seat tests include the following design impulse data (Madayag, unpublished). These data were "suggested as arbitrary initial test impulse criteria until realistic experimental crash data from component or full scale testing of general aviation airplanes are available" (<u>FAA Summary of Crashworthiness Information for Small Airplanes, 1973</u>).

Design Pulses for Dynamic Seat Testing

Direction	Peak G	Pulse Time (secs)*	Pulse Shape
Longitudinal	20	0.15 ± 0.04	Triangular
Vertical	25	0.85 ± 0.03	Triangular
Lateral	10	0.125 ± 0.05	Triangular

* The rise time to Peak G may vary between ± 0.2 T from T/2. (Madayag, unpubl.)

In 1964 a general dynamics study conducted for the FAA on <u>Crashworthy Design Principles</u> presented a number of seat design configurations to improve ductile collapse characteristics (Green, et al, 1964).

(In 1956 the National Advisory Committee for Aeronautics had published a study on principles of seat design for crashworthiness that was based upon previous dynamic test crash studies of light aircraft, experimental tests, and mathematical analysis (Pinkel and Rosenburg, 1956). The experimental designed seat tests used a 200 lb dummy and reduced 40 g (longitudinal) impacts to a uniform 20 g on the dummy's hips. The FAA did no follow-up tests or evaluation.)

The U.S. Army Crash Survival Design Guide recommended in 1967 the following static non-yielding strength factors for seats (note that the Army used 200 lb aviators plus weight of seat in calculations, versus 170 lbs required by FAA).

	Forward	Down	Up	Side	Aft
Crew	25g	17g	8g	9g	12g
Passenger	20g	17g	8g	9g	12g

Dynamic test requirements for U.S. Army aircraft seats were specified under two test conditions. For cockpit seats 60 fps velocity change, 40 g triangular pulse for 0.093 sec, with seat 45 degrees to the horizontal, and 20 degrees yaw. Cabin seats would be dynamically tested under the same conditions except using a 32 g pulse at 0.120 sec time duration (Turnbow, et al., 1967).

A series of static and dynamic tests of passenger seats was conducted at the National Aviation Facilities Experimental Center (NAFEC) by the FAA which was reported in 1969 (Voyls, 1969). The static test procedures of TSO-C-22 and C-39 for certifying aircraft were used, while the dynamic tests combined procedures the FAA developed with test procedures the Navy had developed in previous aircrew seats testing.

This series of tests is important because it documented basic points of comparison between static versus dynamic tests, long an issue, and clearly established the requirement for dynamic seat testing, questioned the validity of static tests:

> "A significant difference between static and dynamic test results was found, thus warranting further investigation of the validity of utilizing static tests alone for the type certification of aircraft passenger seats for a dynamic or crash load requirement. The fact that static test results, in themselves, cannot be related to crash environments is demonstrated and cited as a definite limitation of static tests. Dynamic test results are demonstrated as having the capability of being related to crash environments and are considered to be the more meaningful in defining the behavior of seat/occupant systems when subjected to crash phenomena" (Voyls, 1969, iii).

The need for updating general aviation seats was recognized as an early priority by the SAE's A-23 Committee on General Aviation Safety (Cockpit Standardization) in the late 1960's. Discussions of this committee led in October 1975 to approval of Aerospace Recommended Practice, ARP 1318, (General Aviation Seat Design), intended to provide design criteria for pilot and passenger seats for general aviation aircraft (Part 23). In its preparation "consideration was given to the requirements of the Federal Aviation Regulations, the results of numerous accident investigations and research programs and the recommendations of aircraft operators and manufacturers." Although this 1975 ARP was approved by the committee after a number of years of discussion, it was disapproved by the Aerospace Council and apparently remains in limbo, with the committee subsequently dissolved under industry pressure. However, the guidelines proposed currently represent the state-of-the-art relative to recommended general aviation crash survivability. Note that it was proposed that pilot and passenger seats for general aviation aircraft should be designed to withstand a dynamic ultimate load factor without separation, failure of 16 g's upward and 15 g's downward. Present FAR's (23.561) require design to vertical ultimate inertia forces of only 3.0 g (normal and utility categories). A copy of the entire ARP is provided in Appendix A.

A joint NASA-FAA crashworthiness program is under way at Langley Research Center in which part of the analytical and experimental program include evaluating airframe, seat, and restraint-system concepts for mitigating crash loads imposed on occupants of general aviation aircraft. To date the seat test program is uncompleted and final results may not be available for several years.

Initiative was shown by Piper Aircraft Company in designing and testing a new front seat with improved energy absorption capabilities for the Cherokee (PA-28) aircraft. This program began in April 1971 and included dynamic tests conducted by CAMI in November 1971 (Chandler and Trout, 1978). Particular attention was given to providing the occupant protection for high vertical velocities, since accidents may involve large vertical loads. The design goal for the seat structure was to attenuate "a downward velocity component of 1500 ft/min (7.62 m/s) or more in a distance of about 8 inches (20.3 cm) without exceeding acceptable g loads," and result in a lightweight, economical, energy-absorbing seat (Underhill and McCullough, 1972).

More recently, a private effort to improve general aviation seat crash protection has been initiated by the Mission Aviation Crashworthiness Committee, chaired by Paul Duffy, and particularly by Wycliffe Jungle Aviation and Radio Service (JAARS) of Wax Haw, North Carolina. Operating a large number of light aircraft all over the world under hazardous conditions, this missionary group has not been willing to wait further for the FAA to get around to regulating necessary improvements. They have designed and fabricated energy absorbing seats (for front and rear) in their own shops and recently dynamically tested one installed in a Piper Aztec crash tested by NASA Langley.

2.4 Safety Belts (Part 34.132) TSO-C22f

The minimum performance standards that safety belts must meet are specified in technical standard order (TSO) C-22f. New models of safety belts manufactured after May 1, 1972, also must meet standards set forth in National Aircraft Standards (NAS) Specification 802 (revised May 15, 1950), with important exceptions as will be discussed.

2.4.1 Development of FAA Requirement. In the original Air Commerce Regulations effective December 13, 1926 seat belts were specified for open cockpit airplanes but no strength requirements were listed. This is not unexpected. Considering the history of the development of the regulations,the initial requirements were comparatively brief and simple. However, during the following 10 months there was considerable engineering discussion and a number of additional details and modifications were prepared which were incorporated into the expanded Airworthiness Requirements of Air Commerce Regulations (no.7A) of 1929. The first strength requirement was specified at that time:

> "The strength of the belt and its anchorage shall be sufficient to withstand a pull of 850 pounds applied to the belt in a manner simulating the loading applied by a person weighing 170 pounds with a load factor of 5" (sec.10, p. 43, 1929).

Five years later, the 1934 Airworthiness Requirements for Aircraft as amended October 1, 1934, increased the strength requirements to 1,000 lbs.:

> "Safety belts and their attachments shall be capable of withstanding a design load of 1,000 pounds per person applied upwardly and forwardly at an angle of approximately 45° with the floor line" (Sec.60(A), 1934).

This requirement also specified for the first time how the load was to be applied.

In May 1946 the Department of Commerce issued interpretations to CAR 03 which allowed 1000 pound belts on general aviation aircraft on which original airworthiness certificates were obtained prior to January 1, 1947. This was done despite the requirements of #03.3811 which specified 1600 lb. belts for normal-utility aircraft (passenger weight of 160 lbs x resultant acceleraion of 9.6 G = 1632 lbs). The instructions were stated as follows:

03.38221 Safety Belt or Harness Provisions. This requirement specifies that belts complying with the emergency conditions of 03.3811 shall be installed. The emergency conditions of 03.3811 at present specify resultant accelerations of about 9.6 g and 10.2 g for normal-utility and aerobatic category airplanes respectively. Considering a passenger weight of 170 pounds, these accelerations result in a required belt strength of about 1600 pounds and 1700 pounds respectively.

In view of the fact that the C-46 was certified under mixed requirements (CAR 02.00) with 1000 pound belts installed, and that the DC-4 was certified under mixed requirements (new CAR 04.00) with 1000 pound belts installed, it appears indefensible at this time to require manufacturers of airplanes designed under 03 requirements to install belts meeting the above loading conditions.

Although it is possible to buy belts designed for two people (2000 pound strength) and have them cut to the necessary length for one person, these belts are very difficult to obtain, due to critical shortages of material. In view of the above, it will be considered satisfactory to incorporate 1000 pound belts in CAR 03 airplanes under the provisions of 03.00. However all CAR 03 airplanes on which original airworthiness certificates are obtained on or after January 1, 1947, shall have belts meeting the requirements of 03.3822). (The requirements will not be made retroactive on January 1, 1947, to airplanes which at that time have already received original airworthiness certificates). (Dept. of Commerce CAR 03.2 and CAR 03.3 Revisions and Interpretations. Memo to Regional Administrators, First, Third, Fifth and Sixth Regions. Civil Aeronautics Administration Washington, D.C. May 29, 1946).

2.4.2 Current Requirement (50% of NAS 802, 1950). Current FAA belt strength standards for all categories of civil aircraft are 1500 lb in tension load and 1.9 times rated strength (loop load strength of 2850 lbs) in a static test. The requirement is detailed as follows:

37.132 Safety Belts - TSO-C22f.

(a) Applicability-(1) Minimum performance standards. This technical standard order prescribes the minimum performance standards that safety belts must meet in order to identified with the applicable TSO marking. New models of safety belts that are to be so identified and that are manufactured on or after May 1, 1972, must meet the standards set forth in National Aircraft Standards (NAS) Specification 802 revised May 15, 1950, with the exceptions covered in paragraph (a)(2) of this section. NAS 802 is incorporated by reference herein in accordance with 5 U.S.C 552(a)(1) and # 37.23 and is available as indicated in # 37.23. Additionally, NAS 802 may be examined at any FAA regional office of the Chief, Engineering and Manufacturing Branch (or in the case of the Western Region, the Chief; Aircraft Engineering Division), and may be obtained from the National Standards Association, 1321 14th Street NW., Washington, DC 20005, at a cost of three (3) dollars. Belts approved under prior issuances of this section amy continue to be manufactured under the earlier provisions.

(2) Exceptions. (i) For the purpose of this section the strengths specified in section 4.1.1 of NAS 802 shall be 1,500 pounds and 3,000 pounds instead of 3,000 pounds and 6,000 pounds.

(ii) In complying with section 4.3.2.2 of NAS 802, the curved portion of the test form may be padded with no more than one inch of medium density sponge rubber, or equivalent, and covered with suitable fabric to simulate a person's body and clothing.

(iii) Synthetic material webbing which is not subject to loss of strength due to the influence of humidity, temperature variations, etc., need not be subjected to the first six-month retesting period specified in section 3.1.2 of NAS 802. Retesting in succeeding six-month periods will be necessary if the belt manufacturer is unable to ascertain by means of textile data available to him that the webbing is unaffected by ambient storage conditions for the period of time involved.

(iv) In complying with section 4.2.3 of NAS 802, the two-inch webbing width shall be considered a nominal width. Thus, after considering all manufacturing processes as are necessary such as weaving, dyeing, mildew proofing, flame resistance and abrasion treatments, a webbing width of 1-15/16 inches ± 1/16 inch shall be acceptable.

(v) The slots or openings in the hardware for attachment of the safety belt webbing shall not be less than two inches (14 CFR23 1980, p.621).

(vi) In lieu of compliance with paragraphs 1.1.1, 3.1.4, and 4.3.1.1 of NAS 802, the webbing and all other materials used in the belt assembly must comply with the fire protection provisions of #25.853 (b-2) of this chapter.

(b) Marking. (1) Each half of each safety belt shall be marked in accordance with # 37.7 except that the weight required by paragraph (d)(3) of #37.7 need not be shown and the rated strength of the safety belt assembly shall be shown, and

(2) In liew of the marking requirement in paragraph (d)(4) of #37.7 the date of manufacture is required. The serial number may also be marked on the belt but not in lieu of the date of manufacture.

(c) Data requirements. (1) The manufacturer shall maintain a current file on complete design data.

(2) The manufacturer shall maintain a current file on complete data describing the inspection and test procedures applicable to his product. (See paragraph (d) of this section.)

(3) One copy of the following shall be furnished to the Chief, Engineering and Manufacturing Branch, Flight Standards Division, Federal Aviation Administration, in the region in which the manufacturer is located: A drawing of the complete belt assembly

showing the manufacturer's part numbers together with a notation indicating the minimum webbing strength specified by the belt manufacturer. If the test belts were tested to destruction, the average strength of the belt assembly should also be indicated.

(d) Quality control. Each safety belt shall be produced under a quality control system, established by the manufacturer, which will assure that each belt is in conformity with the requirements of this standard. This system shall be described in the data required under paragraph (c)(2) of this section. The Administrator shall be permitted to make such inspections and tests at the manufacturer's facility as may be necessary to determine compliance with the requirements of this standard.

[Doc.No. 5065, 29 FR 15317, Nov. 17, 1964, as amended by Amdt. 37-3, 30 FR 13210, Oct. 16, 1965; Doc. No. 8084, 32 FR 5769, Apr. 11, 1967; Amdt. 37-32, 37 FR 3973, Feb. 24, 1972] (14CFR23 1980, p.622)

Seat belts manufactured on or after May 1, 1972 must meet National Aircraft Standards (NAS) specification 802 revised May 15, 1950 except that the rated strengths specified for the belt assembly (41.1.1. of NAS 802) shall be 1,500 pounds (single occupancy) and 3,000 lbs. (double occupancy) instead of 3,000 and 6,000 lbs. as specified in the National Aircraft Standard. Belt width shall not be less than 2 inches. NAS 802 defines the minimum performance and safety standards for aircraft safety belts to be installed in certified aircraft and covers all types of safety belts for civil aircraft use. It reflects the judgement of the National Aircraft Standards Committee of the Aircraft Industries Association of America. The latest revision is dated 15 May 1950 (Appendix D).

2.4.3 Discussion and Analysis. Since 1929, there have been only two updatings of the original 850 lb. seat belt strength requirement for civil aircraft. U.S. civil aircraft seat belt strength is promulgated on standards (NAS 802) last revised 32 years ago (1950). The FAA in TSO-C22f allows an exception in seat belt assembly strength, reducing the 1950 standard (4.1.1) by 50%. Current FAA belt strength standards for all categories of civil aircraft are 1500 lb. in tension load and 1.9 times rated strength (loop load strength of 2850 lbs.) in a static test.

The accident record, however, has shown that these minimums have needed to be updated since the original National Research Council crash injury studies of the 1940's. Virtually every report from 1943 from these studies emphasized belt (as well as anchorage, and seat) failures and the need for stronger belts (DeHaven, 1943, p.27). In 1945 NRC report 440 recommended an increase in belt assemblies strength "to 2000-2500 lbs" (DeHaven, 1945, p.26).

The National Research Council Crash Injury Research annual report for the period July 1946 to June 1947 reported that the (1000 lb) safety belt failed in 65% of the cases (p.5). In reporting for the period 1948-1949 CIR it was reported that "in 80% of the cases where safety belt installations failed the breakage occurred in the webbing" (CIR report, 12 Aug. 1949, p.5). In the 1949 report it was reported that the CIR data was being used by the CAA to set up future requirements for 3000 lb (4500 lb. loop) strength belts. This was still being recommended as a result of accident findings in 1954: "Use forward load factors equal to the static loop holding capacity of the safety belt - a minimum of 3000 pounds, or 17-1/2 g, for each person" (Hasbrook, 1952, p.31).

Crash Injury Research had clearly found in accident research conducted during the 1940's and 1950's that 1000 lb and 1500 lb safety belts offered inadequate protection. Pearson reported 220 cases of belt failure (22.1% of all occupants) in 1025 crashes studied from 1942 to 1952 (1961, p.13,14). Comparing the effect of belt failure in injuries, DeHaven et al. compared 221 survivors whose belts failed with 722 survivors whose belts remained intact. The safety belts involved were primarily those with a loop-holding capacity of 2000 lbs (i.e. 1000 lbs in straight tension). They found that 39.8% of those survivors whose belts had failed sustain dangerous-to-life head and body injuries (1953, pp. 16,17).

These accident investigation findings were supported by crash tests of 3 general aviation aircraft conducted by NACA reported in 1953. NACA concluded that "belts should be capable of withstanding higher breaking loads than those presently in use" (p.23). (They found that a "standard lap belt failed at 4400 lbs in a 47 mph crash (147% of breaking force of an identical belt which failed at 3020 lbs under static loading (p.16).

In 1964 the FAA attempted to determine the service life of seat belt webbing and relationship between age, environmental conditions and strength.

Of 399 seat belts tested 42 percent failed to meet the minimum strength requirements (TSO C22), of the cotton webbing belts 86 percent failed the minimum standards. Among recommendations the Aircraft Development Service of the FAA made at that time was that cotton webbing be disallowed, the minimum breaking strength requirements for both the webbing and complete seat belt assembly be raised, and that a dynamic qualification test for belt assemblies be required (Stetson, C.H., et al., 1964).

More recent analysis of belt failures in aircraft accident investigation have indicated similar deficencies have continued. The Department of Civil Aviation, Commonwealth of Australia, has reported a belt or attachment failure rate of 18% in fatal and serious-injury accidents occurring during 1969 and 1970 in general aviation accidents (mainly involving U.S. manufactured aircraft)(1973).

During the 1970's there has been increasing use of stronger belts by the general aviation manufacturers as automotive webbing manufactured to Federal Motor Vehicle Safety Standards FMVSS 209 has been (available for some 20 years) readily in supply. However, although 5500 lb. webbing has been commonly supplied to the manufacturers, and 6000 lb. belts have been recommended by at least one supplier (FAA Public Hearing, 1980) most general aviation belts are still rated at 1500 lbs. This is primarily due to limitations of the hardware (buckle), although some is rated at 3000 lbs. Military restraints and automotive restraints, from the same suppliers, are rated at 6000 lb. (Type I) and above.

A recommendation that restraint systems in general aviation aircraft should be designed for a forward load of 25 G's applied 20 degrees to either side of the airplanes longitudinal axis; an upward load of 15 G; a downward load of 15 G; and an aft load of 5 G, was proposed in ARP 1226 (Appendix H) "Occupant Restraint Systems (Active) for General Aviation Aircraft" by SAE committee A-23 in 1975, but not approved by the SAE Aerospace Council, under industry pressure. For example, one general aviation manufacturer, in a 1971 inter-office communication, commented "This document has been carefully reviewed..... For the SAE to come out with a new group of recommended practices will certainly place us in a rather embarrassing or awkward situation with respect to the minimum

FAA standards that we currently design to; these new standards are far above anything the FAA now requires." However, the 25 G belts (4250 lb. webbing for standard 170 lb. occupant) recommended practice was still less than the production 6000 lb. webbing belts required at that time for Type I automotive restraints (FMVSS 209), and being mass produced for nearly 10 million automotive vehicles per year.

In view of the accident and crash test data over the past 40 years documenting the need for stronger restraint systems, TSO-C22f should long ago have been upgraded to be at least comparable to the webbing strength protection provided in automobiles. The restraint-seat system must be considered as a whole, since restraint is no stronger than its weakest link - in this case the hardware (buckle and attachments), which should be upgraded as well.

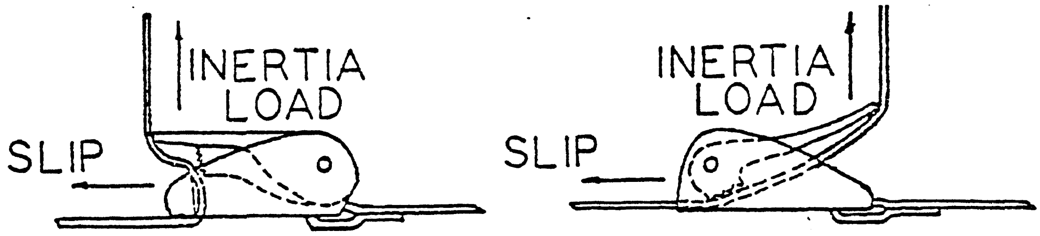
2.5 Safety Belts and Harnesses. #23.1413

2.5.1 Development of FAA Requirement. This has been previously reviewed in Section 2.1 and 2.3, with the exception of #23.1413(c). This is effective December 4, 1981 and states "Each safety belt must be equipped with a metal to metal device." Since this sentence has required 25 years to become a part of the standards, from the time it was first recommended as a safety requirement, the background of this deserves a brief review. Metal-to-metal seat belts have been standard in U.S. automobiles since about 1961. (While the first seat belts apparently were installed on a production basis by Ford, Chrysler and American Motors in 1955 (1956 model year) of metal-to-webbing type construction, some early models used (including some Mercurys in 1957) a metal-to-metal Hickok belt previously available.)

On 17 November 1943, The National Research Council report authored by Dr. Hugh DeHaven presented an analysis of 30 light aircraft accidents in which cause of failure of seat belts included reference to "buckled but ineffective" or only "partially effective," and recommendations that strength of belts and belt fastenings and anchorages be increased (DeHaven, 1943). Other studies during the 1940's and 1950's begin to reveal other belt buckle failures. A further analysis of 308 accidents was reported upon in 1945 in which it was found that 59 safety belts had broken or torn webbing (one cause is webbing slipping through the buckle in older type metal to webbing belts), 4 partly torn, and 6 in which the webbing was cut by the buckle or the buckle slipped (DeHaven, 1945, p.13). Investigation of a DC-6 accident in 1952 revealed that the copilot's seat belt buckle cam had opened up although the webbing was intact (Hasbrook, 1953, p.38).

Finally, by 1955 a memorandum from Aviation Crash Injury Research was sent to all "Users, Manufacturers, and Other Agencies Concerned with Safety Belts" (Hasbrook, 18 May 1955). This memo is reproduced as follows since it clearly outlined the mechanisms involved and provided test results:

> As a result of a recent accident investigation and a preliminary analysis involving a survivable crash, there is some indication that certain types of safety belts may be slipping - and releasing inadvertently - due to inertia loads acting on (a) the "free end" of the webbing (in a whipping motion) and (b) on the lift (to release) latch, when the belt is worn loosely adjusted. (See Diagram).



> In some cases, this slippage appears to be such that the occupant may lose all safety belt restraint. In others, the slippage may occur until all but a few inches of the free end of the webbing has passed through the buckle - thus imparting a heavy jolt load to the belt assembly, seat and seat anchorages, when the belt finally "locks up".

> As a result of an Av-CIR request concerning the possibility of belt slippage and/or buckle release under light inertia loading, some preliminary static tests were conducted by an outside Agency on new buckles and webbing of a cam type buckle and belt assembly.

> It was found that a load of approximately 21 g was required to open the latch itself when no belt webbing was "levering" against the lift latch. However, with 10" of free webbing levering against the lift latch, only $4\frac{1}{2}$ g was required to release the belt. With 15" of free webbing, only $3\frac{1}{4}$ g was required for release.

> Note: These conditions resulted when the cam cerations were brought into contact with the webbing by spring pressure only - without manual squeezing. This lack of squeezing of the latch is typical of some passenger usage.

> There is also a possibility that lower g's than these may open the latch - and permit the webbing to slide free - because of (a) low spring pressure, (b) worn cam cerations, and (c) "slipperiness" of the webbing (due to weakening of the spring and blunting of the cerated edges from operational use, and repeated dry cleaning of the webbing).

It is suggested that (a) latch springs, cam cerations and webbing of present "in-service" belts be inspected for proper condition, (b) engineering consideration be given to the possibility that inertia loads (acting on the "free" webbing and on the lift latches) may inadvertently unlock and release safety belt assemblies when the belt is loosely adjusted, and (c) further tests be made to ascertain the inertia effects on all types of safety belt assemblies.

(Hasbrook, 1955)

On June 27, 1961 a Cessna 170A crash resulted in fatal injury to the pilot, attributed to seat belt and buckle assembly. This resulted in a CAB recommendation on 17 January 1962 that the FAA "take steps to inspect all aircraft fitted with this belt/buckle combination to assure adequate occupant retention is afforded. Also that TSO under which this belt was approved be revised to require positive locking be automatic under application of accelerative or inertial loading. The FAA responded on February 8, 1962 that an Airworthiness Directive (AD) had been issued and TSO C22(d) Safety Belts, was being studied. The metal-to-fabric type of buckle utilizing a serrated cam in the belt buckle as a latching mechanism has had many failures reported during the 1960's and 70's.

In 1964 the FAA conducted a survey of this type of belt on recommendation from the CAB, and found that 4% of the belts examined were defective. At that time the FAA issued a directive to FAA field presonnel to check adequacy of this type of belt. Subsequently, buckle failures were found in a United Airlines accident at Norfolk, Virginia in 1967, and in in-flight turbulence of a United Caravelle in 1965 which injured four passengers, one fatally.

In October 1964 an FAA accident investigation reported in considerable detail was published in Aerospace Medicine which included illustration of tearing of the rear-seat passenger's belt, partial buckle failure, and slippage of the buckle (Hasbrook and Dille, 1964). A 1969 study of impact survival in crashes recommended "use of metal-to-metal buckles on all belt restraints" (Snyder, 1969).

In investigation of a DC-9 ditching 2 May 1970 the NTSB also reported at least six passengers thrown from their seats due to the fabric belt slipping through the buckle (NTSB, May 1970; NTSB, April 1972).

Chairman John Reed of the NTSB, in a letter to FAA Administrator John Shaffer dated September 14, 1970 pointed out the NTSB's conclusion that the demonstrated inadequacy of this seat belt locking mechanism had resulted in a serious question of its reliability. NTSB review of accident records over the period 1960-1970 had revealed no failure in the metal-to-metal type of seat belt. It was recommended in view of this record that the FAA "take the necessary steps to eliminate, within a reasonable time, the use of fabric-to-metal type of seat belts in aircraft of U.S. Registry and require metal-to-metal type of seat belt with a standardized activating device" (Reed, Sept. 14, 1970).

NTSB recommendation A-70-47 requested elimination, within a reasonable period, of metal-to-fabric seat belt buckles and require the use of metal-to-metal type. A further recommendation related to equipping acrobatic aircraft with metal-to-metal buckles (November 1970). In the latter case on November 13, 1970 NTSB advised the FAA of an incident in which an NTSB investigator was performing inverted aerobatics in a 7ECA Citabria when his fabric-to-metal seat belt released completely. The NTSB recommended that FAA "take steps to ensure that no aerobatic aircraft be certified or operated in the acrobatic category unless it is equipped with metal-to-metal safety belts" (Reed, 11/13/70). The manufacturer had issued a service letter in February 1968 which recommended that metal-to-metal belt buckles be used in Model 7 airplanes when performing acrobatic flights, however not all owners were apparently aware of this (Shaffer, 8/12/70).

Military seat belts have utilized metal-to-metal type latches since before World War I and the B-11 safety belt of pre-World War II vintage was typical of the Army Air Corps system (T.O. 03-1-2, 1 Oct. 1940). The Society of Automotive Engineers Aeronautical Recommended Practice (ARP) 682, drafted between 1957 and 1960 and first issued April 15, 1961, did not recommend a metal-to-metal belt (although its sponsor had been responsible for issuing the CIR memo recommending that type buckle in 1955).

On May 6, 1974 a fatal accident occurred to a police officer student pilot in a Hughes 269B, when the seat belt latch failed and he was fatally ejected. The belt conformed to FAA TSO C22-E and NAS-802. On June 9, 1975 NTSB followed up by pointing out two deficiencies found in the seat belt release lever and release mechanism and recommending inclusions in the proposed TSO (Reed, 6/9/75).

The FAA responded May 9, 1975 that four areas of action were anticipated, concluding that an upgrading was desirable (although the FAA 1970 investigation and later review of the service record indicated that experience did not justify mandatory replacement). An updated TSO (Technical Standard Order) was developed, requiring both metal-to-metal buckles and higher load capacity. As part of the upcoming FAR (Federal Aviation Regulations) Operations Review it was planned to require all occupant restraint systems after a given date to incorporate a metal-to-metal buckle. It was noted that as the Aeronca was used for acrobatics, metal-to-metal buckles must be used, and an NPRM (Notice of Proposed Rule Making) was in preparation (Dow, 5/19/75).

On 1 September 1977, the FAA issued a NPRM to amend #23.1413 to require that "(c) Each safety belt must be equipped with a metal-to-metal latching device (Amdt 23-22, 43 FR 46233, October 5, 1978). Adopted 4 December 1978, the effective date, of December 4, 1980, was subsequently delayed 1 year. It is not now effective until December 4, 1981. This new regulation will apply to all normal category aircraft except air ships. Replacement of a seat belt may be performed by a pilot who is not a certified mechanic, as preventive maintenance (FAA General News, May-June 1979).

2.5.2 Current Requirement. The present requirement is published as follows:

§ 23.1413 Safety belts and harnesses.

(a) The rated strength of safety belts and harnesses may not be less than that corresponding with the ultimate load factors specified in § 23.561(b), considering the dimensional characteristics of the belt and harness installation for the specific seat or berth arrangement.

(b) For safety belts for berths parallel to the longitudinal axis of the airplane, the forward load factor specified in § 23.561(b) need not be applied.

(c) Each safety belt must be equipped with a metal to metal latching device.

(Secs. 313, 314, and 601 through 610 of the Federal Aviation Act of 1958 (49 U.S.C. 1354, 1355, and 1421 through 1430) and section 6(c) of the Department of Transportation Act (49 U.S.C. 1655(c)))

[Docket No. 4080, 29 FR 17955, Dec. 18, 1964, as amended by Amdt. No. 23-7, 34 FR 13096, Aug. 13, 1969; Amdt. 23-22, 43 FR 46233, Oct. 5, 1978] (p.182, 1980)

However section (c) is not effective until December 4, 1981.

2.5.3 Discussion and Analysis. Although this study has not included comparison of Part 23 with Part 25 (airworthiness standards: normal category rotorcraft), and Part 29 (airworthiness standards: transport category rotorcraft) such an analysis has been previously published (Snyder, 1977). In this regard it should be noted that there are some important differences in crashworthiness and occupant protection requirements between these categories. One example is found in comparison of section .1413 for Parts 23, 25, 27 and 29. For both #25.1413 (air carriers) and #27.1413 (helicopters) there is an additional requirement not found in Part 23 that the safety belt anchorage cannot fail at a load lower than that corresponding with the ultimate load factors specified in #27.561(b); however in the case of air carriers, this factor must be multiplied by a factor of 1.33 (#23.1413(c). For air transport helicopters there is no strength requirement for either belts or anchorages in this section.

The rated strength of safety belts and harnesses is specified to be not less than the ultimate load factors of #23.561(b), or 3 g upward, 9 g forward, and 1.5 g sideward. Applied to a 170 lb. occupant, this translates to a required minimum belt strength of 510 lbs. upward, 1530 lbs. forward, and 255 lbs. sideward. No fitting factor is involved.

Since FMVSS No. 209 required automobiles manufactured for sale in the U.S. to use 6,000 lb. (2720 kg) webbing for type 1 (lap belt) restraints and 5,000 lb. (2270 kg) pelvic webbing and 4,000 lb. (1810 kg) webbing in the shoulder harness (36 FR 22902, Dec.2, 1971), webbing of this strength has been currently available for many years. Part 23.1413 should be modified to realistically up-date these webbing strength requirements to take into consideration the state-of-the-art of present belt availability. This would also serve to greatly strengthen and upgrade one important link in the occupant crash restraint chain.

2.6 Fitting Factors. #23.625

2.6.1 Development of FAA Requirement. The National Advisory Committee Report on Nomenclature, No. 240, was used as a basis for the first airworthiness requirements (7A) of 1929 relating to factors of design load, ultimate load, load factor, factor of safety, margin of safety, and normal load. Additional special applications of the NAC report to the field of structural design were clarified in the 1929 bulletin in Part 2, and comparison of definitions of the above terms provided. Fittings were first discussed in Part 4.4, and the requirements stated:

> "(A) Fittings, except riveted fittings, shall be designed to carry loads of 20 percent in excess of the design loads in the members to which they are connected. Riveted fittings shall be designed for 25 percent of excess load" (p.51).

Fittings were defined as including rivets, bolts, pins, and all similar secondary members which serve as part of the connection of one main member to another.

In 1929, a "minimumfactor of safety of 1.5 shall be maintained" in fuselage design (Sec. 51), and requirements for fittings was increased over the 1929 standard. In Chapt. IX, Section 61 fittings were now defined as all parts used to connect one primary member to another. Section 61 stated:

> "(B) The minimum factor of safety for fittings shall be 1.80. The design load for fittings therefore shall not be less than 1.80 times the applied load. The factor of safety for any given critical loading condition shall in any case be 20 percent greater than the specified minimum factor of safety for the primary member from which the fitting receives its critical load" (1934 IX, Sec. 61).

The fitting factor was subsequently included, although modified, in all subsequent revisions of the regulations, being incorporated in Part 03 (November 13, 1945). It was renumbered from #3.3112 to #3.306 on July 16, 1949 (F.R. 14/136), and recodified from #3.306 to new #23.625 (Notice 64-17) in 1964. Notice 67-14 added #23.625(d) to consolidate the requirements with no substantive change.

2.6.2 Current Requirement. The present requirement for fitting has been in effect since 1964, as amended by 23-7 (34 FR 13091, August 13, 1969). Section (d) requires a fitting factor of 1.33, as follows. This means that seat and belt attachments must be shown to withstand 1.33 times the 9 g, 3 g, and 1.5 g ultimate inertia forces listed in 23.561, or 4 g (3.99) upward, 12 g (11.97 forward, and 2 g (1.99) sideward."

§ 23.625 Fitting factors.

For each fitting (a part or terminal used to join one structural member to another), the following apply:

(a) For each fitting whose strength is not proven by limit and ultimate load tests in which actual stress conditions are simulated in the fitting and surrounding structures, a fitting factor of at least 1.15 must be applied to each part of—

(1) The fitting;

(2) The means of attachment; and

(3) The bearing on the joined members.

(b) No fitting factor need be used for joint designs based on comprehensive test data (such as continuous joints in metal plating, welded joints, and scarf joints in wood).

(c) For each integral fitting, the part must be treated as a fitting up to the point at which the section properties become typical of the member

(d) For each seat, berth, safety belt, and harness, its attachment to the structure must be shown, by analysis, tests, or both, to be able to withstand the inertia forces prescribed in § 23.561 multiplied by a fitting factor of 1.33.

[Docket No. 4080, 29 FR 17955, Dec. 18, 1964, as amended by Amdt. No. 23-7, 34 FR 13091, Aug. 13, 1969] (14 CFR 23, pp.133-134, 1980)

2.6.3 Discussion and Analysis. The fitting factor has been decreased from the 1929 1.80 requirement to its current value of 1.33. Since this requirement has an important bearing on seat and safety belt attachment strength it deserves further engineering review which is outside the scope of this study.

2.6.3.1 Consolidation of seat, belt, berth, and belt attachment factors. In 1969 the FAA proposed that Part 23 be further amended for small airplane type certification, proposing that 23.625, 23.785, and 23.1413 be consolidated to place seat, berth, and belt attachment factors all in one section, "and to require the installation of effective upper body restraints (harnesses), or the airplane interior to be designed either to eliminate injurious objects within striking radius of the head or to provide energy absorbing support for the upper torso" (32 FR 5791, April 11, 1967). These amendments reflected comments from a notice of proposed rulemaking (NPRM) listed in the Federal Register (32 FR 5791) on April 11, 1967 and circulated as notice 67-14.

At the present time, in order to find pertinent requirements for seats and restraints one must go to three separate parts of Part 23 (23.625, 23.785, and 23.1413), which in turn reference other sections and standards (23.561, NAS 806, NAS 809, #34.132 -TSO-C22f). It would seem more logical to consolidate all seat, berth and belt attachment factor requirements into a single section.

2.7 Child and Infant Restraint (TSO-C100, proposed)

2.7.1 Development of Proposed TSO-C100. A research study to analyze the need for infant and child restraint (primarily in air carrier aircraft) and conduct dynamic testing was proposed in 1961 by the FAA's Civil Aeromedical Research Institute (CARI) (now Civil Aeromedical Institute, CAMI), of Flight Standards Services Office of Aviation Medicine (OAM). However it was not given high priority and no funding or project assignment was made by OAM.

An infant dummy (subsequently identified as Mark I) was designed and fabricated by Swearingen and Young for use in the crash test of a DC-8 in 1964 (Reed, 1965). This was relatively crude, and in 1974 an improved Mark II CAMI Infant Dummy was constructed (Chandler 1974). In 1974 FAA comments on the proposed SAE ARP 766A for small children issued by SAE in 1967 (Appendix F & G) and proposed ARP 1469 for infants, was followed by a draft discussion paper (Chandler, 11 June 1974). In response to a request from AFS-424 to the Federal Air Surgeon, a project was initiated to test and approve infant and child restraint systems for use in civil aircraft. (Chandler, Memo Rept, August 1974). This also included a review of the state-of-the-art with a critique of the 1967 Aeronautical Recommended Practice(SAE), FMVSS 213 (effective April 1, 1971), proposed revisions (Docket 76-9, February, 1974), and Parts 91.14, 121.311, and 127.109 of the Federal Aviation Regulations. This study represents the most complete analysis available to date. It was concluded that NHTSA rulemaking regarding FMVSS 213 was pertinent to any FAA rulemaking activity, but while awaiting NHTSA decisions FAA should make "preliminary efforts" to establish the additional environmental conditions which might be required in aircraft. If the NHTSA decision in final rulemaking was delayed it was recommended that "interim certification of infant or child restraint systems could be provided by subjecting them to a test procedure..."(p.12).

The 1974 state-of-the-art analysis was followed by a test program evaluating 6 models of child and 4 models of infant restraints approved for automotive use under FMVSS 213 (Chandler and Trout, 1975a; 1975b). A test specification was provided which detailed dynamic test conditions. Since an aircraft system must provide protection during takeoff and landing, turbulent flight conditions, and survivable crashes, some conditions (such as seat characteristics, crash impact pulses) were found to differ from needs protecting children and infants in automobile crashes. Various problems were pointed out when restraint systems intended for automobiles are tested in aircraft impact simulations. The results of the 1974-1975 CAMI studies were published as an FAA report in March 1978 (Chandler and Trout, 1978). On October 2, 1980 a draft TSO (C100) was issued for public comment (Notice 45(193):65380) until 2 January 1981. This briefly summarizes the background and status of FAA regulatory action regarding child and infant restraint.

2.7.2 Current Requirement. At present there are no FAA standards providing for infant or child restraint protection aboard aircraft separate from adults. A draft Technical Standard Order was recently proposed as TSO-C100 in the Federal Register of October 2, 1980 (Notice 45(193):65380). Comments were requested by January 2, 1981 (Docket No. TSO-C100). The draft TSO-C100 prescribes the minimum performance standard that child restraint systems must meet.

In general the proposed TSO is based upon the current automotive vehicle Federal Motor Vehicle Safety Standard (FMVSS) No. 213 (49 CFR 571. 213080; 44 FR 72131 and 72147), with additional provisions addressing materials flammability, in-flight body containment, and marking and data requirements.

Draft TSO-C100, as proposed is as follows:

DRAFT - TECHNICAL STANDARD ORDER (TSO) TSO-C100

Subject: TSO-C100, Child Restraint Systems

(a) Applicability.

(1) Minimum Performance Standard. This Technical Standard Order (TSO) prescribes the minimum performance standard that child restraint systems must meet in order to be identified with the applicable TSO marking. New models of child restraint systems that are to be so identified and that are manufactured on or after the date of this TSO must meet the standards set forth in Federal Motor Vehicle Safety Standard (MVSS) No. 213, Child restraint systems effective date June 1. 1980 (49 CFR 571.213080; 44 FR 72131 and 72147).

(2) Additions.

(i) All materials used must be self-extinguishing when tested in accordance with applicable requirements of §§ 25.853 and Part 25, Appendix F of the Federal Aviation Regulations (FAR) effective May 1, 1972. The material may be of a size and be mounted for the test in accordance with paragraph (b) of Appendix F or may be of a size and mounted as used in the aircraft. Small parts (such as knobs, fasteners, seals, and grommets) that would not contribute significantly to the propagation of a fire need not be tested.

(ii) In addition to MVSS No. 213, Section 571.213080, paragraphs S5.1 through S5.13.3:

(A) Child containment for conditions of in-flight turbulence must be determined by inversion tests. The combination of a representative passenger seat, child restraint system, and child dummy must be rotated, from the normal upright position to an inverted position. The combination must remain inverted for a least 3 seconds. Child containment must be rotated in a forward direction, and a sideward direction with respect to a forward facing seat installation. The passenger seat must have a full fold-over seat back.

(B) Each configuration and mode of installation must be tested for containment of the child's weight and size for which the restraint system is designed. The child occupant must be simulated with the appropriate test dummy as specified in paragraph S7 of MVSS No. 213. Installations of the restraint system in the seat and placement of test dummies must be in accordance with the manufacturer's instructions.

(3) Exceptions. In lieu of MVSS No. 213, Section 571.213080, paragraphs S1, S2, S3, S4 subparagraph 1:

(i) Child restraint systems for aircraft must meet the requirements of MVSS No. 213 for seating systems to be attached in the vehicle by means of the vehicle safety belts without supplementary anchorage belts or tether straps, and the provisions of this standard.

(ii) Child restraint systems must provide body support and containment for the dynamic conditions of MVSS No. 213, except the acceleration/time curve of the test platform may be equal to or greater than the criteria of MVSS No. 213, Figure 2. Support and containment must be provided without failure or deformation which could seriously injure or prevent subsequent extrication of a child occupant.

(iii) The child restraint systems must also provide body containment for conditions of minor in-flight turbulence, without failure or deformation which could seriously injure or prevent subsequent extrication of a child occupant.

(iv) The restraint system must withstand a force equal to that generated by an unlatched seatback having a minimum of 25 degrees rotation and subjected to the dynamic impact condiions of MVSS No. 213.

(b) Marking. In addition to the marking specified in FAR §21.607(d), the following information shall be legibly and permanently marked on the equipment:

(1) Instructions for proper use and installation of the system.

(2) Weight and stature capacities of occupants appropriate for the design.

(3) Instructions for proper disassembly/assembly.

(c) Data Requirements. In accordance with FAR § 21.605, the manufacturer must furnish the Chief, Engineering and Manufacturing Branch, Flight Standards Division (or in the Western Region, the Chief, Aircraft Engineering Division), Federal Aviation Administration, in the region in which the manufacturer is located, one copy each of the following technical data:

(1) Operating instructions.

(2) Equipment limitations.

(3) Installation procedures.

(4) Specifications.

(5) Manufacturer's TSO qualification test report.

(d) Availability of Reference Documents. Copies of Federal Motor Vechicle Safety Standard, MVSS No. 213 may be obtained (or purchased) from the National Highway Traffic Safety Administration (NHTSA), Docket Section, Room 5108, 400 7th Street, S.W., Washington, D.C. 20590.

Current FAR operating rules require a seat belt to be used during takeoff and landing, except for a sport parachutist who can sit on the floor, and a child under two years, who may be held by a seated adult. Safety belt use is addressed in Part 91.14, Part 121.311 (for air carriers), and Part 127.109 (helicopter air carriers), as follows:

§ 91.14 Use of safety belts.

(a) Unless otherwise authorized by the Administrator—

(1) No pilot may take off a U.S. registered civil aircraft (except a free balloon that incorporates a basket or gondola and an airship) unless the pilot in command of that aircraft ensures that each person on board is briefed on how to fasten and unfasten that person's safety belt.

(2) No pilot may take off or land a U.S. registered civil aircraft (except free ballons that incorporate baskets or gondolas and airships) unless the pilot in command of that aircraft ensures that each person on board has been notified to fasten his safety belt.

(3) During the takeoff and landing of U.S. registered civil aircraft (except free balloons that incorporate baskets or gondolas and airships), each person on board that aircraft must occupy a seat or berth with a safety belt properly secured about him.
However, a person who nas not reached his second birthday may be held by an adult who is occupying a seat or berth, and a person on board for the purpose of engaging in sport parachuting may use the floor of the aircraft as a seat.

(b) This section does not apply to operations conducted under Part 121, 123, or 127 of this chapter. Paragraph (a)(3) of this section does not apply to persons subject to § 91.7.

§ 127.109 Seat and safety belt.

(a) No person may operate a helicopter unless there are available during the takeoff, en route flight, and landing—

(1) An approved seat for each person on board the helicopter who has reached his second birthday; and

(2) An approved safety belt for separate use by each person on board the helicopter who has reached his second birthday.

(b) During the takeoff and landing of a helicopter, each person on board shall occupy an approved seat with a safety belt properly secured about him. A person who has not reached his second birthday may be held by an adult who is occupying a seat.

However, notwithstanding the provisions of this section, in the case of children who have reached their second birthday, but not their 12th birthday, a safety belt may be used for two in a single seat if the strength requirements of the seat and the safety belt are not exceeded.

§ 121.311 Seat and safety belts.

(a) No person may operate an airplane unless there are available during the takeoff, en route flight, and landing—

(1) An approved seat or berth for each person on board the airplane who has reached his second birthday; and

(2) An approved safety belt for separate use by each person on board the airplane who has reached his second birthday, except that two persons occupying a berth may share one approved safety belt and two persons occupying a multiple lounge or divan seat may share one approved safety belt during en route flight only.

(b) During the takeoff and landing of an airplane, each person on board shall occupy an approved seat or berth with a separate safety belt properly secured about him. However, a person who has not reached his second birthday may be held by an adult who is occupying a seat or berth. A safety belt provided for the occupant of a seat may not be used during takeoff and landing by more than one person who has reached his second birthday.

(c) After September 30, 1969, each sideward facing seat must comply with the applicable requirements of § 25.785(c) of this chapter.

(d) Except as provided in paragraphs (d) (1) and (2) of this section, no certificate holder may take off or land an airplane unless each passenger seat back is in the upright postion. Each passenger shall comply with instructions given by a crewmember in compliance with this paragraph.

(1) This paragraph does not apply to seat backs placed in other than the upright position in compliance with § 121.310(f)(3).

(2) This paragraph does not apply to seats on which cargo or persons who are unable to sit erect for a medical reason are carried in accordance with procedures in the certificate holder's manual if the seat back does not obstruct any passenger's access to the aisle or to any emergency exit.

(e) Each occupant of a seat equipped with a shoulder harness must fasten the shoulder harness during takeoff and landing, except that, in the case of crewmembers, the shoulder harness need not be fastened if the crewmember cannot perform his required duties with the shoulder harness fastened.

2.7.3 Discussion and Analysis. Equal protection has not been provided to all aircraft passengers. To date there are no standards regarding restraint protection at all for children or infants under two years of age. FAR Part 91.14(a)(2) states that "...a person who has not reached his second birthday may be held by an adult who is occupying a seat or berth,...". FAR Part 121.311(b) pertaining to air carrier (not Part 23 operation) includes identical language, and FAR Part 127.109(b) uses a similar statement, which have been provided in the preceding section.

A number of problems have resulted. As soon as child and infant restraints became available for automotive use, some 15 years ago, parents have attempted to take them on board air carriers. The airlines have responded in various ways but generally, in view of a complete lack of standards or even guidelines from the FAA, have not allowed parents to use child or infant restraints during takeoff or landing. The author has several times overheard the cabin attendant explain that "it is an FAA requirement that the parent hold the child in the lap." As noted in Part 121.14(a)(2) that is inaccurate, as well as dangerous, although normal airline procedure is for the parent to hold the younger child on the lap.

Tests conducted at the University of Michigan have clearly documented that in moderate or severe crash decelerations it is not possible for lap and shoulder belted adults to adequately restrain children in their laps by holding on to them (Mohan and Schneider, 1978). For a 7.9 Kg (20 lb.) infant, the inertial forces at 10 g's could be in excess of 1000 N, a strength limit for many adult females. Even low velocity impacts of 25 km/hr chest deceleration can exceed 15 g's (Alem, et al., 1978). At a 50 km/hr crash, in which chest recordings of 35 g's have been measured, the combined inertial force of a 7.9 kg infant and the forearms would be nearly 3800 N, a value about four times greater than any strength value for females and more than twice that for males. The Mohan-Schneider study concludes "...in airplanes, in crash or turbulence situations, the lap-held infant is likely to hit nearby hard structures. The results clearly demonstrate that it is not safe for infants to be transported in adults' laps in automobiles or airplanes even in the relatively rare instances that they are held tightly and the adults are restrained" (p.1). In addition, there is the possibility that the jack-knifing parent (since shoulder harness is not provided) will flex forward and cause crushing injuries to the child. The use of pillows, blankets, and other devices by the airlines may even increase the potential danger of injury to the infant. Another technique, that of placing the infant inside the parents lap belt, is also especially dangerous.

It does not appear that this 3-way conflict between the FAA, the air carriers, and the parents will soon be resolved. Parents attempting to bring infant or child restraints aboard air carriers assume that those certified as meeting the impact protection requirements of FMVSS 213 will offer protection in aircraft as well as the automotive vehicles they were designed for. Unfortunately, there are a number of differences between the aircraft impact environment and that of automobiles which affects the quality of protection an automotive child or infant restraint may offer in an aircraft deceleration. For example, most general aviation aircraft do not have seat-back locks, and air carriers have a breakaway feature, thus the seat back itself may come forward. Some automotive child restraints require over-the-seat or upper attachment to prevent the top to swing forward, not present or ineffective in aircraft. Turbulence can cause a child to slip underneath or be thrown about in a standard car restraint. Also, aircraft seat cushions generally differ from automotive and this influences response. The main difference between automotive and aircraft impacts lies in the multi-directional aspects, with aircraft commonly having a high vertical component, in contrast to most automotive impacts.

It is necessary to conduct tests using aircraft seats in typical aircraft crash profiles to determine how effective seats developed for automobiles may be in aircraft crash environments. Recognizing this need, Chandler conducted a series of tests at CAMI in 1974 (as outlined in 2.7.1), however the FAA did not publish the results until four years later (Chandler and Trout, 1978). Since 1974, several promising restraint systems have been developed for aircraft use. Flight Systems, Inc., of American Safety developed an aircraft infant restraint, tested in 1976. Buckeye Manufacturing filed an application in July 1974 to the FAA's Eastern Region, for a Supplemental Type Certificate (STC) for the Peterson child seat, which is still pending. Buckeye was sold to Cosko in the interim, and the STC application was resubmitted, requesting waivers for flammability and for testing in an aircraft seat (Miller, personal com., 5 March 1981). Other infant restraints have been designed especially for aircraft, but as yet untested, such as the Von Wimmersperg Infant Guard Model C (Patent pending, June 1971).

The National Highway Traffic Safety Administration established standard No. 213 (Child Restraint Systems) in 1971. NHTSA proposed tougher regulations in 1974 that called for testing child restraints in simulated front, side, and rear crashes, although no action was taken until 1978. Amendments were added in 1979 to both FMVSS 213 and 209 (Seat Belt Assemblies and Anchorages) (44 FR 72131, 13 December 1979), and in May 1980 NHTSA responded to several petitions for reconsideration, publishing the present final rule 9 October, 1980 (45 FR 29045). The latest changes changed labeling requirements to permit the use of alternative language, modified the minimum curvature for surfaces, and extended the effective date of the standard from June 1, 1980 to January 1, 1981. NHTSA FMVSS 213 provisions cover all types of systems to restrain children such as infant carriers, child seats, harnesses, and car beds. The most recent requirement replaces static testing with 20 and 30 mph dynamic testing, and prohibits restraints from collapsing during dynamic tests, among other requirements. The current standard for motor vehicles is provided in Appendix E.

In Australia the use of child restraints approved for automotive use is acceptable for use in general aviation if it is manufactured to comply with Australian Standard AS 1754 and secured to the aircraft seat or structure in a way to resist inertia forces of 9 g forward, 3 g upward, and 1.5 g sideward (Aviation Safety Digest 108:6). The Standards Association of Australia keeps available in each capital city a currently approved list of child restraints.

There have been a number of test and evaluations of infant and child restraint systems relative to automotive use (Appoldt, 1966; Aldman, 1966; Robbins, 1970; Stalnaker, 1971; Roberts, 1972; Comsumer Reports, 1974; 1975). One of the most recent studies examined protection in 214 automotive crashes in which child restraints were used, examining 16 cases in depth. Among conclusions are that child restraints that only meet static test criteria provide some injury protection in less severe crashes, while "child restraints that meet dynamic test criteria provide excellent injury protection when used properly and still provide adequate protection in some misuse modes" (Melvin, et al., 1980).

To assist proper restraint design a combined review of the anatomy, anthropometry, growth and development of the infant and child was published pointing out the ways in which they differ from the adult in protective needs (Burdi, et al., 1969). Because younger children are increasingly placed in seats with shoulder restraints, designed for adults, the question of potential hazards with a younger child was subsequently addressed (Snyder and O'Neill, 1975). It was recommended that infants and younger children should use the systems especially designed for them, but that the shoulder harness could be used with parental judgement, but under no circumstances should children and infants be unrestrained and held in the lap.

To date the focus of child and infant restraint usage has been in regard to air carrier operations. But airline crashes involving infants have not been numerous enough to provide a large body of data, nor has there been much information available on children or infants in most accidents when they have occurred. In many air carrier crashes children under two years of age may not occupy a revenue seat and therefore might not have been listed, and also there is a lack of complete human factors and biomedical analysis for most accidents to date. Only limited impact tolerance data for children is known (Snyder, 1967; 1971; 1980)(Foust et al., 1977).

The most tragic air disaster involving children occurred 4 April 1975, when a military Lockheed C-5A transport evacuating personnel from Saigon crashed (USAF Lockheed C5A (Operation Babylift), passenger manifest, 1975). There were about 330 occupants aboard, of which 155 were fatally injured. Of 247 orphans, 98 infants and children were killed. However due to the wartime circumstances accurate investigation of seated positions and degree of restraint for very few are known with any degree of accuracy, and injury data are primarily documented for survivors (USAF Accident Report, 1975; Snyder, 1980; unpublished data; Warren, 1981).

On 28 December 1979 a United Airlines McDonnell Douglas DC-8-61 crashed in Portland, Oregon, in which three of the ten fatalities were children under two years (although the severity of the crash was such that it might not have been survivable at the location the children were seated even with restraints). A total of six "infants in arms" were involved resulting in three fatal, one serious, two minor injuries. As a result a "task force" on child restraint systems was established by the FAA with an objective to develop the options available regarding federal actions needed to permit manufacture and use of effective aircraft child restraint systems. It was reported that the questions posed to the FAA task force was "in view of the fact that we don't have seat standards and do not permit people to use automobile seats during takeoffs and landings because they must be stowed as luggage, what are our options for standards?" (Aviation Week, p. 28, February 5, 1979). However, the FAA has "no statistics available in our administration to determine the ratio of children killed or injured in airline crashes as compared to the percent of adults killed or injured" (J.A. Ferrarese, Acting Director, Flight Standards Services, letter to Hon. E.I. Koch, House of Representatives, 16 July 1976.)

On February 6, 1974 the FAA received a petition from S.R. Miller to revise Part 91, subpart A91.14 in the public interest. The recommended revisions were:

"1. All children who have reached the age of one year old or who weighs 20 lbs. or more and have not reached their 4th birthday, shall be required to be seated in their own seat, belted in a certified children's safety seat on takeoff and landings, and/or at such times that the pilot in command so deems necessary.

2. Those persons under 1 year old and who weigh less than 20 lbs. shall also be required to have his or her own seat and be securely belted in a certified safety seat FOR THEIR SIZE."

These rules shall apply to all U.S. Certified Civil Aircraft.

No adult may hand hold a child during the aforementioned times. It shall further be expressly prohibited for the practice of two persons, regardless of age, doubling up under one seat belt. The use of a bassinette type berth should no longer be permitted during takeoffs and landings. These safety seats should be located in such a manner as not to interfere with the egress of other passengers in the event of an emergency" (Miller, letter to FAA administrator Butterfield, 6 February 1974).

On April 2, 1976 Mr. Miller received a reply from the FAA, requesting that he withdraw his petition "in order that the Agency may avoid delay," since in view of the CAMI tests the "Agency is finalizing design and strength requirements for these devices." (letter from A.R. Pearsall, Chief FSS Air Carrier Regulations Branch).

The General Accounting Office (GAO) recently examined the FAA's safety effectiveness and recommended a number of changes "to make the FAA able to respond more quickly and effectively to aviation hazards" (Comptroller General Report, February 29, 1980). Child restraints were used to illustrate the "untimely or inadequate" corrective actions to protect against safety hazards. The GAO report concluded:

"..Child Restraint System. FAA has conducted research on infant/ child restraint since the early 1960's. However, as of September 1979 FAA's efforts had failed to produce new requirements. Efforts had centered on developing standards and testing procedures to be used in manufacturing child restraints for use on aircraft. FAA officials told us that allowing use of National Highway Transportation (sic) Safety Administration - approved car seats as an interim measure was not possible because (1) these seats had not been tested for aircraft use and (2) they could cause injury to other passengers during evacuation.

A September 1972 FAA research progress report, however, stated that when properly used, two types of auto seats would provide improved crash protection for children sitting in aircraft. The report suggested that the seats be used only at window locations so as not to restrict other passenger evacuation. This effort was similar to FAA's latest approach, which was to use updated National Highway Transportation (sic) Safety Administration car seat standards with modest additional FAA requirements. It would appear then that FAA may have been able to be more timely with at least an interim solution to this problem had it pursued the 1972 research effort more diligently" (p. 40, 1980).

The GAO study found that injuries to unrestrained infants in aircraft prompted the FAA in 1973 to place a "high priority" on development of requirements for suitable restraints. However the study was cancelled in 1977 because it failed to develop them. Subsequently another unit began another project that developed requirements but that project was cancelled and they were not adopted because the unit "wanted to concentrate on higher priority work" (GAO, 1980). After a December 1978 airline crash in which two infants were killed, the FAA again placed a "high priority" on the restraint problem. Another project, similar to the study in 1973 was started but not yet completed. The GAO concluded that interim measures using child restraints in aircraft could have been used, and cited a 1972 FAA report which concluded that two types of automotive restraints could provide improved crash protection for children in aircraft.

Despite the emphasis on the air carrier problems, a recent study suggests that general aviation pilots, having received no guidance from the FAA, are going ahead and using child/infant restraints anyhow. In a survey of women pilots ("99's") it was found that 39% of the 250 pilot responses received carry infants (weighing less than 20 lbs.) in aircraft using commercially available automobile child/infant restraints. Yet 33% reported no restraint for infants other than "held in arms." Small children of 20-40 lbs. were most often restrained by a lap belt, often combined with an extra seat cushion

(Foley and Snyder, unpublished report, 1980). A comprehensive and useful review of infant/child restraint systems potential for use in general aviation business aircraft was conducted by Business and Commercial Aviation in 1976 along with discussion outlining the need (Day, June 1976).

The number of infant/child restraints which are actually in use in general aviation aircraft are unknown, but some attempt to educate pilots concerning adequate protection of their younger passengers should receive wider attention until the FAA gets around to rulemaking. In view of the measures recommended by GAO, Miller, and others cited, an interim action in allowing certain automotive infant/restraint systems be used on aircraft seats (not blocking emergency egress) would offer considerably greater impact protection to children than is presently the case where an infant must be held in the parents lap without restraint or children are improperly and inadequately placed in adult restraints.

3.0 BACKGROUND - State-of-the-Art in Crashworthiness

3.1 Beginnings to World War I (1908-1919)

From the earliest days of aviation there have been observations related to crashworthiness and the recognition in numerous reports and publications of measures which might have prevented death and injury in the accident.

During the first two years of fixed-wing aviation the French reported 98 crashes (of 18 pilots in 1909 and 354 total in 1910). There were 61 accidents of monoplanes with 10 fatalities in 1909 and 83 accidents with 21 deaths in 1910 as reported by La Commission d'Aviation de l'Aero-Club (Dumas, 1910). A large number of accidents occurred in early air-races. During the first Gordon Bennett Trophy Race of 1909, which attracted 38 aircraft, there were reportedly 12 crashed aeroplanes scattered about the aerodrome (Kinnert, p.12, 1967). In 1910 37 race pilots were killed in the United States. The hazards of early flying were typified by the 12 to 15 crashes during the first coast-to-coast trans-continental flight* by Cal Rodgers in 1911 (Harris, 1964; Kane, 1950). Ironically a few months later (3 April 1912) Rodgers became the 127th person to be killed in an aircraft accident (Mahoney, p.72). As the death toll mounted various problems were identified with crash survival, although the emphasis remained upon pilot error and luck as a cause, and various means of prevention were proposed with only limited consideration for the occupant.

The first airplane built by the Wright Brothers had the engine offset to one side so that in case of a crash the engine would not fall on top of the pilot (Lederer, 1920).

Crashworthiness has been of continuing concern to United States Military Aviation, and in particular the Army has led in this field from the beginnings of aviation to the present. The U.S. Army Signal Corps formed an Aeronautical Division in August 1907 (Wolk, 1977), less than 4 years after the first flight at Kitty Hawk. The first airplane built in the United States and purchased under contract by the Army contained a requirement for incorporation of "some device" designed to improve the "safe descent" of the operator in case of "an accident to the

*This first transcontinental flight took 49 days: 82 hours, 4 minutes actual flying time, for an average speed of 52 mph.

propelling machinery" (Signal Corps Specification #486, 1907), although emphasis was on performance and attaining a speed of 40 miles per hour with a one hour flight endurance. The first emergency landing requirement for aircraft is found in General Requirement No. 8, which stated that "It should also land in a field without requiring a specially prepared spot and without damaging its structure". (Signal Corps, 1907). Signal Corps Specification No. 486 also noted that "the flying machine must be designed to carry two persons having a combined weight of 350 pounds,..." (Signal Corps, 23 December 1907). Thus an average occupant weight of 175 lbs. was first specified in 1907.

The entire U.S. Army Air Corps (Signal Corps) consisted of one airplane, one pilot (Lt. Foulois), eight enlisted men, and one civilian mechanic from 1909 to March 1911 (Considine, B, 1972).

In 1908 the fatal skull fractures of Lt. Selfridge, the first Army Air Service pilot, probably influenced Lt. Arnold, the second Air Service pilot, to wear a football helmet. Probably this was the first example of a crash helmet (Reals, 1968). A picture accompanying the report of the first two fatalities in the new Royal Flying Corps (Capt. Loraine and Staff-Sgt. Wilson) on 5 July 1912 while flying a Neuport monoplane, shows Capt. Loraine at the controls preceeding the flight wearing a helmet, but no seat belt is evident (Aeronautics p. 235, 1912). In 1917 U.S. Naval aviators candidates were detached to active duty with the Royal Flying Corps at Toronto for training. All wore leather helmets, however the rear seat gunner, who stood in the rear cockpit during aerial gunnery, was provided with no safety belt (Halstead, 1965). Photos also describe a "leather helmet over steel lining" (Halstead, p. 29, 1969).

The "safety belt" in aviation probably originated primarily to keep the pilot from falling out, although the crash protection advantage had also been stressed (see Aero-Aviation, 1910).* The first lap belt

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*It should be noted however, that restraint systems for automobiles predated aircraft use. As early as 1881 A.M. Freeman filed a patent on a combination brace plate with angular slots and hook for suspenders, the first of a long-line of restraint investigations(Freeman,1881).By 1903, Leveau of France had devised a sophisticated motor car restraint system consisting of adjustable cross-chest straps, and lap straps, as well as a high-backed seat for each vehicle occupant. He also included an intergrated harness system in which the shoulder straps attached to the seat back (Leveau, 1903). Some 77 years later this is still a "future" concept, incorporated in very few corporate aircraft, and crew stations of air carriers.

in aviation was reportedly made for Lieut. (later General) Foulois and installed in U.S. Army aeroplane No. 1, by an Army Field Artillary saddle maker, who modified a trunk strap (Foulais, 1960). A description of the motion picture film of the 1909 test flights of the Army's first aeroplane relates "you see Orville (Wright) drop to his seat alongside Lieut. Ben Foulois, watch him jerk his safety belt tight and see the unwieldy 'box-kite' slide down the monorail and soar up into air" (p.16 Army Air Corps Newsletter, 1940). The lap belt was thus apparently initially used by Lieut. Foulois in 1909 and 1910 (Foulois, 1960; Aero-Amateur, 1910). In the fall of 1913 Glenn H. Curtis devised a simple lap belt which could be used to secure the pilot to his seat. This resulted from the first death of a U.S. Naval Aviator, Ensign William D. Billingsley (Naval Aviator #9) and serious injury to John H. Towers (Naval Aviator #3) when they fell out of their Wright hydroaeroplane in a downdraft over the Chesopeake Bay (Naval Aviation News, 1981).

An upper torso restraint was used in the Spad III (Snyder, 1970), Fokker Tri-planes, and Sopwith Camel and other aircraft by 1917. Contoured bucket seats with side protection were adopted in the WWI Spad and Westland Wagtail aircraft of 1917, the latter featuring an aluminum bucket seat (Snyder, 1969, 1970). Although these efforts at improving crashworthiness were not universally adopted at the time, they illustrate the leadership which Army aviation has had in this field since the development of aircraft through the present. (The current Army Aircraft Crash Survival Design Guide, (1980) represents the current state-of-the-art for crashworthiness design, far exceeding civil requirements found in the present Federal Air Regulations.)

In 1910 Jorge Chavez fatally crashed while flying the Andes in a Bleriot-X1 monoplane. In 1962-63 a detailed accident reconstruction was conducted for biomedical, engineering, and crashworthiness factors of (Snyder, 1962; Guillermo Garrido, Lecca Frias, 1963). Use of very good original photographs of the crash together with a detailed medical history and other details pieced together by a number of specialists allowed some interesting crash forces and a crash acceleration time history to be estimated. Impact angle was probably less then 40°, with an impact velocity of 37 to 50 ft./sec. Calculated forces on the seat were only 4 G at 25 to 34 mph change of velocity (equivalent to a free-fall from 18.5 to 40 ft). A seat-belt would have undoubtably saved his life.

A letter to the Editor of Scientific American entitled "Prevention of Aviation Accidents" by E.G. Still on 4 October 1913 (p.259) reviewed several recent accidents in which the pilots (Navy Ensign Billingsley, Army Capt. Hennessy, civilian Harriet Quimby and a passenger, Moissant, (see Scientific American, 104:43, 14 January 1911), and "numerous other aviators") had fatally fallen out of their aircraft. The lesson that Still pointed to was the need that "the aviator and passengers should be held in their seats by a strap or similar device passing in front of them" (p. 259). In 1913 Pegoud, flying a 50 h.p. modified 1911 single-seater, demonstrated that a pilot can survive flying upside down, "looping the loop", rolling over sideways and "diving tail first", situations which had proven fatal to many earlier pilots. (Sci. Amer., 1915). This also showed that a seat belt was essential to remaining with the aeroplane. A description of U.S. Navy aeroplane accidents in 1916 attributed great emphasis to the problem of "get aways" (take-offs) and gust loads, "rear gusts, downward gusts, head gusts, upward gusts" and the effect of these g loadings on the airframe, but did not consider occupant protection per se: "were it not for errors in piloting, casualties due to material would be few indeed, and fatalities to personnel even rarer" (Saufley, Aero. 1916). This problem of accelerative stress on the airframe was recognized early (Zahn, 1911; 1913) and addressed early in the formation of the National Advisory Committee for Aeronautics (NACA) in 1915 (Wilson, 1916; 1917; 1918).

By December 1910 the U.S. had recorded at least 24 fatal accidents, and this death toll inspired one of the earliest technical discussions of crashworthiness design, which appeared in a series of articles appearing the The Aero in 1910 and authored by "Aero-Amateur". A number of ways to protect the pilot were considered. For example, "instead of using the big clumsy tail boom arrangement at present so popular in biplanes, the engine should be placed in front of everything as it is in the modern monoplanes and some biplanes, that the pilot should sit behind the engine, so that he is not likely to be crushed in a fall", (The Aero 7 Dec. 1910, p.445). Boat-type curved skids were suggested as a fuselage to "materially reduce the impact" (p.445), and a leather driving helmet to prevent the pilot from getting his head "smashed" or "to preserve one's head from knocking against the cabane* itself as the machine turns over" (p.445). Similarly, to replace the mast and enclose the pilot to protect him from being crushed in an accident. (See also Bergey, 1973; 1974).

The 1910 "suicidal" practice of placing the pilot in front of the engine was strongly objected to as "he is practically the first thing that hits the ground, and where, if nothing actually falls on top of him, he is shot out and breaks his neck." (The Aero, 30 November 1910, p.424). A number of accidents in which fatality was attributed to this type of aircraft design was discussed, including that of Lieut. Selfridge in 1908 (the first fatal aircraft accident on record), and Capt. Ferber (the second fatal accident). An "enclosed body" was recommended as an improved design to protect the pilot (p.424).

After investigating a large number of French and British "monoplane smashes" one "obvious lesson is that the driver must at all costs stick to his seat," and he recommends a broad chrome leather belt ("adopted by the R.E.P. and Antoinette" pilots), which extends from the hip to the breast-bone. In this design, the ends are hooked into rubber extension springs which are attached to the fuselage behind the pilots seat. "When the pilot takes his seat he hooks the belt across the front of himself, leaving it quite loose, so that it does not in the least hamper his movements; then if the machine dives and hits the ground he is simply shot into the belt and back again into his seat" (p.444).

It is concluded "that it is quite possible to build an aeroplane so that if it hits the ground head first, or even sideways, at its proper flying or gliding speed, as it should do if its wings and empennage do not break in the air, it is practically impossible for any sound and healthy man inside it to be killed or even seriously injured" ("Aero-Amateur" 7 December 1910, p.446).

Early accidents in England were investigated by the Royal Aero Club, which also issued aviation accident reports. Several clear examples are

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* A cabane, pylone, or mast is used to support the weight of the wings when the 1910 machine is on the ground and right side up.
Note underlining is added by present author.

found in the published reports of the Public Safety and Accident Investigation Committee of the Royal Aero Club. For example, a fatal accident to C.L. Campbell, holder of RAC aviator's certificate #220, occurred while he was flying a Bristol monoplane on 3 August 1912 at 300 feet when the engine stopped and "the machine struck the ground." Among the facts "clearly established" was "(4) That the aviator was not thrown out of his seat and was not wearing either belt or helmet." It was the opinion of the investigating committee "that since that portion of the aircraft in which the aviator was seated was undamaged, his life might have, perhaps, been saved had he used a helmet and belt, as his injuries were caused by his being thrown violently forward against the structure" (Aeronautics, p.314, October 1912).

By 1912 multiple fatalities begin to occur in aircraft accidents. The first U.S. Aircraft accident in which two or more military personnel were killed occurred in a crash 28 September 1912 in Signal Corps airplane No. 4, a Wright "B" model, at College Park, MD., involving Lieut. Lewis Rockwell, the pilot, and Corporal Frank Scott, the passenger and the first enlisted man fatality (USAF Museum, Dayton).

Restraint systems were installed and required to be worn in all WWI training and combat aircraft. Army "General Rules and Regulations Governing Flying on Individual Fields" (Oct. 21, 1918), No. 17. stated "all machines must be equipped with safety belts for pilot and passengers." Rule No. 18 stated "always wear safety belts." In case of accident, do not release belt until after accident. It will probably save injury, especially if the machine turns over." (Rountree, 1920, p. 231).

During WWI all fatal AEF accidents were investigated by a specially appointed accident board of five members, however the objectives were to fix responsibility, determine whether an aviation accident, and whether it occurred in line of duty. Non-fatal accidents were not investigated (Rountree, p.241) at that time. The A.E.F. in November 1918 consisted of a total of 5,646 (3905 pilots and 1741 observers) aviators, of which 169 American flyers were killed in combat, and 245 fatally injured in accidents in France or at the front. WWI aircraft accidents have been analyzed by

Rountree (1920) for 341 accidents. By 1919 The American Air Service reported 681 fatalities of which 508 were due to accidents (involving fire in 13 accidents, 3 falls from planes). At the onset of WWI (1914) France and Germany each had about 1,500 aircraft (Connors, 1967).

Probably the most detailed early analysis of aeroplane accidents was published in the Medical and Surgical Aspects of Aviation in 1919, with numerous illustrations of accidents. Investigation of mechanisms of head and brain injuries in several WWI military crashes were attributed to "being thrown out or from his head being violently jerked forward and hitting the nacelle edge, windscreen or instrument board." (Anderson, p.158). It was also believed that "should the safety belt hold the sudden impact of the pilots' abdomen and lower part of the chest against it, it may cause internal injuries" (p. 159). Of interest, the author stated (this is dated 1919) "nowadays most nacelle edges are padded and safety belts are stronger and broader." Thus the concept of energy absorption cockpit protection of the pilot in a crash, through padding had been advanced early in the medical literature.

The merits of pre-1919 safety belts, based upon accident observations have been presented by Anderson in great detail. In 58 accidents investigated prior to 1919, 24 belts were reported to have failed (belt gave way"), (p. 139-140), but aside from the large failure rate and inconclusive relationship to injury several erroneous conclusions were also drawn. In the cases of post-crash fire the observation was made "certainly if the aeroplane catches fire in a crash little hope can be entertained for the pilot being thrown clear of the machine." (p. 160). However, this conclusion was drawn apparently from only one accident where fire occurred. On the basis of the injuries noted in pre-1919 crashes Anderson concluded that "a narrow belt is to be condemmed. The ideal safety belt should be broad and resilient, attached to the framework of the aeroplane and not to the pilots seat, not at the centre of the pilots' body but at the side, where it is attached to the aeroplane..." (p. 160).

A 1919 medical review reported "during World War I medical officers of the various air services had observed that more than half of the injuries sustained in crashes were caused by the aviator striking his head against the cowl. It was suggested that the cowl be cut out so as to give 8 inches more in front. A report just received from the Royal Air Force, Canada, states that since this change in the cowl has been made these head injuries have been practically eliminated. Another suggestion was to lash the safety belt to the machine by a simple rubber shock absorber; the same report states that since this has been done, the number and extent of injuries to the upper abdomen and ribs have been decidedly reduced" (Air Service Medical, 1919, pp. 30 & 32).

In summary, during the period 1907 through World War I the military, especially the Signal Corps (formed in 1907) led the way in occupant safety devices. The seat (lap) belt appeared in Army aeroplane No. 1 (1909), and leather helmets, followed by leather and steel helmets were introduced in the period 1910-1917. One of the earliest technical discussions of crashworthiness design methods to protect the aircraft occupant appeared in a series of engineering articles in The Aero in 1910. Among the design criteria recommended were enclosed cockpits and placing the engine in front to protect the pilot, using a leather helmet, (head injuries were already recognized as a major cause of fatality by 1910), steel tube airframe, and use of a broad leather seat belt. A reconstruction of a 1910 crash was conducted in 1962, indicating fatality occurred at only 4 G. A detailed medical analysis of WWI pre-1919 military crashes found many belt failures were also found and it was recommended that a broad belt be used and attached to the framework rather than seat. Padded nacelle edges were found standard by 1919 in military aircraft.

3.2. Post-World War I 1920-1939. During the 1920's civil aircraft design, manufacture, and flight was completely uncontrolled and without regulations until December 1926. Accident data for this period are also incomplete. The first Department of Commerce report on civil air accidents and casualties was issued 10 March 1928 (Information Bulletin No. 30). For the year 1927 there were reported 200 accidents involving 164 fatalities and 149 injuries, with 167 aircraft being "washouts." Only 34 of the 200 accidents occurred with licensed planes, and only four of the pilots were licensed. Charles Lindbergh, with four bailouts by 1927, typified the hazards of early flying and was nearly grounded by the Department of Commerce prior to his transatlantic flight in 1927 (Time, 28 November 1977, p.24). While there was mounting concern about the accident toll, the emphasis was on prevention rather than occupant crash protection. Nevertheless, even during this early period various individuals drew attention to the need to better protect the pilot.

The first requirements for seat belts in U.S. civil aircraft were published in the Air Commerce Regulations effective 31 December 1926. This rule, under "equipment," specified that "3. Safety belts or equivalent apparatus for pilots and passengers in open cockpit airplanes carrying passengers for hire or reward;" (p.11). But since the rule specified "open cockpit airplanes," it did not apply to all aircraft. This is why the enclosed-cabin passenger aircraft such as the Ford Tri Motor, with its wicker seats, did not have seat belts installed as standard equipment.

In the early 1920's Doolittle, then a Lt. in the Army Air Service, presented a paper at the ASME emphasizing a need for better cockpit design, so that if a pilot crashed there would be less chance of a fatal injury (Doolittle, 1929). He discussed the effect of velocity on aircraft damage and occupant injury, and went on to point out "feature to which insufficient attention is given in designing and constructing an airplane so that it crashes well. This sounds odd, but many lives have been saved because the cockpit was strong and there was sufficient material between the pilot and the ground to absorb the shock of crashing. This permits gradual, uniform deceleration between the instant of impact and the pilots' eventual coming to rest" (Doolittle, 1929, p.147).

The first attempt at dynamic crash testing aircraft took place in 1924 at McCook Field (Wright-Patterson AFB) Dayton, Ohio (Lederer, 1971). The three aircraft tested were run down an incline and crashed against a concrete wall for crash-fire testing. This study was prompted by the heavy loss of U.S. Air Mail pilots in fires following the crash of DeHavilland bombers with plywood fuselages and cloth-covered wings.

In 1925 Lederer, aeronautical engineer for the U.S. Air Mail Service, attempted to reduce head injury in crashes (one of four was fatal) by installing a net of elastic cords in front of the instrument panel. But it was feared that it might break the pilot's neck, and was abandoned (Lederer, 1971).

Between 1930 and 1932 air carrier operations suffered a passenger fatality rate of 22.34 for every 100 million passenger miles, although this fell to 6.14 by 1935 (U.S. Dept. of Commerce, 1944, p.49). Approximately 90% of the aviation fleet was wood and fabric covered, with 320 of the 400 airliners of 1931 single-engine, flown by a single pilot. Of the first 40 pilots hired by the U.S. Post Office Department in 1919, 31 (77.5%) had been killed in crashes by 1925 (Serling, 1971, p.7).

Studies of catapulting of airplanes from ships in the early 1930's showed that aircraft structures of that time could not be economically strengthened beyond 3-4 g, although it was thought that the crew could withstand accelerations of 5 g. (The first successful launch had been made in 1912 at a speed of 46 mph and mean acceleration of 2.3 g). Limits of acceleration on the body was the subject of increasing interest in the 1930's, but primarily from an operational viewpoint. In a 1932 paper presented at the Royal Aeronautical Society, RAF Wing Commander Marshall proposed an air cushion seat attached to a wide abdominal belt composed of air sacs which would provide increasing body restraint the more g pressure was exerted on the seat (<u>Flight</u>, p.99, 1933). An article in <u>Scientific American</u> in 1933 discussed the safety belt as an indicator of abnormal aircraft attitude (Klenin, p.124).

The heavy incidence of head and facial injuries in Army Air Corps accidents of the late 1930's led Lt. Col. Malcolm, then chief of the medical section, to send a request to Capt. Harry Armstrong, Director of the Physiological Research Laboratory at Wright Field, Dayton, Ohio, to give priority to designing and testing a shoulder safety belt. This resulted in the B-12 shoulder harness. Seat belt experiments at the Equipment Branch of the Material Division at Wright Field had been going on since about 1936. They had found that at 8 G's the subject jackknifed when the lap belt was used alone. But when both lap and shoulder belts were used no jackknifing occurred up to 15 G's. It was estimated in 1939 that an impact deceleration of 30 G's could be withstood without serious injury, provided the belt anchorages were designed to take the drop tests conducted at that time (Air Corps News Letter, 15 October 1939). At about the same time as this U.S. Army Air Corps study, similar efforts were under way in Germany.

In 1937 Beechcraft staged a crash-landing ("belly landing") daily at the National Air Races at Los Angeles and subsequently at the 1937 Miami Air Show. This was intended to demonstrate that under emergency conditions the Beechcraft C17B biplane could be safely landed with gear retracted, even on rough terrain, without major damage to the aircraft or injury to its occupants. From 2000 feet altitude the engine was cut, the propeller locked in a horizontal position, and a dead stick landing gear-up was made on the hard ground in front of the grandstand - sliding to a stop in "170 feet or less." A standard commercial biplane, it was equipped with a pair of "sled-like steel runners mounted on the bottom of the fuselage, to protect the fabric covering." "After each demonstration it was hoisted up, the gear was extended, and it taxied away." "Successful belly landings were made on plowed ground, on hillsides, and even in pine woods where trees eight inches in diameter were mowed down by the airplane on its landing run." (McDaniel, 1947).

In Germany medical investigation of aircraft accidents had been conducted since at least 1934, and it was soon recognized that besides the causes of pilot failure "it is imperative to determine whether failures of the structure or design of the plane have contributed directly to injury of the occupants" (Ruff, Compendium, 1939, English Translation, 1942). Accident data showed an overwhelming number of head injuries in airplane crashes. In 1937 alone five fatalities of German flying students, 14 serious injuries, and 64 cases of slight injury were attributed to "forces produced by bouncing. In nearly all of these accidents the flying craft was undamaged or only slightly damaged and the safety belt and the seat were usually intact" (Ruff, On Resistance in Man, p.3, 1941). It was recommended that in addition to the crash helmet, and improvements to the seat, the pilot should be fastened to the seat by both a lap belt and shoulder belt (Ruff, Unfallerfahrungen, 1937).

As a result of these medical findings a series of scientific biomedical studies of crash forces, pilot tolerances, and structure and belt restraints was initiated. It was found that carrier landings could produce decelerations of 4-5 g, "forced alighting" of fast landcraft such as the Messerschmidtt 109 could result in decelerations up to 20 g - exceeding 30 g in forced landings, and that "the forces of inertia which come into operation, and if they do not exceed the tearing limits of the belt, are transmitted via the safety belt to the strapped-in occupant of the plane." In order to determine the strength of the restraint, seat, and anchorage points, tests with human subjects were conducted.

The abdomen was found capable in early tests of an ability to bear a load in the direction of flight of "up to twice the breaking point of the single belt band,* which is at least 1200 Kg (1500 Kg for the latest belts)" (Ruff, p.4, 1941). The arrangement and belt angles were also found to be important concerns. A dynamic testing apparatus consisting of a seat and cables in a pendulum configuration tested subjects almost to the failure ("tearing") limit of the belt, of 1200 Kg. The belts

*This belt is described as a "16" wide lap belt" in German Aviation Medicine in WWII, and has subsequently been referred to as such in various references by other authors (including myself). A recent analysis of this point by R.F. Chandler, Chief of the Protection and Survival Laboratories, Civil Aeromedical Institute, FAA, is included in the interests of clarifying this since these data are frequently referred to. "I believe this is a mis-interpretation of what was really done. On the same page, the advantages of spacing the seat belt anchorages 16 to 20 inches apart (wide?) are discussed. This is followed by a discussion of human tests in which the "subject wore an abdominal belt 40 cm (16") wide."

In Ruff's paper "Concerning Human Tolerance of Acceleration as it Applies to Certain Jerking Types of Acceleration Which Occur in Flying," Oct.31, 1941, Vol.47, Trans. Ger. Acad. of Avia. Development, a very similar discussion of the advantages of 40 to 50 cm spacing of seat belt anchorages, not the width of the belt. (In the discussion after Ruff's presentation, Madelong speculates about a belt covering the whole abdominal region. If Ruff had presented data about such a belt, speculation about its performance would have been out of place.)

Since both of these papers refer to the same work, and since it would be illogical to consider an impractical 16" wide belt (especially in wartime), I feel that continued reference to the "16 inch wide" seat belt is perpetuating an unfortunate myth."

(Chandler, personal communication, 1981) used were of an energy absorbing type (German Aviation Medicine in World War II, p. 596). In a subsequent investigation of a glider accident in 1939, a belt deceleration load of 1700 Kg (or 26 g) "produced not the slightest injury" to the lap-belted student pilot, showing that tolerance values had not yet been reached.

3.3. 1940-1949. Attention to crashworthiness considerations, restraint systems, and human tolerance increased greatly during and subsequent to World War II. Military studies led to improved restraint systems, and Air Force studies initiated at Murroc, Edwards, and Holloman AFB, particularly by Captain John Paul Stapp greatly increased knowledge of human impact tolerances. During this period the National Research Council and its newly formed Crash Injury Project under DeHaven was studying causes of occupant injuries in civil crashes and CAB injury data. A large body of crash injury data was analyzed.

A key developer of crash impact protection in general aviation aircraft during the 1940's was Dr. Hugh DeHaven. Drawing upon his own crash experience in 1917, he pioneered accident investigation studies and free-fall investigations to determine the relationship of crash injuries with structure and human tolerances to impact. In 1941 he noted that "we have air-safe light airplanes which are not safe...the cockpit and cabin is set up today substantially as it was twenty-five years ago, and there is no reason to expect less injury now when a crash does come than in 1915" (DeHaven, 1941, p.25). In November 1941 the National Research Council (NRC) Committee on Aviation Medicine recommended that a special three-person committee possibly chaired by DeHaven be formed to study airplane crashes, the nature of injuries, and measures to prevent injury in crash impacts. Ironically, it was stated (by Dr. Fulton of Yale) that "seat belts are highly dangerous" (NRC Rept. 34, 14 November 1941).

The NRC Crash Injury Conferences were established to bring together the Army, Navy, civil and industry engineering, and medical groups interested in the development of safer aircraft from a crash injury viewpoint. In August 1942 the CAB first started to include the survey of injury causes as part of accident investigation. Sponsored by the NRC, the Crash Injury Project under DeHaven studied the CAB medical reports to relate the extent of injuries to the nature and placement of causative objects, indentify hazardous structure responsible for unnecessary injury, and observe causes of survivable accidents. Study of injury in 30 light-aircraft accidents revealed that the force of most crashes is within human tolerance, and many severe or fatal injuries stemmed from mechanical design factors which could be modified or eliminated (DeHaven, 1942).

With the outbreak of the second World War the National Research Council formed a Committee on Aviation Medicine. In 1942 the Office of Scientific Research and Development and U.S. Navy Bureau of Aeronautics contracted to Cornell University Medical College work concerned with aircraft crash injuries and their prevention, through the NRC Committee. This work was coordinated with the new Army and Navy effort in these areas with the CAA accident investigation. Eugene DuBois, M.D., a Navy Captain and Flight Surgeon and Professor of Physiology and Biophysics at Cornell, published several papers in the engineering and medical literature reporting cockpit hazards and the special need for head protection. He noted that "the human body when properly held in harness would stand 30 G and probably 40 G without material injury" (DuBois, 1945, p.3; 1954a p.41).

By 1943 DeHaven had developed a 10-point injury scale (with four degrees of fatal injury), and CIR crash data had been provided to the CAA to set up future requirements for 3,000-lb. safety belts. An aircraft accident and injury report form was provided to CAB and CAA investigators.

In May 1944 the Crash Injury Committee made 18 recommendations for a safer cockpit, recommending contoured metal seats; further shock absorbers of 25 to 50 G's capability to replace wooden seats; redesign of control stick, control column, cowling, and rudder pedals; strengthened longerons; turnover protection; reinforced firewall; elimination of sharp edges in cockpit design; and an instrument panel with 6-8" head clearance. It was emphasized that the shoulder harness, seat belt, seat, and attachments should remain intact under a force of 50 G's applied AP or vertically. They also suggested integrated design of an entire cockpit assembly mounted on shock absorbers capable of 25 to 100 G's.

Biomechanics was urged as a new approach to airplane crash safety in a 1944 paper pointing out the military coordination of medical and engineering studies (Gratz, 1944). Noting that head injuries "occur in 90% of major crashes," aircraft crash protection could be improved by use of protective features such as crash-pads and elimination of projections in the cockpit. Aircraft biomechanical studies of this nature were initiated in the combat zone of the Pacific Theater of Operations in June 1942.

The Fourth Crash Injury Conference was held in Washington, D.C., 21, 22 February 1945. A major subject reported upon was the recommendation for a 40 G seat for military fighter aircraft (1/3 load to shoulder harness and 2/3 to the lap belt), and discussion of seat failures in current accident studies. It was evident in medical data from crashes that the the strength of the human body had been "grossly misjudged and that designers have been working in complete ignorance of the proper strength of seats, harness, and cockpit structures. These and other cockpit installations have failed to give adequate protection in crashes where adequate protection would have spared injury and saved valuable personnel." The existance of war surplus aircraft led to consideration of future crash tests (Randall, 9 March 1945).

In July 1945, DeHaven of the NRC made a detailed report to the CAB, based upon medical data and crash details from field investigations of the CAB Safety Bureau. This study supplemented the 1943 study of 30 crashes with 185 more crashes (110 in tandem and 75 in side-by-side seating). It concluded that failure of 1000 lb. safety belts occurred in 94 cases among 260 survivors, human tolerance has been grossly underestimated, head injury is related to heavy instruments, solid panels, seat backs, and unsafe design and arrangement of control wheels. It was noted that in certain military aircraft pilot protection has increased to the point where current seats with harness are capable of withstanding 40 g impacts (NRC, Rept. 440, July 9, 1945).

In April 1947 the Crash Injury Research project of the National Research Council published a listing from general aviation manufacturers of new features on 10 models of aircraft which were advances in occupant protection. These included the following:

- 1 new production model had shoulder harness attachment point
- 3 aircraft had engine sections and supports desinged to protect the occupant through progressive collapse in a crash
- In 6 new aircraft occupants are seated further aft to get increased protection from forward structures
- In 4 aircraft using control wheels, the instrument panels have been moved froward away from the pilot
- 4 aircraft use no horizontal or vertical tubing around the pilot
- 1 aircraft has a landing gear of "extraordinary energy-absorbing characteristics." 3 manufactuers state their gear is extra rugged and designed to increase the protection of occupants in crashes
- Strong turnover structures are provided in 4 planes
- 5 instrument panels are designed to lessen the danger of head injury
- All 10 planes have moderated or eliminated solid structures within forward range of the head
- 3 planes are reported to have "special ruggedness" in all cockpit structure
- 3 manufacturers reported use of stronger seats and seat anchorages
- Pivoted backrests on forward seats, to lessen chances of injuries caused by rigid structure, are used in 6 planes
- 5 aircraft have developed keel or skid structure to help prevent the nose from digging into the ground during wheels-up landings or low angle crashes
- 1 manufacturer has placed the baggage compartment forward between the engine and pilot, to provide increased crash protection

Many of these improvements were as a result of the NRC crash safety work (NRC, 3 April 1947).

A 1948 CAA/CAB working group studied the question of effect of a shoulder harness on pilot operational ability in five transport models, and concluded that 18" forward movement allowed did not interfere (King, 1948). Other questions about seat belts asked in the 1940's related to injuries that might be caused by the seat belt and the belief that the shoulder harness might break the neck. DeHaven (1948) and DuBois

(1945, 1946) showed that injuries attributed to the lap belt were in fact less than 1%; 2.4% in 1949 (CIR, P. 9, 1949), significantly less than if the occupant were not wearing a belt. Military crashes calculated at over 40 G and Air Force tolerance tests initiated at Muroc, and later Holloman AFB, would prove that impacts to 57 G forward facing were tolerable without neck injury .

Crash Injury Research (CIR) reports and accident findings under auspices of the NRC during the 1940's documented the need for crash-worthiness improvements, and pinpointed the changes that could make future aircraft safer in a crash (DeHaven 1944; 1944a; 1944b; 1945; 1946; 1948; 1948a; CIR 1949; 1950; 1950a; ; NRC 1947; <u>Aviation Week</u> 1949; DuBois 1945; 1945a; 1946). By 1947 there had been a 27.9% gain in the number of fatal accidents over 1946. By mid-1949 manufacturers' had responded to CIR recommendations by reporting a number of crash design improvements:

- forward diagonal braces designed to buckle outward under heavy crash loads (1 aircraft)
- engine sections designed for progressive collapse (3 aircraft)
- occupants seated further aft (6 aircraft)
- no horizontal or vertical tubing around the pilot (4 aircraft)
- protective energy-absorbing landing gear (2 aircraft)
- stronger cockpit structure (2 aircraft)
- instrument panels moved forward (4 aircraft)
- instrument panels designed to lessen head injury (5 aircraft)
- <u>shoulder harness standard equipment</u> (1 new crop duster)
- stronger seats and seat anchorages (3 aircraft)
- pivoted backrests on forward seats, to lessen chances of injuries caused by rigid structure (6 aircraft)
- Windscreen and side windows designed to knock our rather than shatter (1 aircraft)
- Safety control wheels (6 aircraft)

(CIR Report 12 August 1949, Appendix A).

Many of these features had also been reported as improvements in 1947 (CIR 3 April 1947).

"Must the Airplane Be Designed for Crashes?" was the subject of a 1948 confidential report by the Chief Engineer of a major air carrier airframe manufacturer. The report analyzed the direction that the safety regulations were going as promulgated by the CAB and administered by the CAA. In particular it questioned the regulation of strength of aircraft seats and belts, and the extent to which the aircraft must be designed for crashes. This analysis was inspired by the new 6 g forward CAR requirement of November 1945, based upon findings that the 170 lb. body could take considerably more than 1000 lbs., which was a 50% increase in the previous 4 g forward load component. It was noted that CAR requirements for non-carrier aircraft at the time were 9 g, Air Force requirements increased to 18 g and 40 g was strongly advocated, as many specifications for Navy aircraft were already at 40 g. The CAB Safety Bureau was advocating 20 g. The body could tolerate much higher values, perhaps to 200 G. Thus the trend seemed clear. The viewpoint was brought forth that the 6 g seat requirement was going too far, that the general public judges the acceptable risk, and that increased cost and weight penalities were calculated to result. The argument was given that the trend toward increasing crash protection is contrary to the public good, and that this should be abandoned "before the industry is irrevocably committed to it as a matter of policy" (McBrearty, 1948, (revised 1951) p. 16). It was concluded that efforts should instead be directed to accident prevention. This may be the first such document expressing one viewpoint which has continued to the present.

An internal analysis of 1442 light plane accidents involving 1942 occupants was made by the Civil Aeronautic Administration in 1949. However, this study was not published (Morrow, 1949).

Three aircraft were being developed in 1949 "which include most of the features recommended by Crash Injury Research" (DeHaven, CIR 6007, 1950, p.5). The Koppen-Bollinger Helioplane, with progressive collapse design, "extra strong" seats and belt anchorages, and shoulder harness for each occupant; the Meyers 145 with optional shoulder harness; and the Texas A & M Cropduster designed by Prof. Fred Weick with 40 g seat, 40 g cockpit, 40 g safety belt and shoulder harness, which DeHaven reported "probably will provide greater crash protection for the pilot than any aircraft developed to date" (p. 6).

By 1949 Crash Injury Research, started in 1942 under auspices of the NRC, was functioning under the Cornell Committee for Air Safety Research, with support from AOPA, CAA, Air Force, Navy, and Personal Aircraft Council of the Aircraft Industries Association. Results of the first six years of crash injury investigation (655 accidents) were summarized in Aviation Week (pp. 19-22, May 2, 1949). Unnecessary injuries in crashes were found due to the head striking instrument panels, structural tubing, and control wheels or rigid seat backs. The 2000 lb. seat belts and seats were found to fail often, and 4000 lb. belts were recommended by CIR (while noting that Air Force and Navy pilots can be court martialed (1949) for not wearing the 40 G/8000 lb. shoulder harness and seat belt). More rugged cockpits, progressive collapse characteristics, crash-absorbing aircraft structure, and cockpit tubing designed to buckle outward and stressed to prevent cabin collapse in turnovers were among crash protection findings recommended. Twelve current general aviation aircraft had reportedly adopted various crash protection changes as a result of this study.

In 1949 CIR compiled a report, "Features Governing Safety in Aircraft Accidents," with illustrations of ways of increasing crash protection in small planes. A summary was published in Aviation Week on 13 March 1950 entitled "Crash Safety Can be Engineered," and an abbreviated list of recommendations was provided in the CIR annual report for 1949-1950 (No. 6008, Sept. 1950).

In 1950 DeHaven reported "in January 1950, information was released on Air Force Experiments being conducted at Edwards Air Force Base, Muroc, California, on human tolerance of crash decelerations. These experiments conclusively demonstrated that the human body can withstand near decelerations of 35 g (and peak loads of 57 g) without injury. They therefore corroborate estimates made by Armstrong and Grow in 1939 that human beings could survive 30 to 50 g and statements by CIR that a person can, if properly protected, withstand decelerations which will demolish the cockpit and cabin structures of existing aircraft...For many years CIR has been trying to persuade airplane manufacturers and engineers that increased crash protection in their planes would be a worthwhile investment in terms of lives saved" (p. 8).

A summary of light aircraft accident studies conducted during the 1940's shows that crash injury aspects had received extensive investigation during this period. Some 2375 accidents occurring between 1942 - 1952 have been studied for crashworthiness and injury causation by various investigators, although some of these cases may have overlapped:

1943	30 light-aircraft accidents (DeHaven NRD Rept.230, 17 Nov. 1943) 60 occupants (included 60 accidents, 30 side by side occupants and 30 in tandem seating, 120 injured occupants)
1948	655 accidents, 1105 injured occupants (DeHaven 1948)
1949	1442 accidents, 1942 occupants (Marrow, 1949)
1942-1952	248 front-seated occupants (Pearson, 1961) selected sample

Military Research. Military studies and findings during this 1940-1949 period made major contributions to crashworthiness design knowledge. During World War II the Germans increased the research efforts initiated in the mid-thirties in study of ejection seats and acceleration effects upon the pilot. Work at the Medical Research Institute at Garmissh-Partenkinchen by Henschke investigated the effect of maximum accelerations on the pilot (Lovelace, 1945; Lovelace and Wulff, 1946). A major objective, as with the British and American military efforts, was to protect personnel in aircraft crashes.

One specialized objective of the German studies was to design tactical use of aircraft for mid-air ramming of other aircraft. The limit of tolerance of the human body for acceleration forces of short duration was thought to allow considerable emphasis on this work. Ruff had initiated tests showing that 100 g impacts for 0.01 might be expected (Army Air Forces, 28 February 1946, p. 3).

It was found that an accelerative force of 10 g during 0.01 seconds against the head causes symptoms of cerebral concussion. The limit of deceleration force with an occupant protected by lap belt and shoulder harness was 34.3 g, without symptoms of concussion. This work was conducted on a swing. It was concluded that aircraft cockpits should be designed to withstand crashes of at least 34 g (Andrews, 1946).

German findings that 50% of all injuries in aircraft accidents were head injuries, and that they accounted for 70 to 80% of the fatal injuries, led Ruff to request a shoulder harness be worn in all German Air Force aircraft, and that in training aircraft the flier be prevented from striking a structure even when only a lap belt is worn. This required a free space between the belt and panel of 31.5 to 45.4 inches (80-90 cm). "Thus in a crash landing, the upper part of the body can freely swing forward without striking against solid parts. The practical application of these ideas in small private and training planes proved satisfactory" (Ruff, 1942, p. 597). Ruff's work in crash landing protection, determining human tolerances, and seat-restraint studies was probably the most extensive to that time. From tests and analysis of accident data he concluded that forward impacts of 20 g could be tolerated without injury with a lap belt only, and rear-facing impacts of 28-30 g could be tolerated without injury. In cadaver spine vertical studies he determined that 26 g was the limit, and conducted ejection tests of human subjects to 30 g (at 0.1 sec) which he felt "almost" the limit of non-reversible injury tolerance, and this subsequently was the basis for German ejection seat specifications. The first test track facility, designed in Germany in 1939, consisted of a light cabin propelled by a falling weight. However, air raids destroyed this facility before it was used.

Early in World War II the Germans used a shoulder harness that would withstand 25 G's. This was several years before the U.S. or British increased their requirements (AAF memo Rept., 20 March 1945, p. 9).

In England the Royal Air Force, concerned about the losses of flying personnel in crashes, had instituted a number of engineering studies at the Royal Aeronautical Establishment (R.A.E.) in 1941 through 1943 (Watson Jones, 1941; Pekarek, 1941; 1941a; 1942; 1943; 1943a). These dealt with various aspects, including cause of injuries and relationship to structures, deceleration forces, deficiencies of existing equipment, testing of seats and restraint systems. It was concluded by 1943 that high priority should be given to organization of a specialized group to investigate the correlation of aircrew injuries occurring with aircraft design. Improvements in crash design and safety harnesses were proposed - that cockpits be strengthened, and that a system be started to correlate aircraft damage and crash factors with injury sustained. It was found that head injuries resulted in up to 63% fatalities in various commands (Cade, 1942; Gilson and Stewart, 1943). Pekarek safety cells, designed to distribute the impact forces on the body, were proposed (Pekarek, 1943), and the Sutton Harness (7-8g) was modified with a 4-5" lap belt to withstand 10 g. In addition, the R.A.E. conducted tests on captured German Air Force 10 g safety harnesses (R.A.E. 1942; 1942a; 1942b). In the 1947-58 period, human deceleration experiments were conducted at Farnborough using a rocket driven trolley along a railroad track (Ellis, 1955).

By 1944 the British had raised crash deceleration requirements for all future pilot's seats and harness from 10 to 25 G, and 25 G for crew. For passengers in transport aircraft the British proposed 10 G as absolute minimum and 25 G as the goal (Ministry of Aircraft Production, 5 Jan. 1944; AAF memo report, 20 March 1945).

During this period the U.S. Army Air Corps was developing a major role. Technical order 03-1-2 (dated 1 October 1940) and technical order 03-1-2 (of 16 July 1941) specified that army airplanes in active service would be equipped with a suitable safety belt which included the Types A-1, B-6, B-10, B-11 "and commercial type safety belts." F.O. Memorandum No. 32, Addendum No. 21 (dated 8 June, 1942) and Revision No. 1, Addendum No. 21 (dated 30 March, 1943) were superseded by F.O. Memorandum No. 7-21 (dated 29 December 1943) which set forth Military Requirements Policies for "Pilot's Safety Belt and Shoulder Harness." This stated that it was policy that "Pilot's safety belt and shoulder harness shall be installed in all Army Air Forces aircraft in service or production in all positions where such type of belt is needed, i.e., pilot and co-pilot; and in tandem seated training aircraft - pilot and student." In December 1943, the AAF equipment board recommended a safety belt, shoulder harness, and inertia lock be required.

A compilation of U.S. Army Air Corps memorandum and reports between 1943-1945 dealing with the shoulder harness has been made by Lovelace (1945). One study showed that 80% of those using a shoulder harness in crash landings (belly landings) were unhurt, while 94% of those not using a harness were injured. A report by the Office of Flying Safety analyzed 168 cases and found, of 95 cases of concussion in head impact, the shoulder harness was not used or furnished in 78 cases (AAF memo, 20 March 1945).

A study of 1,536 accidents during three months of 1943 in the training command showed that the head was involved in 87.5% of the non-fatal injuries. About 10% of the fatalities could have been prevented with head protection and use of the shoulder harness (10 August 1943).

Studies by Haas at the School of Aviation Medicine at Randolph Field, Texas were aimed at determining the nature of injuries to the abdominal area as a result of aircraft accidents (Hass, 1944; 1944a; 1944b). He concluded that structural redesign of cockpits and strengthening of assemblies was necessary, finding that some cockpit hazards and collapse of aircraft structures are the cause of many abdominal injuries.

Concurrently, studies of crash injuries were continued by the Aeromedical Laboratory of the Engineering Division, Material Center, at Wright Field. A January 1943 questionnaire on use of shoulder harness and crash injuries, responded to by all Air Force commands, revealed that the shoulder harness was not universally available or used at that time (Benson, 1943).

In February 1945 Army Air Forces Air Technical Command issued a Military Requirements Policy (No. 21, 18 January 1945) requiring installation of pilot's safety belts and shoulder harness on all Army Air Force combat aircraft, single-engine trainers, cargo gliders, troop carrier aircraft, and all cargo aircraft (except UC and ATC) in service and in production. This established a general policy for future aircraft procurement, although some military aircraft had shoulder harnesses much earlier, and No. 7-21 of December 1943, established this as policy.

The B-15 shoulder harness was standardized for the Army Air Forces in 1945. This had a static tensile strength of 1,400 lbs. (or 7 g for 200 lb. man). The B-14 seat (lap) belt was standard at this time and had a static strength of 3,200 lbs. (16 g for 200 lb. man). This belt and seat assemblies were recommended to be increased to 25 to 40 g.

Prior to 1945, Navy seats were stressed between 5 and 15 G's "so that in crashes exceeding this amount the pilot and his seat both are catapulted onto the rigid projecting structures of the cockpit" (Bierman, 1947a, p. 126). In 1945 it was decided to stress military seats to 40 G's, although this had been recommended for many years previously.

In 1946 Bierman et al. of the Navy's Bureau of Medicine designed and tested a new "Model C" semi-rigid belt type harness which distributed the load over the body, protected volunteer subjects against 2,500 lbs. force (equal to 10,000 lbs. in conventional harness), and was designed for 40 G (Bierman, et al., 1947). A subsequent investigation of nine aircraft, crashed experimentally into a solid dirt barrier at approximately 100 mph, and decelerating within 5 ft., was conducted to simulate stalls from 300-500 feet altitude. It was found that the human injury threshold is exceeded only during the first 0.15 second. He concluded that restraint protection up to 65 G's is possible (Bierman, 1946; 1947a).

In 1947, the U.S. Navy dynamically tested some 77 civil aviation safety belts supplied by the National Research Council. They concluded that individuals have frequently survived impact loads of 2,500 lbs., even where the belt covered less than 15 square inches of body surface at greater than 150 psi, without injury. Comparative tests disclosed that static tests gave values 22% less than dynamic tests (Wurzel et al., 1948).

An air inspector report on Army Air Force accidents in 1947 noted that "safety belts in general use by the AAF are not designed to withstand over 10 G's," and seat assemblies "are designed to withstand 10 G's or less," 50 G's was recommended. Seat failure was found to occur in 4.9% of accidents and accounted for 62 fatalities in 1,620 accidents (AAF, 1947, pp. 8-9).

On 5 May, 1945, a joint conference of NRC, Navy and the Air Force was held to investigate the possibility of a joint project to study effects of Crash Forces on Man and Material. Investigations to be undertaken included (1) comparison of dynamic and static testing, (2) investigation of stress failures of aircraft seats, shoulder harness, safety belts, inertia locks, and other experimental devices which may increase man's tolerance against crash forces, and (3) use of animals and cadavers to determine man's tolerance to withstand the effects of crash forces. The project originally was to be under the direction of E.J. Baldes at the Mayo Clinic, but required laboratory facilities which could best be provided by the Air Corps.

As a result of the NRC Crash Injury Conferences, the Aero Medical Laboratory developed a linear rocket sled decelerator at Muroc Experimental Air Base, California, which was operational by December 1947. In June 1949, Major John Paul Stapp made the first report of 15 tests of three male subjects (including himself) decelerated in 5 G increments to 30 G's for .11 second in the backward facing position, without reaching voluntary tolerance levels (Stapp, 1949).

By March of 1945 Army Air Corps accidents in the continental limits of the U.S. were costing 13 fatalities and 12 aircraft demolished every day. A memorandum report from the Aero Medical Laboratory reviewed both military and civil findings in detail. Among conclusions were that numerous aircraft design changes were necessary. These included removing hazardous projections in cockpits, use of turnover protection, and that the cowling of the instrument panel should either be eliminated, constructed of resilient, pliable material, or redesigned to give adequate head clearance in a crash. Current light metal and wooden seats were found to frequently fail, and a minimum of 25 G and preferably 40 G seats were recommended. Rearward facing passenger seats were recommended.

In 1945 AAF seat specification ANS-1 stated that a seat belt fastening would be tested to a breaking strength of 1,600 lbs. at 40° from the horizontal for bomber aircraft, and 2,400 lbs. at 40° in fighter aircraft. These were found inadequate and 25 G (5,000 lbs. at 40° angle) belts recommended. The Aircraft Laboratory, AAF, stated their objective was to require 5,550 lb. belts (AAF Memo Report, 20 March 1945). Attention was paid to the DeHaven study of 30 light plane accidents in which seat belt failure occurred in 43% of the crashes and the belt failed to hold 30% of the persons involved (DeHaven, 1944). These recommendations were circulated to "all design engineers of the aircraft companies for incorporation of such recommendations in future aircraft," including the general aviation manufactuers, Beech, Piper, Cessna, Waco, Taylorcraft, and Stinson (AAF Memo Report, p. 25, 20 March 1945).

In Navy tests of the F6F fighter seat it was found that the applied static loads of 7,300 lbs. (equivalent to 36.5 g for 200 lb. pilot) will impose loads on the seat structure equivalent to the 40 g dynamic test (Gottlieb, S., 1948).

During 1948 and 1949 "radically new crashworthy features" were embodied in preliminary designs for the CAA Texas A & M Cropduster, the Helioplane, and Beech Twin Bonanza, and details of their structure provided. Crash design improvements were also noted for the Twin Cessna, Meyers 4-place, and Mooney 4-place, (p.iv). The crash design features, including standard upper torso restraint of the Meyers 145 were reviewed in Aviation Week (March 13, 1950). The development of crash-survival design was subsequently detailed in a report by DeHaven in 1953 in which "crashworthiness was featured in the design and engineering of basic structures" in three small airplanes during World War II - the Bendix, Fairchild, and Waco (p.iii).

In June 1949 a USAF Air Material Command Engineering Division study concluded that the minimum strength recommended for USAF aircraft is 16 g forward (except for 8 g seats in helicopters, liason aircraft, and troop seats), and that a 40 g forward strength requirement (already required by the Navy) be established for fighter and trainer aircraft.* There was considerable controversy over the effect that increased seat strength would have on weight. Boeing Aircraft Company reported to the Air Force that 40 g seats on the B-52 bomber would increase weight for all crew stations by 290 lbs. for a total increase of 2,320 lbs., since it reportedly required 7 lbs. of fuel for each additional pound of weight. AMC estimated seat weights would increase to 345 lbs. but only 4 lbs. of fuel would be required, thus 1,725 total weight increase. However any weight penalty was balanced by the potential number of lives which could be saved. The Air Inspector General in a communication to the USAF

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* For clarification, references to a 40 g Navy seat are based on the Navy definition using a 200 lb. man, therefore a 40 g Navy seat is equivalent to a 8,000 lb. ultimate load strength (40 x 200 - 8,000 lb.). However the USAF definition differs since it is based on a 250 lb. occupant, thus the USAF 16 g seat is equivalent to a Navy 20 g seat (16 x 250 = 4,000 lb.). The USAF 8 g and 6 g seats used in this period are therefore equal to 10 g and 7.5 g seats, using Navy standards.

Chief of Staff pointed out that a study of USAF accidents had found seat failure in 5% of "sudden stoppage accidents" with a fatality rate of 65% for personnel occupying those seats, and disputed that a significant weight penalty would be involved in increasing seat requirements to 40 g longitudinally and 20 g vertically for tactical aircraft, and 20 g longitudinally and 10 g's vertically for non-tactical aircraft (letter of 28 April 1949; Aircraft Seat Failures).

The Crash Injury Research annual report for the period July 1, 1948 to June 30, 1949 reviewed data from 655 crashes involving 1,105 individuals. It was found that in 80% of the cases where safety belt installations failed the breakage occurred in the webbing. "New "3000 pound" belts will require webbing with a loop holding capacity of 4500 pounds" (CIR, August 12, 1949).

The interchange of knowledge concerning crash impact protection between the medical and engineering communities, established during WWI, was demonstrated in the 1940's by numerous examples as previously noted. In 1949 the Engineering section of Aviation Week published a summary of aviation medical knowledge of how much force the body can withstand, together with some of the first tolerance tables and a complex chart providing body positions, accelerations, stopping distances, and time duration factors (Lombard, 1949). Further articles on crashworthiness appeared in the issues of 20 February 1950 and March 13, 1950. During the 1940's it became evident that crash testing of aircraft under controlled conditions would become an important means of learning more about crashworthiness. Such tests were urged by the military, National Research Council and Crash Injury Research, and by the airline industry (Littlewood, 1945). By 1950 a substantial body of crash research data was available, relating to crash injury causation and protection in crash investigations, restraint systems, and crashworthiness.

4.0 CONCLUSIONS

Review of accident statistics provides a basis for concern. The U.S. general aviation aircraft fleet has increased during the past five years (1976-1980) at a rate of 3.4 to 7.3% per year and presently numbers about 208,000 active aircraft, with an estimated 250,000 total aircraft. General aviation aircraft are expected to number 315,500, a 44.1% increase, by 1992. It is apparent that general aviation is the most rapidly growing form of transportation. The following statistics show why there is increasing urgency to deal with general aviation crashworthiness safety:

1. Probability of an Accident. During the past decade (1969-1978 over 100,000 occupants have been involved in 43,557 general aviation accidents. Of these, 6,996 were fatal (that is, one or more occupants were fatally injured) and during this period 14,194 fatalities occurred. Accidents were equivalent to 38% of the total U.S. non-carrier aircraft production during this 10-year period, and ranged from 25 to 65% of annual production. It has been estimated that 60-70% of all aircraft manufactured will be involved in an accident during their lifespan.

2. Probability of Fatality When Accident Occurs. Annually there are about twice the incidence of fatal injuries when compared to serious injuries. The chances of being killed in a general aviation accident appear to be about 2 in 3, as compared to receiving more than minor injury. One's chances of receiving disabling (serious) injury are about 25.8 times that of being fatally injured in an automotive accident, given that the accident is severe enough to cause at least serious injuries.

3. General Aviation Fatality Rate. The fatality rates provide another means by which the crash safety record of general aviation aircraft can be judged, relative to other forms of transportation. Published figures to date consistently indicate that no other form of transportation except motorcycles is more dangerous when a crash occurs. The following statistics have not previously been published. Assuming an average load factor of 2.0, in 1979 there were 25.9 occupant fatalities per 10^8 million miles; with a load factor of 2.5 this changes to 17.3. Even the lower figure is 432 times that of air carriers, and 13 times the rate for automobiles. To be conservative, assuming passen-

ger fatalities are 50% of total fatalities, and reducing the 1979 general aviation occupant fatality rate from 17.3 to 8.7, the general aviation aircraft fatality rate is still 216 times that for the airlines* and 6.5 times that of the automobile.

4. Aircraft Damage and Occupant Injury Relationships. With 180,854 active general aviation aircraft registered in 1976, the 1,075 aircraft "destroyed" represented only 0.6% of the entire fleet, or 7% (6.959) of the 15,447 aircraft manufactured that year. However, if planes receiving substantial damage are also included, over 2.3% of the total fleet was involved, and the equivalent of 27% of all aircraft manufactured that year were either destroyed or received substantial damage. There is a lack of direct relationship between aircraft structural damage and resultant injuries.

5. FAA Certification. An important point often overlooked in considering state-of-the-art with respect to FAA certification requirements is that a newly manufactured 1981 aircraft may have been certified under earlier Part 3 requirements and "grandfathered." Most of today's general aviation fleet was certified under earlier CAR requirements effective prior to Part 23 (1964).

One especially important crashworthiness area where the problem of "newly certified" aircraft is apparent is in the FAA's amended shoulder harness rule. With a compliance date of 18 July 1978, this amendment added requirements concerning shoulder harnesses and compartment interior design for the type certification of small airplanes and an operating rule requiring a shoulder harness for each front seat in certain newly manufactured small airplanes (Part 23.785 (g). Thus only "certain newly manufactured" aircraft are actually required by the FAA to meet this amended standard.

Yet the FAA stated that "over the next 25 years, it is estimated that approximately 1,875 lives may be saved by this amendment at an average cost of less than $5.5 million per year" (F.R. 42(116): 30603, 16 June 1977). These data show that shoulder harnesses (even just in the front seats) represent a major step in occupant crash protection, supporting the NTSB position. However the FAA has chosen to limit this requirement to the relatively few "newly certified" aircraft and has not extended it to other seat positions.

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*Domestic scheduled air carrier, .04 passenger fatalities per 100 million passenger miles.

Part 23.561 Emergency Landing Conditions

The current FAR #23.561 contains problems for the user in interpretation, confusion in terminology, and, perhaps most importantly, requirements considered to be outdated for occupant protection in today's technology. Thus, rather than forming a set of basic requirements for improved design, it encourages continuing the design standards of 40 years ago, resulting in second-rate ("minimum") crash protection for aircraft occupants.

1. "Minor Crash Landing." At present there is no objective description for the term "minor crash landing" in requirement #23.561(b). These conditions were set forth in 1946, although they were not state-of-the-art at that time. If a "minor crash landing" is considered to imply that the resulting damage to the aircraft is "minor" or less, this appears to be unrealistic when compared to accident data showing that only 1.2% of accidents between 1968 and 1976 were assessed as resulting in minor damage.

The concept of the "survivable crash" was developed in the 1940's by DeHaven, and resulted from accident findings in innumerable investigations to study the problem of occupant survival in aircraft crashes. The U.S. Army currently uses the term survivable accident, and has defined a "survival envelope" of environmental conditions in providing design guidance for the aircraft engineer.

RECOMMENDATION: It is recommended that the term "survivable accident," or "survivable crash," be substituted in this requirement [23.561(b)].

2. "Every Reasonable Chance." #23.561(b) Paragraph (b) currently reads "the structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing..." Changing "every reasonable probability" to "reasonable assurance" weakened this requirement in 1946 and 1950, and modifying to "every reasonable chance" in 1964 did little to strengthen it. The original wording of 35 years ago was stronger

than that of today, and today's requirement, changing "probability" to "chance," appears weakened by this modification, particularly in combination with the undefined term "minor crash landing."

RECOMMENDATION: Eliminate the subjective terms altogether, and consider rewording to "the structure must be designed so that each occupant will escape serious injury in a surviviable crash..."

3. "Ultimate Inertia Forces." #23.561(b)(2). The load factors criteria for occupant protection has not changed in 35 years despite substantial advances in research on human tolerances since 1945; and terminology changes have produced some apparent technical errors which remain unclarified at this date. It appears that the ultimate inertia forces criteria originally specified in 1945 originated from the airframe structure rather than that of the human occupant. The basic structural load factors of fuselage strength dating back to 1926 required load factors of 4.5 to 6.5, while structural strength of landing gear in the 1926 requirements called for a side load of 1.5 times the (airplane).weight. Fifty-five years later the FAA standard still requires only 1.5 g for side loads on the occupant.

Human impact tolerance design limits. The published data relative to human tolerances to crash impact landings is extensive. In most instances the "limits" derived from human subject tests do not refer to fatal, or even severe (non-reversible) injury levels, but have resulted from voluntary "whole body" tests up to a subjective pain or discomfort level. The deceleration referred to is "whole body" impact; contact with the chest, legs, or head on interior structure is localized "regional" impact. These are three levels of whole body "tolerance": subjective pain limits, an irreversible or serious injury level, and a fatal level. In contrast to the current FAR requirements discussed in regard to forces on the restrained general aviation aircraft occupant

(#23.561), field data from aircraft crash investigations and research data related to human impact testing have long documented that current requirements provide considerably less occupant protection than has been the state-of-the-art. In the forward-facing ($-G_x$) seated position, protected only by the lap belt restraint, human subjects have been voluntarily tested to 32 G (at a velocity of 10.5 mph with a duration of 0.001 sec. at an onset rate of 1600 g/sec) with no significant injury (Test No. 5), (Stapp, 1971).

In human deceleration tests conducted in 1957 at the University of Minnesota, a subject restrained by a lap belt only received no injury in a forward impact of 23 G's and seat belt force of 2800 lbs (at 25 mph impact velocity). It was concluded that a seat-belt force of 7000 lbs. and deceleration force of 60 G's could be sustained with "no permanent injuries." It has been found that seated human occupants restrained by a 3-in. lap belt only and subjected to aircraft crash forces can survive 30 peak G at rates of onset below 1,500 G/sec with only minor reversible injurious effects. But if the torso is not also restrained, the lap-belted occupant will almost certainly strike any forward structure. Use of an upper torso restraint can increase whole-body human tolerance limits to approximately 50 G peak (at 500 G/sec rate of onset for 0.25 sec duration) (Stapp, 1951): "Abrupt decelerations of 50 G's can be sustained without loss of consciousness or injury and impact of more than 100 G's can be survived" (Stapp, 1971).

Rearward-facing ($+G_x$) tolerances are considerably higher than for either forward- or side-facing positions, primarily due to the greater distribution of loading throughout the entire back area of the seated occupant, and thus the lower kg/sq cm (psi) per unit area. This results in greater stress on the seat back which must be constructed to fail at higher levels than a forward-facing seat. While human tolerance for rearward-facing body orientation has not been clearly established, the occupant so protected can be expected to withstand 40 G peaks at 30 G for 0.11 sec duration when calculated rate of onset is 1,065 G/sec (Stapp, 1949), and 40 G peaks at 2,000 G/sec with severe but transient responses (Stapp, 1961). To date, a level of 83 G (chest acceleration), at 3,800 G/sec for 0.04 sec duration, has been tolerated, with only transient injuries reported (Beeding and Mosely, 1960). The current Air Force design limit falls between this and 45 G for 0.1 sec endpoint (AFSC, 1969; 1974). Knowledge of human response to lateral deceleration forces ($\pm G_y$) is very limited, but subjects with lap belt and upper torso restraint have been exposed to 40 G, and 35 G for durations up to 0.1 seconds duration is the estimated exposure limit to prevent injury (Stapp, 1971). The voluntary subjective tolerance level was found to be 14.1 peak sled G at 600 G/sec for 0.122 sec duration.

General aviation aircraft have no design standards, in contrast to all other categories, for downward forces. A downward value of 0 to 4.5 g was required for general aviation design in 1945, but was dropped in 1946 (03.3811) without explanation. In contrast, military aircraft design standards have directly utilized results of human tolerance tests and have reflected the state-of-the-art fairly closely for the past 30 years. An FAA Office of Aviation Medicine staff study in 1968 concluded that "there are no standards dealing with occupant protection in moderate to severe survivable accidents. It is concluded that human tolerance to acceleration forces is much greater than the forces generated during some of today's "nonsurvivable" accidents. We have 40 g people riding in 20 g airplanes, and sitting in 9 g seats and restraint systems."

RECOMMENDATION: Human impact tolerance levels for injury are far above present requirements. This fact should be taken into consideration in updating and increasing seating, restraint, and attachment design criteria. Part #23.561 should be amended to include downward (vertical) and rearward design values (since rearward facing seats are being used).

Confusion in terms. A technical problem that has not apparently received further attention was expressed in an internal FAA analysis which questioned the substitution of the term "force" for "acceleration" without reversing the directions. In 1946 the term "ultimate accelerations" was used (and retained in the revision adding #3.386 in 1950). However, the present #23.561(b)(2) has used the term "ultimate inertia forces" since 1964. (The original expression in 1945 also used "ultimate inertia forces" in "all combinations"). The question was whether the upward and forward force is not actually in the opposite direction of upward and forward acceleration. Similarly, in Part 23.561(b)(2) is "upward ultimate inertia forces" the same thing as "upward utlimate accelerations" (Car 3.386)?

RECOMMENDATION: A solution to clarify this point is simply to add a definition (or reference in glossary) together with a simple coordinate system figure illustrating exactly what is meant relative to direction of loading on the occupant.

4. "Moderate Descent Velocity". This phrase cited in #23.561(c)(2) provides that "Each airplane with retractable landing gear must be designed to protect each occupant in a landing - (1) with wheels retracted; (2) with moderate descent velocity ...". The original #04.260 (14CFR3, 1945) requirement specified an "ultimate descent velocity of 5 fps," but this was modified the following year to the present "moderate descent velocity." Other than the 5 fps original requirement, no further definition has been found in the FAR's or amendments. The FAA requirements for vertical descent velocity protection is presently on the order of only 1/3 to 1/8 that of military aircraft (Air Force standards are 25.0 G for 0.1 sec; Army Design Guide specifies protection in the vertical impact di-

rection for a velocity change of 42 ft/sec.) In view of technology which has produced the UTTAS crashworthy military helicopter, there is no doubt that the state-of-the-art and technology is considerably beyond the FAA requirement of 35 years ago. "Moderate descent velocity" is an unclear term that must be better defined and upgraded to provide the improved protection available with today's technology.

RECOMMENDATION: An objective and meaningful definition is needed to clarify specifically what this requirement means. Part #23.561(c)(2) needs to be upgraded to better reflect the state-of-the-art for vertical impact protection and the multitude of structural means to accomplish improved energy-absorption and reduce loads on the seated occupant in a crash.

5. "Turnover..Upward Ultimate Inertia Force of 3 g." Part #23.561(d)(1) states "If a turnover is reasonably probable, the structure must be designed to protect the occupants in a complete turnover, assuming in the absence of a more rational analysis - (1) an upward inertia force of 3 g; and (2) a coefficient of friction of 0.5 at the ground." The origins of the present turnover requirement have roots back to at least 1938. Since 1946, when the distinction between up and down vertical forces was abandoned, it has not been clear what the present "upward" force referred to in 23.561(b)(2) and (d)(1) means. Turnovers are not uncommon. In one study of crashes, 38% of the high-wing general aviation accidents studied ended up inverted, and 24% of the low-wings overturned. In northern states such as Michigan in the winter, 3 out of 5 aircraft accidents in winter months may involve overturns. The requirement for 3 g protection was established some 34 years ago. Both aircraft performance and structures have changed since that time, but there is no evidence that the FAA has attempted to improve this requirement.

RECOMMENDATION: In view of the apparent incidence of overturns, attention should be given to upgrading this section of #23.561, to require stronger cabin rollover protection.

6. Title and Content Revision. The present #23.561 as the primary occupant protection standard, has a number of weaknesses, inconsistencies, and many outdated requirements discussed previously. In many ways it is not even as useful as the earlier CAR 3.386-1 (crash protection), which between 1951 and 1964 provided a series of guidelines for crashworthy design. In the past, modifications have been made piecemeal by adding or dropping words or patching-in phrases.

RECOMMENDATION: In view of the number of places needing updating in this section, it would make better sense to modify 23.561, by starting all over and developing a totally new section on occupant protection. Such a new section should reflect the emphasis on crashworthiness by retitling it from "emergency landing conditions" (of 1945) to something like "emergency crash landing conditions," "crashworthiness protection," or "occupant crash protection." Further, additional guidelines should be incorporated to provide more meaningful information to the designer.

Part 23.785 provides requirements for seats, berths, safety belts, and harnesses. It references emergency landing conditions in #23.561, flight control reactions in part #23.395, and fitting factors in #23.625. Safety belts have been required in open cockpit airplanes since 1926. In 1934 belts and their attachments were first required to withstand 1000 lb crash loads, and this was upped to 1500 lbs in 1950 (although the FAA made an exception to the NAS Standard 602 which specified 3000 lbs for a single belt). There has been no increase in safety belt strength requirements in 31 years.

1. Occupant Weight (#23.785(a)). The present general aviation aircraft design structural requirements for both seat and restraint strength are based upon a 170-pound occupant. This stan-

dard has not been modified since first specified in 1929, fifty-one years ago. The importance of the occupant weight specification to crashworthiness is often overlooked. However, it forms the basis for required seat belt and seat structural strength load tests.

The U.S. population of 1980 is significantly larger than that of the 1920's. In a nationwide (HANES) health survey in the 1970's U.S. males were found to range from 129 lbs. (5th percentile) to 173 lbs. (50th percentile) to 224 lbs. (95th percentile). Given that a 5th percentile female with a mass of 104 lbs., and a 95th percentile male (224 lbs.), are each exposed to a 9 g acceleration (F=MA), the force on the seat/restraint/anchorage system will range from 936 lbs. to 2016 lbs. - more than a two-fold difference. A 170 lb. occupant weight is close (170 vs 173 lb.) to that of the 50th percentile U.S. male. However, it is far short of today's 95th percentile male of 224 lbs., considerably less than the 225 lbs. used by NASA in transport seat design, the 250 lb. USAF design occupant weight, (MIL-S-26688), and the Army's 222 lbs. pilot, or troop/passenger 95th percentile clothed weight of 265 lbs. (MIL-STD-1290 AV).

At present about 15% of U.S. females and approximately 50% of U.S. males weigh more than 170 lbs. Thus a significant portion of general aviation pilots and passengers are not protected under #23.785(a). The CAA's first articulated crash dummy in 1950 weighed 215 lbs. From the point of view of protecting the greatest number of occupants, use of the 95th-percentile male basic weight of 224 lbs. (101.8 kg) would be current human factors design practice. That would protect the middle 90% of the population. This would be in line with current military use of the 95th percentile of the male population at risk. Continued use of the 170 lb. standard means that only 50% of the male population (and 85% of the female population) is within this range. The Army Crash Survival Design Guide recommends that the upper and lower limits of occupant weights be considered in seat design and that, ideally, seat stroke limits should be sized for the 95th-percentile occupant, while the occupant acceleration limits should be determined by the 5th-percentile.

RECOMMENDATION: Part 23.785(a) should be amended to increase the occupant weight requirement from the present 170 lbs. to 224 lbs., and the Army's practice of using both 5th- percentile and 95th-percentile occupant weights should be adopted. (A U.S. 5th-percentile woman weighs 104 lbs.).

Static Load Reaction. #23.785(e). Part e presently requires that the forward end of a berth be constructed to withstand the static load reaction of the occupant, when the occupant is subjected to forward inertia loads specified in #23.561. A static test does not realistically simulate a crash environment, and a structure designed to accommodate a static load reaction, particularly at the low levels specified in #23.561, may fail when subjected to the dynamic loading of a crash impact. FAA tests comparing dynamic and static tests of aircraft seats concluded that static testing cannot be related to crash environments.

RECOMMENDATION: Part 23.785(e) should be amended to require dynamic test criteria (already developed and used by the FAA).

Static Load Tests. #23.785(e)(3). Three alternative proofs of compliance are listed for safety belt attachments to the berth under emergency landing conditions prescribed in #23.561 for lateral ultimate inertia forces of 1.5 g and upward forces of 3.0 g. No test is required for forward forces. At present compliance is allowed by structural analysis, static load tests, or a combination. There is no provision for more realistic dynamic load tests. 1969 FAA tests comparing procedures of TSO C-22 and C-39 for certifying aircraft were compared to the dynamic test procedures the FAA developed. These tests documented and clearly established the requirements for dynamic seat testing, and questioned the validity of static tests.

RECOMMENDATION: Part 23.785(e)(3) should be amended to require dynamic test criteria.

Safety Belt (Shoulder Harness). Part 23.785(g). Section g presently requires a safety belt and shoulder harness only in the front seats, despite a considerable body of data dating back to the 1940's (and earlier) documenting the crash protection offered the occupant. The NTSB has recommended to the FAA since 1964 that shoulder harnesses by required for each occupant. The FAA responded in 1965 by saying there was not sufficient justification (despite the FAA's own research studies to the contrary). The 1973 NPRM included proposals to install shoulder harnesses. A final rule was published in 1977, and harnesses in the front seat were not required in newly certified aircraft until after 18 July 1978. It required 14 years for FAA to act on this NTSB recommendation.

RECOMMENDATION: (1) Amend part 23.785(g) to require installation of approved shoulder harnesses at all seat locations (as outlined in NPRM 73-1 and recommended in A-77-70 December 8, 1977 by the NTSB). (2) Amend 14 CFR 91.33 to require installation of approved shoulder harnesses on all general aviation aircraft manufactured before July 18, 1978, after a reasonable lead time, and at all seat locations as outlined in NPRM 73-1 and recommended in A-77-71 December 8, 1977 by the NTSB. (3) The FAA has no standard related to shoulder harness performance. Test procedures for compliance should be issued immediately. (4) The FAA has no standard related to inertia reel test performance. Test procedures for compliance should be issued immediately.

TSO's. The Technical Standard Order system is one of several methods of obtaining approval for a material, part, process or appliance to be used on an aircraft. It was established by the Civil Aeronautics Act of 1938 and is found in Part 514 of the Regulations of the Administrator. All TSO's have been previously listed in Part 37 of 14 Code of Federal Regulations. Effective September 9, 1980 under a TSP Revision Program intended to expedite the issuance of standards a new public procedure has been adopted, and Part 37 has been revoked. The manufacturer obtains a TSO authorization by submitting an application and various supporting documents to the region in which the manufacturer is located, although there is "shopping around" since until December 1980 each region set its own interpretations. The FAA found 47 of the 86 current TSO's obsolete in a 1971 review.

RECOMMENDATION: All TSO's should be immediately reviewed relative to state-of-the-art and amended to reflect the updating necessary. Priority attention should be given to former Part 37.136 (TSO-C39a) for seats (also TSO-C25a for air carrier seats), and former Part 37.132 (TSO-C22f) for safety belts.

TSO-C39a/NAS 809. The minimum performance standards for seats and berths to be installed in certified general aviation aircraft is currently provided in TSO-C39a for Type II - normal and utility category. The present FAA requirements for seats and seat tests were last revised in 1956 (when NAS 809 replaced NAS 806, dating from 1950) as referenced in TSO-C39a. The FAA published a NPRM including a proposal to increase certain aircraft seat strength requirements in 1969, and initiated development of new seat TSO standards in 1970, which included general aviation by 1977, with new draft. TSO seat standards completed in 1978. A 1967 FAA report had shown seat strengths "inadequate" in 17% of accidents in the forward direction, 36% to 58% downward (Part 23 has no requirement for this direction Another 1967 FAA report stated that 1.5 g side load requirement is inadequate. In one 1978 study seat failure was found in 28% of all fatal and serious injury accidents. Military standards have long been significantly higher, and at least one manufacturer has developed a 25 g seat.

RECOMMENDATION: General aviation seat strength requirements specified in TSO-C39a should receive priority attention to upgrade. As an interim measure the new FAA TSO completed in 1978 should replace the present TSO.

Safety Belts. TSO-C22f formerly (Part 34.132). Since 1929, there has been only two updatings of the original 850 lb. seat belt strength requirement for civil aircraft. Increased to 1000 lbs. in 1934, U.S. civil aircraft seat belt strength is promulgated on standards (NAS 802) last revised 27 years ago (1950). The FAA in TSO-C22f allows an exception in seat belt assembly strength, reducing the 1950 standard by 50%. Current FAA belt strength standards for all categories of civil aircraft are 1500 lb. in tension load and 1.9 times rated strength (loop load strength of 2850 lbs.) in a static test. The accident record, however, has shown that these minimums have needed to be updated since the original National Research Council crash injury studies of the 1940's. Virtually every accident survey from 1943 on emphasized belt (as well as anchorage, and seat) failures and the need for stronger belts. In 1961 the FAA found that 42% of seat belts tested failed to meet minimum webbing strength tests. The Commonwealth of Australia has reported a belt or attachment failure rate of 18% in fatal and serious-injury accidents occurring during 1969 and 1970 in general aviation accidents. Accident studies results have been supported by crash seats. NACA in 1953 concluded that belts should be capable of withstanding higher breaking loads than those presently in use. During the 1970's there has been increasing use of stronger belts by the general aviation manufacturers as automotive webbing manufactured to FMVSS 209 has been readily in supply. However, although 5500 lb. webbing has been commonly supplied to the manufacturers, most general aviation belts are still rated at 1500 lbs., primarily due to limitations of the hardware (buckle), although some is rated at 3000 lbs. Military restraints and automotive restraints, from the same suppliers, are rated at 6000 lb. (Type I) and above.

RECOMMENDATION: In view of the accident crash test data over the past 30 years documenting the need for stronger restraint systems, TSO-C22f should be upgraded to be at least comparable to the webbing strength protection provided in automobiles. The restraint-seat system must be considered as a whole, since restraint is no stronger than its weakest link - in this case the hardware (buckle and attachments), which should be upgraded as well. It is recommended that restraint systems in general aviation aircraft should be designed for a forward load of 25 G's applied 20 degrees to either side of the airplane's longitudinal axis; an upward load of 16 G; a downward load of 15 G; and an aft load of 5 G.

Safety Belts and Harnesses. #23.1413. The rated strength of safety belts and harnesses is specified to be not less than the ultimate load factors of #23.561(b), or 3 g upward, 9 g forward, and 1.5 g sideward. Applied to a 170 lb. occupant, this translates to a required minimum belt strength of 510 lbs. upward, 1530 lbs. forward, and 255 lbs. sideward. No fitting factor is involved. Since FMVSS No. 209 requires automobiles manufactured for sale in the U.S. to use 6,000 lb. webbing for Type 1 (lap belt) restraints and 5,000 lb. pelvic webbing and 4,000 lb. webbing in the shoulder harness (36 FR 22902, Dec. 2, 1971), webbing of this strength has been currently available for many years.

RECOMMENDATION: Part 23.1413 should be modified to realistically update these webbing strength requirements to take into consideration the state-of-the-art of present (5500-6000 lb.) belt availability. This would also serve to greatly strengthen and upgrade one important link in the occupant crash restraint chain.

Fitting Factors. #23.625. The present requirement for fitting has been in effect since 1964, as amended by 23-7 (34 FR 13091, August 13, 1969). Section (d) requires a fitting factor of 1.33, as follows. This means that seat and belt attachments must be shown to withstand 1.33 times the 9 g, 3 g, and 1.5 g ultimate inertia forces listed in 23.561, or 4 g (3.99) upward, 12 g (11.97) forward, and 2 g (1.99) sideward. The fitting factor has been decreased from the 1929 1.80 requirement to its current value of 1.33.

RECOMMENDATION: Since this requirement has an important bearing on seat and safety belt attachment strength, it deserves further engineering review.

Consolidation of seat, belt, berth, and belt attachment factors. In 1969 the FAA proposed that Part 23 be further amended for small airplane type certification, proposing that 23.625, 23.785, and 23.1413 be consolidated to place seat, berth, and belt attachment factors all in one section. At the present time, in order to find pertinent requirements for seats and restraints one must go to three separate parts of Part 23 (23.625, 23.785, and 23.1413), which in turn reference other sections and standards (23.561, NAS 806, NAS 809, #34.132 - TSO-C22f).

RECOMMENDATION: Consolidate all seat, berth, and belt attachment factor requirements into a single section.

Child and Infant Restraint (TSO-C100, proposed). Equal protection has not been provided to all aircraft passengers. To date there are no standards regarding restraint protection at all for children or infants under two years of age. FAR Part 91.14(a)(2) states that a person who has not reached his second birthday may be held by an adult who is occupying a seat or berth. FAR Part 121.311(b) and FAR Part 127.109(b) uses similar statements. Yet tests conducted at the University of Michigan have clearly documented that in moderate or severe crash decelerations it is not possible for lap and shoulder belted adults to adequately restrain children in their laps by holding on to them. FAA testing of infant/child restraints has been proposed since 1961. In 1974 a CAMI test study was conducted, followed by further infant/child dynamic tests in 1975, and draft TSO specifications. The 1974 study was not published for four years, and the draft TSO not issued for public comment until October 1980. Proposed as TSO-C100 in the Federal Register of October 2, 1980, in general the proposed TSO is based upon the current automotive vehicle FMVSS No. 213 (49 CFR 571), with additional provisions addressing materials flammability, in-flight body containment, and marking and data requirements. The number of infant/child restraints which are actually in use in general aviation aircraft are unknown.

RECOMMENDATIONS: (1) Pilots should be educated concerning adequate protection of their younger passengers.
(2) An interim action in allowing certain automotive infant/restraint systems be used on aircraft seats (not blocking emergency egress) would offer considerably greater impact protection to children than is presently the case where an infant must be held in the parent's lap without restraint or children are improperly and inadqequately placed in adult restraints.

The purpose of this study was to provide AOPA with an in-depth review of the current FARS in Part 23 related to general aviation aircraft crashworthiness safety, to see how well the FAA has kept up with the state-of-the-art, and suggest any areas where improvements should be considered. The basic question is, how well are today's general aviation aircraft pilots and passengers protected from crash impact? It is concluded that present standards for general aviation aircraft do not provide the levels of occupant crash protection feasible within the technical state-of-the-art, and "minimum" standards must be raised (ref. 49 U.S. Code Sect. 1421(a) minimum standards (1), p. 12057).

In reviewing the monumental literature and documents available regarding research results (many conducted by or for the FAA itself), one is struck by the realization that "this has all been said before." There are literally thousands of studies (over 6000 on restraints alone to 1964) documenting all aspects of occupant protection. As is discussed in the body of this report, many excellent studies have provided crashworthiness recommendations for the past 70 years. But, in particular, much information from experimental and crash research investigations dating from the 1940's appears not to have been utilized in the regulatory process. Ironically, today's FAR's provide even less guidance to the manufacturer and require less crash protection in some areas than the preceding CAR's of 30 years ago (see Part 3.386-1, 1950).

Periodically over the past 40 years, excellent summaries of the crashworthiness state-of-the-art have been produced. All of them provide documentation and say essentially the same thing. Some outstanding examples include the series of accident studies and reports of the National Research Council and Crash Injury Research, and the publications of DeHaven and DuBois and the NRC in the engineering and medical literature of the 1940's; the numerous NACA documents of the early 1950's resulting from dynamic crash tests at Cleveland of light aircraft, summarized in "NACA Conference on Airplane Crash-Impact Loads, Crash Injuries and Principles of Seat Design for Crashworthiness" (1956); Hegenwald's analysis of the crash protection state-of-the-art transport design in 1962; Bruggink's 1961 Aviation Crash Injury Research (Av-CIR) report on impact survival in air transport accidents; 20 years of crash injury/safety/occupant protection recommendations -- and more recently, the U.S. Army's Aircraft Crash Survival Design Guide (Versions 1967 through 1980), and the proceedings of the 1975 Aircraft Crashworthiness Conference, to select but a few. The pioneering work of Beechcraft, which in 1951 led the general aviation industry by conducting dynamic shoulder restraint tests resulting in a 20.3 G shoulder harness (the 216 lb. dummy used was equal to 25 G protection for a 160 lb. man)-- which still exceeds many present installations 30 years later, apparently made no impression on the FAA. Upper shoulder harnesses had been installed in aircraft in the 1940's (at Ohio State University since 1948), and one model has had upper shoulder harness in the rear seat as well as the front seat since 1954.

By the 1940's there was not only abundant documentation from both civil accident investigation and military studies of the need for improved crashworthiness protection, but what could be done and how. The findings of "needless injury" described by DeHaven in 1943 have been supported by a number of studies in the 1950's and 1960's (particularly by FAA's own researchers) warning that as many as half of those killed annually in accidents could survive, and dangerous-to-life injuries could be prevented in 1000 individuals per year if existing information on occupant protection were incorporated in aircraft design. As the above documents illustrate, there was a growing body of knowledge available 30-40 years ago. This knowledge has been incorporated into military aircraft design specifications for 35 years. Some features, such as shoulder harnesses in civil aircraft purchased by the military, or exported to England or Australia, have been required for over a decade. This knowledge has been the basis for Federal Motor Vehicle Safety Standards that make today's automobiles far safer in a crash than in a general aviation aircraft.

It is concluded that the FAA has given insufficient attention to, and has in the past resisted, updating regulations in the area of crashworthiness which would effectively reduce fatalities and serious injuries in general aviation crashes. Since general aviation is the most rapidly growing forms of transportation, with a 44.1 percent increase to 315,000 aircraft estimated by 1992, priority attention should be given to updating the FAR's related to crashworthiness.

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APPENDICES

APPENDIX A

PROPOSED

SAE ARP 1318

AEROSPACE RECOMMENDED PRACTICE

GENERAL AVIATION SEAT DESIGN

Approved by SAE Committee A23 October 21, 1975
Disapproved by SAE Aerospace Council/Equipment Division December 30, 1975. Published as Appendix in SAE Publication No. 780017, February 1978. Reprinted in SAE Transactions, Vol. 87, 1978.

1. PURPOSE

The purpse of this ARP is to provide design criteria for pilot and passenger seats for general aviation aircraft. It includes recommendations for features involving function and utility as well as for minimum strength and energy absorption capabilities.

In the preparation of this recommended practice, consideration was given to the requirements of the Federal Aviation Regulations, the results of numerous accident investigations and research programs and the recommendations of aircraft operators and manufacturers.

2. SCOPE

The pilot/passenger seat is the basic link between the occupant and the primary structure of the aircraft. It is essential that the support and tie-down functions be accomplished in a manner that will provide maximum practical safety and security during all normal conditions of flight, emergency flight maneuvers, crash landings and survivable type accidents. These basic functions shall be given major consideration as compared to other factors such as comfort or appearance.

This ARP is intended for application to aircraft approved under Part 23 of the Federal Aviation Regulations. Although most general aviation aircraft in this category are approved for single pilot operation, those recommendations noted as applying specifically to pilot seats will be understood to apply to any seats for which the occupant has access to the airplane flight controls.

In the design areas for which they apply, the Federal Aviation Regulations should be considered minimum requirements.

3. DEFINITIONS

3.1 Seat Assembly - One complete seat unit, whether for single or multiple occupancy. The seat assembly may include but not be limited to the seat structure, cushions, trim panels, arm rests, dress covers, ashtrays, headrests and accessory pockets or shelves as applicable.

It does not implicitly include seat belts, shoulder harnesses, seat tracks or other equipment normally attached to the primary structure of the aircraft.

3.2 Seat Primary Structures - That portion of the seat structure which provides the support, restraint and energy absorption link between the occupant and the aircraft primary structure.

3.3 Seat Secondary Structure - That portion of the seat structure intended to meet comfort, utility or appearance requirements.

3.4 Seat Ultimate Static Load - The highest load to which the seat may be subjected for a minimum of three (3) seconds without failure.

3.5 Seat Ultimate Dynamic Load - The highest load to which the seat may be subjected under conditions of dynamic arrest without failure or loss of restraint function.

3.6 Standard Occupant Weight - Static and dynamic seat loads shall be based on a standard occupant weight of 170 pounds (acrobatic 190 pounds).

3.7 Neutral Seat Reference Point - The intersection of a line tangent to the surface of the seat bottom cushion and a line through the seat back cushion representative of a back tangent line, under a no-load condition.

3.8 Seat-Back Breakover - The design feature which permits the seat-back to fold forward from the normal upright position for purposes of passenger access or seat installation, removal or storage.

4. RECOMMENDATIONS

4.1 Dimensions - The recommended ranges for seat dimensions are given in Figure 1. Illustrations are for dimensional purposes only and are not intended to fix the actual shape of the seat. It is understood that all dimensions influenced by passenger weight (i.e., cushion deflection) are to be measured under 1 g static loading with an occupant of standard weight.

4.2 Adjustment - Adjustable pilot seats are recommended in order to insure that occupants of different sizes and weights can perform their work in the most efficient and comfortable manner. When such adjustable seats are provided, the following adjustment ranges are recommended.

4.2.1 Vertical Adjustment - Where practical, the pilot seats should be adjustable vertically through a range of at least four (4) inches in increments of no greater than 1 inch throughout the entire range. The purpose of seat adjustment is to provide the optimum eye location for visibility inside and outside the cockpit and to provide comfortable and efficient access to the controls. The adjustment mechanism should incorporate a means of raising the seat freely to the maximum up position. It should be designed in such a way as to insure against inadvertant actuation to extreme positions during normal or emergency flight conditions. It is recommended that the vertical adjustment controls for the seat should be located under the left hand forward portion of the seat.

4.2.2 Angular Adjustment of Seat-Back - If angular adjustment is provided or if the seat-back has breakover provisions, it need not be restrained in the normal upright position against forward motion under the loads specified in Section 4 unless the shoulder restraint harness is attached to the seat back structure. If the shoulder restraint harness is attached to the seat back, then the seat back should be capable of withstanding, in any normal position, the inertia loads specified in Section 4.4.2.

4.2.3 Fore and Aft Adjustments - Where practical, the pilot seat should be adjustable in the fore and aft direction for a distance of at least eight (8) inches in increments of not less than one (1) inch. For aircraft equipped with adjustable rudder pedals, appropriate reductions in fore and aft adjustment are acceptable so long as the relationship between the seat position(s) and the control for pitch and roll permits efficient and comfortable operation.

The fore and aft adjusting mechanism and latches should be designed in such a way as to insure against inadvertant actuation, either by the occupant or by inertial forces, to extreme positions during normal or emergency flight conditions. In the interest of standardization, the fore and aft seat actuation controls should be located under the right forward portion of the seat.

4.3 Arm Rests - If arm rests are provided as part of the seat structure, they should be designed to fold in such a way as to minimize interference with entrance to or exit from the seat. Insofar as practical, arm rests should be padded or designed to reduce the likelihood of injury to the occupants in the event of a survivable crash.

4.4 Strength - Pilot and passenger seats should be designed to the following general and specific strength recommendations.

4.4.1 General

4.4.1.1 Failure of the seat secondary structure under crash landing conditions should not affect the strength of the seat basic structure. Consideration should be given to design features which would minimize the possibility of incapacitating or fatal injury to occupants in the event of a failure.

4.4.1.2 Likely deflection of floor and sidewall structure under crash landing conditions should be considered in establishing seat and seat attachment integrity.

4.4.1.3 Wear and Tear due to normal use should be considered in designing the seat basic structure to meet the specified load conditions. Special consideration should be given to the design of adjustment mechanisms.

4.4.1.4 Material selection and testing should take into account possible deterioration of strength properties with time for those materials which have an effect on seat strength.

4.4.1.5 The seat basic structure should be suitably protected against corrosion of all types to which it may be subjected in service. The design should avoid wherever practical trapped areas where spilled liquids can accumulate and cause corrosion.

4.4.1.6 Seat design, construction and attachment should be such as to prevent objectable flexing of the seat under turbulent flight conditions.

4.4.2 Dynamic Ultimate Loads - The pilot and passenger seats and their attachment to the airframe should be designed in conjunction with the occupant restraint system, to withstand the following dynamic load factors without separation failure (refer to 4.5 on Energy Absorption).

4.4.2.1 A forward load of twenty-five (25) g's applied twenty (20) degrees to either side of the longitudinal axis an aft load of 5 g's, an upward load of 16 g's and a downward load of 15 g's. Load directions should be determined with respect to the longitudinal axis of the airplane. The pulse shapes and durations for the above loads are specified in Figure 2. Load factors should be measured at the seat tracks or on the corresponding airframe support structure.

4.4.2.2 Structural compliance should be demonstrated for the most adverse combination of the loads specified in 4.4.2.1.

4.4.2.3 Aft-facing seats should be designed and qualified to the loads specified in 4.4.2.1. The occupant center-of-gravity to be used in the analyses of tests for aft-facing seats is given in Figure 1. When headrests are incorporated as part of the restraint system, considerations should be given to the resulting body load distribution.

4.4.2.4 Side-facing seats are not recommended. If used, they should be designed or located so that the occupant is restrained from lateral loadings in excess of the side loads resulting from the loadings specified in 4.4.2.1 in case of forward facing seats.

4.4.3 Static Loads - Since there does not appear to be a consistent relationship between static and dynamic strength of complex structures, no alternate static loads are recommended for structural substantiation of aircraft seats for use in lieu of the dynamic loads given in 4.4.2.

4.5 Energy Absorption - As a minimum requirement, the seat structure should be designed to deform progressively when the ultimate dynamic load is exceeded and, during deformation, to absorb as much energy as possible. For seats designed specifically to attenuate crash forces, plastic deformation of the energy absorption elements should not be considered to be a structural failure so long as the occupant support function [illegible]

4.6 Restraint Systems - The seat represents one part of the over-all occupant restraint system, which may also include the lap belt and upper torso restraint. The seat should be designed in conjunction with the other elements of the restraint system and should not interfere with their proper function. Specifically:

4.6.1 Upper Torso Restraint - Seat-back height specifications of Figure 1 are based on considerations of protection, comfort and convenience. If the seat-back incorporates provision for shoulder harness attachment, the attachment position should be located above shoulder height or be designed so as to prevent the shoulder harness from imposing uncomfortable down loads under normal operating conditions. If attach point is located lower on the seat back, the seat-back should not fail under the specified dynamic conditions. (Refer to SAE ARP 1226, Occupant Restraint System (Active) for General Aviation Aircraft).

4.6.2 Lap Belt - If restraint system loads are carried by the seats, the seat-to-airframe attachment strength should be equal to or greater than the dynamic load factors given in 4.4.2.

4.6.3 General - Seat belts and shoulder harness should be designed to be used and stored in such a way as to prevent entanglements with seat, controls or structure. Automatic storage provisions are desirable.

4.7 Design - The following general design recommendations are intended to improve the comfort, utility and the safety of the pilot and passenger seats.

4.7.1 The seat should be designed to support the occupant within the normal flight envelope and under crash conditions as defined by the minimum applied unit loadings of 4.4.2.1 and 4.4.2.3. The provision is particularly important for the design of seat pans to absorb vertical impact forces.

4.7.2 Seat materials should comply with the flammability requirements of Flight Standards Service Release No. 453 or later applicable documents. In addition, seat and armrest cushions and dress covers should be self-extinguishing when subjected to cigarette burns.

4.7.3 Materials and finishes which generate appreciable amounts of toxic gases or dense smoke when subject to flame or heat should be avoided.

4.7.4 The seat should be free from sharp edges or projections which could cause damage to the safety belt or clothing of the occupant or which might injure the hands of the occupant as he operates equipment within his reach.

NATIONAL AIRCRAFT STANDARDS COMMITTEE

AIRCRAFT INDUSTRIES ASSOCIATION OF AMERICA, INC.. 610 SHOREHAM BUILDING, WASHINGTON 5, D. C.

SPECIFICATION - AIRCRAFT SEATS AND BERTHS

This specification defines the minimum performance and safety standards for seats and berths to be installed in certificated aircraft.

1. APPLICABLE SPECIFICATIONS

1.1 The latest issue and amendment of the following documents are made a part of this specification by reference to the applicable sections hereinafter noted.

1.1.1 CAA Safety Regulation Release No. 259, "Compliance of Equipment and Materials Used in Air Carrier Aircraft with Fire Prevention Requirements".

2. TYPES

2.1 This specification covers all types of crew and passenger seats and berths for civil aircraft use in the following categories:

Type I	Transport
Type II	Normal - Utility
Type III	Acrobatic

3. MATERIAL AND WORKMANSHIP

3.1 Materials shall be of a quality which experience and/or tests have conclusively demonstrated to be suitable for use in aircraft seats and berths. Workmanship shall be consistent with high-grade aircraft manufacturing practice.

3.1.1 Protection: All members of the structure shall be suitably protected against deterioration or loss of strength in service due to weathering, corrosion, abrasion or other causes where the type of material requires such protection.

3.1.2 Fire Precaution: The covering and upholstery and all other exposed material used in the seat or berth shall have flame-resistant properties as specified by CAA Safety Regulation Release No. 259. If ashtrays are installed in, or attached to, the seat or berth, they shall be of a self-contained, completely removable type.

4. DETAIL REQUIREMENTS

(1) INACTIVE FOR NEW DESIGN

SEE NAS809

4.1 Design

APPROVAL DATE April 1, 1950 REVISION (1) 1 JAN. 1956

TITLE	CLASSIFICATION
SPECIFICATION - AIRCRAFT SEATS AND BERTHS	SPECIFICATION
	NAS 806 (1) SHEETS 1 THRU 4

4.1.1 General: The seat shall be designed so that in any of its adjustable positions and when installed facing in a specified direction or directions, it will provide protection for the occupant in a manner compatible with the function for which the seat is designed, i.e., pilot, cabin attendant, check pilot, passenger, and the like.

4.1.2 Strength: All seats and berths intended for single occupancy shall be designed for the ultimate loads specified in Table I to which occupants are subjected. The loads shall be considered as acting separately and shall be based on a passenger weight of 170 pounds for Type I and 190 pounds (includes parachute) for Types II and III. The sideward, upward and downward loads, as specified in Table I, are the minimums corresponding to flight and ground load conditions prescribed in the applicable Civil Air Regulations. The forward loads correspond to the emergency conditions prescribed in the applicable Civil Air Regulations. For seats intended for multiple occupancy the loads must be increased accordingly. Ultimate loads are 1.5 times the limit loads.

TABLE I

Force Direction	Type I	Type II*	Type III
Forward	1020 lbs. (6.0 g)	1710 lbs. (9.0 g)	1710 lbs. (9.0 g)
Sideward	255 lbs. (1.5 g)	285 lbs. (1.5 g)	285 lbs. (1.5 g)
Upward	340 lbs. (2.0g)	570 lbs. (3.0 g)	855 lbs. (4.5 g)
Downward	765 lbs. (4.5 g)	1254 lbs. (6.6 g)	1710 lbs. (9.0 g)

*Civil Air Regulations require use of parachute in utility category aircraft operated in acrobatic flight when carrying passengers.

4.1.2.1 Ultimate Load Strength: The seat or berth in any of its adjustable positions while installed facing in a specified direction or directions, when occupied by maximum number of occupants, shall be capable of withstanding ultimate loads without failure for at least three (3) seconds.

4.1.2.2 Limit Load Strength: The seat or berth in any of its adjustable positions shall be capable of withstanding the limit loads without suffering detrimental permanent deformation. At all loads up to these limit loads the deformation shall be such as not to interfere with safe operation of the airplane. (Note: this limit load requirement is not applicable to the forward loading since it is an emergency condition).

4.1.3 Safety Belt Anchorages: When anchorages for safety belts are provided they shall be of a type which will permit self-aligning of the belt and fitting.

4.1.4 Shoulder Harness Anchorages: When anchorages for shoulder harnesses are provided, they shall be so located as to ensure they will be above the shoulder level of the occupant.

4.1.5 Projections: The surfaces of the seat shall be free from sharp edges or any projections which may chafe the safety belt or harness webbing. Projections, sharp corners, and other hazardous features, against which occupants may be thrown during a crash, shall be avoided insofar as possible. Any unavoidable features of this nature shall be adequately padded.

4.2 Marking: Each seat or berth shall be legibly and permanently marked with the following information:

Manufacturer's Name
Model Number or Model Name
Seat Type
Serial Number or Date of Manufacture
National Aircraft Standard Number (NAS____)

4.3 Qualification Tests: Tests shall be conducted as necessary to demonstrate the following: (a) that seats or berths manufactured in accordance with this specification are capable of supporting the limit loads without detrimental permanent deformation; (b) that, at all loads up to limit loads, the deformation shall be such as not to interfere with the safe operation of the aircraft; and (c) that the structure is capable of supporting the ultimate loads specified herein without failure for at least 3 seconds.

4.3.1 Detail Qualification Test Requirements: The seat or berth shall be loaded in tests such that the loads imposed on the seat or berth by the occupant(s) in conjunction with the safety belt or belts and their attachments are accurately simulated by means of a block or frame or dummy, said block or frame or dummy being restrained in the seat or berth by the belt or belts attached to their fittings. The tests may be conducted in a jig simulating installation conditions.

4.3.1.1 When a seat or berth is to be installed or adjusts to face in other than the forward direction, sufficient tests shall be made to substantiate the seat strength for all intended positions.

4.3.1.2 When testing for a particular load condition of a vertically or horizontally adjustable seat, the most critical seat position associated with that load shall be used for the test.

4.3.1.3 Where the safety belt or belts or harness are not attached to the seat or berth structure, the seat or berth shall be tested for the loads which would be imposed on such installation.

4.3.2 <u>Flame-Resistance Test of Seat Covers</u>: Specimens of the seat covering and upholstery shall meet the tests outlined in CAA Safety Regulation Release No. 259.

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SPECIFICATION - AIRCRAFT SEATS AND BERTHS

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1. SCOPE

1.1 Scope - This specification defines the minimum performance and safety standards for seats and berths to be installed in certificated aircraft.

1.2 Types - This specification covers all types of crew and passenger seats and berths for civil aircraft use in the following categories:

Type I	Transport
Type II	Normal & Utility
Type III	Acrobatic
Type IV	Rotorcraft

2. APPLICABLE SPECIFICATIONS

2.1 The latest issue and amendment of the following documents are made a part of this specification:

SAE Aeronautical Material Specification AMS 3852, "Flame Resistant Properties for Aircraft Materials"

3. MATERIAL AND WORKMANSHIP

3.1 Materials shall be of a quality which experience and/or tests have demonstrated to be suitable for use in aircraft seats and berths. Workmanship shall be consistent with high-grade aircraft manufacturing practice.

3.1.1 Protection: All members of the structure shall be protected against deterioration or loss of strength in service due to weathering, corrosion, abrasion or other causes where the type of material used requires such protection.

3.1.2 Fire Protection: The covering and upholstery and all other exposed material used in the seat or berth shall have flame-resistant properties as specified in Aeronautical Material

APPROVAL DATE 1 JAN. 1956 REVISION

PREPARED BY THE AIRWORTHINESS REQUIREMENTS COMMITTEE

TITLE	CLASSIFICATION
SPECIFICATION - AIRCRAFT SEATS AND BERTHS	SPECIFICATION
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Specification (SAE) AMS 3852. If ash trays are installed in or attached to the seat or berth, they shall be of a self-contained, completely removable type.

4. DETAIL REQUIREMENTS

4.1 Design

4.1.1 General: The seat shall be designed so that in any of its adjustable positions and when installed facing in a specified direction or directions, it will provide protection for the occupant, i.e., pilot, cabin attendant, check pilot or passenger.

4.1.1.1 Accommodation for Parachutes: Types II and III seats shall be designed to accommodate passengers wearing parachutes, except that Type II seats designed specifically for NORMAL CATEGORY AIRCRAFT need not comply with this requirement but shall be identified in the marking required in 4.2 as, "FOR NORMAL CATEGORY AIRCRAFT ONLY."

4.1.1.2 Aft Facing Seats: The seat back height shall be sufficient to provide 36-1/2 inches support for the occupant as measured from the point of maximum seat cushion depression to the top of the seat back. This dimension may be determined with the seat statically subjected to the loads specified in Table I. Padding for the back of the head should prevent "bottoming" on the seat structure unless this structure is designed to absorb the remaining energy.

4.1.2 Strength: All seats and berths intended for single occupancy shall be designed for the ultimate loads specified in Table I. The loads shall be considered as acting separately and shall be based on a passenger weight of 170 pounds for Types I and IV seats and 190 pounds (includes parachute) for Types II and III seats. The weight of the seat or berth times the approximate "g" value shall be added to the ultimate loads specified in Table I. For seats intended for multiple occupancy the loads must be increased accordingly. Ultimate loads are 1.5 times the limit loads.

TABLE I

Load Direction	Type I	Type II**	Type III	Type IV
Forward	1530 lbs. (9.0g)	1710 lbs. (9.0g)	1710 lbs. (9.0g)	680 lbs. (4.0g)
Sideward***	510 lbs. (3.0g)	570 lbs. (3.0g)	570 lbs. (3.0g)	340 lbs. (2.0g)
Upward	340 lbs. (2.0g)	570 lbs. (3.0g)	855 lbs. (4.5g)	255 lbs. (1.5g)
Downward	1020 lbs. (6.0g)*	1330 lbs. (7.0g)*	1710 lbs. (9.0g)	680 lbs. (4.0g)

* The reason for the down loads exceeding those prescribed in the emergency landing conditions of the applicable Civil Air Regulations is to provide for the reduced weight gust-load-factor or special landing requirements which, in some cases, may be greater than the emergency landing loads.

4.1.2 (Cont'd.)

** Civil Air Regulations require use of parachute in UTILITY CATEGORY AIRCRAFT operated in acrobatic flight.

*** See 4.3 pertaining to side load for arm rests, Item (c).

4.1.2.1 Pilot and Co-Pilot Seat Loads: In addition to the loads specified in Table I above, pilot and co-pilot seats shall be designed to withstand the following rearward loads applied 8 inches above the intersection of the seat back and seat bottom to provide for the application of pilot forces to the flight controls:

Type I seats	450 pounds
Type II and III seats	300 pounds for aircraft weighing 5000 pounds or under, and 450 pounds for aircraft weighing over 5000 pounds.
Type IV seats	195 pounds

4.1.2.2 Back Rest Loads: The back rest of rearward facing seats, when in the most vertical position, shall withstand the following airplane forward loads applied separately:

Type I Seats - 1530 pounds distributed over the seat back with the load C.G. located 10.5 inches up from the base of the seat back as described in the note in Section 4.3.1.

Types II and III Seats - 1710 pounds distributed over the seat back with the load C.G. located 10.5 inches up from the base of the seat back as described in the note in Section 4.3.1.

4.1.2.3 Casting Factors: If castings are used in the construction of the seat the castings shall have a factor of safety of 2.0 where only visual inspection is employed except that it need not exceed 1.25 with respect to bearing stresses. A safety factor of 1.25 is satisfactory if the casting is substantiated by testing at least three samples and if visual and radiographic inspection is employed on all production castings to assure that they are at least equivalent to the test specimens. The samples shall withstand the ultimate loads multiplied by the 1.25 factor and the limit loads multiplied by the factor of 1.15. These loads should be applied separately. Die castings shall not be used in the primary structure of the seat without 100% radiographic inspection. Casting factors other than those

4.1.2.3 (Cont'd.)
specified above shall be acceptable if they are found to be appropriately related to tests and to inspection procedures.

4.1.2.4 Ultimate Load Strength: The seat or berth in any of its adjustable positions, when installed facing in a specified direction or directions and when occupied by maximum number of occupants, shall be capable of withstanding ultimate loads without failure for at least three (3) seconds.

4.1.2.5 Limit Load Strength: The seat or berth in any of its adjustable positions shall be capable of withstanding the limit loads without suffering detrimental permanent deformation. At all loads up to these limit loads the deformation shall be such as not to interfere with safe operation of the airplane. (Note: this limit load requirement is not applicable to the forward or the 3 "g" side loading since it is an emergency condition.)

4.1.3 Attachments: For Types I, II and III seats and berths the strength of the seat or berth attachments to the structure and safety belt or shoulder harness attachments to the seat or structure, shall be 1.33 times the ultimate loads specified in Table I except that the down load need not be considered for the safety belt or shoulder harness attachments. When anchorages for safety belts are provided, they should be of a type which will permit self-aligning of the belt or fitting. For berth belt attachments, the factor shall be 1.15.

4.1.4 Projections: The surfaces of the seat shall be free from sharp edges or projections which may chafe the safety belt or shoulder harness webbing. Projections, sharp corners, and other hazardous features, against which the seat occupant may be thrown during a crash, shall be avoided insofar as possible. Any unavoidable features of this nature shall be padded to prevent serious head, neck or chest injury to the occupants.

4.2 Marking: Each seat or berth shall be legibly and permanently marked with the following information:

Manufacturer's Name
Model Number or Name
Seat and Facing Direction (e.g., forward, aft, sideward, swivel)
Serial Number or Date of Manufacture
National Aircraft Standard Number (NAS______)

4.3 Qualification Tests: Tests shall be conducted as necessary to demonstrate:

(a) that the seats or berths are capable of supporting the limit loads without detrimental permanent deformation;

(b) that, at all loads up to limit loads, the deformation shall be such as not to interfere with the safe operation of the aircraft;

4.3 (Cont'd.)

(c) that the structure is capable of supporting, without failure for at least 3 seconds, the ultimate loads specified herein when applied separately.

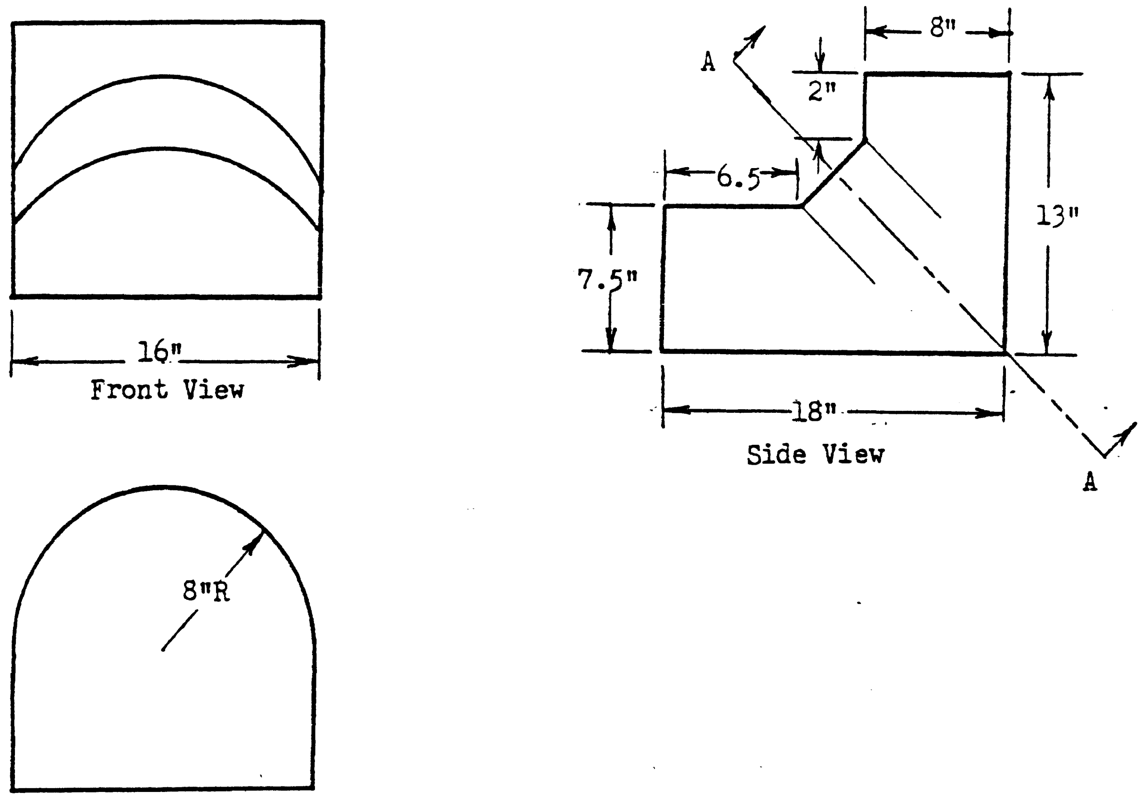
If it can be shown that failure of an arm rest on a seat assembly does not reduce the degree of safety afforded the occupant, such failure will not be cause for rejection.

4.3.1 Detail Qualification Test Requirements: The seat or berth shall be loaded in tests such that the loads imposed on the seat or berth by the occupant(s) in conjunction with the safety belt or belts and their attachments are accurately simulated by means of a block or frame or dummy which is restrained in the seat or berth by the belt or belts attached to their fittings. The tests may be conducted in a jig simulating installation conditions. The ultimate loads, when applied separately, will serve to simulate the loads imposed by the occupant.

	Forward Facing Seat	Sideward Facing Seat	Rearward Facing Seat
Down Load	Evenly over seat bottom	Evenly over seat bottom	Evenly over seat bottom
Side* Load	10.5" up from base of block and about 8.5" forward from back of block.	10.5" up from base of block and about 8.5" forward from back of block.	10.5" up from base of block and about 8.5" forward from back of block.
Up* Load	"	"	"
Forward Load	"	"	Applied as specified in 4.1.2.2

*Note: These dimensions for the location of load application assume that the seat and back cushion are in place and that the seat cushion is compressed 2 inches. If the cushions are removed for the test or if the seat cushion compression varies from 2 inches, the location for applying the loads shall be changed accordingly.

This simplified body block is satisfactory for test purposes. It may be refined or modified if desired; however, the application of all test loads should be modified accordingly if necessary.



Front View

Side View

Section A-A

4.3.1.1 When a seat or berth is to be installed or adjusts to face in other than the forward direction, sufficient tests shall be made to substantiate the seat strength for all intended positions.

4.3.1.2 When testing for a particular load condition of a vertically or horizontally adjustable seat, the most critical seat position associated with that load shall be used for the test.

4.3.1.3 Where the safety belt or belts or harness are not attached to the seat or berth structure, the seat or berth shall be tested for the loads which would be imposed on such installation.

4.3.2 Flame-Resistance Test of Seat Covers: Specimens of the seat covering and upholstery shall meet the applicable tests specified in 3.1.2.

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SPECIFICATION - AIRCRAFT SAFETY BELTS

This specification defines the minimum performance and safety standards for aircraft safety belts to be installed in certificated aircraft.

1. APPLICABLE SPECIFICATIONS

1.1 The latest issue and amendment of the following documents are made a part of this specification by reference to the applicable sections hereinafter noted.

1.1.1 Aeronautical Materials Specifications (SAE)
AMS 3852, Flame-Resistant Properties for Aircraft Materials

2. TYPES

2.1 This specification covers all types of safety belts for civil aircraft use.

3. MATERIAL AND WORKMANSHIP

3.1 Materials shall be of a quality which experience and/or tests have conclusively demonstrated to be suitable for use in aircraft safety belts. Workmanship shall be consistent with high-grade aircraft manufacturing practice.

3.1.1 Strength of Webbing Material: The rated minimum breaking strength of the webbing to be used in belts shall be at least 50% greater than the rated strength of the complete belt assembly as specified in Section 4.1.1 when tested under standard test conditions (see 4.3.1.2).

3.1.2 Age of Webbing: No webbing which is more than six (6) months old from date of weaving shall be used in the manufacture or fabrication of a safety belt assembly unless the webbing has been retested in accordance with Section 4.3.1.2.

3.1.3 Protection: All portions of the belt assembly shall be protected against deterioration or loss of strength in service due to weathering, corrosion, abrasion from sharp corners, or other causes where the type of material requires such protection. Belt webbing which is subject to effects of mildew shall be treated against mildew.

3.1.4 Fire Precaution: The webbing and all other materials used in the belt assembly shall have flame-resistant properties as specified by Aeronautical Material Specification AMS 3852.

APPROVAL DATE 2-9-1948 REVISION (1) 5-15-50

4. DETAIL REQUIREMENTS

4.1 Design

4.1.1 Rated Strength of Belt Assembly: The safety belt assembly, intended for use with a seat designed for single occupancy, including webbing, release mechanism, and all parts integral with the belt which are necessary for installing the belt, shall be designed to withstand at least a 3000 pound load applied in alignment with the anchored belt according to the test requirements specified in Section 4.3.2.1. If designed for double occupancy, the rated strength shall be increased to at least 6000 pounds. The rated strength of the safety belt assembly shall be suitably marked upon each half of the safety belt assembly.

4.1.2 Safety Belt Release Mechanism: The safety belt assembly shall be adjustable and shall include an easily operable quick-release mechanism which will enable the wearer to release himself easily under a load simulating the wearer hanging in the belt after an application of a load that will impose a tensile loading on the belt webbing at least equal to the rated strength of the belt assembly as defined in Section 4.1.1.

4.1.3 Width of Webbing: The width of the safety belt webbing shall not be less than 2 inches.

4.2 Marking: Each half of the belt assembly shall have legibly and permanently marked on or attached to it a nameplate or identification label bearing the following information:

Manufacturer's name
Model number or model name
Date of manufacture of the safety belt assembly (Note Section 3.1.2).
Rated strength of safety belt assembly
National Aircraft Standard Number (NAS 802)

4.3 Qualification Tests

4.3.1 Webbing Tests

4.3.1.1 Flame Resistance Test: Specimens of the belt webbing shall pass the tests outlined in AMS 3852, Flame-Resistant Properties of Aircraft Material.

4.3.1.2 Tensile Test - Rated Minimum Breaking Strength: After all special finishing processes which may be required have been accomplished to provide for mildew and flame resistance, three samples of webbing shall be prepared for testing. It is desirable that the three samples be taken at random from different rolls or lots of

4.3.1.2 Continued

the type of webbing intended to be used in the manufacture of the safety belt being tested. The tests shall be conducted when each sample is in moisture equilibrium with an atmosphere having a relative humidity of 65% and a temperature of 70°F. A tolerance of plus or minus 2% is permitted in relative humidity and plus 10°F. in temperature. The samples shall be tested in a suitable textile testing machine acceptable to the manufacturer. The samples shall be mounted in the machine when the heads are 10 inches apart. The heads shall separate at the rate of 4 inches per minute maximum under no load. Each test sample of the webbing shall withstand a load at least equal to its rated minimum breaking strength without failure for at least three seconds.

4.3.2 Complete Belt Assembly Tests

4.3.2.1 Tensile Test - Rated Strength: Three identical samples of a safety belt assembly shall be tested to determine the rated strength. If the design incorporates adjustment adapters, the adapters shall be positioned approximately halfway between the buckle and the end fittings. If a cam-type buckle is used, about 10 inches of the free end of the webbing shall extend beyond the cam when the latch is in the locked position. The tests may be conducted under prevailing atmospheric conditions. The ends of the assembly shall be attached to the stationary and movable heads of the testing machine by means of adequate fittings. The heads shall separate at the rate of 4 inches per minute maximum under no load. The buckle shall be in a locked position and the entire assembly should be in axial alignment with the heads of the testing machine. All precautions shall be taken to prevent eccentric loading. Each sample shall be pulled at least to the load designated in 4.1.1 as the rated strength. After removal of the load, the webbing and stitching shall show no signs of failure or weakening and the metal components shall show no permanent deformation which will result in malfunctioning of the belt assembly. The total slippage in the adjusting arrangement or the quick-release machanism shall not exceed 1 inch.

4.3.2.2 Functional Test - Release Mechanism: At least three identical samples of a safety belt assembly shall be tested to determine the functional characteristics of the quick-release mechanism. (NOTE: It is desirable that the sample safety belts used in performing the tensile tests for rated strength be used in this test. However, the samples may be new, untested assemblies if desired by the test witnesses.) The safety belt assemblies shall be adjusted to approximately 36 inches in length, this distance being measured from the bolt hole in one end fitting to the bolt hole in the other.

4.3.2.2 Continued

Each safety belt sample in turn shall then be tested in a test jig, the end fittings being attached to jig anchorage fittings located 20 inches apart horizontally and so positioned as to suspend the belt in a vertical plane. It shall be possible to apply the required loading vertically downward through a 6-inch thick semicircular wooden form having a radius of not more than 8 inches. The curved portion of this test form may provide a cut-out to accommodate the belt buckle and may have installed on it padding to simulate the wearer's clothes. The tests may be conducted under prevailing atmospheric conditions.

A static load of 1.9 times the rated strength of the belt assembly shall be applied to the belt assembly through the wooden form for a one- or two-person belt and then relieved to 250 pounds for a one-person belt or 500 pounds for a two-person belt.

The quick-release mechanism shall then be operable at no more than a 45-pound pull applied in the direction which would normally actuate the release. The latter measurement may be taken by using a small precision hand scale. After removal of the loads, the quick-release mechanism shall show no signs of failure or sufficient permanent deformation to prevent the operation of the release. The total slippage in the adjusting arrangement or the quick-release mechanism shall not exceed 1 inch.

APPENDIX E

code of federal regulations

49

Transportation

PARTS 400 TO 999

Revised as of October 1, 1980

CONTAINING
A CODIFICATION OF DOCUMENTS
OF GENERAL APPLICABILITY
AND FUTURE EFFECT

AS OF OCTOBER 1, 1980

With Ancillaries

Published by
the Office of the Federal Register
National Archives and Records Service
General Services Administration

as a Special Edition of
the Federal Register

S6.4 Tires are inflated to the vehicle manufacturer's specifications.

S6.5 The windshield mounting material and all vehicle components in direct contact with the mounting material are at any temperature between 15° F and 110° F.

[41 FR 36494, Aug. 30, 1976, as amended at 42 FR 34289, July 5, 1977; 45 FR 22046, Apr. 3, 1980]

§ 571.213 Standard No. 213; child restraint systems.

S1. *Scope.* This standard specifies requirements for child restraint systems used in motor vehicles.

S2. *Purpose.* The purpose of this standard is to reduce the number of children killed or injured in motor vehicle crashes.

S3. *Application.* This standard applies to child restraint systems for use in motor vehicles.

S4. *Definitions.*

"Car bed" means a child restraint system designed to restrain or position a child in the supine or prone position on a continuous flat surface.

"Child restraint system" means any device, except Type I or Type II seat belts, designed for use in a motor vehicle to restrain, seat, or position children who weigh not more than 50 pounds.

"Contactable surface" means any child restraint system surface (other than that of a belt, belt buckle, or belt adjustment hardware) that may contact any part of the head or torso of the appropriate test dummy, specified in S7, when a child restraint system is tested in accordance with S6.1.

"Seat orientation reference line" or "SORL" means the horizontal line through Point Z as illustrated in Figure 1A.

"Torso" means the portion of the body of a seated anthropomorphic test dummy, excluding the thighs, that lies between the top of the child restraint system seating surface and the top of the shoulders of the test dummy.

S5. *Requirements.* Each child restraint system shall meet the requirements in this section when, as specified, tested in accordance with S6.1.

S5.1 *Dynamic performance.*

S5.1.1 *Child restraint system integrity.* When tested in accordance with S6.1, each child restraint system shall:

(a) Exhibit no complete separation of any load bearing structural element and no partial separation exposing either surfaces with a radius of less than $\frac{1}{4}$ inch or surfaces with protrusions greater than $\frac{3}{8}$ inch above the immediate adjacent surrounding contactable surface of any structural element of the system;

(b) If adjustable to different positions, remain in the same adjustment position during the testing as it was immediately before the testing; and

(c) If a front facing child restraint system, not allow the angle between the system's back support surfaces for the child and the system's seating surface to be less than 45 degrees at the completion of the test.

S5.1.2 *Injury criteria.* When tested in accordance with S6.1, each child restraint system that, in accordance with S5.5.2(f), is recommended for use by children weighing more than 20 pounds, shall—

(a) Limit the resultant acceleration at the location of the accelerometer mounted in the test dummy head as specified in Part 572 such that the expression:

$$\left[\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a\,dt\right]^{2.5}(t_2-t_1)$$

shall not exceed 1,000, where a is the resultant acceleration expressed as a multiple of g (the acceleration of gravity), and t_1 and t_2 are any two moments during the impacts.

(b) Limit the resultant acceleration at the location of the accelerometer mounted in the test dummy upper thorax as specified in Part 572 to not more than 60 g's, except for intervals whose cumulative duration is not more than 3 milliseconds.

S5.1.3 *Occupant excursion.* When tested in accordance with S6.1 and adjusted in any position which the manufacturer has not, in accordance with S5.5.2(i), specifically warned against using in motor vehicles, each child restraint system shall meet the applicable excursion limit requirements specified in S5.1.3.1–S5.1.3.3.

S5.1.3.1 *Child restraint systems other than rear-facing ones and car beds.* In the case of each child restraint system other than a rear-facing child restraint system or a car bed, the test dummy's torso shall be retained within the system and no portion of the test dummy's head shall pass through the vertical transverse plane that is 32 inches forward of point z on the standard seat assembly, measured along the center SORL (as illustrated in Figure 1B), and neither knee pivot point shall pass through the vertical transverse plane that is 36 inches forward of point z on the standard seat assembly, measured along the center SORL, and at the time of maximum knee forward excursion the forward rotation of the dummy's torso from the dummy's initial seating configuration shall be at least 15° measured in the saggital plane along the line connecting the shoulder and hip pivot points.

S5.1.3.2 *Rear-facing child restraint systems.* In the case of each rear-facing child restraint system, all portions of the test dummy's torso shall be retained within the system and no portion of the target point on either side of the dummy's head shall pass through the transverse orthogonal planes whose intersection contains, the forward-most and top-most points on the child restraint system surfaces (illustrated in Figure 1C).

S5.1.3.3 *Car beds.* In the case of car beds, all portions of the test dummy's head and torso shall be retained within the confines of the car bed.

S5.1.4 *Back support angle.* When a rear-facing child restraint system is tested in accordance with S6.1, the angle between the system's back support surface for the child and the vertical shall not exceed 70 degrees.

S5.2 *Force distribution.*

S5.2.1 *Minimum head support surface—child restraints other than car beds.*

S5.2.1.1 Except as provided in S5.2.1.2, each child restraint system other than a car bed shall provide restraint against rearward movement of the head of the child (rearward in relation to the child) by means of a continuous seat back which is an integral part of the system and which—

(a) Has a height, measured along the system seat back surface for the child in the vertical longitudinal plane passing through the longitudinal centerline of the child restraint systems from the lowest point on the system seating surface that is contacted by the buttocks of the seated dummy, as follows:

Weight[1] (in pounds)	Height[1] (in inches)
Less than 20 lb	18
20 lb or more, but not more than 40 lb	20
More than 40 lb	22

[1] When a child restraint system is recommended under S5.5(f) for use by children of the above weights.

[2] The height of the portion of the system seat back providing head restraint shall not be less than the above.

(b) Has a width of not less than 8 inches, measured in the horizontal plane at the height specified in paragraph (a) of this section. Except that a child restraint system with side supports extending at least 4 inches forward from the padded surface of the portion of the restraint system provided for support of the child's head may have a width of not less than 6 inches, measured in the horizontal plane at the height specified in paragraph (a) of this section.

(c) Limits the rearward rotation of the test dummy head so that the angle between the head and torso of the dummy specified in S7 when tested in accordance with S6.1 is not more than 45 degrees greater than the angle between the head and torso after the dummy has been placed in the system in accordance with S6.1.2.3 and before the system is tested in accordance with S6.1.

S5.2.1.2 A front-facing child restraint system is not required to comply with S5.2.1.1 if the target point on either side of the dummy's head is below a horizontal plane tangent to the top of the standard seat assembly when the dummy is positioned in the system and the system is installed on the assembly in accordance with S6.1.2.

S5.2.2 *Torso impact protection.* Each child restraint system other than a car bed shall comply with the applicable requirements of S5.2.2.1 and S5.2.2.2.

S5.2.2.1(a) The system surface provided for the support of the child's back shall be flat or concave and have a continuous surface area of not less than 85 square inches.

(b) Each system surface provided for support of the side of the child's torso shall be flat or concave and have a continuous surface of not less than 24 square inches for systems recommended for children weighing 20 pounds or more, or 48 square inches for systems recommended for children weighing less than 20 pounds.

(c) Each horizontal cross section of each system surface designed to restrain forward movement of the child's torso shall be flat or concave and each vertical longitudinal cross section shall be flat or convex with a radius of curvature of the underlying structure of not less than 2 inches.

S5.2.2.2 Each forward facing child restraint system shall have no fixed or movable surface directly forward of the dummy and intersected by a horizontal line parallel to the SORL and passing through any portion of the dummy, except for surfaces which restrain the dummy when the system is tested in accordance with S6.1.2.1.2 so that the child restraint system shall conform to the requirements of S5.1.2 and S5.1.3.1.

S5.2.3 *Head impact protection.*

S5.2.3.1 Each child restraint system, other than a child harness, which is recommended under S5.5.2(f) for children weighing less than 20 pounds shall comply with S5.2.3.2.

S5.2.3.2 Each system surface, except for protrusions that comply with S5.2.4, which is contactable by the dummy head when the system is tested in accordance with S6.1 shall be covered with slow recovery, energy absorbing material with the following characteristics:

(a) A 25 percent compression-deflection resistance of not less than 0.5 and not more than 10 pounds per square inch when tested in accordance with § 6.3.

(b) A thickness of not less than ½ inch if the material has a 25 percent compression-deflection resistance of not less than 3 and not more than 10 pounds per square inch when tested in accordance with S6.3. If the material has a 25 percent compression-deflection resistance of less than 3 pounds, it shall have a thickness of not less than ¾ inch.

S5.2.4 *Protrusion limitation.* Any portion of a rigid structural component within or underlying a contactable surface, or any portion of a child restraint system surface that is subject to the requirements of S5.2.3 shall, with any padding or other flexible overlay material removed, have a height above any immediately adjacent restraint system surface of not more than ⅜ inch and no exposed edge with a radius of less than ¼ inch.

S5.3 *Installation.*

S5.3.1 Each child restraint system shall have no means designed for attaching the system to a vehicle seat cushion or vehicle seat back and no component (except belts) that is designed to be inserted between the vehicle seat cushion and vehicle seat back.

S5.3.2 When installed on a vehicle seat, each child restraint system, other than child harnesses, shall be capable of being restrained against forward movement solely by means of a Type I seat belt assembly (defined in S571.209) that meets Standard No. 208 (S571.208), or by means of a Type I seat belt assembly plus one additional anchorage strap that is supplied with the system and conforms to S5.4.

S5.3.3 *Car beds.* Each car bed shall be designed to be installed on a vehicle seat so that the car bed's longitudinal axis is perpendicular to a vertical longitudinal plane through the longitudinal axis of the vehicle.

S5.4 *Belts, belt buckles, and belt webbing.*

S5.4.1 *Performance requirements.* The webbing of belts provided with a child restrain system and used to attach the system to the vehicle or to restrain the child within the system shall—

(a) After being subjected to abrasion as specified in S5.1(d) or S5.3(c) of FMVSS 209 (§ 571.209), have a breaking strength of not less than 75 percent of the strength of the unabraded webbing when tested in accordance with S5.1(b) of FMVSS 209.

(b) Meet the requirements of S4.2 (e) through (h) of FMVSS No. 209 (S571.209); and

(c) If contactable by the test dummy torso when the system is tested in accordance with S6.1, have a width of not less than 1½ inches when measured in accordance with S5.4.1.1.

S5.4.1.1 *Width test procedure.* Condition the webbing for 24 hours in an atmosphere of any relative humidity between 48 and 67 percent, and any ambient temperature between 70° and 77° F. Measure belt webbing width under a tension of 5 pounds applied lengthwise.

S5.4.2 *Belt buckles and belt adjustment hardware.* Each belt buckle and item of belt adjustment hardware used in a child restraint system shall conform to the requirements of S4.3(a) and S4.3(b) of FMVSS No. 209 (S571.209).

S5.4.3 *Belt Restraint.*

S5.4.3.1 *General.* Each belt that is part of a child restraint system and that is designed to restrain a child using the system shall be adjustable to snugly fit any child whose height and weight are within the ranges recommended in accordance with S5.5.2(f) and who is positioned in the system in accordance with the instructions required by S5.6.

S5.4.3.2 *Direct restraint.* Each belt that is part of a child restraint system and that is designed to restrain a child using the system and to attach the system to the vehicle shall, when tested in accordance with S6.1, impose no loads on the child that result from the mass of the system or the mass of the seat back of the standard seat assembly specified in S7.3.

S5.4.3.3 *Seating systems.* Except for child restraint systems subject to S5.4.3.4, each child restraint system that is designed for use by a child in a seated position and that has belts designed to restrain the child, shall, with the test dummy specified in S7 positioned in the system in accordance with S6.1.2.3 provide:

(a) Upper torso restraint in the form of:

(i) Belts passing over each shoulder of the child, or

(ii) A fixed or movable surface that complies with S5.2.2.1(c), and

(b) Lower torso restraint in the form of:

(i) A lap belt assembly making an angle between 45° and 90° with the child restraint seating surface at the lap belt attachment points, or

(ii) A fixed or movable surface that complies with S5.2.2.1(c), and

(c) In the case of each seating system recommended for children over 20 pounds, crotch restraint in the form of:

(i) A crotch belt connectable to the lap belt or other device used to restrain the lower torso, or

(ii) A fixed or movable surface that complies with S5.2.2.1(c).

S5.4.3.4 *Harnesses.* Each child harness shall:

(a) Provide upper torso restraint, including belts passing over each shoulder of the child;

(b) Provide lower torso restraint by means of lap and crotch belt; and

(c) Prevent a child of any height for which the restraint is recommended for use pursuant to S5.5.2(f) from standing upright on the vehicle seat when the child is placed in the device in accordance with the instructions required by S5.6.

S5.4.3.5 *Buckle release.* Any buckle in a child restraint system belt assembly designed to restrain a child using the system shall, when tested in accordance with S6.2, not release when a force of nor more than 12 pounds is applied before the test specified in S6.1, and (b) release when a force of not more than 20 pounds is applied after the test specified in S6.1.

S5.5 *Labeling.*

S5.5.1 Each child restraint system shall be permanently labeled with the information specified in S5.5.2 (a) through (k).

S5.5.2 The information specified in paragraphs (a)-(k) of this section shall be stated in the English language and lettered in letters and numbers that are not smaller than 10 point type and are on a contrasting background.

(a) The model name or number of the system.

(b) The manufacturer's name. A distributor's name may be used instead if the distributor assumes responsibility for all duties and liabilities imposed on the manufacturer with respect to the system by the National Traffic and Motor Vehicle Safety Act, as amended.

(c) The statement: "Manufactured in ——," inserting the month and year of manufacture.

(d) The place of manufacture (city and State, or foreign country). However, if the manufacturer uses the name of the distributor, then it shall state the location (city and State, or foreign country) of the principal offices of the distributor.

(e) The statement: "This child restraint system conforms to all applicable Federal motor vehicle safety standards."

(f) One of the following statements, inserting the manufacturer's recommendations for the maximum weight and height of children who can safely occupy the system:

(i) This infant restraint is designed for use by children who weigh —— pounds or less and whose height is —— inches or less; or

(ii) This child restraint is designed for use only by children who weigh between —— and —— pounds and whose height is —— inches or less and who are capable of sitting upright alone; or

(iii) This child restraint is designed for use only by children who weigh between —— and —— pounds and are between —— and —— inches in height.

(g) The following statement, inserting the location of the manufacturer's installation instruction booklet or sheet on the restraint:

WARNING! FAILURE TO FOLLOW EACH OF THE FOLLOWING INSTRUCTIONS CAN RESULT IN YOUR CHILD STRIKING THE VEHICLE'S INTERIOR DURING A SUDDEN STOP OR CRASH.
SECURE THIS CHILD RESTRAINT WITH A VEHICLE BELT AS SPECIFIED IN THE MAUFACTURER'S INSTRUCTIONS LOCATED——.

(h) in the case of each child restraint system that has belts designed to restrain children using them:

SNUGLY ADJUST THE BELTS PROVIDED WITH THIS CHILD RESTRAINT AROUND YOUR CHILD.

(i) In the case of each child restraint system which is not intended for use in motor vehicles at certain adjustment positions, the following statement, inserting the manufacturer's adjustment restrictions.

DO NOT USE THE——ADJUSTMENT POSITION(S) OF THIS CHILD RESTRAINT IN A MOTOR VEHICLE.

(j) In the case of each child restraint system equipped with an anchorage strap, the statement:

SECURE THE TOP ANCHORAGE STRAP PROVIDED WITH THIS CHILD RESTRAINT AS SPECIFIED IN THE MANUFACTURER'S INSTRUCTIONS.

(k) In the case of each child restraint system which can be used in a rear-facing position, one of the following statements:

(i) PLACE THIS CHILD RESTRAINT IN REAR-FACING POSITION WHEN USING IT WITH AN INFANT; or

(ii) PLACE THIS INFANT RESTRAINT IN A REAR-FACING POSITION WHEN USING IT IN THE VEHICLE.

(l) An installation diagram showing the child restraint system installed in the right front outboard seating position equipped with a continuous-loop lap/shoulder belt and in the center rear seating position as specified in the manufacturer's instructions.

S5.5.3 The information specified in S5.5.2 (g)-(k) shall be located on the child restraint system so that it is visible when the system is installed as specified in S5.6.

S5.6 *Installation instructions.* Each child restraint system shall be accompanied by printed instructions in the English language that provide a step-by-step procedure, including diagrams, for installing the system in motor vehicles, securing the system in the vehicles, positioning a child in the system, and adjusting the system to fit the child.

S5.6.1 The instructions shall state that the rear center seating position is the safest seating position in most vehicles for installing a child restraint system.

S5.6.2 The instructions shall specify in general terms the types of vehicles, seating positions, and vehicle lap belts with which the system can or cannot be used.

S5.6.3 The instructions shall explain the primary consequences of noting following the warnings required to be labeled on the child restraint system in accordance with S5.5.2 (g)-(K).

S5.6.4 The instructions for each car bed shall explain that the car bed should position in such a way that the child's head is near the center of the vehicle.

S5.6.5 The instructions shall state that child restraint systems should be securely belted to the vehicle, even when they are not occupied, since in a crash an unsecured child restraint system may injure other occupants.

S5.6.6 Each child restraint system shall have a location on the restraint for storing the manufacturer's instructions.

S5.7 *Flammability.* Each material used in a child restraint system shall conform to the requirements of S4 of FMVSS No. 302 (S571.302).

S6 *Test conditions and procedures.*

S6.1 *Dynamic systems test.*

S6.1.1 *Test conditions.*

S6.1.1.1 The test device is the standard seat assembly specified in S7.3. It is mounted on a dynamic test platform so that the center SORL of the seat is parallel to the direction of the test platform travel and so that movement between the base of the assembly and the platform is prevented. The platform is instrumented with an accelerometer and data processing system having a frequency response of 60 Hz channel class as specified in Society of Automotive Engineers Recommended Practice J211a "Instrumentation for Impact Tests." The accelerometer sensitive axis is parallel to the direction of the test platform travel.

S6.1.1.2 The tests are frontal barrier impact simulations and for—

(a) Test configuration I specified in S6.1.2.1.1, are at a velocity change of 30 mph with the acceleration of the test platform entirely within the curve shown in figure 2.

(b) Test configuration II specified in S6.1.2.1.2, are at a velocity change of 20 mph with the acceleration of the test platform entirely within the curve shown in figure 3.

S6.1.1.3 Type I seat belt assemblies meeting the requirements of Standard No. 209 (S571.209) and having webbing with a width of not more than 2 inches are attached, without the use of retractors or reels of any kind, to the seat belt anchorage points (illustrated in Figure 1B) provided on the standard seat assembly.

S6.1.1.4 Performance tests under S6.1 are conducted at any ambient temperature from 66° to 78° F and at any relative humidity from 10 percent to 70 percent.

S6.1.2 *Dynamic test procedure.*

S6.1.2.1 *Test configuration.*

S6.1.2.1.1 *Test configuration I.* In the case of each child restraint system, install a new child restraint system at the center seat position of the standard seat assembly in accordance with the manufacturer's instructions provided in accordance with S5.6 with the system.

S6.1.2.1.2 *Test configuration II.* In the case of each child restraint system, other than a child harness, which is equipped with an anchorage belt or a fixed or movable surface described in S5.2.2.2, install a new child restraint system at the center seat position of the standard seat assembly using only the standard seat lap belt to secure the system to the standard seat.

S6.1.2.2 Tighten all belts used to attach the child restraint system to the standard seat assembly to a tension of not less than 12 pounds and not more than 15 pounds, as measured by a load cell used on the webbing portion of the belt.

S6.1.2.3 Place in the child restraint any dummy specified in S7 for testing systems for use by children of the heights and weights for which the system is recommended in accordance with S5.6.

S6.1.2.3.1 When placing the 3-year-old test dummy in child restraint systems other than car beds, position the test dummy according to the instructions for child positioning provided by the manufacturer with the system in accordance with S5.6 while conforming to the following:

(a) Place the test dummy in the seated position within the system with the midsagittal plane of the test dummy head coincident with the center SORL of the standard seating assembly, holding the torso upright until it contacts the system's design seating surface.

(b) Extend the arms of the test dummy as far as possible in the upward vertical direction. Extend the legs of the dummy as far as possible in the forward horizontal direction, with the dummy feet perpendicular to the centerline of the lower legs.

(c) Using a flat square surface with an area of 4 square inches, apply a force of 40 pounds, perpendicular to the plane of the back of the standard seat assembly, first against the dummy crotch and then at the dummy thorax in the midsagittal plane of the dummy. For a child's restraint system with a fixed or movable surface described in S5.2.2.2 which is being tested under the conditions of test configuration II, do not attach any of the child restraint belts unless they are an integral part of the fixed or movable surface. For all other child restraint systems and for a child restraint system with a fixed or movable surface which is being tested under the conditions of test configuration I, attach all appropriate child restraint belts and tighten them as specified in S6.1.2.4. Attach all appropriate vehicle belts and tighten them as specified in S6.1.2.2. Position each movable surface in accordance with the manufacturer's instructions provided in accordance with S5.6.

(d) After the steps specified in paragraph (c) of this section, rotate each dummy limb downwards in the plane parallel to its midsagittal plane until the limb contacts a surface of the child restraints system or the standard seat. Position the limbs, if necessary, so that limb placement does not inhibit torso or head movement in tests conducted under S6.

S6.1.2.3.2 When placing the 6-month-old dummy in child restraint systems other than car beds, position the test dummy according to the instructions for child positioning provided with the system by the manufacturer in accordance with S5.6 while conforming to the following:

(a) With the dummy in [illegible] in the supine position on a horizontal surface, and while preventing movement of the dummy torso by placing a hand on the center of the torso, rotate the dummy legs upward by lifting the feet until the legs contact the upper torso and the feet touch the head, and then slowly release the legs but do not return them to the flat surface.

(b) Place the dummy in the child restraint system so that the back of the dummy torso contacts the back support surface of the system. For a child restraint system with a fixed or movable surface described in S5.2.2.2 which is being tested under the conditions of test configuration II, do not attach any of the child restraint belts unless they are an integral part of the fixed or movable surface. For all other child restraint systems and for a child restraint system with a fixed or movable surface which is being tested under the conditions of test configuration I, attach all appropriate child restraint belts and tighten them as specified in S6.1.2.4. Attach all appropriate vehicle belts and tighten them as specified in S6.1.2.2. Position each movable surface in accordance with the manufacturer's instructions provided in accordance with S5.6. If the dummy's head does not remain in the proper position, it shall be taped against the front of the seat back surface of the system by means of a single thickness of ¼-inch-wide paper masking tape placed across the center of the dummy face.

(c) Position the dummy arms vertically upwards and then rotate each arm downward toward the dummy's lower body until it contacts a surface of the child restraint system or the standard seat assembly, ensuring that no arm is restrained from movement in other than the downward direction, by any part of the system or the belts used to anchor the system to the standard seat assembly.

S6.1.2.3.3 When placing the 6-month-old dummy or 3-year-old dummy in a car bed, place the dummy in the car bed in the supine position with its midsagittal plane perpendicular to the center SORL of the standard seat assembly and position the dummy within the car bed in accordance with instructions for child positioning provided with the car bed by its manufacturer in accordance with S5.6.

S6.1.2.4 If provided, shoulder and pelvic belts that directly restrain the dummy shall be adjusted as follows:

Tighten the belts until a 2-pound force applied (as illustrated in figure 5) to the webbing at the top of each dummy shoulder and to the pelvic webbing two inches on either side of the torso midsagittal plane pulls the webbing ¼ inch from the dummy.

S6.1.2.5 Accelerate the test platform to simulate frontal impact in accordance with S6.1.1.2(a) or S6.1.1.2(b), as appropriate.

S6.1.2.6 Measure dummy excursion and determine conformance to the requirements specified in S5.1 as appropriate.

S6.2 *Buckle release test procedure.* The buckles on the belts of each child restraint system equipped with buckled belts shall be tested in accordance with S6.2.1 through S6.2.5.

S6.2.1 Install the child restraint system on a standard seat assembly and place the appropriate test dummy in the system in accordance with S6.1.2.1 through S6.1.2.4.

S6.2.2 Tie a self-adjusting sling to each ankle and wrist of the dummy in the manner illustrated in figure 4.

S6.2.3 Pull the sling horizontally in the manner illustrated in figure 4 and parallel to the center SORL of the seat assembly and apply a force of 20 pounds in the case of a system tested with a 6 month-old dummy and 45 pounds in the case of a system tested with a 3 year-old dummy.

S6.2.4 While applying the force specified in S6.2.3, operate the buckle release mechanism in the manner specified in S5.2(d) of Standard No. 209 (S571.209).

S6.2.5 Measure the force required to release the buckle.

S6.3 *Head impact protection—energy absorbing material test procedure.*

S6.3.1 Prepare and test specimens of the energy absorbing material used to comply with S5.2.3 in accordance with the applicable 25 percent compression-deflection test described in the American Society for Testing and Materials (ASTM) Standard D1056-73, "Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber," or D1564-71 "Standard Method of Testing Flexible Cellular Materials—Slab Urethane Foam" or D1565-76 "Standard Specification for Flexible Cellular Materials—Vinyl Chloride Polymer and Copolymer open-cell foams."

S7 *Test dummies.*

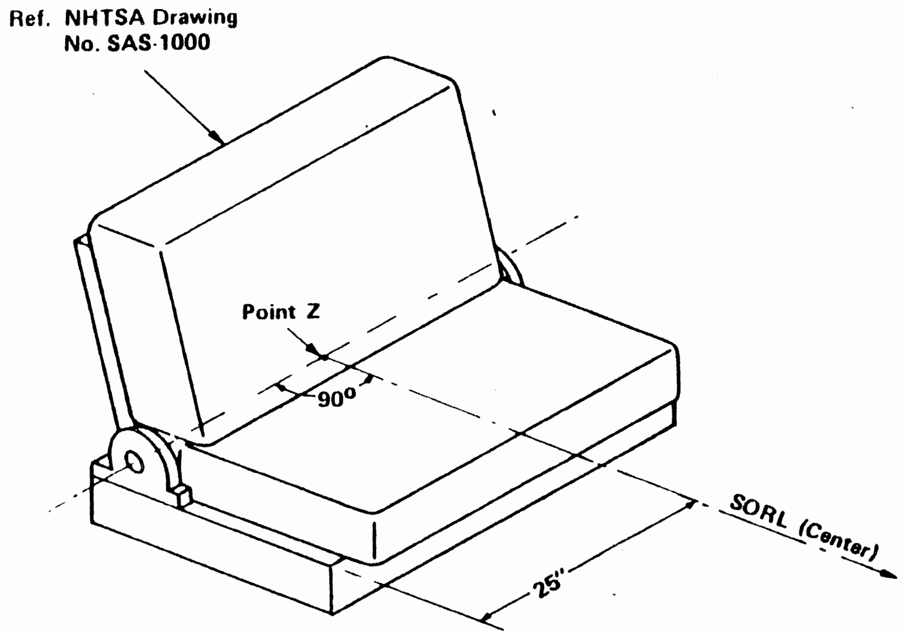
S7.1 *Six-month-old dummy.* An unclothed "Six-month-old Size Manikin" conforming to Subpart D of Part 572 of this chapter is used for testing a child restraint system that is recommended by its manufacturer in accordance with S5.6 for use by children in a weight range that includes children weighing not more than 20 pounds.

S7.2 *Three-year-old dummy.* A three-year-old dummy conforming to Subpart C of Part 572 of this chapter is used for testing a child restraint that is recommended by its manufacturer in accordance with S5.6 for use by children in a weight range that includes children weighing more than 20 pounds.

S7.2.1 Before being used in testing under this standard, the dummy is conditioned at any ambient temperature from 66° F to 78° F and at any relative humidity from 10 percent to 70 percent for at least 4 hours.

S7.2.2 When used in testing under this standard, the dummy is clothed in thermal knit waffle-weave polyester and cotton underwear, a size 4 long-sleeved shirt weighing 0.2 pounds, a size 4 pair of long pants weighing 0.2 pounds and cut off just far enough above the knee to allow the knee target to be visible, and size 7M sneakers with rubber toe caps, uppers of dacron and cotton or nylon and a total weight of 1 pound. Clothing other than the shoes is machine-washed in 160° F to 180° F water and machine-dried at 120° F to 140° F for 30 minutes.

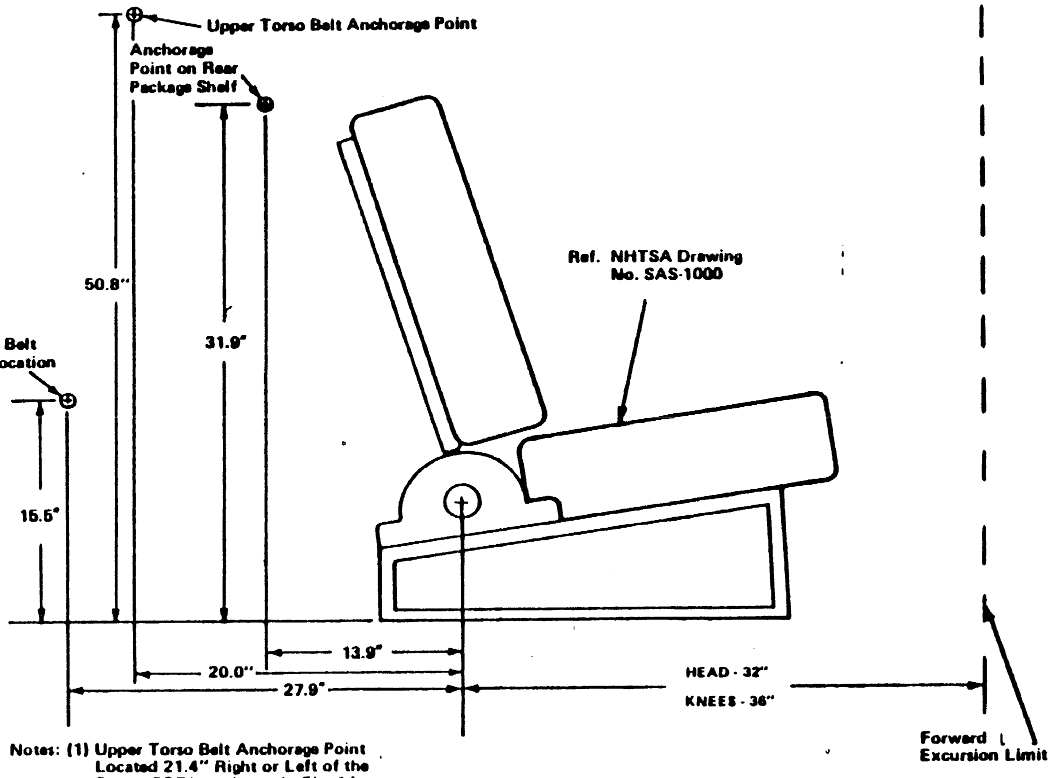
S7.3 *Standard seat assembly.* The standard seat assembly used in testing under this standard is a simulated vehicle bench seat, with three seating positions, which is described in Drawing Package SAD-100-1000 and consists of drawings and a bill of materials.



SORL–SEAT ORIENTATION REFERENCE LINE (HORIZONTAL)

SORL LOCATION ON THE STANDARD SEAT

FIGURE 1A

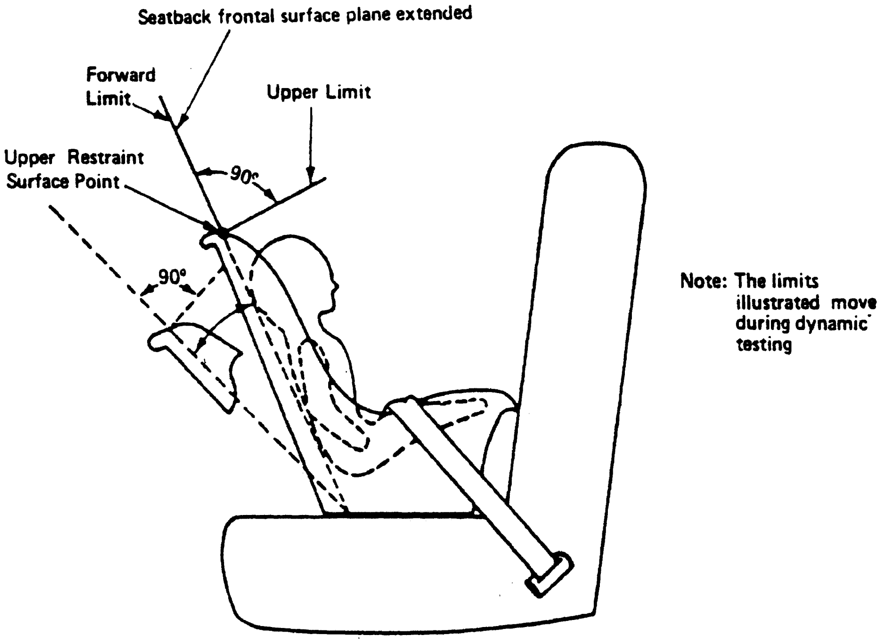


Notes: (1) Upper Torso Belt Anchorage Point Located 21.4" Right or Left of the Center SORL as shown in Fig. 1A.

(2) Rear Lap Belt Buckle Located 7.0" Right or Left of the Center SORL as shown in Fig. 1A.

LOCATIONS OF ADDITIONAL BELT ANCHORAGE POINTS AND FORWARD EXCURSION LIMIT

FIGURE 1B



REAR FACING CHILD RESTRAINT
FORWARD AND UPPER HEAD EXCURSION LIMITS

FIGURE 1C

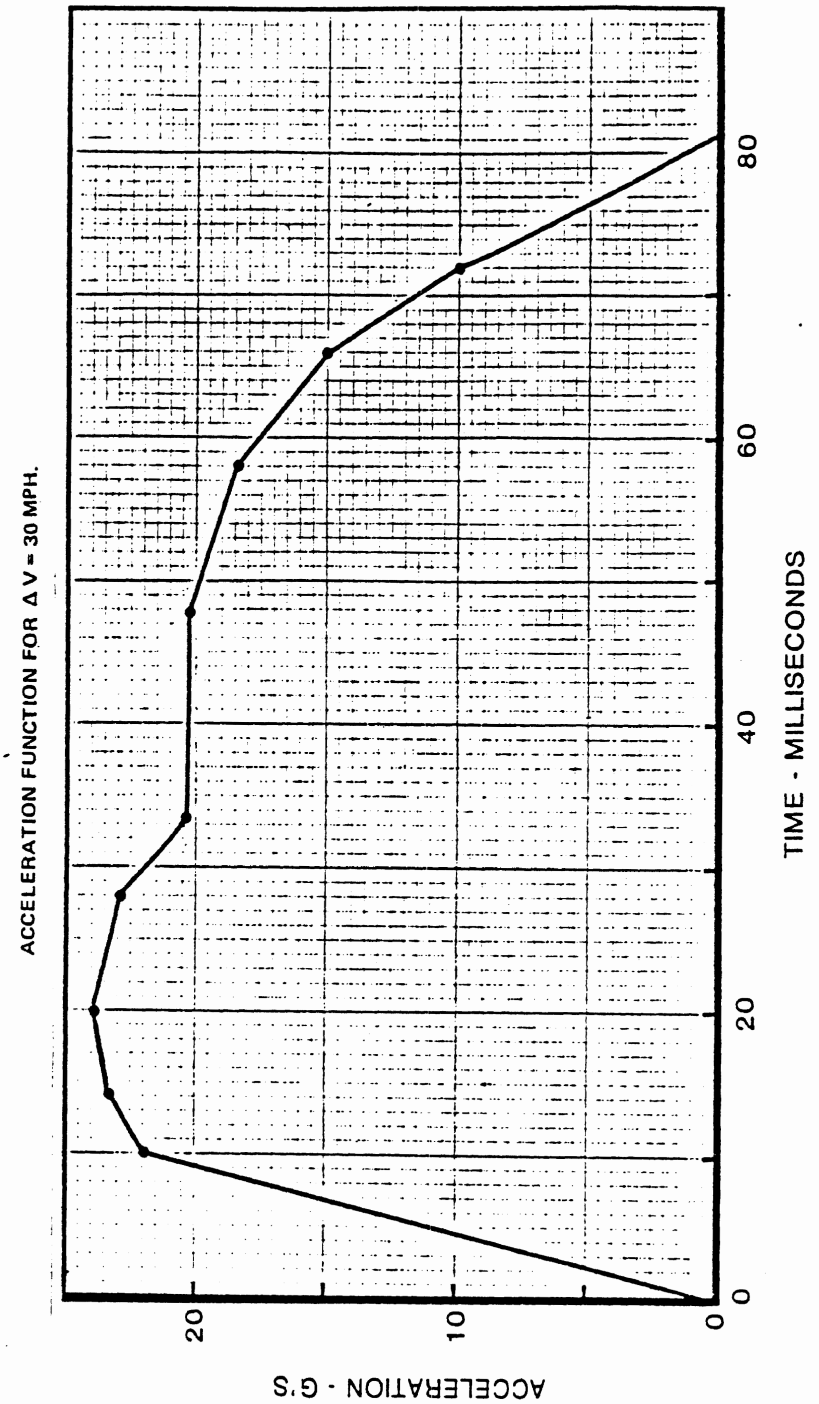

ACCELERATION FUNCTION FOR Δ V = 30 MPH.
0
20
40
60
80
TIME - MILLISECONDS
0
10
20
ACCELERATION - G'S

FIGURE 2

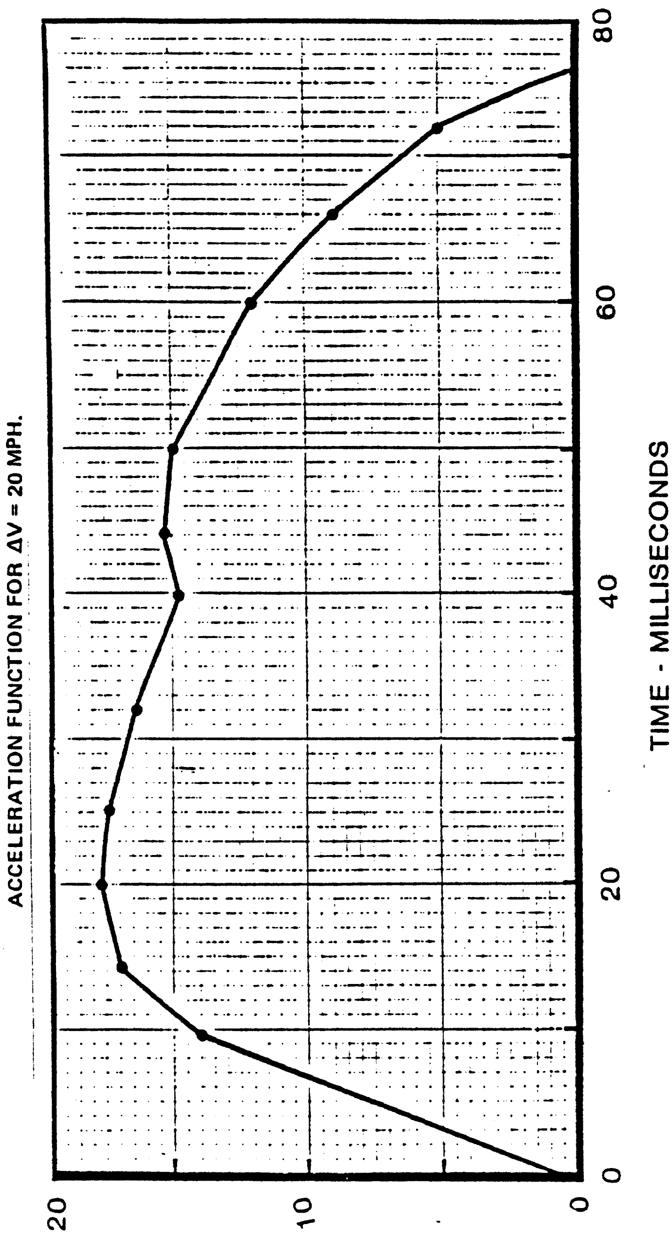
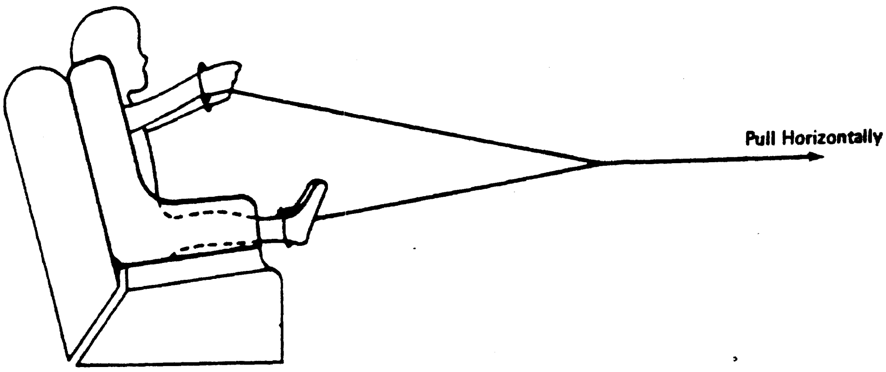
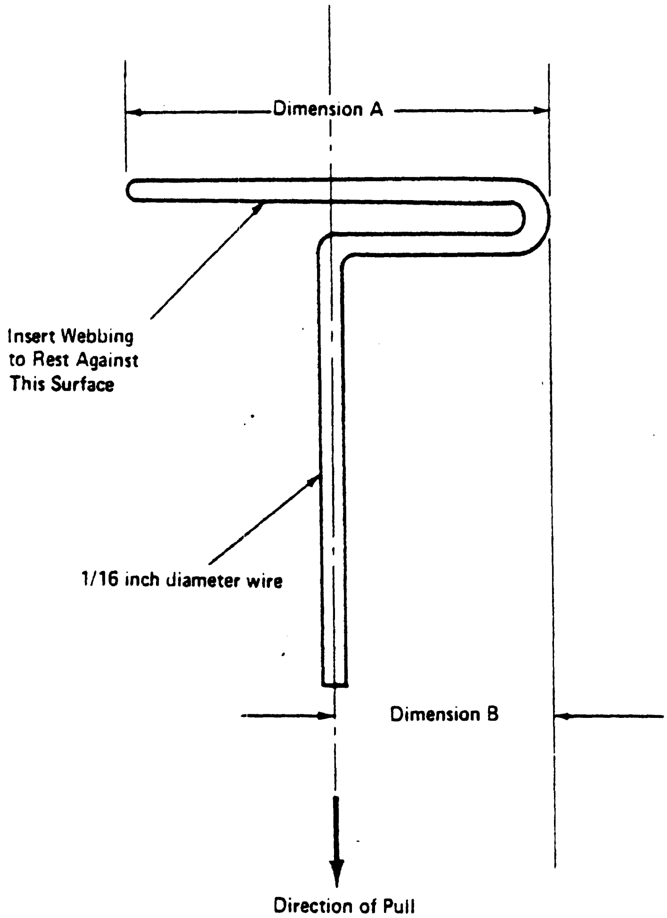

ACCELERATION FUNCTION FOR ΔV = 20 MPH.
ACCELERATION - G'S
20
10
0
TIME - MILLISECONDS
0
20
40
60
80

FIGURE 3



BUCKLE RELEASE TEST
FIGURE 4



Dimension A - Width of Webbing Plus 1/8 inch

Dimension B - 1/2 of Dimension A

WEBBING TENSION PULL DEVICE
FIGURE 5

(Secs. 103, 112, 119 Pub. L. 89-563, 80 Stat. 718 (15 U.S.C. 1392, 1401, 1407); delegation of authority at 49 CFR 1.50)

[44 FR 72147, Dec. 13, 1979, as amended at 45 FR 29047, May 1, 1980]

EFFECTIVE DATE NOTE: At 44 FR 72147, Dec. 13, 1979, § 571.213 was revised at 45 FR 29047, May 1, 1980, the effective date of this revision was changed to January 1, 1981. For the convenience of the user, the superseded text appears below.

§ 571.213 Standard No. 213; Child seating systems.

S1. *Purpose and scope.* This standard specifies requirements for child seating systems to minimize the likelihood of death and injury to children in vehicle crashes or sudden stops by ejection from the vehicle, contact with the vehicle interior, or contact with a child seating system.

S2. *Application.* This standard applies to child seating systems for use in passenger cars, multipurpose passenger vehicles, trucks and buses. This standard does not apply to Type 3 seat belt assemblies, as defined in § 571.209, or to systems for use only by recumbent or semirecumbent children.

S3. *Definitions.* "Child seating system" means an item of motor vehicle equipment for seating a child being transported in a motor vehicle.

S4. *Requirements.* Each child seating system manufacturer before June 1, 1980, shall meet, at the option of the manufacturer, either the requirements of S4.1 through S4.11 of this standard, or the requirements of § 571.213 of this part (Standard No. 213, Child Restraint Systems).

S4.1 *Labeling.* Each child seating system shall have a label permanently affixed to it. The label shall contain the following information in the English language in letters and numerals not less than 3/32-inch high:

(a) The manufacturer's name. However, a distributor's name may be placed on the label in place of the manufacturer's name if the distributor assumes responsibility for all duties and liabilities imposed on the manufacturer by the National Traffic and Motor Vehicle Safety Act with respect to the system.

(b) Model number or name.

(c) Month and year of manufacture.

(d) Place of manufacture (city and State or foreign country). However, if the label contains the distributor's name in place of the name of the manufacturer, the city and State or foreign country of the distributor's principal offices shall appear on the label.

(e) A statement describing in general terms both the types of motor vehicles and the designated seating positions in those vehicles in which the system is either recommended or not recommended for use. A child seating system may not be recommended for use in other than a designated seating position. The following, either stated separately or in combination, are examples of acceptable statements:

(1) "Recommended for use only on bench seats of passenger cars manufactured after January 1, 1968, by the ———— Motor Company."

(2) "Recommended for use only on seats that have head restraints on (make or model designation(s)) passenger cars manufactured after January 1, 1969."

(3) "Not recommended for use in trucks and buses."

(f) Except as provided in S4.1.1, the following statement: "Not for use on hinged or folding vehicle seats or seat backs unless the seat or seat back is equipped with a latch."

(g) Unless the system is a rearward-facing child seating system, the following statement: "For use only on forward-facing vehicle seats."

(h) The following statement, inserting in the blank spaces the manufacturer's recommendations of the maximum height and the minimum and maximum weight of children who can safely occupy the system: "For use only by children who weigh between ——— and ——— pounds and whose height is ——— inches or less."

S4.1.1 *Exemption.* A part of the warning required by S4.1(f) relating to use of a child seating system on a hinged or folding vehicle seat or on a vehicle seat having a hinged or folding back, or on both, may be omitted in the following circumstances:

(a) The part of the warning that relates to vehicle seats may be omitted if the child seating system includes a component to restrain a hinged or folding vehicle seat and if, when the system and the component are both installed in the seat in accordance with the recommendation required by S4.1(e) and the instructions required by S4.2, the component will not fail when a forward longitudinal force equal to 20 times the weight of the vehicle seat is applied through the seat's center of gravity and maintained for 10 seconds.

(b) The part of the warning that relates to seat backs may be omitted if the child seating system includes a component to restrain the hinged or folding seat back and if, when the system and the component are both installed in the vehicle seat in accordance with the recommendation required by S4.1(e) and the instructions required by S4.2, the component will not fail when a forward longitudinal force equal to 20 times the weight of the vehicle seat back is applied through the back's center of gravity and maintained for 10 seconds.

(c) The entire warning may be omitted if the child seating system includes the components for restraining the seat and seat back specified in (a) and (b).

S4.2 *Installation instructions.* Each child seating system shall be accompanied by an instruction sheet, providing a step-by-step procedure (which may include diagrams) for installing the system in the vehicles in which it is recommended for use in accordance with S4.1(e), securing the system with a Type 1 or Type 2 seat belt assembly, positioning a child in the system, and adjusting the system to fit the child.

S4.3 *Adjustment.* Each adjustable child seating system component and each belt system designed to restrain the child directly shall be sufficiently adjustable to fit a child of any size for which the seat is recommended pursuant to paragraph S4.1(h) and who is positioned in the system in accordance with the instructions required by S4.2. A belt system used to restrain the child directly shall be sufficiently adjustable to fit snugly any such child.

S4.4 *Attachment.* Each child seating system shall be designed and constructed so that—

(a) The system has no provision for attachment to a vehicle seat back other than by means of a component that is inserted between the vehicle seat back and the vehicle seat cushion; and

(b) When installed in accordance with the instructions required by S4.2, a system installed on a forward-facing vehicle seat shall be restrained against forward movement, and a system installed on a rearward-facing vehicle seat shall be restrained against rearward movement, by a Type 1 or Type 2 seat belt assembly as defined in § 571.209.

S4.5 *Distribution of restraint forces.*

S4.5.1 *Forward-facing systems.* When a forward-facing child seating system is installed in a vehicle and a child is positioned in the system in accordance with the instructions required by S4.2, components of the child seating system and the vehicle's seat belt assemblies that apply restraining forces directly to the child shall, during forward movement of the child relative to the vehicle in which the system is installed, distribute those forces on both the pelvis and thorax of the child. Restraint forces may also be distributed over other areas of the child's body as long as both the pelvis and thorax are restrained.

S4.5.2 *Rearward-facing systems.* When a rearward-facing child seating system is installed in a vehicle and a child is positioned in the system in accordance with the instructions required by S4.2, the components of the child seating system and the vehicle's seat belt assemblies that apply restraining forces directly to the child shall—

(a) During forward movement of the child relative to the vehicle in which the system is installed, distribute those forces on both the back of the child's torso and the back of the child's head; and

(b) During rearward movement of the child relative to the vehicle in which the system is installed, distribute those forces on both the pelvis and thorax of the child. Restraint forces may also be distributed over other areas of the child's body as long as both the back of the torso and head are restrained during forward movement and both the pelvis and thorax are restrained during rearward movement.

S4.6 *Head restraint.*

S4.6.1 Except as provided in S4.6.2, each forward-facing child seating system shall have a head restraint that limits rearward angular displacement of the child's head relative to the child's torso line. The height of the head restraint, measured as the straight line distance between the highest point at the lateral center of the head restraint and the point on the longitudinal centerline of the seating surface at the intersection of a plane parallel to the rear surface of the torso block through the torso block reference specified in S5.1, when the torso block is positioned in the child seating system in accordance with the instructions required by S4.2, shall be as follows:

If the maximum weight of children for whom the system is recommended is:	*The height of the head restraint shall be at least: (inches)*
20 pounds or less	15
More than 20 pounds but not more than 25 pounds	16.2
More than 25 pounds but not more than 30 pounds	17.9
More than 30 pounds but not more than 35 pounds	18.9
More than 35 pounds	20

S4.6.2 Paragraph S4.6.1 does not apply to a child seating system if—

(a) In accordance with S4.1(e), the system is recommended for use only at designated seating positions in makes and models of vehicles at which the vehicle's seat back or head restraint limits rearward angular displacement of the child's head relative to the child's torso line; and

(b) When the system is installed in accordance with the instructions required by S4.2, the distance from the lowest point at the lateral center of the child seating surface to a horizontal plane tangent to the highest point of the vehicle seat back or head restraint in its highest adjustable position, at the lateral center of the designated seating position, measured on a line parallel to the rear surface of the vehicle seat back, is at least equal to the seat back height specified for the seating system in S4.6.1.

S4.7 *Webbing.* If a child seating system has webbing to distribute restraint forces as required by S4.5—

(a) The webbing that directly contacts the child's body shall have a minimum width of 1½ inches; and

(b) The webbing that sustains restraint forces shall meet the requirements for webbing in a Type 3 seat belt assembly specified in paragraph S4.2(b) through paragraph S4.2(h) of § 571.209.

S4.8 *Hardware.* Attachment hardware of each child seating system that sustains restraint forces shall meet the corrosion resistance requirements for attachment hardware of a seat belt assembly specified in paragraph S4.3(a) of § 571.209. Buckles, retractors, and metallic parts other than attachment hardware that sustain restraint forces shall meet the corrosion resistance requirements for buckles, retractors, and metallic parts other than attachment hardware of a seat belt assembly specified in paragraph S4.3(a) of § 571.209.

S4.9 *Release mechanism.* The mechanism for releasing components of a child seating system that directly restrain the child shall release when a force of not more than 20 pounds is applied in accordance with S5.3.

S4.10 *Impact protection.*

S4.10.1 *Head and torso.* Except as provided in S4.10.2, any rigid component of a child seating system (except restraint buckles, and belt adjustment hardware attached only to webbing) that, during forward, right side, left side, or rearward impact, may contact the head or torso of a child within the height and weight range recommended in accordance with S4.1(h) shall:

(a) Have no corner or edge with a radius of less than one-quarter inch; and

(b) Except as provided in S4.10.2, be covered with deformable force-distributing material having a thickness of at least one-half inch.

S4.10.2 *Exception.* S4.10.1(b) does not apply to the area of a rigid back or side of a child seating system that is contactable only by the child's torso, if the contactable area of the back or side is at least 24 square inches.

S4.11 *Performance.*

S4.11.1 *All child seating systems.*

(a) When tested in accordance with S5.1 each child seating system shall—

(1) Retain the torso block in the system;

(2) Sustain a static load of 1,000 pounds in the forward direction; and

(3) Restrict forward horizontal movement of the torso block reference point:

(i) When the vehicle seat is in its forwardmost adjustment position, to not more than 12 inches;

(ii) When the vehicle seat is rearward of its forwardmost adjustment position, to not more than 12 inches plus the distance, measured horizontally, that the vehicle seat is rearward of its forwardmost adjustment position.

(b) A child seating system in which the attitude of the child is adjustable pursuant to the instructions provided in accordance with paragraph S4.2 shall meet these requirements at each designed adjustment position.

S4.11.2 *Rearward-facing child seating systems.*

(a) When tested in accordance with S5.2, each rearward-facing child seating system shall—

(1) Retain the torso block in the system;

(2) Sustain a static load of 500 pounds in the rearward direction; and

(3) Restrict rearward horizontal movement of the torso block reference point to 12 inches or less.

(b) A child seating system in which the attitude of the child is adjustable pursuant to the instructions provided in accordance with paragraph S4.2 shall meet these requirements at each designed adjustment position.

S5. *Test procedures.*

S5.1 *All seating systems.* The child seating system shall be subjected to a static load, using the torso block shown in Figure 6 of Federal Motor Vehicle Safety Standard No. 209, as follows:

(a) Locate the torso block reference point, which is 2.9 inches above the bottom surface of the torso block and 2.1 inches forward of the back surface of the torso block.

(b) Install the system in accordance with the manufacturer's instructions required by S4.2 on a vehicle seat other than a seat on which the manufacturer does not recommend its installation in the recommendation required by S4.1(e).

(c) Position the torso block in the system in accordance with the manufacturer's instructions required by S4.2, and adjust the system in accordance with those instructions.

(d) Apply an increasing load to the torso block in a forward direction, not more than 15° and not less than 5° above the horizontal, until a load of 1,000 pounds is achieved. The intersection of the load application line and the back surface of the torso block, at the time that the force removes the slack from the load application system, shall not be more than 8 inches or less than 6 inches above the bottom surface of the torso block. Maintain the 1,000-pound load for 10 seconds.

(e) Measure the horizontal movement of the torso block reference point.

S5.2 *Rearward-facing child seating systems.* The rearward-facing child seating system shall be subjected to the test procedure specified in S5.1, except that—

(a) A load of 500 pounds shall be achieved; and

(b) The load shall be applied in a rearward direction.

S5.3 *Release mechanism.* Conduct the following tests for forward-facing and rearward-facing child seating systems, as appropriate, using a torso block configured so that it does not contact the buckle in a manner as to affect the buckle release force.

S5.3.1 For forward-facing child seating systems—

(a) Test the system with a 1,000-pound force as specified in S5.1;

(b) Reduce the force to 45 pounds; and

(c) Release the mechanism in a manner typical of that employed in actual use.

S5.3.2 For rearward-facing child seating systems—

(a) Test the system with a 500-pound force as specified in S5.2;

(b) Reduce the force to 45 pounds; and

(c) Release the mechanism in a manner typical of that employed in actual use.

(Secs. 112 and 114, Pub. L. 89-563, 80 Stat. 718, 15 U.S.C. 1401, 1403; delegation of authority at 49 CFR 1.51)

[36 FR 22902, Dec. 2, 1971, as amended at 38 FR 7563, Mar. 23, 1973; 44 FR 72147, Dec. 13, 1979]

AEROSPACE RECOMMENDED PRACTICE

Society of Automotive Engineers, Inc.
400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

ARP 766A

Issued 9-30-67
Revised 10-15-78

RESTRAINT DEVICE FOR SMALL CHILDREN

1. PURPOSE

This Aerospace Recommended Practice (ARP) establishes guidelines for the performance of restraint systems, applicable for use in civil transport aircraft, for small children weighing between 20 lb (9.1 kg) and 40 lb (18.1 kg). (For guidance on infants under 20 lb (9.1 kg) and/or too young to sit up, and utilizing a recumbent infant restraint, see ARP 1469).

2. INTRODUCTION

The restraint device described in this ARP is intended to be used by small children able to sit up, and weighing up to 40 lb (18.1 kg), to provide improved protection during landings and take-offs, turbulence, and survivable aircraft impacts. The device will be used in a not otherwise occupied adult passenger seat in a civil transport aircraft, and be held to the seat by the adult seat belt, or by the adult belt attachment.

3. DYNAMIC IMPACT PROTECTION

The restraint device, when occupied by a small child and while installed in a typical civil transport passenger seat, shall be capable of providing protection during an impact which produces a 44 ft/sec. (13.4 m/sec.) velocity change with g levels not exceeding the range specified in Fig. 1, and with the deceleration vector at any angle within a forward 45° cone of the longitudinal axis of the aircraft. The child occupant shall be retained within the system; the system shall show no separation of components or joints; no portion of any belt restraint system should release; the child occupant shall be protected against compression between any parts of the restraint device and/or the passenger seat back; and if the child's restraint is forward facing, it shall be installed in seating positions where more than 18 in. (457.2 mm) of unobstructed distance exists from the seat reference point forward to the back surface of the seat or bulkhead ahead.

4. PROTECTION AGAINST TURBULENT FLIGHT CONDITIONS

To provide protection against turbulence encountered in normal flight, the restraint device installed in a civil transport passenger seat with folding back, shall retain the child occupant in a normal position throughout two cycles of complete inversion (roll-over upside down and remain in place).

5. RESTRAINT DEVICE RELEASE

5.1 Operation of the restraint device and its release shall be obvious. The force required to release the restraint device shall not exceed 14 lb (6.4 kg) while a horizontal load of 45 lb (20 kg) is being applied to the system. It shall be possible to release the device with the aircraft in an inverted position.

5.2 The mechanism by which the child is released either from the unit or the seat, shall be accessible, and visible under emergency light conditions.

6. INSTALLATION

Each child restraint device shall be capable of being properly installed in a civil air transport passenger seat, using only the standard adult lap belt assembly which is provided with the adult seat. Additional attachment to the seat, seat cushion, seat back, or to the aircraft shall not be necessary.

7. BODY CONTACT SURFACES

When the primary reaction of the impact load is provided by a surface supporting the child's back, that surface shall have a continuous area of at least 85 sq. in.

When the primary reaction to the impact crash load is provided by a surface supporting the front of the child's torso, that surface shall have a continuous area of at least 48 sq. in., with a minimum bowing of at least 6 in. (152.4 mm).

Each restraint device shall provide a surface for head support and for limiting head and neck rotation relative to the body during impact deceleration. Surfaces of the restraint, such as webbing or belts, shall be capable of distributing the impact load and absorbing impact energy to prevent localized injuries. There shall be no sharp edges which might puncture any inflatable emergency egress/flotation equipment or be an injury hazard.

8. LABELING

Each child seating system shall have a label permanently affixed to it. The label shall contain the following:

a) The manufacturer's name and location

   However, a distributor's name may be blaced on the label in place of the manufacturer's name if the distributor assumes the responsibility for all duties and liabilities imposed on the manufacturer by Federal Aviation Regulations with respect to the system.

b) Model number or name

c) Date of manufacture

d) Place of manufacture

e) Any specific recommendations and instructions relating to use

f) Weight capacity

9. SANITATION

The device shall be easily cleanable for sanitary reuse.

10. FLAMMABILITY

The flammability should be no less than flame resistance of the seat to which it is attached.

11. NOTES

11.1 Marginal Indicia: No phi (ø) symbol is used to indicate technical changes from the previous issue of this ARP because of the extensive nature of all changes.

12. REFERENCES

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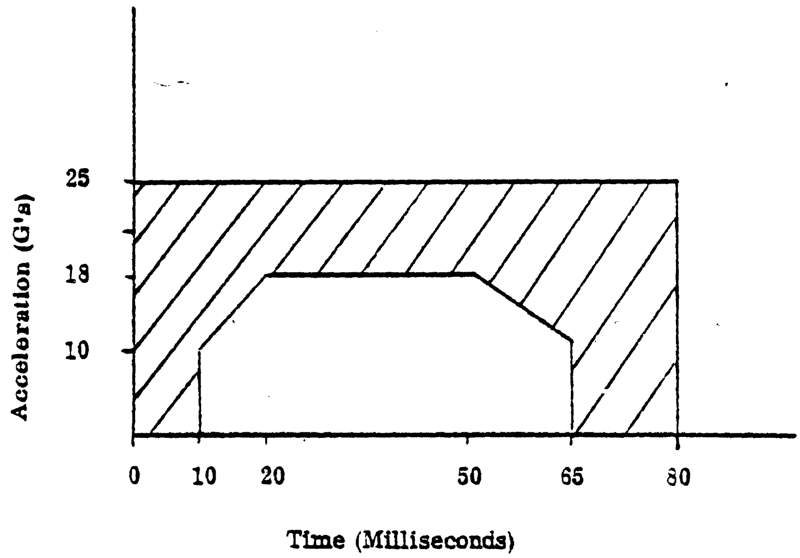
PREPARED BY:

SAE COMMITTEE S-9, CABIN SAFETY PROVISIONS



When subjecting the system to a dynamic test having a velocity change of at least 30 mph (44 ft/sec.) the sled acceleration-time profile must be contained entirely within the shaded area of Fig. 1 when filtered at SAE Class 60 (as specified by SAE J211b).

Figure 1

Permissible Range of Acceleration Function for ΔV = 30 MPH

AEROSPACE RECOMMENDED PRACTICE

Society of Automotive Engineers, Inc.
400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

ARP 1469

Issued October 1978
Revised

RESTRAINT DEVICE FOR INFANTS

1. PURPOSE

This Aerospace Recommended Practice (ARP) establishes guidelines for the performance of restraint systems, applicable for use in civil transport aircraft, for recumbent position infants weighing up to 20 lb (9.1 kg).

2. INTRODUCTION

The restraint device described in this ARP is intended to be used by infants weighing up to 20 lb (9.1 kg) (and unable to sit up) to provide improved protection during landings and takeoffs, turbulence, and survivable impacts. The device will be used in a not otherwise occupied adult passenger seat in civil transport aircraft, and be held to the seat by the adult seat belt or attachment.

3. DYNAMIC IMPACT PROTECTION

The restraint device, when occupied by an infant in a civil transport passenger seat with folding back, shall be capable of providing impact protection during an impact which produces a 44 ft/sec. (13.4 m/sec.) velocity change with g levels not exceeding the range specified in Fig. 1, with the deceleration vector at any angle within a forward 45° cone of the longitudinal axis of the aircraft. The infant shall be restrained within the system; the system shall show no separation of components or joints; no portion of any belt restraint system shall release; the infant shall be protected against compression between any parts of the restraint device and/or the passenger seat back.

4. PROTECTION AGAINST TURBULENT FLIGHT CONDITIONS

To provide protection against turbulence encountered in normal flight, the restraint device, installed in a civil transport passenger seat with folding back, shall retain the infant in a normal position throughout two cycles of complete inversion (roll-over upside down and remain in place).

5. RESTRAINT DEVICE RELEASE

5.1 Operation of the restraint device and its release shall be obvious. The force required to release the restraint device shall not exceed 14 lb (6.4 kg) while a horizontal load of 45 lb (20 kg) is being applied to the system. It shall be possible to release the device with the aircraft in an inverted position.

The mechanism by which the child is released either from the unit or the seat, shall be accessible, and visible under emergency light conditions.

6. INSTALLATION

Each infant restraint device shall be capable of being properly installed in a civil air transport passenger seat, with folding back, using only the standard adult lap belt assembly which is provided with the adult seat.

Additional attachments to the seat, seat cushion, seat back, or to the aircraft shall not be necessary.

7. BODY CONTACT SURFACES

When the primary reaction of the impact load is provided by a surface supporting the infant's back, that surface shall have a continuous area of at least 35 sq. in.

When the primary reaction to the impact crash load is provided by a surface supporting the front of the infant's torso, that surface shall have a continuous area of at least 48 sq. in., with a minimum bowing of at least 6 in. (152.4 mm).

Each restraint device shall provide a surface for head support and for limiting head and neck rotation relative to the body during an impact deceleration.

Any surface which can be contacted by the head or body of the infant shall be capable of distributing the impact load and absorbing impact energy to prevent localized injuries.

There shall be no sharp edges which might puncture a slide/raft or be an injury hazard.

8. LABELING

Each infant seating system shall have a label permanently affixed to it. The label shall contain the following information in the English language in letters and numerals not less than 3/32-in. (2.38-mm) high; the label shall contain the following:

a) make, model

b) manufacturer's name, location

c) date of manufacture

d) installation instructions

e) weight capacity

f) in addition the following label must state this device is in compliance with ARP 765 unless superseded by FAR or TSO.

9. VISIBILITY

The mechanism for releasing the infant from the unit shall be readily visible under emergency lighting conditions utilizing color and/or independent lighting technique.

10. SANITATION

The device shall be easily cleanable for sanitary reuse.

11. FLAMMABILITY

Flammability shall be no less than flame resistance of seat to which it is attached.

12. REFERENCES

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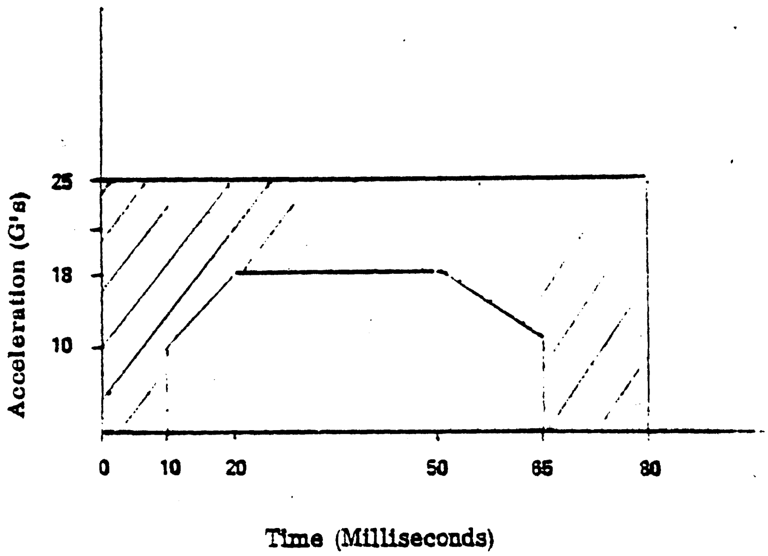


When subjecting the system to a dynamic test having a velocity change of at least 30 mph (44 ft/sec) the sled acceleration-time profile must be contained entirely within the shaded area of Fig. 1 when filtered at SAE class 60 (as specified by SAE J211b).

Figure 1

Permissible Range of Acceleration Function for $\Delta V = 30$ MPH

APPENDIX H

PROPOSED

SAE ARP 1226

AEROSPACE RECOMMENDED PRACTICE

OCCUPANT RESTRAINT SYSTEMS (ACTIVE)

FOR GENERAL AVIATION AIRCRAFT

Approved by SAE Committee A23 October 21, 1975
Disapproved by SAE Aerospace Council/Equipment Division December 30, 1975. Published as Appendix in SAE Publication No. 770154, February 1978. Reprinted in 1978 SAE Transactions.

1.0 PURPOSE - The purpose of this ARP is to provide recommendations that will lead to advancement of restraint protection for occupants of general aviation aircraft and to provide increased safety during survivable accidents, emergency landings and turbulent flight. It is not the purpose of this document to specify design methods or mechanisms to be used in accomplishing the objectives of this document or to recommend specific test methods to verify performance of the system.

2.0 LIMITATIONS - This ARP is applicable only to those active restraint systems such as conventional webbing strap devices. Advanced systems, such as passive restraints, air cushions, rigid load distribution systems, etc., are not considered by this ARP. ARP 1318, General Aviation Seat Design, should be consulted to assure compatibility of restraint system and seating system configurations.

3.0 INTRODUCTION - A restraint system (which may include seat belt/shoulder harness systems) comprises all components of the occupant restraining device, exclusive of the seat, couch or berth structure. However, since the seat normally assumes the function of providing restraint against crash loads imposed from the bottom and rear of the aircraft and of absorbing rebound energy of the occupant resulting from restraint elastic properties, attention should be given to ARP 1318 to assure seat design compatible with the objectives of this restraint system ARP. Consideration should also be given to details of cabin interior, seat adjustment range, and restraint structural anchorage location, all of which can modify performance required of the restraint system. Particular concern should be given to designs incorporating seats which deform (absorb energy) during a crash to assure that the deformation does not alter the occupant/restraint relationship and increase injury potential.

3.1 Restraint systems are provided for the protection of occupants of aircraft during routine takeoffs and landings, turbulent flight, emergency conditions (such as intentional ditchings and crash-landings) and unexpected crash conditions of a survivable nature. Restraint integrity should be maintained through crash conditions having multiple impacts.

3.2 A restraint system's primary function is to safely retain the occupant in his seat, couch or berth and prevent secondary impact between the occupant and the cabin interior, without, in itself, endangering the occupant during or immediately after an incident or accident.

3.3 To encourage constant use during routine flight, the restraint system should provide a high degree of comfort, ease of adjustment, and be easily donned, removed and stowed convenient for ready access.

3.4 Requirements of FAA FAR's and Technical Standard Orders for occupant restraint systems should be considered as minimum requirements, limited by the necessary condition that they be applicable to any general configuration. Specific configurations of seating, cabin interiors, airframe design or operational application may generate more stringent requirements for the occupant restraint system.

4.0 RECOMMENDATIONS - The recommendations contained herein apply primarily to restraints for forward-facing seating positions; however, design of restraint systems should take into account the fact that crash loads may be applied from any direction; i.e., combinations of forward, lateral and spinal loadings, and may be in excess of those specified in current FAR's.

The following criteria are recommended:

4.1 Upper torso restraints shall not be used in the absence of an appropriate lower torso restraint.

4.2 If the restraint system is attached to the seat, the strength of the restraint system/seat combination should not be less than the strength of the seat/aircraft attachment, even after degradation due to environmental exposure.

4.3 If the restraint system is attached directly to the aircraft structure (by-passing the seat) the ultimate load capacity of the restraint system/aircraft attachment should be sufficiently high as to insure integrity of the restraint-to-aircraft-load-path even after seat failure.

4.4 Each occupant should be provided with his own individual restraint system; shared systems are not considered acceptable.

4.4.1 For criteria relating to special restraint devices for small children, see ARP 766, Restraint Device for Small Children.

4.5 In the absence of crash environmental data or test requirements for the specific application under consideration, the system should at least provide restraint against the static load vectors shown in Figure 1, acting independently or concurrently, whichever is most critical.

4.6 Elongation of any portion of the restraint system (other than that specifically designed for controlled energy absorption), due to impact loading, should be held to a minimum to provide maximum benefit from crush characteristics of the aircraft structure and to reduce potential for secondary impact between the occupant and the aircraft interior.

4.7 The attachment point(s) of the upper torso restraint systems (or the harness guide, if used) should be located, insofar as possible, to minimize lateral movement of the upper torso during sideward deceleration of the aircraft, to avoid discomfort due to neck chafing by the restraint, to assure proper location of the restraint over shoulder, and to reduce elastic deformation of the system under dynamic load.

4.8 Integrity of the restraint system should not be compromised by deformation of the attachment structure that can be reasonably expected in a survivable crash.

4.9 The material composing those portions of the restraint system in contact with the occupant's body should be pliable (with the exception of necessary buckle or adjuster hardware), and should have no sharp cutting edges. Sharp discontinuities between component widths should be eliminated wherever possible. Lower torso restraint material should not be less than two inches in width; upper torso material should not be less than 1-1/2 inches in width.

4.10 Restraint loads should be distributed by the system so as to apply minimal pressure on vital body areas, exploiting, as much as possible, the strength and resiliency of the heavily muscled and/or skeletal structure of the body, such as the pelvis, rib cage, and shoulders. Heavy restraint loads should not be applied against the abdominal area. Excessive compression, torsion or bending loads should not be induced on the occupant's spine because of the restraint system configuration.

4.11 The restraint system should provide necessary upper torso freedom of movement during normal flight as is required for all necessary flight duties under all operating conditions.

4.12 The lower torso portion of the restraint system should maintain firm, but comfortable, contact of the buttocks with the seat, so as to reduce unwanted movement, regardless of the direction of crash loading or of gust (rough air) accelerations. During crash loading of the restraint system by the occupant, the resultant load vector should cross the iliac crests (hips) between 45° and 55° relative to the compressed plane of the seat cushion as shown in Figure 2. The tendency of the upper torso restraint to displace the lower torso restraint in an upward direction under high dynamic loading conditions must be given special design attention.

4.13 The restraint system should provide freedom from undue fatigue during normal flight over extended periods of time, such as two or more hours of uninterrupted use.

4.14 The buckle, or other such locking-unlocking device, should be minimal in size, lightweight, easily operable by the user in any position of his body with respect to the seat, and should have no sharp cutting edges nor protuberances that might be injurious to the occupant. False latching of the buckle should not be possible.

4.15 The system configuration should be such that the correct method of wearing the restraint is obvious to the occupant. The system should be capable of being easily donned and removed by an inexperienced user, and its manner of use, locking, adjustment and unlocking should be obvious without the need for printed or verbal instruction.

4.16 If conventional type shoulder harness straps are used in the system, the straps should be installed so as to prevent their snagging on near-by structures; splices should pass freely through the harness guides or fittings to preclude "false" deceleration/acceleration and subsequent inadvertent locking of the inertia reel (if used).

4.17 When shoulder straps are used in the system, they should cross the shoulder to prevent edge chaffing against the neck (see Figure 3.)

4.18 The angle of the shoulder straps to the shoulder should be between 0° and 30° above a line parallel to the longitudinal axis of the aircraft (see Figure 4.)

4.19 If a single diagonal strap type of upper torso restraint is utilized, the strap should cross the chest above the c.g. of the torso (Figure 3) so as to minimize the chance of the shoulders rolling out of the "open" side of the restraint system during accelerations involving a combination of lateral and forward loads.

4.20 When a single diagonal strap type of upper torso restraint is utilized on a forward-facing seat, the upper part of the strap should preferably cross the "outboard" shoulder-trapezial slope, so as to provide maximum lateral restraint of the upper torso relative to near-by structure. The lower end of the strap should be located near the inboard hip (see Figure 5).

4.21 When a single diagonal chest strap is utilized on a side-facing seat, the upper end of the strap should cross the forward shoulder; the lower end should attach near the "rear" hip (see Figure 5). Side-facing seats are not recommended.

4.22 If an inertia reel or similar device is utilized to maintain contact between the restraint system and the occupant's upper torso during normal movement and activity, the "reel-in" or retraction tension load imposed on the shoulders should be minimal (less than one-half pound).

4.23 The cabin interior should be designed so that serious injury cannot be sustained by the occupant as his torso moves forward at rates below the "lock-up" level of the inertia reel.

4.24 Automatic "lock-up" of the upper torso inertia system should result solely from a 2.5 $\pm$ 0.5 g acceleration of the occupant's torso.

4.25 Manual release of the restraint system should be easily accomplished by the occupant regardless of body attitude (hanging inverted or on side, etc.,) and should require only a single motion of the release device.

4.26 Manual release of the restraint system should not require the use of more than any one finger or thumb of either hand of the wearer, after limit loading and while the occupant is hanging inverted in the restraint system.

4.27 Manual release of the restraint system should require release of only one unlocking device in order to release the total system from the user.

4.28 The design of the restraint system should minimize the possibility of inadvertent release through accidental contact with the user's body, apparel, or any near-by component.

4.29 The restraint system should not be capable of inadvertently releasing the occupant from its protective confines due to accelerations/decelerations imposed on the system or on its associated devices.

4.30 Automatic release of the occupant from the restraint system while the aircraft is undergoing deceleration and/or while the occupant is hanging inverted in the system should not be acceptable.

4.31 To prevent "snap" loads being imposed on the occupant's body and on the restraint system and its anchorages, the system should be designed in such a manner as to encourage its use in snug - but comfortable - contact with the occupant's body at all times.

4.32 Unused restraint systems in unoccupied seats should not cause an operationally unsafe condition.

4.33 Automatic storage of the restraint system, when not in use, is a desirable feature.

4.34 The restraint system and its fittings should be designed so as to reduce the potential for improper installation in the aircraft by production and/or maintenance personnel.

4.35 The restraint system should be lightweight, easily cleaned, and incapable of supporting combustion or of emitting poisonous fumes when subjected to flame or heat.

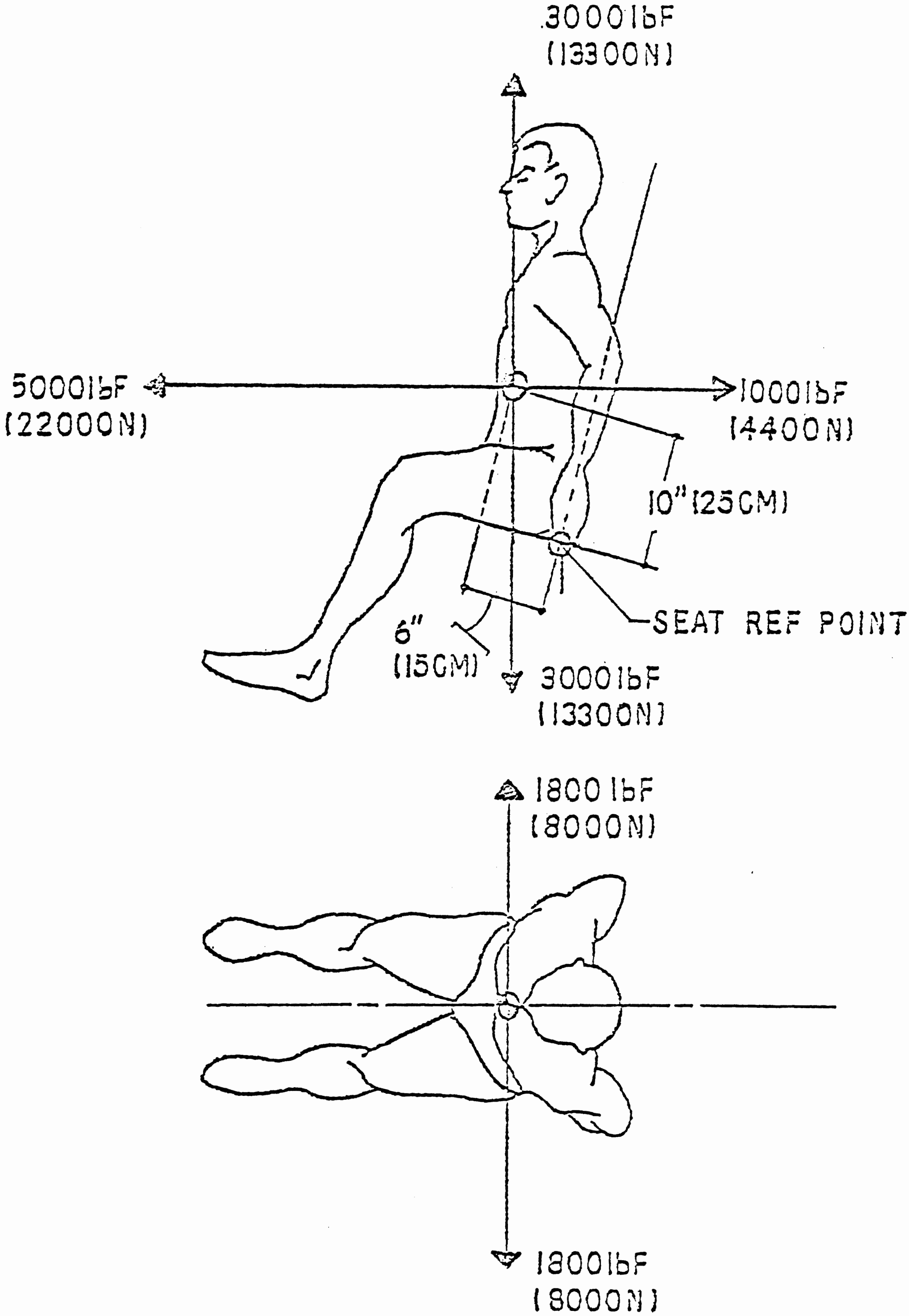
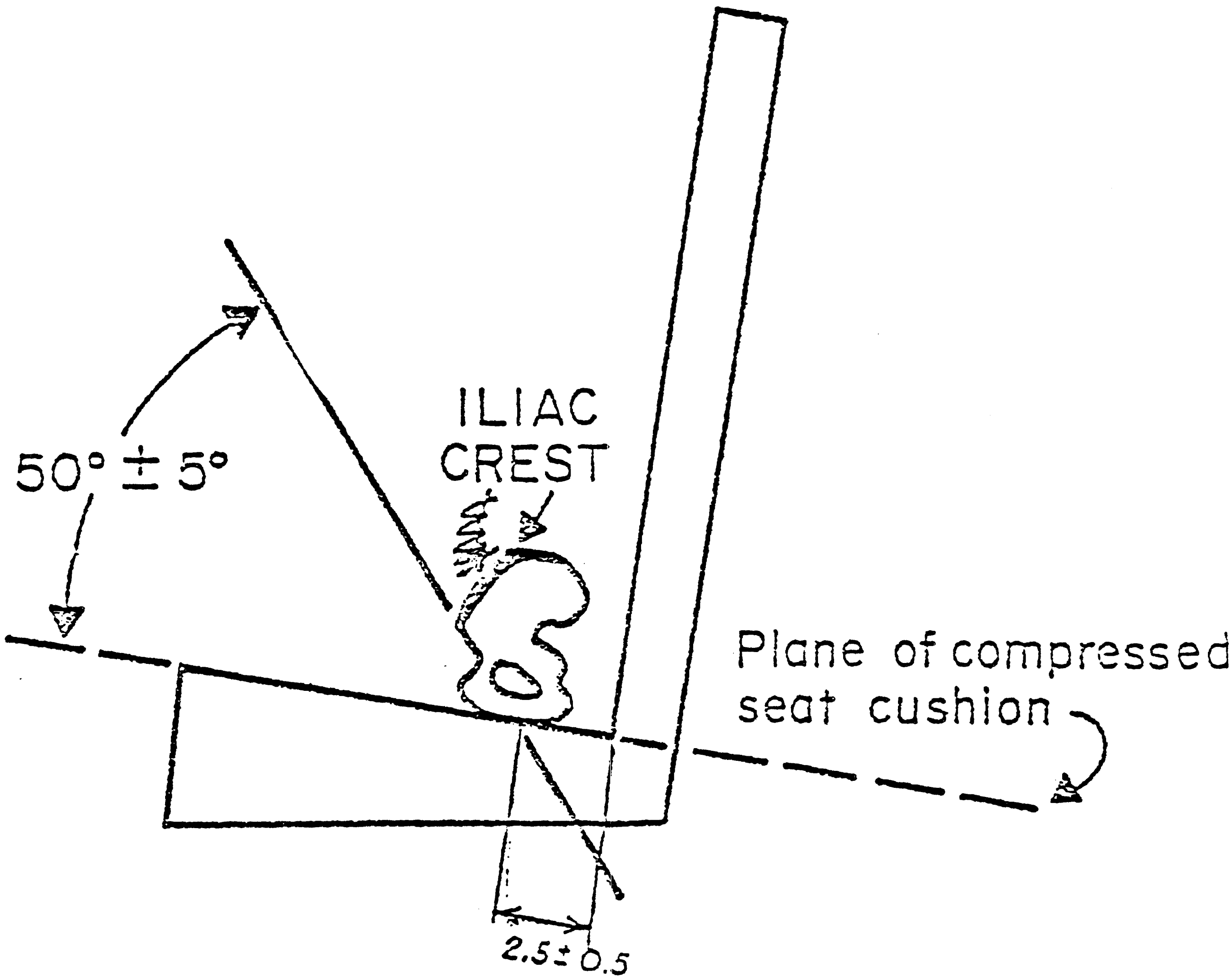

3000lbF
(13300N)
5000lbF
(22000N)
1000lbF
(4400N)
10" (25CM)
SEAT REF POINT
6"
(15CM)
3000lbF
(13300N)
1800 lbF
(8000N)
1800lbF
(8000N)

FIGURE I

Recommended angle and location of seat belt centerline to pelvis and seat.



Belt centerline should cross most forward point on iliac crest, at 50° ± 5° relative to the plane of the compressed seat cushion.

FIGURE 2.

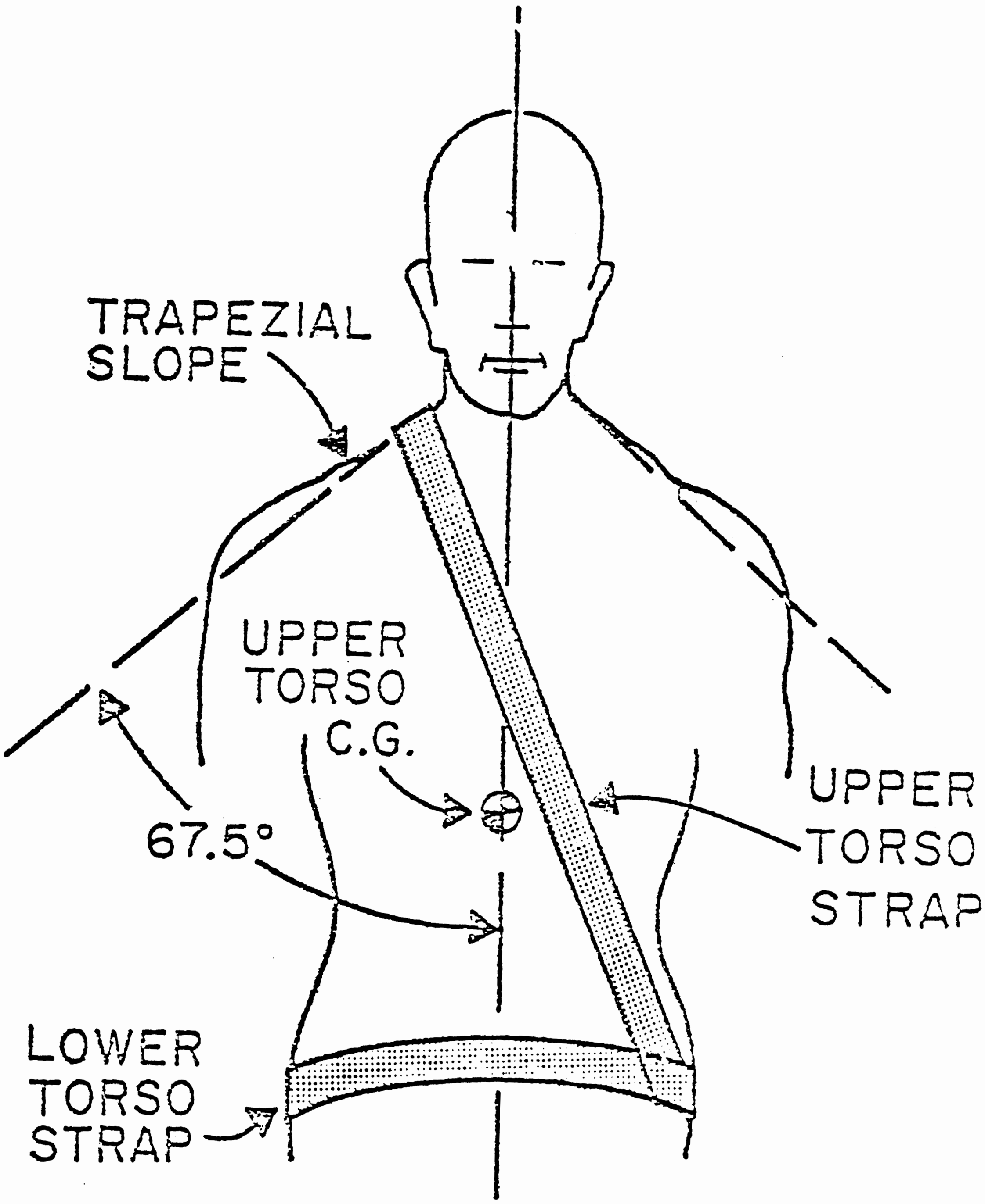

TRAPEZIAL SLOPE
UPPER TORSO C.G.
67.5°
UPPER TORSO STRAP
LOWER TORSO STRAP

FIGURE 3.

Recommended angle of shoulder straps to shoulder of 95 percentile man, referenced to longitudinal axis of aircraft.

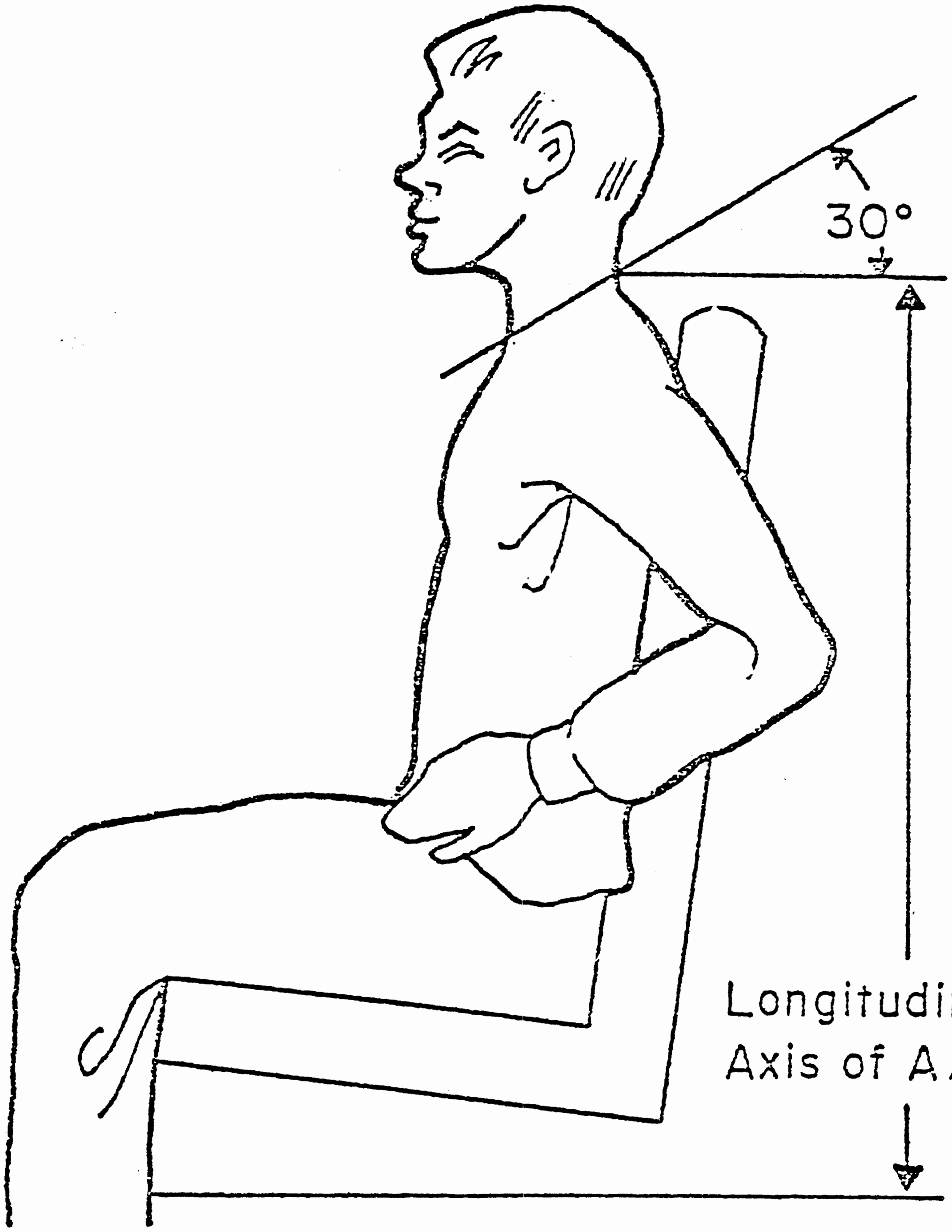


Figure 4.

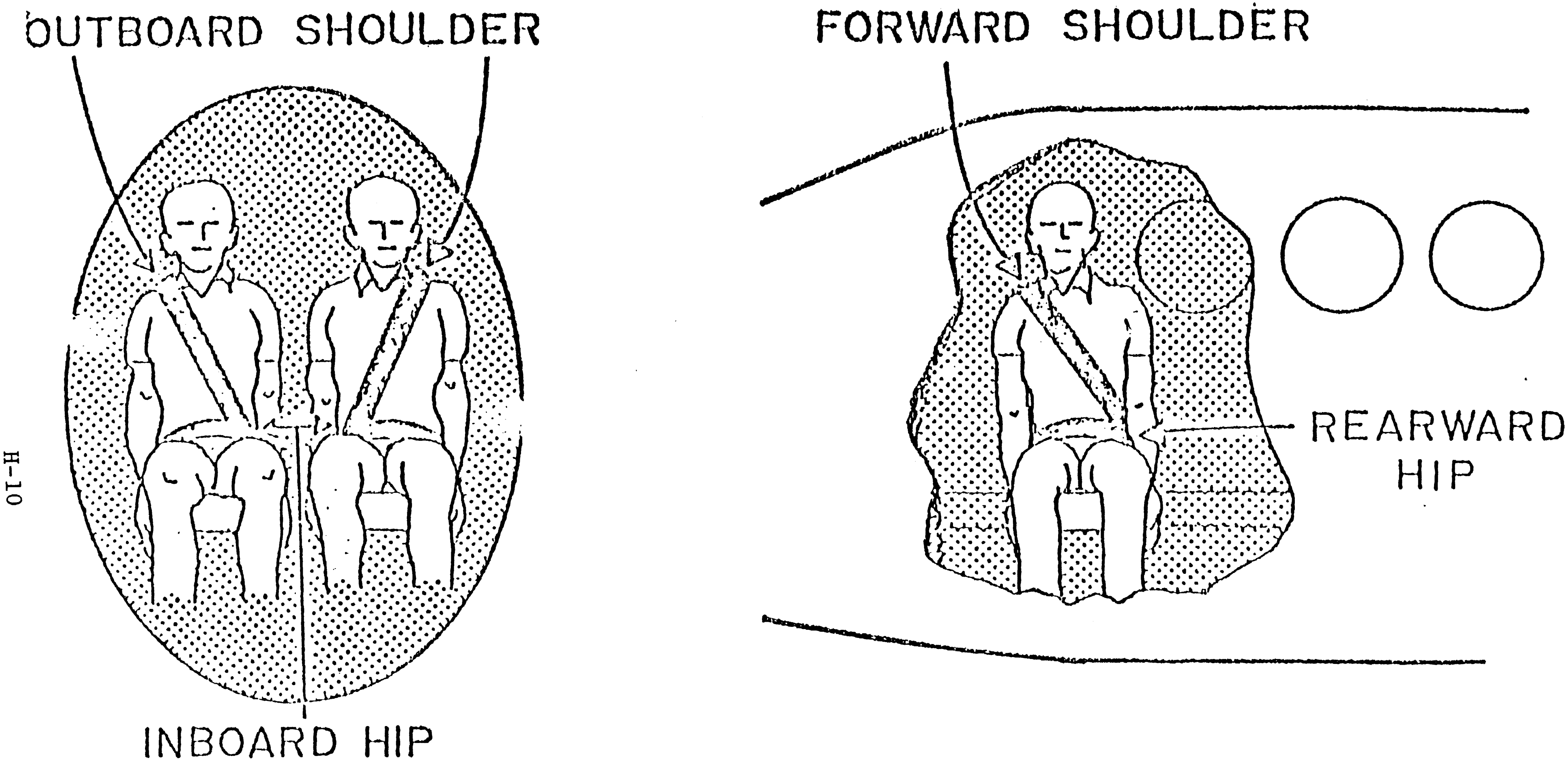

OUTBOARD SHOULDER
INBOARD HIP
FORWARD SHOULDER
REARWARD HIP

FIGURE 5.

ACKNOWLEDGEMENTS

The author wishes to thank in particular Russell Lawton, Assistant Vice President for Industry and Technical Affairs, AOPA Safety Foundation, for his encouragement, patience, and foresight in supporting and monitoring this study.

The author is grateful for the technical assistance and support of professional colleagues, present and past, in NTSB, FAA, and other organizations who provided information relative to this study. While some chose to remain anonymous, particular thanks should go to Gary Wullenwaber, Chief, Flight Standards Technical Division, FAA Aeronautical Center; Richard F. Chandler, Chief, Protection and Survival Laboratories, FAA Civil Aeromedical Laboratories, Oklahoma City; Miss Jane Braucher, Legal Librarian and Ann LaFoy, Librarian, Department of Transportation Library, Washington, D.C.; the late Pat Cunningham, President, Davis Aircraft Restraint Systems, Inc., Alhambra, Calif; Gerrit Walhout,Chief, Human Factors Branch, NTSB, Matt McCormick; and Starke Jett,Information Systems Division, NTSB.

Thanks are also due to technical inputs from HSRI staff members David Thompson, Ph.D., Richard Kaplan, Ph.D., William Ladd, and Ann Grimm, Technical Librarian. The manuscript was typed by Beverly Ball, and editorial assistance was provided by Jim Haney.

The author must take full responsibility for any errors in material contained herein not otherwise referenced. With any work of this scope, despite the attempt to document as accurately as possible, errors may still occur, and the author would appreciate having any corrections brought to his attention.