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# **A Summary of Crashworthiness Information of Small Airplanes**

**Federal Aviation Administration**

**FEBRUARY 1973**

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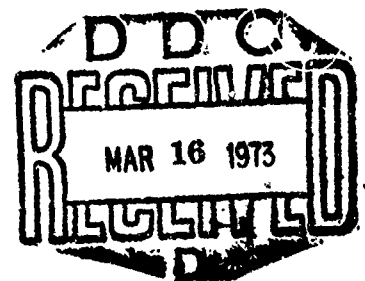
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# A SUMMARY of CRASHWORTHINESS INFORMATION for SMALL AIRPLANES

Flight Standards Technical Division  
FAA Aeronautical Center  
Oklahoma City, Oklahoma

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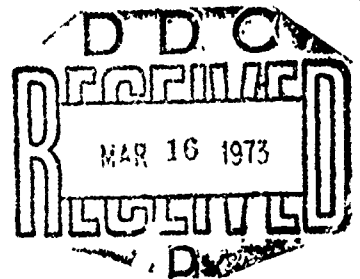
Prepared For:

**DEPARTMENT OF TRANSPORTATION**  
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Flight Standards Service  
Washington, D. C.

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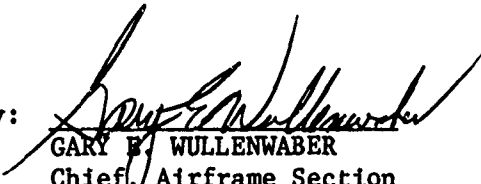
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A SUMMARY OF  
CRASHWORTHINESS INFORMATION  
for  
SMALL AIRPLANES

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## A Summary of Crashworthiness Information for Small Airplanes

### Introduction

Aviation safety is concerned with the elimination or reduction of injuries and fatalities in the operation of aircraft. The principle safety goal in the aircraft design must be to avoid accidents. Secondly, the best practical crash protection should be provided for the occupants.

The safety of flight in a small aircraft is determined by three prime areas--pilot performance, airworthiness, and crashworthiness. Historical accident statistics show that pilot error is responsible for 70 to 80% of all accidents. Consequently, all possible consideration must be given in the design to improving the pilot performance. Airworthiness must be given primary consideration also in order to avoid crashes. Crashworthiness must be given all practical consideration but only insofar as it does not compromise either pilot performance or airworthiness.

Crashworthiness is a term borrowed from the definition of airworthiness, which is the state of being airworthy or "fit to be flown". The obvious parallel is that a crashworthy aircraft is "fit to be crashed". This could be interpreted that we intend aircraft to be crashed. This could not be further from the truth. Our primary interest is to keep aircraft safe to be flown. However, in spite of all effort to achieve that goal, aircraft have crashed. The primary technological efforts must continue to be devoted to bettering the aircraft design to reduce the number of crashes by improving pilot performance and airworthiness. The crashworthiness technology is intended to apply knowledge in an effort to provide a reasonable probability of the occupants survival in an aircraft accident.

Crashworthiness is centered around the condition most formidable in terms of protection of occupants, the crash landing, and this report is concerned mostly with that condition. While encouraging progress in aviation safety has been made during recent years, accidents continue to happen, and experience has shown that prudent design can result in the saving of lives.

As more people become reliant on the small airplane for everyday transportation, demand for safety increases, and this demand must be met in part, but secondarily, through improvement in occupant survivability. With increased interest in the benefits to be gained, design innovations and improved hardware can result. This report is intended to help prepare the hardware designer for meeting this demand.

The basic purpose of this report is education. It discusses some of the problems encountered and provides significant accident histories. It provides an analysis of historical accident statistics to illustrate the

principal accident modes. It also provides technical data on human exposure and tolerances, plus other areas of information of potential value to the aircraft designer.

Technical contents have been kept relatively basic and understandable by a person familiar with small airplanes and elementary engineering principles. The report should be useful to the aviation community in general, aircraft manufacturers, equipment manufacturers, researchers, and many others, all of whom have contributed in the past toward improvement of aviation safety. However, while being useful to the aviation community in general, it is intended especially for the small airplane designer who brings together data and, through his judgment, applies them to a particular design problem. In effect, this report contains information the designer might find helpful in understanding his task related to safety design.

The information herein is not intended to expand or amplify mandatory requirements for design. Such requirements are contained in Federal Aviation Regulations which are revised through established rule making procedures. This report does not expressly contain "acceptable means of compliance" with the FAR airworthiness standards, but rather it is intended to assist the designer in developing his own acceptable means.

Crashworthiness design exerts strong, but secondary, influence on the overall airplane. It must be well founded in preliminary airplane design and followed-up throughout development of the airplane. Examples of far reaching effects of cabin safety design are numerous. For instance, emergency egress features depend primarily on cabin configuration and seating arrangement which, in turn, determine the all-important passenger payload capacity. Wing tanks and fuel systems configured so as to have crash protection and to avoid hazardous fuel spillage affect mass distribution of the wing, which in turn, affects flutter speed. Configuration of emergency exit doors, particularly in the aft cabin, affects tail rigidity and, therefore, strength and flutter.

In a time when the small airplane is becoming increasingly commonplace, need for higher safety becomes unmistakably clear. Already, work toward higher safety is in full swing throughout aviation in engineering, operations, and maintenance. And, by far, the greatest portion of this work will be carried out by industry. This report is intended as a contribution to the overall effort.

Acknowledgement is made to the various industry and government sources whose reports were the sources for much of the information contained herein. Separate acknowledgements are made throughout the text, but here particular acknowledgement is made to those individuals whose pioneering efforts and achievements in crashworthiness have become the foundation of this developing technology. At the risk of inadvertent omission of equally significant crashworthiness pioneers, we wish to recognize the early efforts of the following:

Hugh DeHaven, A.H. Hasbrook, Colonel J.P. Stapp, and John J. Swearingen

## CHAPTER I

### DESIGN PHILOSOPHY

The purpose of crashworthiness is to protect lives and prevent injuries in airplane accidents. This may be done by providing protection to the airplane occupant(s) from impact decelerations and injurious contact between the occupant and the aircraft primary crash hazards. The airplane designer is concerned with how to protect occupants from these hazards.

The design goals for protection from impact deceleration injury are complicated by the question of "how much impact deceleration can a human tolerate?" The designer cannot prevent the occupant's exposure to impact unless he can prevent all crashes. And lacking a completely effective crash preventive, the designer is faced with learning, 1) what the ranges of human tolerances to impact decelerations are, and 2) if and how the airplane can be constructed to prevent an occupant's exposure to impact decelerations beyond those tolerances.

One approach would be to design a completely crash proof, structural shell which could absorb, without collapse of occupiable cabin and cockpit volume, crash forces of all possible directions and magnitudes. This design would be impractical as a useful airplane. It is not known if such a design is technically possible, but it is believed that it would not be economically feasible. No matter how safe a design may be, if it cannot be economically manufactured, sold, and operated, it is useless to the public.

Another approach would be to design a system which would prevent the occupants' exposure to a crash by separating the cabin from the airplane and floating it to the ground. However, this approach would not assure complete protection since it would depend upon the human element for operation and upon a complex system subject to malfunction. Technical and operational limitations would cause an inefficient and uneconomical design.

Another approach would be 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 practically attainable deceleration environment. Further protection would be provided through the

use of energy-absorbing interiors. This approach appears to be most practical. And, it is with this approach in mind that this report has been prepared.

## CHAPTER II

### AIRFRAME CRASHWORTHINESS

#### Introduction:

Probably the most important aspect of airframe crashworthiness is the ability to provide and maintain living space. Obviously, if the cockpit or cabin structure collapses on the occupant, there is little chance that he will escape without injury. A few accident cases are on record where an occupant was ejected from the airplane during the crash and survived. However, serious or fatal injuries normally result, and the number of these incidents is relatively insignificant. Under the majority of crash circumstances, airplane occupants have the best chance of escaping serious/fatal injury when they remain in their relative positions within the airplane.

#### Airframe Crash Experience:

Early proponents of crashworthiness observed that the airframes of the era (tubular or wooden truss) were performing the "living space" function in the majority of accidents, yet serious/fatal injuries resulted in many cases. The rigid nature of the truss construction provided a good "crash cage." Current statistics (Reference (1), page 139), indicate that the percentage of fatal accidents has remained reasonably constant since about 1946, even though semimonocoque structure has become predominant. Of the 4665 small, fixed-wing aircraft accidents occurring in 1968, 1040 were considered destroyed, yet there were only 976 serious or fatal injuries (Reference (1), page 73). Figures 2-1 and 2-2 are pictures of recent accidents which illustrate typical severe but survivable accidents.

The accident shown in Figure 2-1 involved a high-wing, fixed landing gear, light airplane. This accident occurred enroute with only the pilot on board. The airplane contacted electrical power lines approximately 33 feet above the ground and dived into the ground. As measured from the compressed aircraft nose, the impact angle was approximately 55°. The cockpit was partially compressed, but living space was maintained (note the outline of the cabin box in Figure 2-1(a)). Figure 2-1(c) shows how the landing gear beam erupted the floor in the area of the rudder pedals and how the engine forced the instrument panel back slightly. The pilot survived the accident, but he received debilitating leg fractures from the ruptured floor.

The accident shown in Figure 2-2 involved a low-wing, retractable landing gear, light airplane. The circumstances leading to this accident are not known, but the consequences are apparent. Wings, aft fuselage, and



Figure 2-1(a).  
Typical Severe Accident, Fixed, High-wing, Light Aircraft



Figure 2-1 (b)





Figure 2-1 (c)

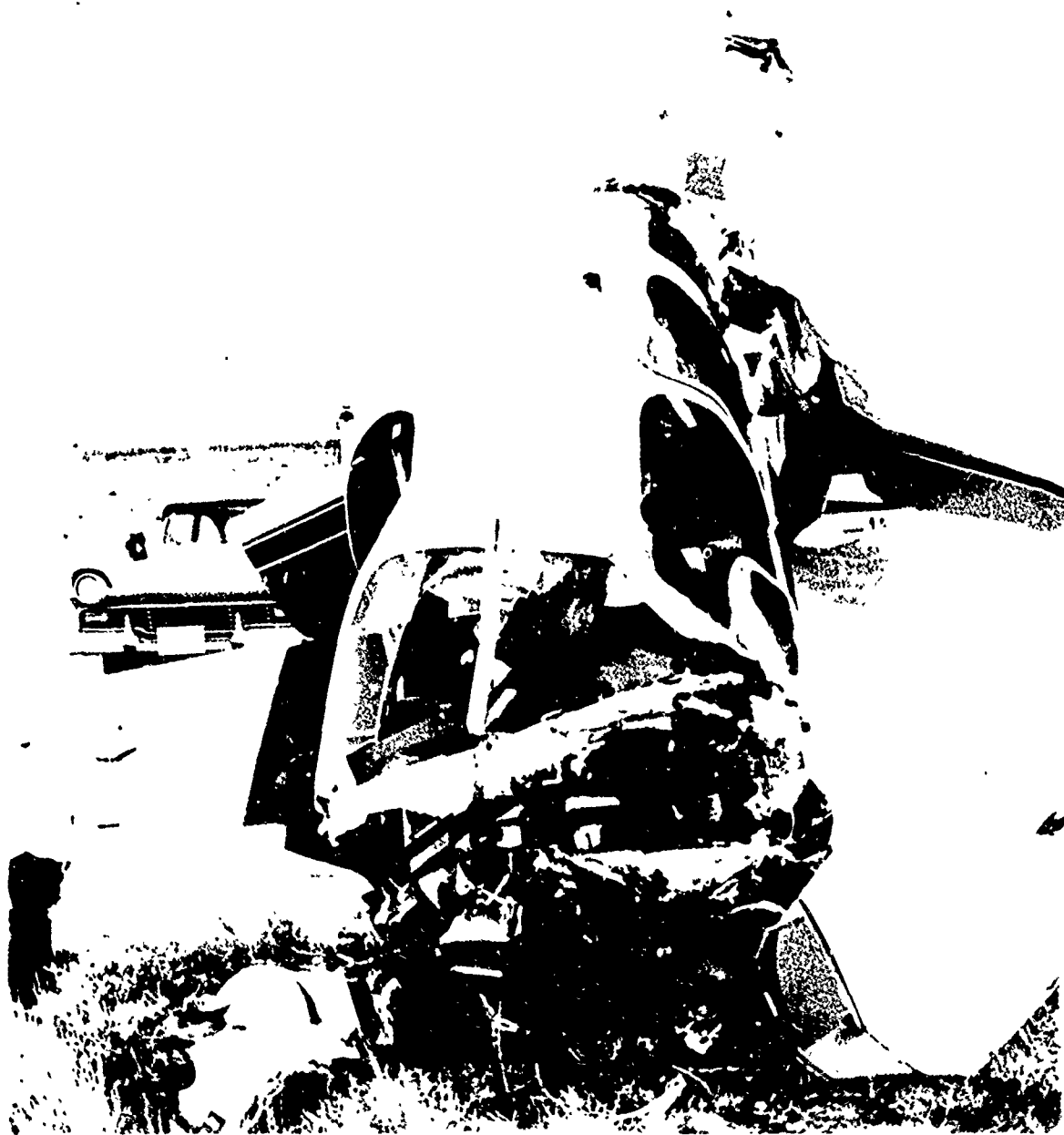


Figure 2-2(a)  
Typical Severe Accident Fixed, Low-wing, Light Aircraft



Figure 2-2(a)  
Typical Severe Accident Fixed, Low-wing, Light Aircraft



Figure 2-2 (b)



Figure 2-2 (c)

empennage were destroyed, but the cockpit/cabin remained relatively intact. Four adults and an infant were aboard. The adults were using lap belts and shoulder harness. The infant was held by one of the adults. All occupants survived with only minor injuries.

Of the two accidents shown in Figures 2-1 and 2-2, the latter appears to have been the more severe. The damage shown in Figure 2-2 may have been caused by a series of impacts, rather than by a single impact like that of Figure 2-1. Although both airframes provided a basic crash cage, the low-wing design provided protection to the floor area. However, the high-wing design provided substantial protection in the roll-over position. Also, the landing gear location, remote from the cabin, prevented the landing gear's protuberance into the cabin floor.

The circumstances of an accident usually govern the resulting decelerations and velocity changes transmitted to the occupants. For example, two identical airplanes striking identical terrain at the same velocity, but at different angles with the terrain, will undoubtedly produce different deceleration environments. Terrain conditions will also affect deceleration. Rocky or wooded terrain tends to rip and shear airframe structure, thereby reducing energy absorption potential. Water impacts also produce different effects. A series of consecutive impacts adds to the problem of maintaining cockpit or cabin integrity. Since the circumstances of accidents are so variable, it is most difficult to determine resulting deceleration environments after-the-fact.

Without deceleration recording equipment on the airplane, it is necessary to rely on evidence at the accident scene. Impact velocities can be estimated by phase of operation, such as takeoff or landing speeds for the aircraft. Throttle settings coupled with prop marks in the ground often provide velocity data. Sometimes a needle slap mark on the speed indicator provides the impact velocity.

Impact attitudes can be estimated by initial impact marks on trees or the ground. Witnesses sometime provide reasonable estimates of impact attitudes also.

Deceleration distances and durations are more difficult to judge, especially if a series of consecutive impacts is involved. For the present, physical evidence must be relied upon. Deceleration distance can be obtained by a combination of skid marks, earth deformation or plowing, and airframe deformation.

If the mechanical characteristics of the airframe and soil or other impacted objects are known, average deceleration levels can be estimated through conservation of energy methods. In some cases, deceleration magnitudes can be bracketed by the failure (or nonfailure) of certain equipment such as seats or restraint systems. In any case, the methods currently available for determining after-the-fact deceleration levels provide only average (constant) decelerations.

### Accident Data Summary:

The Summary of General Aviation Accidents shown on pages 14-20 was investigated by the Crash Investigation Team from the Civil Aeromedical Institute (CAMI) located at the FAA Aeronautical Center in Oklahoma City, Oklahoma. The crash investigation by CAMI began in 1966 and covers only a selected number of accidents that occurred mostly in the states of Oklahoma, Texas and Arkansas. Minor and catastrophic type accidents were avoided because of the limited value of crashworthiness data obtainable. Information was taken from the accident files with emphasis on the occupant and his environment. Hence, the relationship of cabin damage with seat and restraint systems information and occupant injuries are recorded. A few accidents involving agricultural airplanes are listed and can be compared to other general aviation type accidents.

For use in the Summary of Selected General Aviation Accidents, the following words or phrases are defined as follows:

**FATAL INJURY** - Any injury which results in death within seven days.

**SERIOUS INJURY** - Any injury which (1) requires hospitalization for more than 48 hours, commencing within seven 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 hemorrhages, 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% of the body surface.

**DESTROYED** - Consumed by fire, demolished or damaged beyond repair.

**INTACT** - Cabin volume reduction of not more than 15% of original volume.

A SUMMARY OF SELECTED GENERAL AVIATION ACCIDENTS

ITEM	AIRCRAFT TYPE	ACCIDENT TYPE	IMPACT ANGLE	AIRCRAFT DAMAGE	CABIN DAMAGE	(1) SEAT, SEAT TRACK, PASSENGER INFORMATION										(2) INJURY SCALE		AREA OF MAJOR INJURY	AREA OF IMPACT BY OCCUPANT	REMARKS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
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(3) ALSO SEE REMARKS COLUMN

(2) INJURY SCALE:  
NONE-1 SERIOUS-3  
MINOR-2 FATAL-4

OCCUPANT POSITION:  
RIGHT FRONT-RF, FRONT-F  
LEFT REAR-LR, REAR-R  
RIGHT REAR-RR, LEFT FRONT-LF

CREW-C  
PASSENGER-P

EXAMPLE: 2P-1 (TWO PASSENGERS WITH NO INJURIES)



# A SUMMARY OF SELECTED GENERAL AVIATION ACCIDENTS

ITEM	AIRCRAFT TYPE	ACCIDENT TYPE	IMPACT ANGLE	AIRCRAFT DAMAGE	CABIN DAMAGE	(1)										(2)		AREA OF MAJOR INJURY	AREA OF IMPACT BY OCCUPANT	REMARKS
						HEAD, BEAT TRACK FAILURE INFORMATION	BEAT BELT INFORMATION	HEAD, BEAT TRACK FAILURE INFORMATION	BEAT BELT INFORMATION	HEAD, BEAT TRACK FAILURE INFORMATION	BEAT BELT INFORMATION	HEAD, BEAT TRACK FAILURE INFORMATION	BEAT BELT INFORMATION	HEAD, BEAT TRACK FAILURE INFORMATION	BEAT BELT INFORMATION	HEAD, BEAT TRACK FAILURE INFORMATION	BEAT BELT INFORMATION			
13	SINGLE ENGINE BI-PLANE FIXED CONVENTIONAL GEAR, 1 PLACE	ENROUTE - CROP DUSTING	UNK	ENGINE AND RIGHT WING SEPARATED	INTACT												1C-4	THROAT CUT AND SPINAL CORD SEVERED	TOP EDGE OF PLEXIGLASS WINDSHIELD	SHOULDER HARNESSES NOT WORN, SEAT BELT LOOSELY SECURED.
14	SINGLE ENGINE HIGH WING FIXED CONVENTIONAL GEAR 2 PLACE	LANDING - EMERGENCY, BLACK TOP ROAD	UNK	RIGHT AND LEFT SIDES OF NOSE DENTED AFT TO INSTRUMENT PANEL	INTACT												1C-2	HEAD, TORSO, RIGHT KNEE	INSTRUMENT PANEL, CONTROL WHEEL	CONTROL WHEEL BENT
15	SINGLE ENGINE HIGH WING FIXED CONVENTIONAL GEAR 2 PLACE	ENROUTE - HIT POWER LINE, LOST AIRSPEED, HIT GROUND	30°	FUSELAGE BUCKLED, NOSE DISPLACED AFT TO INSTRUMENT PANEL.	PARTIALLY DESTROYED												1C-3	HEAD, SPLEEN, RIBS, KNEES, RIGHT ANKLE	INSTRUMENT PANEL, CONTROL WHEEL, RUDDER PEDAL, LOWER FUSELAGE STRUCTURE	
16	SINGLE ENGINE HIGH WING FIXED TRI GEAR 2 PLACE	ENROUTE - HIT TREE, ROCK	15° INV.	NOSE DISPLACED AFT TO INSTRUMENT PANEL	INTACT												1C-3 1P-3	1C-3: CONCUSSION DISLOCATED VERTEBRA 1P-3: CONCUSSION	UPPER CABIN STRUCTURE	
17	SINGLE ENGINE HIGH WING FIXED TRI GEAR 2 PLACE	ENROUTE - CIRCLED FARM, HIT GROUND	UNK	ENGINE BENT RIGHT AND UP	INTACT												1C-3	HEAD	INSTRUMENT PANEL	
18	SINGLE ENGINE HIGH WING FIXED TRI GEAR 2 PLACE	ENROUTE - FUEL EXHAUSTED, EMERGENCY LANDING	UNK	EXTENSIVE DAMAGE TO WINGS, LANDING GEAR, LOWER NOSE SECTION	INTACT												1C-1			
19	SINGLE ENGINE HIGH WING FIXED TRI GEAR 2 PLACE	LANDING/FIRST SOLO	25°	NOSE, LEFT WING TIP, FIN DAMAGED	INTACT												1C-1	HEAD LACERATIONS, LEG AND SHINS BRUISED	OVERHEAD MAP LIGHT, UNDER-SIDE INSTRUMENT PANEL	SEAT BELT PRAYED SLIGHTLY
20	SINGLE ENGINE HIGH WING FIXED TRI GEAR 2 PLACE	ENROUTE - AIRWORK, AIRCRAFT BECAME VIOLENT	UNK	WINGS AND L. G. CRUMPLED, ENGINE AND PROPELLER SEPARATED	DESTROYED												1C-3	HEAD, TORSO, EXTREMITIES	CONTROL WHEEL INSTRUMENT PANEL, DOOR POST	
21	SINGLE ENGINE HIGH WING FIXED TRI GEAR 2 PLACE	ENROUTE - PIPE LINE OPERATION	UNK	DESTROYED	DESTROYED												1C-4	UNKNOWN		
22	SINGLE ENGINE HIGH WING FIXED TRI GEAR 2 PLACE	TAKE OFF-CONTROL WHEEL LOCKED	UNK	DESTROYED	DESTROYED	X											1C-2 1P-3	1C-2: HEAD, EXTREMITIES 1P-3: HEAD, ELBOW	1C-2: INSTRUMENT PANEL CONTROL WHEEL GROUND 1P-3: INSTRUMENT PANEL CONTROL WHEEL GLARE SHIELD	
23	SINGLE ENGINE HIGH WING FIXED CONVENTIONAL GEAR, 4 PLACE	TAKE OFF-STALLED BECAME INVERTED	UNK	RIGHT AND LEFT SIDES OF NOSE DENTED AFT TO INSTRUMENT PANEL	INTACT												1C-3	HEAD, TORSO, EXTREMITIES LIVER, SHOCK	CONTROL WHEEL INSTRUMENT PANEL	CONTROL WHEEL BROKE OFF, BOTH SEATS SLIPPED TO FORWARD POSITION
24	SINGLE ENGINE HIGH WING FIXED TRI GEAR 4 PLACE	ENROUTE - HIT POWER LINE OVER RIVER	UNK	RIGHT WING CRUMPLED, EMPENNAGE SEPARATED	INTACT												1C-4 1P-4(RF) 1P-4(RR)	1C-4: NO, RIBS 1P-4(RF): HEAD, TORSO, RIBS, SPLEEN 1P-4(RR): LUNGS	1C-4: INSTRUMENT PANEL CONTROL WHEEL 1P-4(RF): INSTRUMENT PANEL CONTROL WHEEL DROWNED 1P-4(RR): DROWNED	

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RIGHT FRONT-RF, FRONT-F  
LEFT REAR-LR, REAR-R  
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EXAMPLE: 2P-1 (TWO PASSENGERS WITH NO INJURIES)

# A SUMMARY OF SELECTED GENERAL AVIATION ACCIDENTS

ITEM	AIRCRAFT TYPE	ACCIDENT TYPE	IMPACT ANGLE	AIRCRAFT DAMAGE	CABIN DAMAGE	(1)										(2)		AREA OF MAJOR INJURY	AREA OF IMPACT BY OCCUPANT	REMARKS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
						SEAT BACK	SEAT BELT	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK				SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT 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RIGHT REAR- RR, LEFT FRONT- L

SEAT- S  
PASSENGER- P

EXAMPLE: P-1 (TWO PASSENGERS WITH NO INJURIES)

# A SUMMARY OF SELECTED GENERAL AVIATION ACCIDENTS

ITEM	AIRCRAFT TYPE	ACCIDENT TYPE	IMPACT ANGLE	AIRCRAFT DAMAGE	CABIN DAMAGE	(1) SEAT, SEAT TRACK FAILURE INFORMATION										(2) SEAT BELT INFORMATION										SHOULDER HARNESS INFORMATION		AREA OF MAJOR INJURY	AREA OF IMPACT BY OCCUPANT	REMARKS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
						SEAT BACK	SEAT PAN	SEAT TUBING	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK				SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT 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TRACK

NOTES: (1) "INTACT" DEFINED AS CABIN VOLUME REDUCED APPROXIMATELY 15% OR LESS  
(2) ALSO SEE REMARKS COLUMN

(2) INJURY SCALE:  
NONE-1 SERIOUS-3  
MINOR-2 FATAL-4

OCCUPANT POSITION:  
RIGHT FRONT-1, FRONT-2  
LEFT REAR-3, REAR-4  
RIGHT REAR-5, LEFT FRONT-6

CREW-1  
PASSENGER-2

EXAMPLE: 2P-1 (TWO PASSENGERS WITH NO INJURIES)

# A SUMMARY OF SELECTED GENERAL AVIATION ACCIDENTS

ITEM	AIRCRAFT TYPE	ACCIDENT TYPE	IMPACT ANGLE	AIRCRAFT DAMAGE	CABIN DAMAGE	(1)										(2)		AREA OF IMPACT BY OCCUPANT	REMARKS
						SEAT, SEAT TRACK FAILURE INFORMATION					SEAT BELT INFORMATION					OCCUPANT CONDITION			
						SEAT BACK	SEAT BASE	SEAT LUMBAR	SEAT TRACK TYPING	SEAT TRACK TYPING	SEAT BELT	SEAT BELT	SEAT BELT	SEAT BELT	SEAT BELT	SEAT BELT	SEAT BELT	SEAT BELT	
49	SINGLE ENG- INE HIGH WING, FIXED CONV. GEAR, 2 PLACE	TAKE OFF - SHARP PULL UP, STALLED SPIN IN	UNK	WINGS, LANDING GEAR AND NOSE, FUSELAGE BROKEN	INTACT		X									1C-4	BLEEDING FROM EARS, RIGHT ANKLE DIS- LOCATED	INSTRUMENT PANEL, BAR RUDDERS	
50	SINGLE ENG- INE HIGH WING, FIXED CONVENTIONAL GEAR, 2 PLACE	ENROUTE - COYOTE HUNTING	45° 800	FIREWALL DIS- PLACED AFT HALF WAY TO INSTRU- MENT PANEL	INTACT	X	X									1C-4(R) 1P-4(R)	HEAD, TORSO EXTREMITIES	INSTRUMENT PANEL, FOR- WARD CABIN STRUCTURE	FOOT DISLOCATED ON RUDDER BAR
51	SINGLE ENG- INE HIGH WING, FIXED CONVENTIONAL GEAR, 2 PLACE	ENROUTE - LOW ALTITUDE, STALLED HIT RAVINE	85°	DESTROYED	DESTROYED	DESTROYED										1C-4 1P-4	OCCUPANTS MANGLED	FORWARD CABIN STRUCTURE	
52	SINGLE ENG- INE HIGH WING, FIXED TRI GEAR 4 PLACE	TAKE OFF - STALLED, HIT BLACK TOP ROAD	UNK	PARTIALLY DESTROYED	PARTIALLY DESTROYED											1C-4 2P-3 1P-3	1C-4: HEAD TORSO, IN- TERNAL INJURIES 2P-3: VERTE- BRA COMPRES- SION 1P-3: SKULL FRACTURE	1C-4: CONTROL WHEEL, INSTRU- MENT PANEL 2P-3: SEAT PAN 1P-3: UNK	PILOT'S CONTROL WHEEL BROKE OFF
53	SINGLE ENG- INE HIGH WING, FIXED TRI GEAR 4 PLACE	LANDING - HIT WAKE OF JET AIRCRAFT TAKING OFF	50°	FIREWALL DIS- PLACED AFT HALF WAY TO INSTRU- MENT PANEL	INTACT		X		X							1C-3 1P-3	HEAD, TORSO, EXTREMITIES	INSTRUMENT PANEL, CON- TROL WHEEL RUDDERS	LEFT CONTROL WHEEL BROKE, FOOT INJURED ON RUDDER BARS
54	SINGLE ENG- INE HIGH WING, FIXED TRI GEAR 4 PLACE	TAKE OFF - ENG- INE FAILURE LANDED IN FIELD	12°	LEFT WING CRUMPLED, FUSELAGE BROKEN	INTACT		X									1C-3 1P-2(RF) 1P-1(R)	1C-3: HEAD CUTS AND CONCUSSION 1P-2(RF) CUTS AND BRUISES ON HEAD	1C-3: INSTRU- MENT PANEL (CONTROL WHEEL WINGS-HIELD POST 1P-2(RF), INSTRUMENT PANEL, CON- TROL WHEEL	
55	SINGLE ENG- INE HIGH WING, FIXED TRI GEAR 4 PLACE	TAKE OFF - WIND- SHIELD FOGGED, ABORTED TAKE OFF	UNK	NOSE LANDING GEAR COLLAPSED, WING STRUTS AND VERTICAL STAB- ILIZER DAMAGED	INTACT				X	X						1C-2	HEAD, NECK AND BACK SORE	DURING GRESS SEAT BELT RELEASED WHILE AIR- CRAFT INVERT- ED, PILOT FELL ON HEAD.	
56	SINGLE ENG- INE HIGH WING, FIXED TRI GEAR 2 PLACE	ENROUTE - ENG- INE FAILURE, HIT TREE	UNK	RIGHT SIDE OF FUSELAGE DAMAGED	PARTIALLY DESTROYED		X		X							1C-2 1P-2	1C-2: CON- CUSSION 1P-2: LEG FRACTURE	1C-2: LOOSE FIRE EXTING- UISHER HIT PILOT ON HEAD 1P-2 R. DOOR	RIGHT CONTROL WHEEL BENT
57	SINGLE ENG- INE HIGH WING, FIXED TRI GEAR 4 PLACE	ENROUTE - OVER- CAST, FOG, LOST CONTROL	87° INVERTED	DESTROYED	DESTROYED	UNK										1C-4	OCCUPANT MANGLED	INSTRUMENT PANEL	
58	SINGLE ENG- INE LOW WING RETRACTABLE TRI GEAR 4 PLACE	ENROUTE - FOR REASONS UNKNOW- N, AIRCRAFT HIT GROUND IN A FLAT ATTITUDE	0°	NOSE AND BOTTOM DAMAGED	INTACT											1C-2 1P-3(RF)	1C-2: RIBS FRACTURE, ANKLE SPRAIN 1P-3: CUTS AND BRUISES ON FACE, VERTICAL FRACTURE	1C-2: CONTROL WHEEL, RUDDER PEDAL 1P-3: CONTROL WHEEL, INSTRU- MENT PANEL, VERTICAL LOADS	BOTH CONTROL WHEELS BROKE
59	SINGLE ENG- INE LOW WING RETRACTABLE TRI GEAR 4 PLACE	TAKE OFF - ENGINE FAILED, HIT FENCE, DAM AND FARM POND	45°	LANDING GEAR SEPARATED, NOSE DAMAGED.	INTACT		X									1C-4 1P-4(RF) 1P-4(RF) (1)	1C-4, 1P-4(RF) LUNGS (1) 1P-4(RF) HEAD	1C-4, 1P-4 (R) (DOWNWARD 1P-4(RF) INSTRUMENT PANEL	1C-4, 1P-4(RF) BOTH HAD CUTS AND BRUISES ON HEAD 1P-4(RF): SEAT BELT NOT SECURED DURING FLIGHT

NOTES: (1) "INTACT" DEFINED AS (A) IN VOLUME  
REDUCED APPROXIMATELY 15% OR LESS

(3) ALSO SEE REMARKS COLUMN

(2) INJURY SCALE:  
NONE-1 SERIOUS-3  
MINOR-2 FATAL-4

OCCUPANT POSITIONS:  
RIGHT FRONT-RR, FRONT-IF  
LEFT REAR-LR, REAR-RL  
RIGHT REAR-RR, LEFT FRONT-LF

CREW-C  
PASSENGER-P

EXAMPLE 2P-1 (TWO  
PASSENGERS WITH NO INJURIES)

# A SUMMARY OF SELECTED GENERAL AVIATION ACCIDENTS

ITEM	AIRCRAFT TYPE	ACCIDENT TYPE	IMPACT ANGLE	AIRCRAFT DAMAGE	CABIN DAMAGE	(1)										(2)		AREA OF MAJOR INJURY	AREA OF IMPACT BY OCCUPANT	REMARKS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
						HEAD	NECK	THORAX	ABDOMEN	PELVIS	LEG	ARM	HEAD TRACK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK				DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH RISK	DEATH 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NOTES: (1) "INTACT" DEFINED AS CABIN VOLUME REDUCED APPROXIMATELY 15% OR LESS  
(2) ALSO SEE REMARKS COLUMN

(2) INJURY SCALE:  
NONE-1 SERIOUS-3  
MINOR-2 FATAL-4

OCCUPANT POSITION:  
RIGHT FRONT-RF, FRONT-F  
LEFT REAR-LR, REAR-R  
RIGHT REAR-RR, LEFT FRONT-LF

CREW-C  
PASSENGER-P

EXAMPLE: 2P-1 (TWO PASSENGERS WITH NO INJURIES)

# A SUMMARY OF SELECTED GENERAL AVIATION ACCIDENTS

ITEM	AIRCRAFT TYPE	ACCIDENT TYPE	IMPACT ANGLE	AIRCRAFT DAMAGE	CABIN DAMAGE	(1) SEAT, SEAT TRACK FAILURE INFORMATION										(2) SHOULDER HARNESSES INFORMATION			AREA OF MAJOR INJURY	AREA OF IMPACT BY OCCUPANT	REMARKS
						SEAT BELT	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK	SEAT TRACK			
73	SINGLE ENG- INE LOW WING FIXED TRI GEAR, 6 PLACE	ENROUTE - FUEL EXHAUSTED, LANDED IN WHEAT FIELD	0°	BOTTOM OF FUSE- LAGE DISPLACED TO FLOOR LEVEL	INTACT	X												1C-4 SP-4	UNKNOWN		
74	SINGLE ENG- INE LOW WING FIXED TRI GEAR, 6 PLACE	ENROUTE - ENG- INE FAILURE, HIT POWER LINE	UNK	WINDSHIELD, WINDOWS BROKEN RIGHT WING CRUMPLED	INTACT		X	UNKNOWN										1C-3 1P-2 1P-3 1P-4	1C-3: HEAD- CONCUSSION CUTS 1P-2: COLLAR BONE 1P-3: VERTE- BRA FRACTURE	1C-3: INSTRU- MENT PANEL 1P-2: UNK 1P-3: SEAT PAN	
75	SINGLE ENG- INE LOW WING FIXED CON- VENTIONAL GEAR, 2 PLACE	TAKE OFF - STALLED, CART- WHEELED	UNK	ENGINE DISPLACED AFT TO FORWARD INSTRUMENT PANEL EXTENSIVE DAMAGE TO WINGS, TAIL.	PARTIALLY DESTROYED									C P	C P			1C-2(R) 1P-3(F)	1C-2(R): SHOULDER 1P-3(F): LTG	1C-2(R): UNK 1P-3(R): ENG INE	TANDON SEATING
76	SINGLE ENG- INE HIGH WING FIXED CONVENTIONAL GEAR, 2 PLACE	ENROUTE - ENG- INE FAILURE, LANDED IN FIELD	UNK	WINGS, FIN DAMAGED	INTACT													1C-2 1P-1	1C-2: HAND LUT 1P-1: NONE	UNKNOWN	THROTTLE KNOB BENT DOWN, HOMEBUILT AIRCRAFT
77	SINGLE ENG- INE HIGH WING FIXED CONVENTIONAL GEAR, 3 PLACE	LANDING - ENGINE FAILED AT ATTEMPTED "GO AROUND". HIT FENCE AND GROUND RISE.	15°	ENGINE PUSHED UP, WINDSHIELD FAILED	INTACT													1C-3	HEAD CUTS VERTEBRA FRACTURE	INSTRUMENT PANEL, CONTROL WHEEL, SEAT PAN	
78	SINGLE ENG- INE HIGH WING FIXED CONVENTIONAL GEAR 2 PLACE	LOCAL AIRWORK - STALLS AND ROLLS AT 200 FEET ALTITUDE	80°	WINGS CRUMPLED, FUSELAGE BUCK- LED	INTACT													1C-4	HEAD, TORSO EXTREMITIES	INSTRUMENT PANEL CONTROL WHEEL	

NOTES: (1) "INTACT" DEFINED AS CABIN VOLUME  
REDUCED APPROXIMATELY 15% OR LESS  
(3) ALSO SEE REMARKS COLUMN

(2) INJURY SCALE:  
NONE-1 SERIOUS-3  
MINOR-2 FATAL-4

OCCUPANT POSITION:  
RIGHT FRONT-UF, FRONT-F  
LEFT REAR-LR, REAR-P  
RIGHT REAR-RH, LEFT FRONT-LF

CREW-C  
PASSENGER-P

EXAMPLE: 2P-1 (TWO  
PASSENGERS WITH NO INJURIES)

### Test and Research Data:

Experimental crash testing of full scale, fixed wing airframes has been very limited. References (2) and (3) present the results of some classic crash testing done by NACA. The two airplanes involved in the tests described were a Piper Cub and a Lockheed Loadstar. It should be pointed out that these two airplanes are, in some ways, not structurally representative of current production small airplanes. These two aircraft are probably similar to the end points of the weight spectrum of current FAR 23 aircraft.

Details of the Piper J-3 Cub tests are reported in NACA TN 2991(3). The Cub was crashed into a mound of earth which was sloped  $55^\circ$  to the horizontal. A schematic of a test set-up is shown in Figure 2-3. Three crashes were made at impact velocities of 60, 45, and 42 mph. Figure 2-4 shows a film strip from the motion pictures of one of these crashes. Figures 2-5, 2-6, and 2-7 show the various longitudinal deceleration traces recorded during the crash tests. Accelerometers were located on the fuselage floor under the rear seat, on the head and chest of the dummy in the rear seat, and on the engine. Figure 2-8 illustrates the effects of impact speed on longitudinal decelerations under the particular test conditions.

The structure that collapsed in the Piper Cub tests was that forward of the rear seat. The deceleration traces illustrate the effects of the strength of the forestructure. There were differences of about 30g, 12g, and 5g, between the engine compartment and the rear seat location. This points out a significant effect of the forestructure under the tested conditions.

The 60 mph impact on the  $55^\circ$  slope would normally be considered a severe crash, yet collapse of the nose section absorbed enough energy to reduce the impact forces at the rear seat to a survivable level as defined by the human tolerance envelope in Appendix A. The approximate trapezoidal pulse gives an onset of about 500g/sec, about 25g magnitude, and a duration of about .04 sec. It is unfortunate that the vertical and lateral deceleration environments are not reported for the 60 mph test. However, they were reported for the 42 mph test, as shown in Figures 2-9 and 2-10.

Crash tests of the Loadstar are reported in Reference (2). Two tests were conducted. The first crash involved an initial impact with a  $12^\circ$  sloped mound of earth at 87 mph. After initial impact the aircraft bounced and contacted a series of poles with the left wing tip. This rotated the longitudinal axis about parallel to a bank with which it collided. Upon hitting the bank, the aircraft rose about 2 feet in passing over the barrier. It then rolled to its right wing, which dug into the mound and pitched the aircraft to its nose. The aircraft then settled back on its belly and continued to slide sideways to a stop. Film strips of the 3-phase crash test are shown in Figure 2-11.

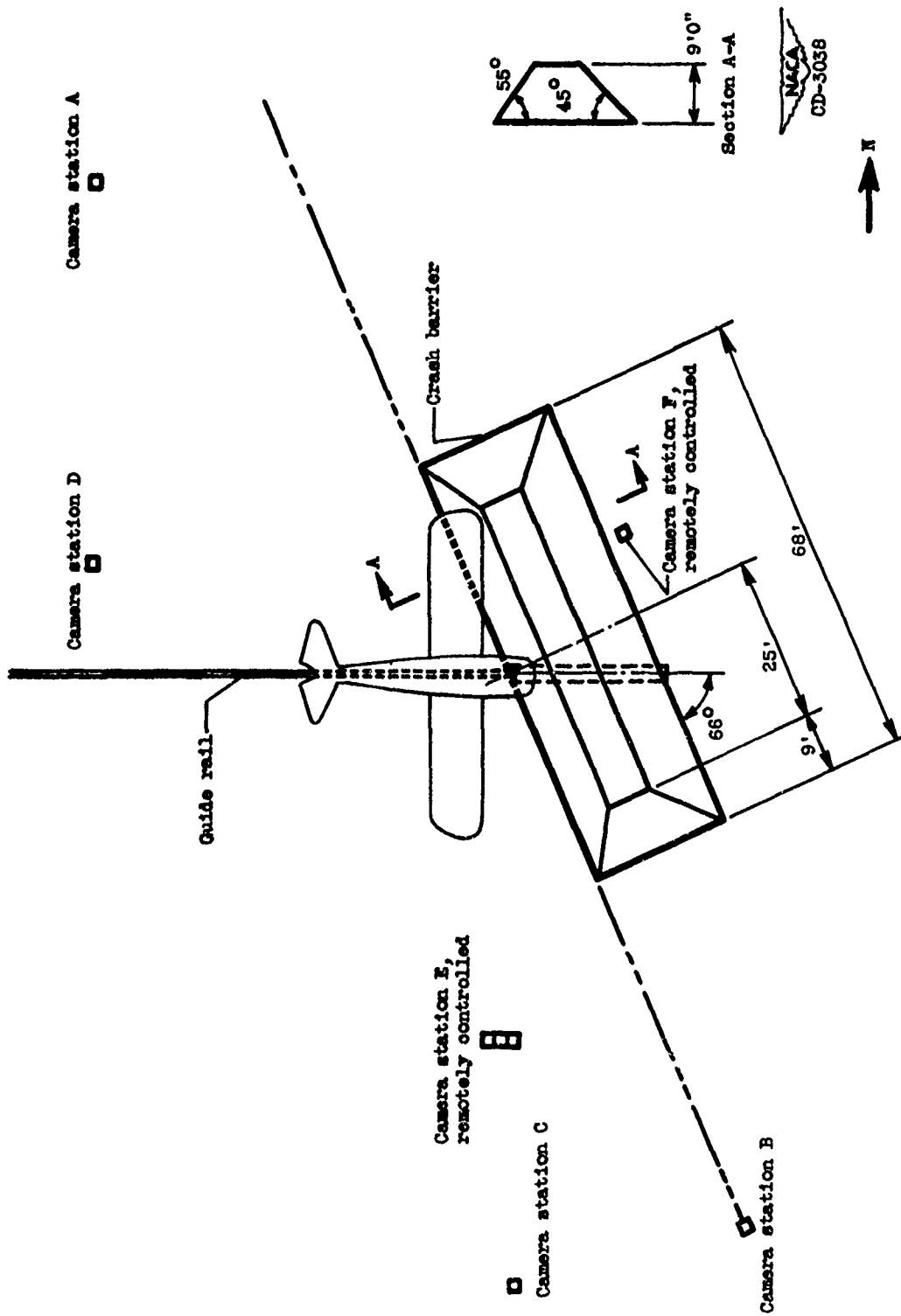


Figure 2-3. Plan view of crash area for conducting light-airplane crash investigation.

[Source: NACA TN 2991 (3)]



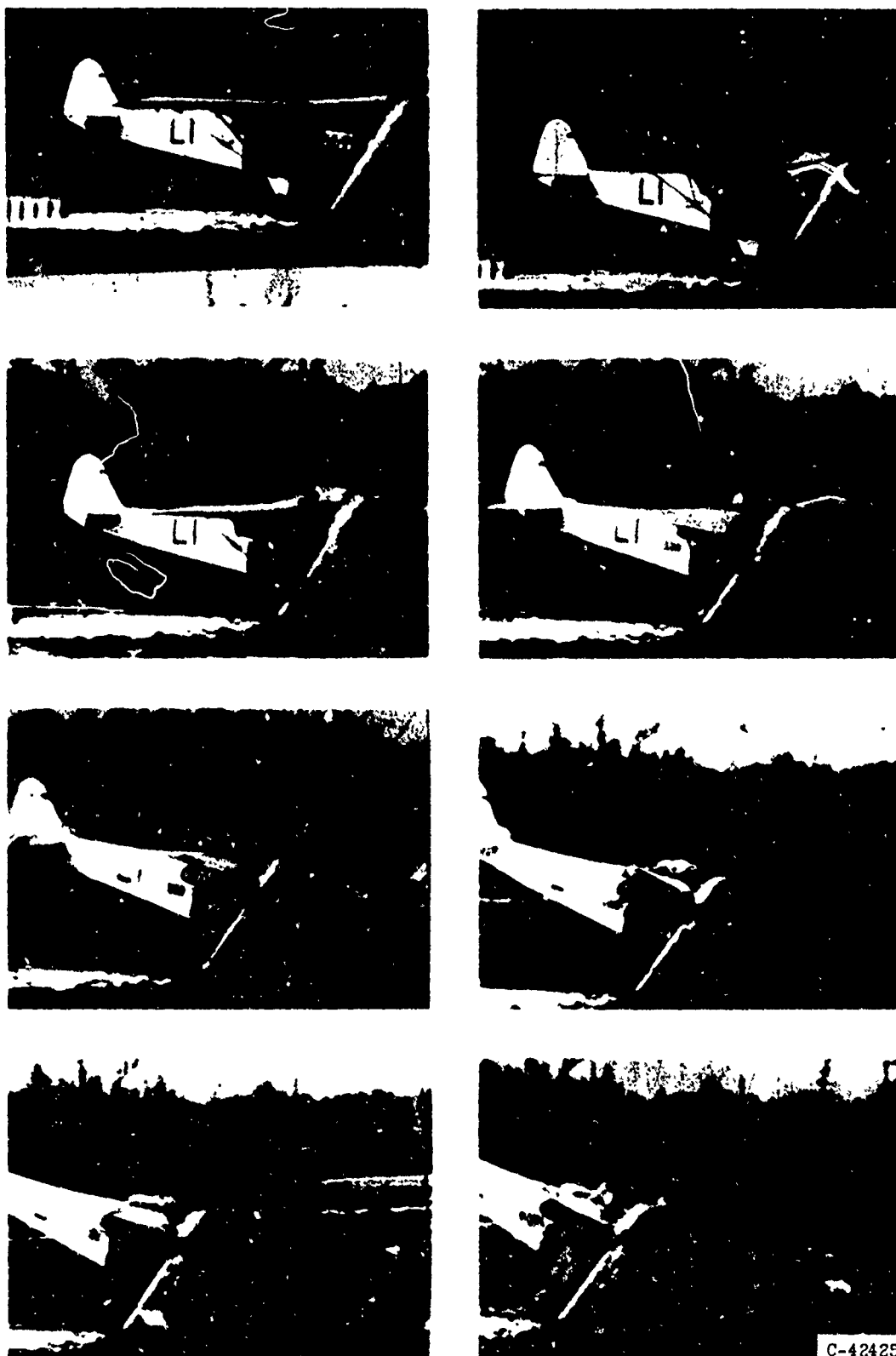
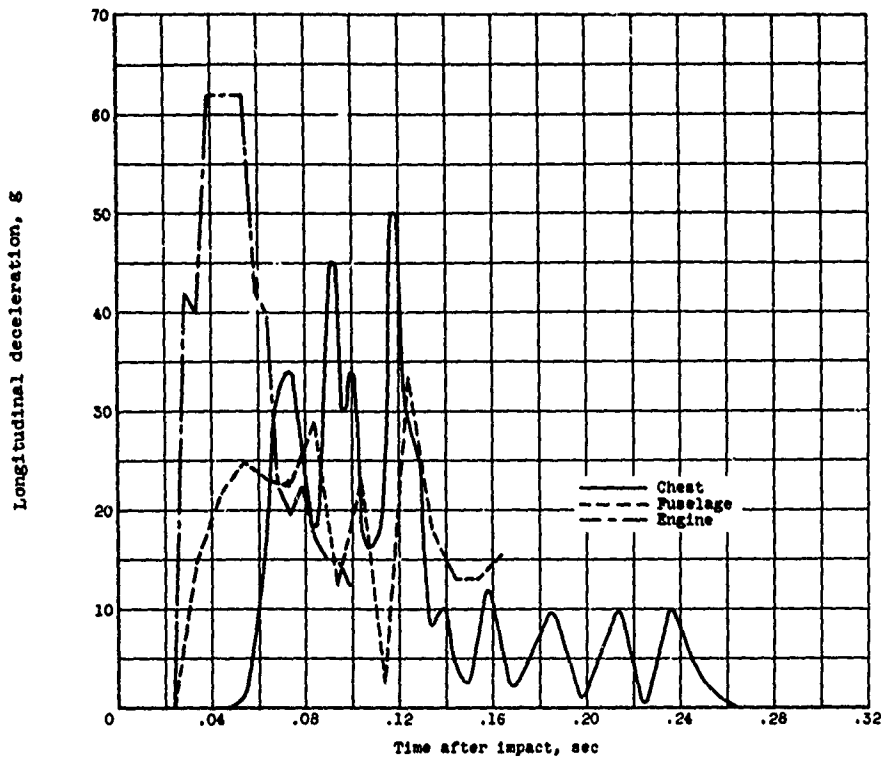


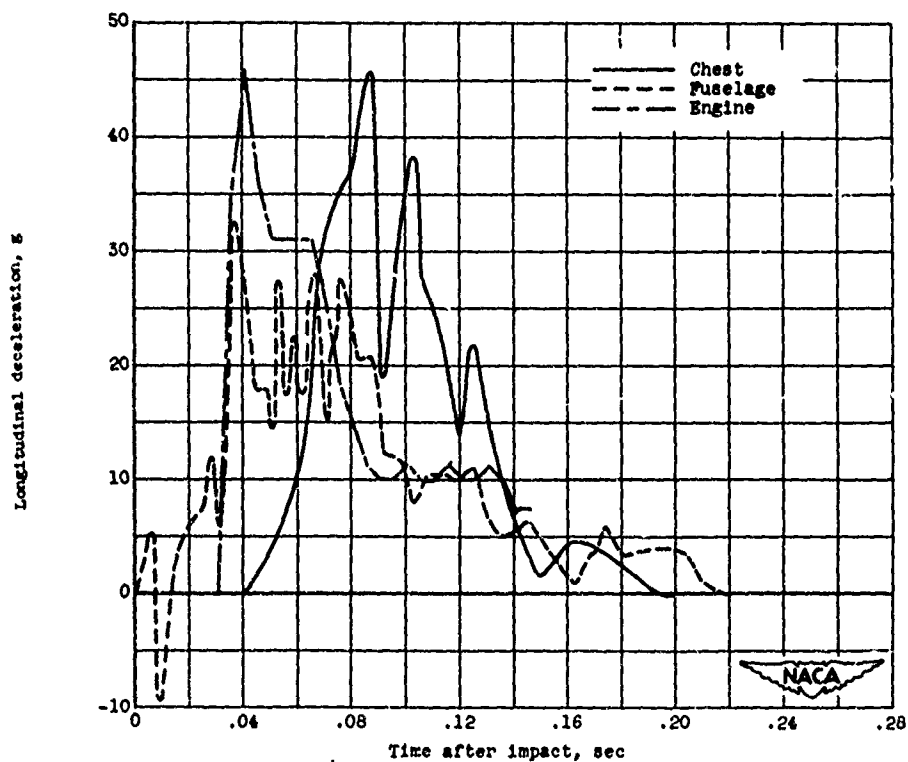
Figure 2-4. Film strip of crash of cub-type light airplane.

[Source: Reference (2)]



(a) Impact speed, 60 mph.

Figure 2-5. Longitudinal deceleration of engine, fuselage floor at rear seat, and chest and head of rear dummy.



(b) Impact speed, 47 mph.

Figure 2-6. Longitudinal deceleration of engine, fuselage floor at rear seat, and chest and head of rear dummy.

[Source: NACA TN 2991 (3)]

[Source: NACA TN 2991 (3)]

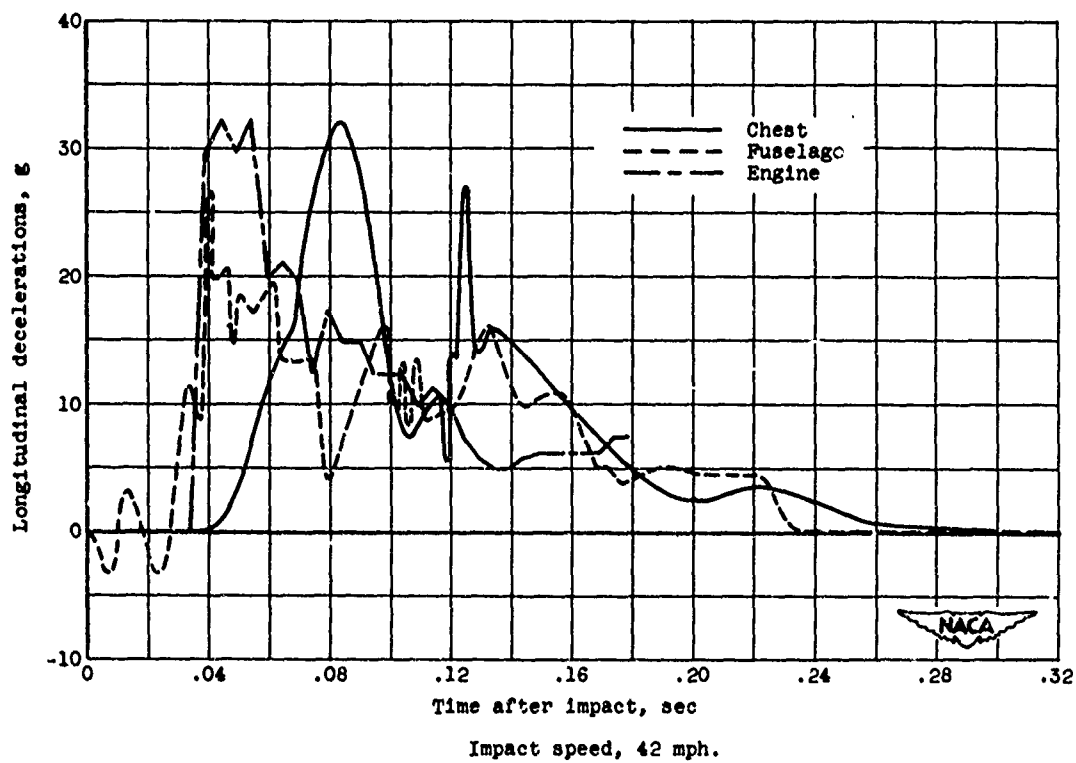


Figure 2-7. Longitudinal deceleration of engine, fuselage floor at rear seat, and chest and head of rear dummy.

[Source: NACA TN 2991 (3)]

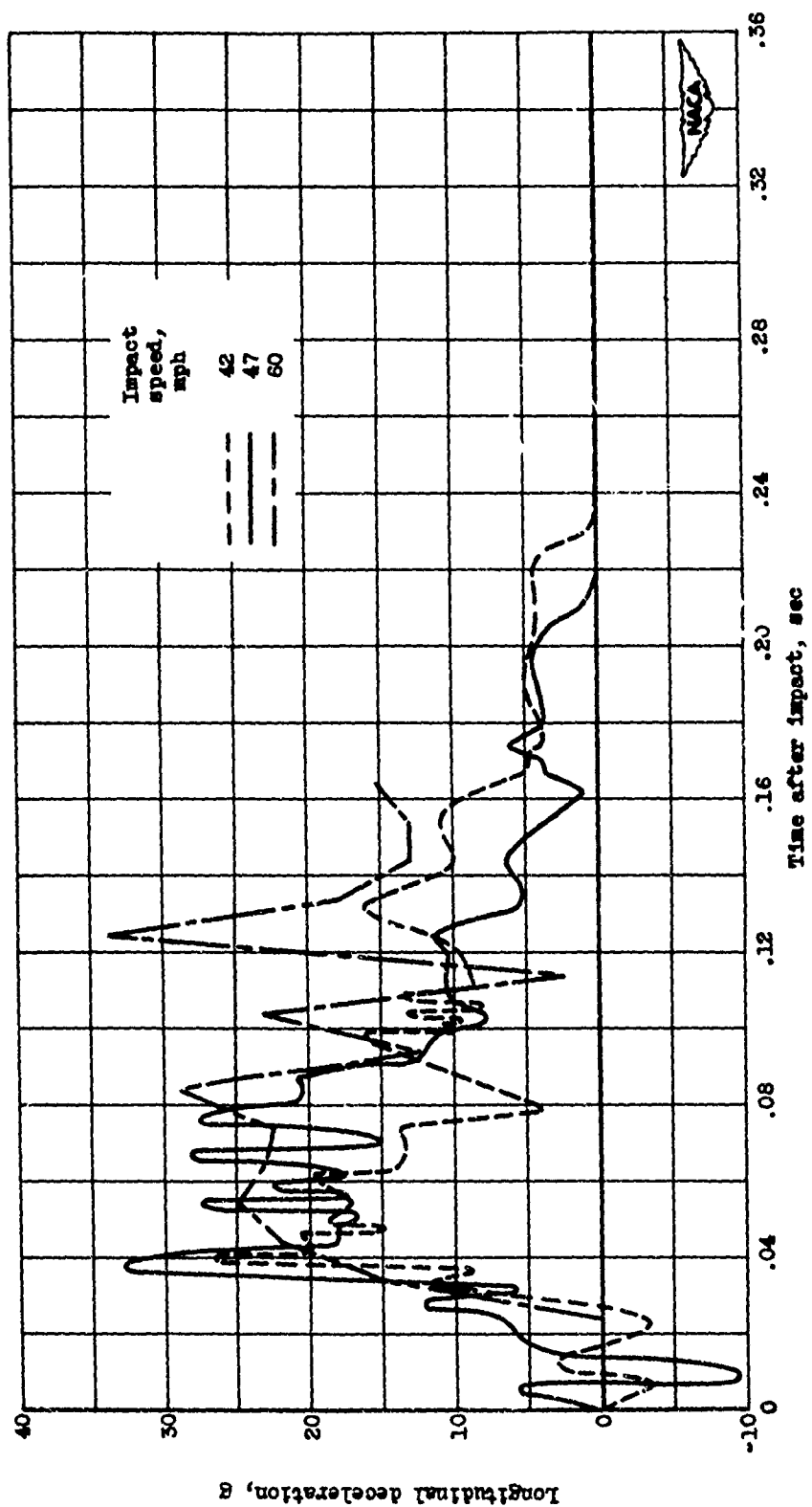


Figure 2-8. Effect of impact speed on longitudinal deceleration of fuselage at rear seat.

[Source: NACA TN 2991 (3)]

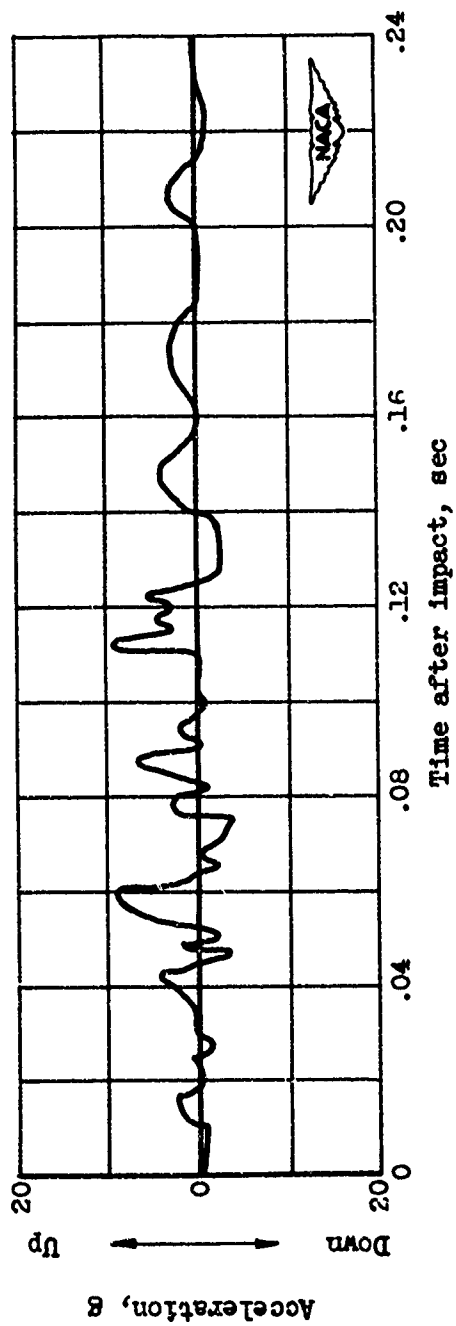


Figure 2-9. Vertical acceleration of fuselage floor at rear seat in 42-pmh crash.

[Source: NACA TN 2991 (3)]

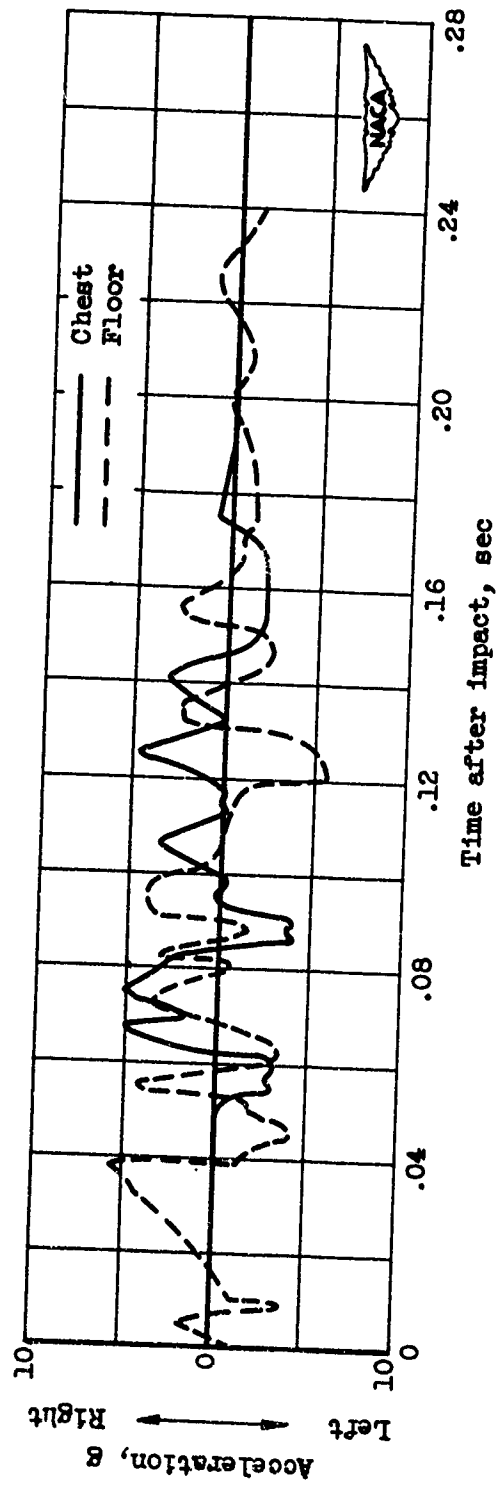


Figure 2-10. Time history of lateral acceleration as measured on chest of rear dummy and fuselage floor at rear seat in 42 mph crash.

[Source: NACA TN 2991 (3)]

The primary purpose of the first Loadstar test was to answer the question of what magnitude decelerations might occur in those crashes where the aircraft turns around and strikes an object while travelling sideways or backwards. As shown in Figure 2-11, the test aircraft never turned around. Therefore, no significant rearward decelerations were recorded.

The major decelerations of the first (12°) Loadstar test occurred during the second impact. Peak deceleration records of this impact are shown in Figure 2-12. These records were taken on the fuselage floor at the indicated stations. Maximum decelerations in the forward direction were approximately the same at the two floor stations (243 and 312). Decelerations in the lateral direction reached a significant magnitude of about 20g at station 243 and 40g at station 312. Station 312 was nearer the point of impact, thus the higher lateral deceleration. As indicated in Figure 2-12, the lateral decelerations were in opposite directions. This was produced by a yawing motion as the aircraft pivoted about the point of impact on the fuselage. Hence, floor station 243 actually experienced an acceleration.

The vertical decelerations of the first (12°) Loadstar test were the most severe. Magnitudes of about 75g and 50g downward were recorded at floor stations 243 and 312, respectively. Upward decelerations reached about 25g at both locations. Serious or fatal injuries may be expected at these levels without some form of force attenuation in the vertical direction.

The second Loadstar crash test involved a head on collision with 16° sloped mound of earth at approximately the same velocity as the first test. Figure 2-13 is a film strip of the second test. Figures 2-14 and 2-15 show a comparison of the longitudinal and vertical decelerations recorded in the first and second Loadstar tests. The primary difference was the magnitude of the longitudinal deceleration. Decelerations attained during initial impact may be considered survivable in both cases.

The film strips of both Loadstar crash tests (Figures 2-11 and 2-15) show very little distortion or crushing damage to the cockpit and cabin structure. Therefore, the structural ability of the test aircraft to maintain living space was something greater than the recorded deceleration loads.

Aviation Safety Engineering and Research (AVSER), a division of Flight Safety Foundation, Incorporated, developed a crash test program involving two TC-45J twin-engine aircraft. The controlled tests were conducted to provide information on basic structural crashworthiness. Two tests were completed 6 November 1964 and 22 April 1965 and designated T-16 and T-19, respectively.

Prior to simple modifications performed, both aircraft had identical structures. The intent of the tests was to determine the effect of small structural changes on impact energy felt by the occupants. Each test specimen received the same severe impact load conditions. The crash attitude chosen was wing-low, high angle of attack and at a velocity approximating initial climb-out and approach speeds.

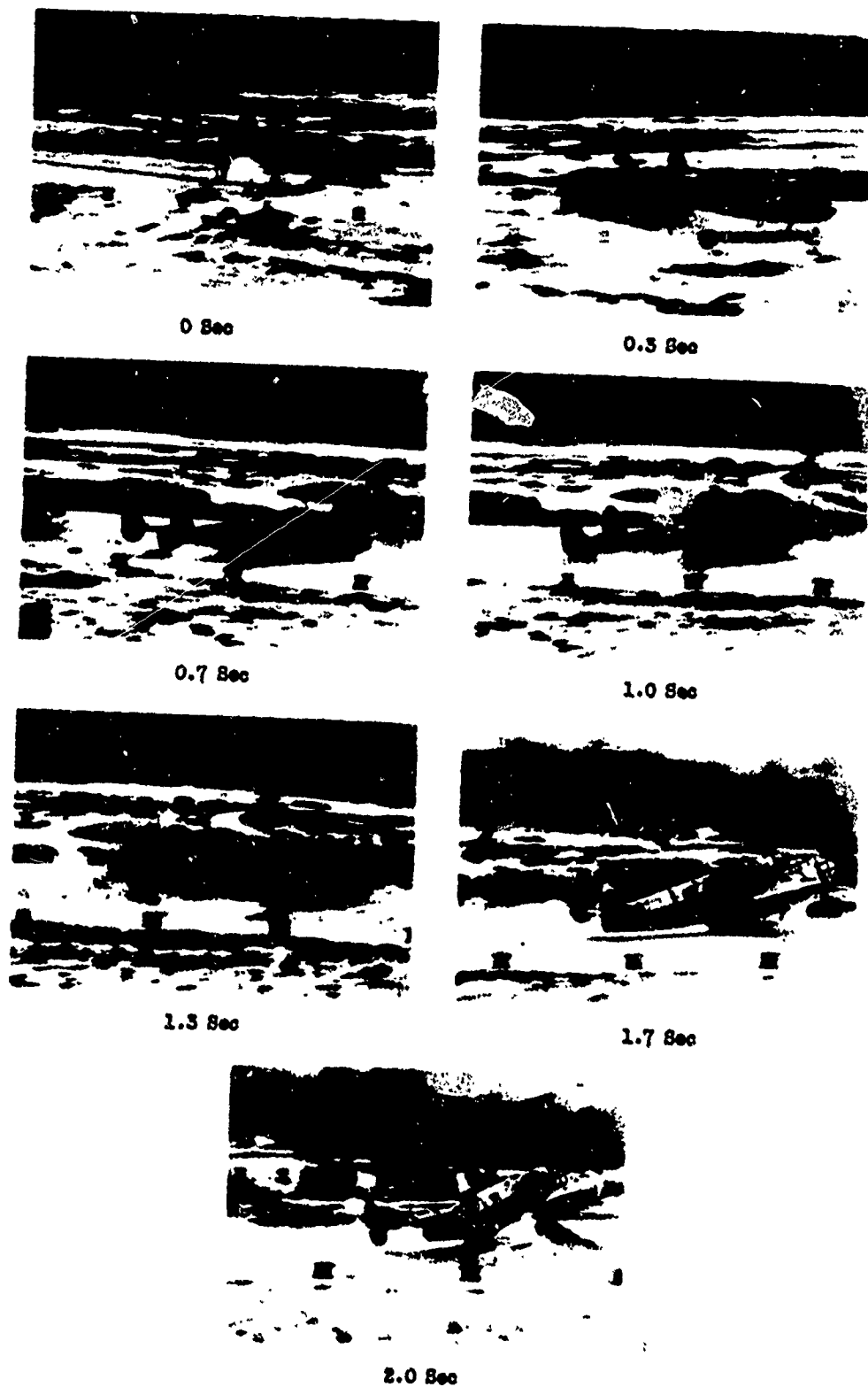


Figure 2-11. Film strip of 12° crash of R-5-0 Loadestar transport airplane.

[Source: Reference (2)]





2.1 Sec



2.3 Sec



2.5 Sec



2.6 Sec



2.8 Sec



3.0 Sec



3.1 Sec

Figure 2-11 (Con't) Film strip showing how wing breaks fall of crashing airplane  
[Source: Reference (2)]

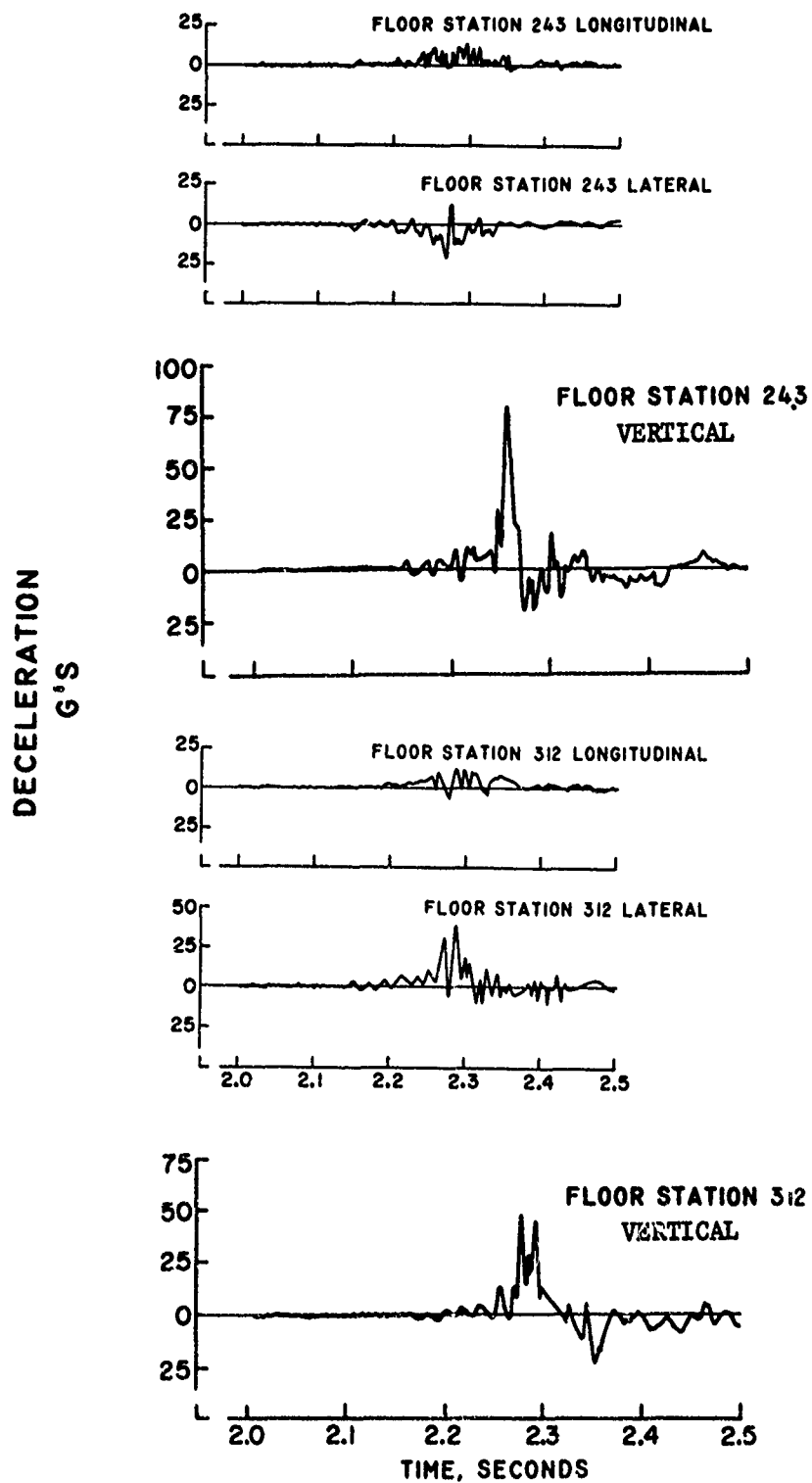


Figure 2-12  
Longitudinal, Lateral and Vertical deceleration resulting  
from second impact, 12° crash of R-5-0 Loadstar airplane.

[Source: Reference (2)]

In each test, the airplane was accelerated along a guide rail for a distance of 2,000 feet, with maximum power applied and at a maximum gross weight of 8,700 pounds. See Figures 2-16, 2-17, and 2-18. Impact velocity was 90 knots, plus or minus 10 knots. As the aircraft reached the impact area, the following sequence of events occurred:

1. The landing gear and aircraft guidance system were broken free by impact against a prepared barrier, allowing the aircraft to become completely airborne in free flight.

2. The aircraft flew into prepared barriers simulating an impact with trees with the right wing and wing-low impact with the left wing.

3. The fuselage impacted an earthen barrier designed to produce severe loading to the cockpit/cabin area.

Wooden utility poles, 14 - 16 inches in diameter, were implanted vertically to simulate tree impacts against the right wing.

The barrier for the left wing and fuselage was an earthen mound with a prepared surface sloping 35° to the flight path.

The aircraft guidance system consisted of two guide shoes installed as shown in Figure 2-19 to provide positive alignment and control of the test aircraft. Engine power was set manually prior to release of the aircraft for the acceleration run.

#### T-16 Test Objectives:

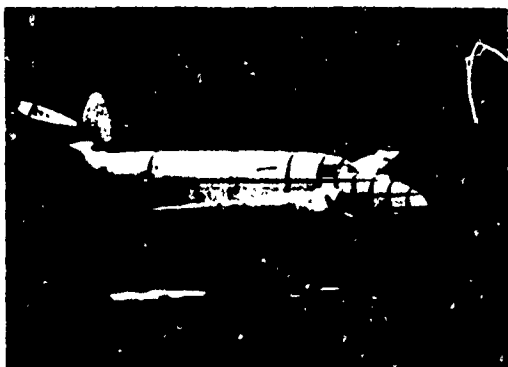
T-16, the first of two tests, was conducted without modification to the basic structure of the test vehicle. This provided base line data for use in determining the effectiveness of structural changes to be made in succeeding tests. Accordingly, the primary objectives of the test were:

1. To obtain the time histories of fuselage longitudinal, vertical and lateral accelerations at strategic locations along the fuselage.

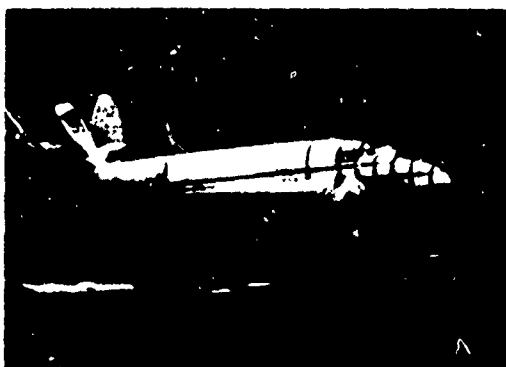
2. To observe the pattern and severity of structural deformations, especially the deformations of the cockpit/cabin area.

Electronic transducers were installed and used to obtain data on forces or accelerations and the following measurements were recorded:

1. Longitudinal acceleration, cockpit location
2. Vertical acceleration, cockpit location
3. Lateral acceleration, cockpit location
4. Longitudinal acceleration, center of gravity location



0.09 Sec



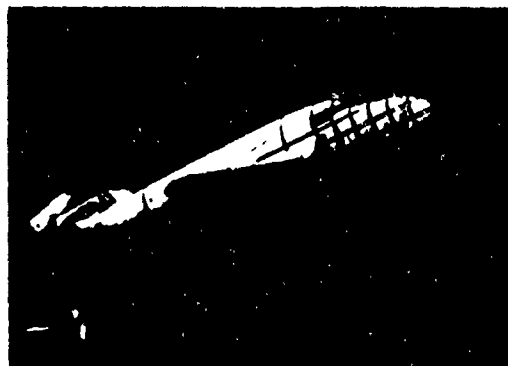
0.18 Sec



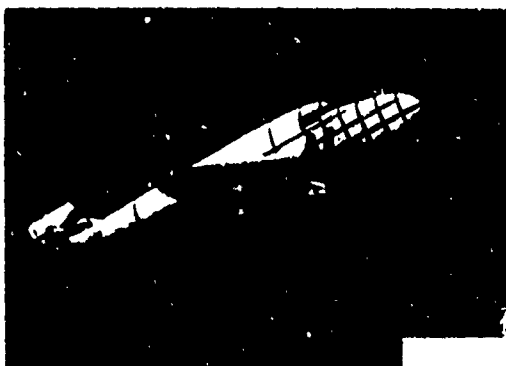
0.26 Sec



0.35 Sec



0.44 Sec



0.53 Sec

Figure 2-13. Film strip of 16° crash of R-5-0 Lodestar transport airplane.

[Source: Reference (2)]

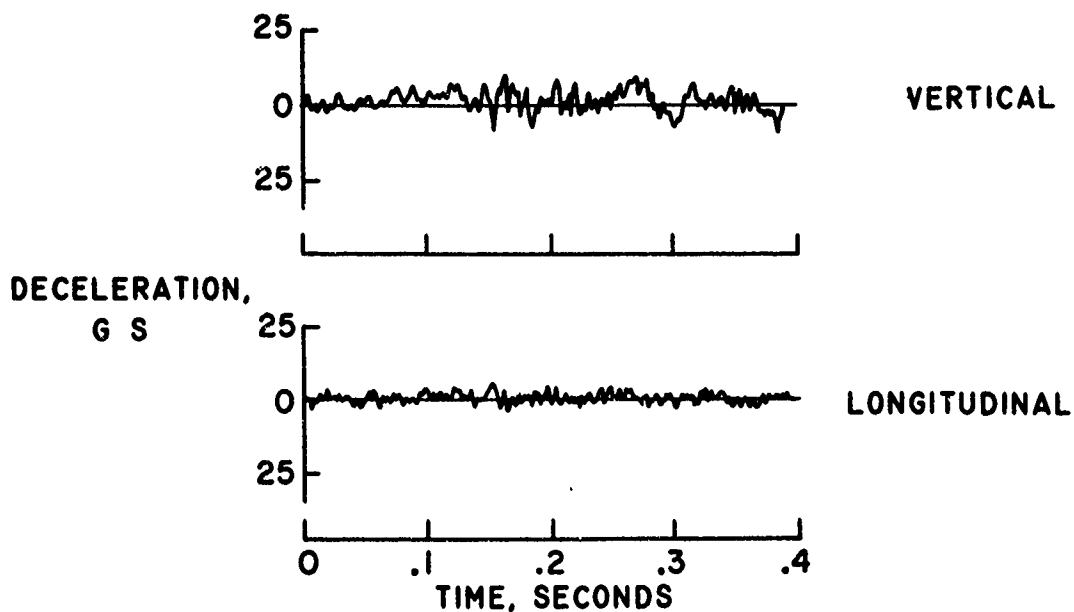


Figure 2-14. Longitudinal and vertical decelerations resulting from first impact in 12° crash of R-5-0 Lodestar transport airplane.

[Source: Reference (2)]

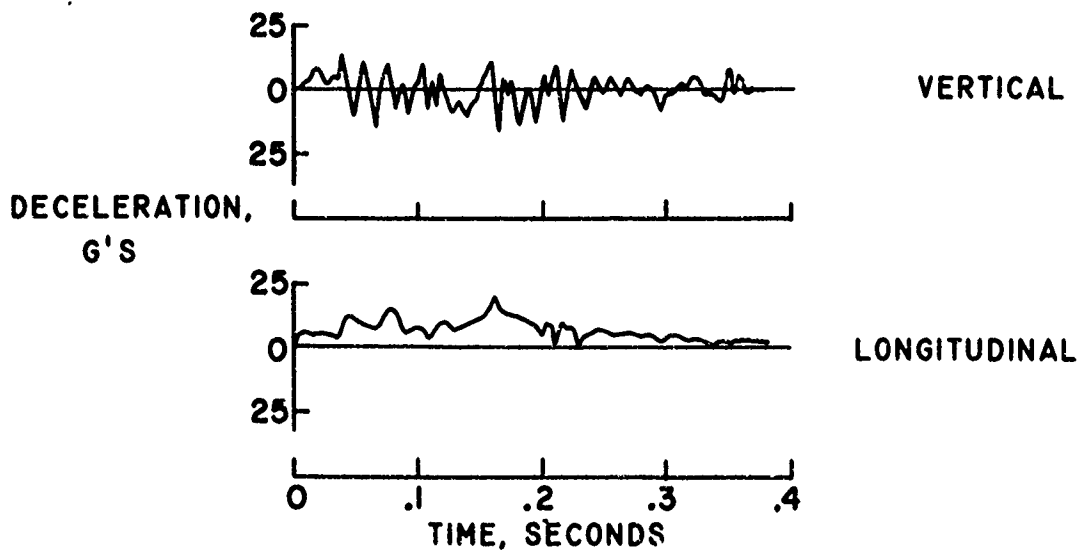


Figure 2-15. Longitudinal and vertical decelerations resulting from first impact in 16° crash of R-5-0 Lodestar transport airplane.

[Source: Reference (2)]



Figure 2-16

T-16 Airplane, Prior to Crash Test.  
(The configuration of this aircraft was typical of that of all aircraft used in this test series.)



Figure 2-17 Typical Front View of Test Aircraft, Precrash.



Figure 2-18

Test Site Viewed From Left, Showing Landing Gear Barriers, Utility Poles, and Earth Impact Barrier.

[Source: USAAVLABS TR 66-39]

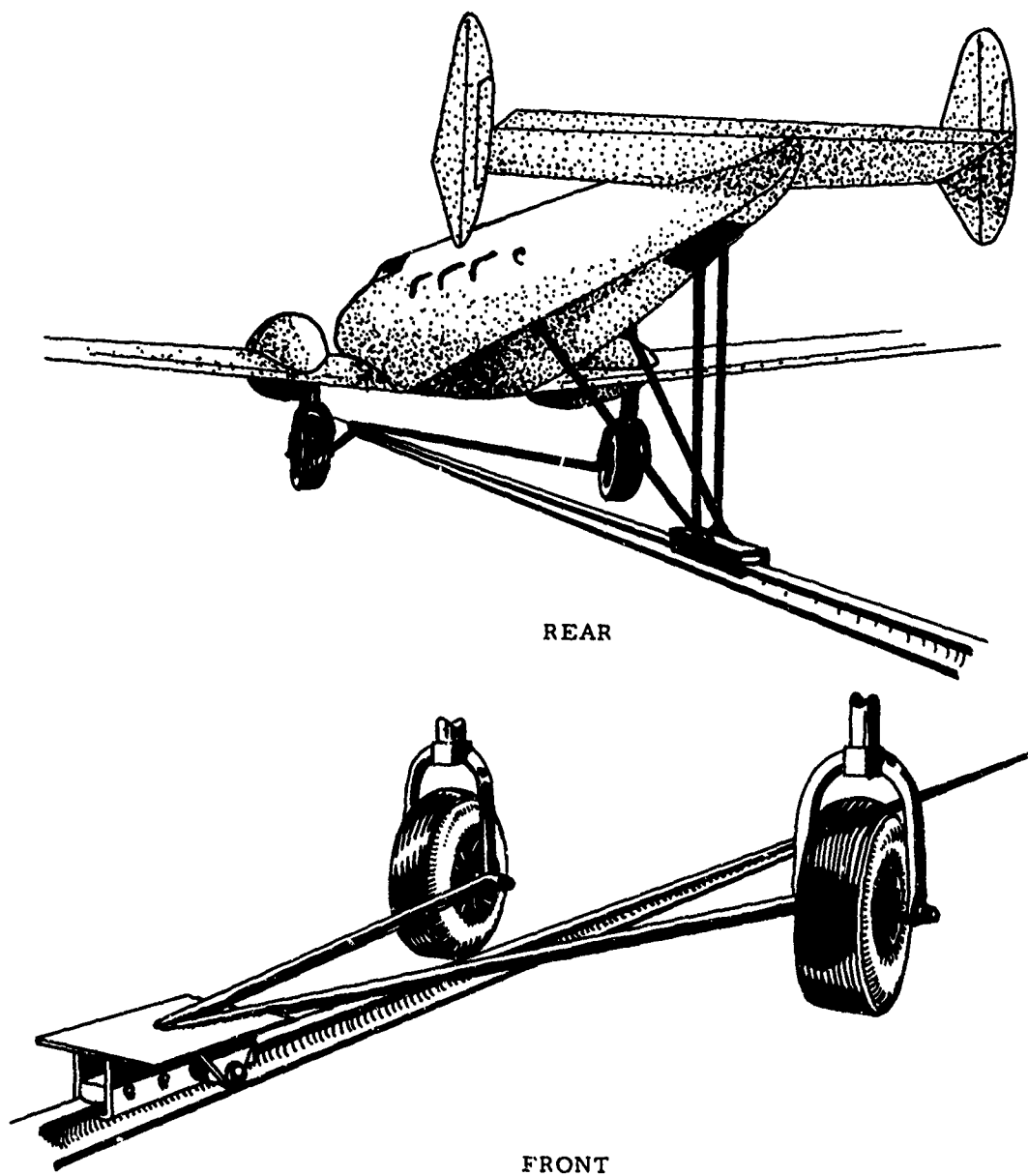


Figure 2-19. Aircraft Guidance System - Front and Rear Views.

[Source: USAAVLABS TR 66-39]

5. Vertical acceleration, center of gravity location
6. Longitudinal acceleration, aft cabin location
7. Vertical acceleration, aft cabin location
8. Lateral acceleration, aft cabin location

Photographic data and post crash observations provided information concerning the pattern and severity of structural deformation. See Figures 2-20 through 2-26.

#### Test Results and Analysis:

The aircraft (test T-16) struck the landing gear barriers with an initial velocity of 84 knots. The main landing gear failed immediately, placing the aircraft in free flight. The aircraft then struck the two barrier poles (simulating trees) with the right wing, and the earth barrier with the left wing. The wing impacts were immediately followed by impact of the nose against the earth barrier.

Large structural deformations occurred from the results of the crash test, yet the cockpit/cabin area was not totally destroyed. The nose structure, forward of the cockpit bulkhead, collapsed. The structure buckled inward abruptly which allowed the lower forward cockpit structure to contact the earth barrier. The forward section of the cockpit collapsed reducing the survivability chances of the occupants. Large masses of earth were scooped by the broken section of the nose.

Motion pictures and recorded electronic data analysis indicated that impact with the wing and fuselage barriers produced a single primary impact. During this impact, longitudinal velocity was reduced from approximately 144 feet per second to 40 feet per second in 0.22 second. The maximum longitudinal accelerations were 78g measured in the cockpit, 66g measured at the center of gravity, and 28g measured in the aft cabin.

The vertical acceleration pulse was shorter in duration than the longitudinal pulse, lasting for approximately 0.16 second. The highest vertical acceleration, 40g, was measured at the cockpit floor.

Lateral accelerations were also highest in the cockpit, being approximately 20g in each direction. See Figures 2-27 through 2-35.

Postcrash investigation revealed that the dummies placed in the pilot's and co-pilot's seats were displaced forward and their heads had impacted the instrument panel. The instrument panel had been displaced aft when the lower nose structure collapsed. The cockpit seats were displaced forward due to loads imposed by the restraint system. The lower section of the cockpit bulkhead was displaced aft, wedging the dummies feet between displaced structure and the rudder pedals.



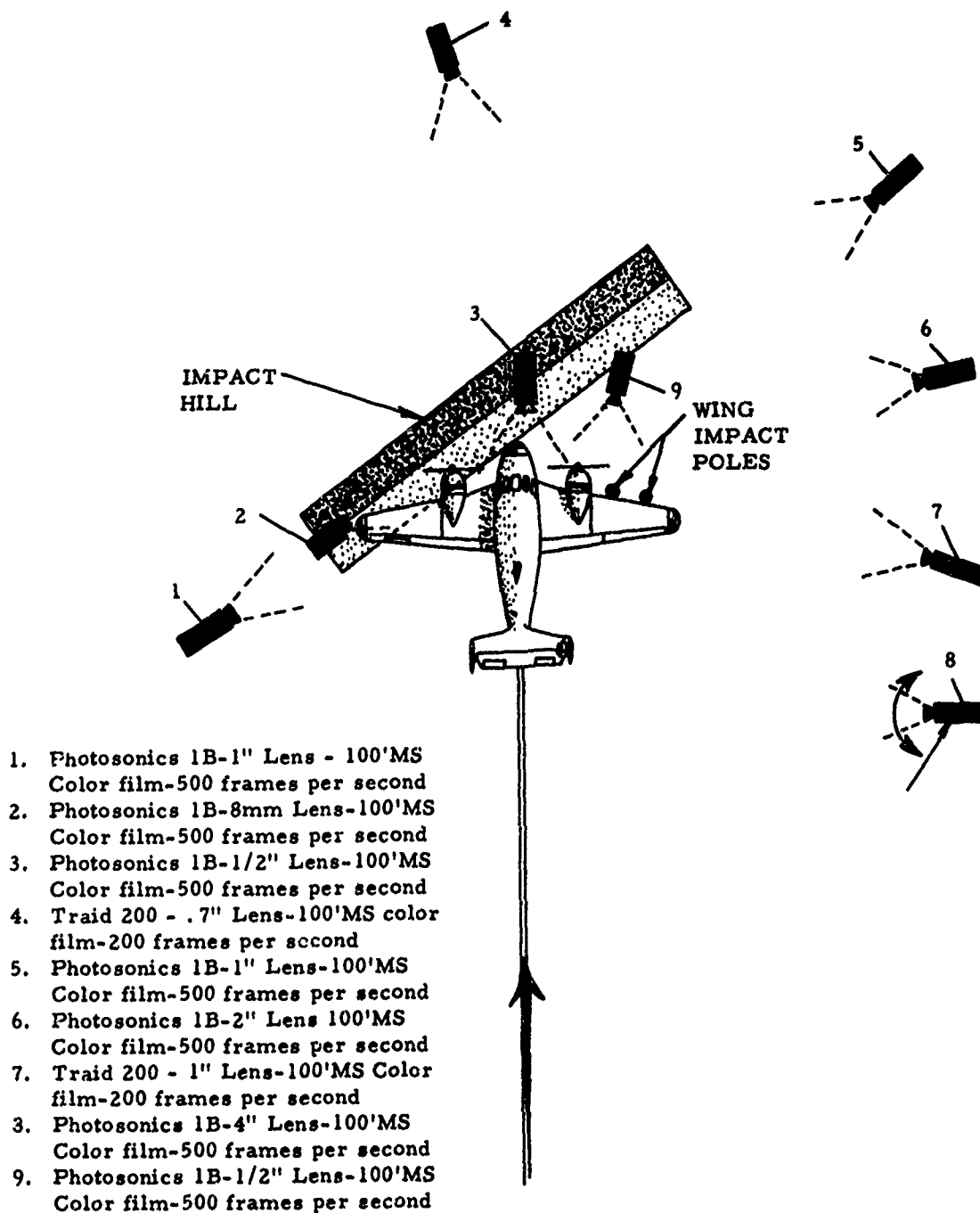


Figure 2-20. Ground Camera Locations

[Source: USAAVLABS TR 66-39]

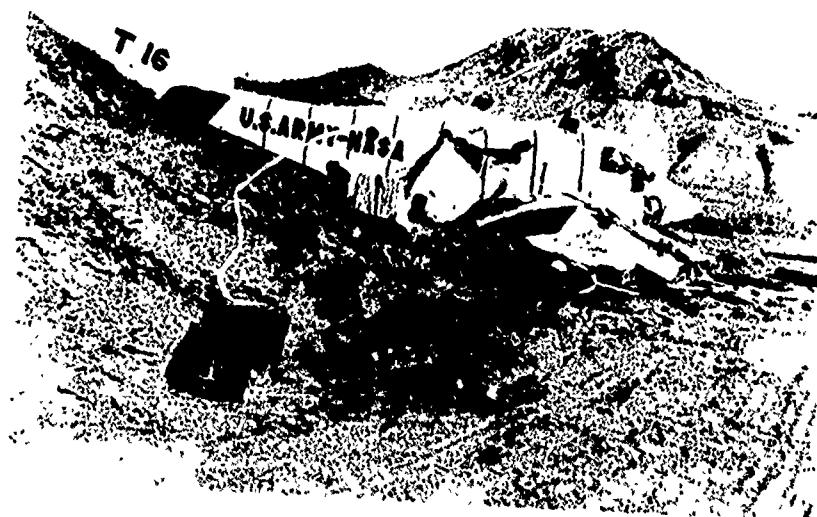


Figure 2-21. Right-Side View of T-16 Vehicle, Postcrash.

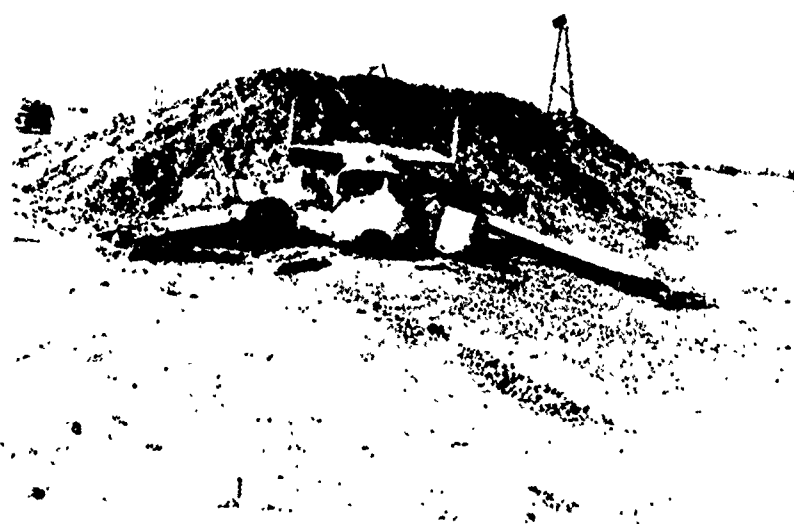


Figure 2-22. Front View of T-16 Vehicle, Postcrash.  
[Source: USAAVLABS TR 66-39]



Figure 2-23. Left-Side View of T-16 Vehicle, Postcrash.

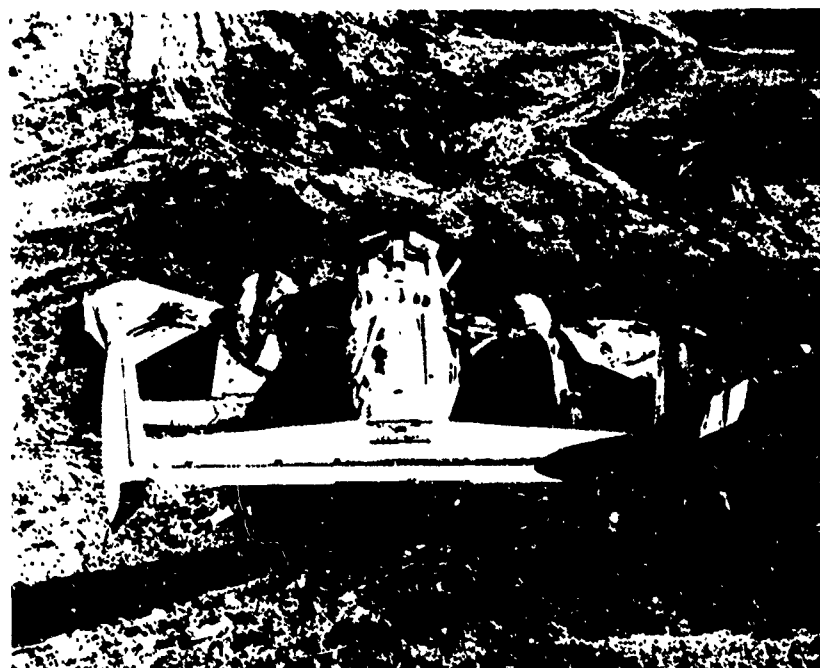


Figure 2-24. Aft View of T-16 Vehicle, Postcrash

[Source: USAAVLABS TR 66-39]



Figure 2-25 View of Cockpit Area of T-16 Vehicle, Showing Buckling of Side Structure Caused by Aft Forces on Forward Cockpit Bulkhead.

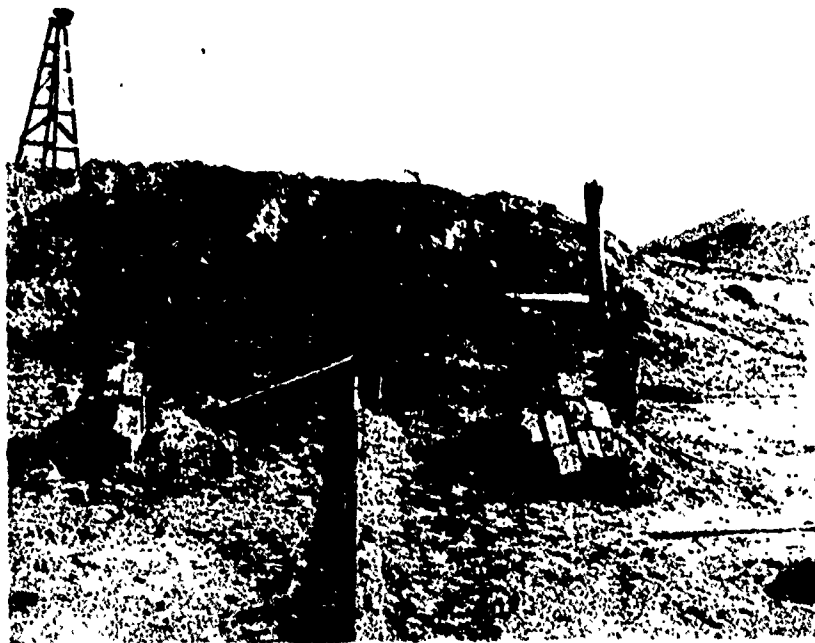


Figure 2-26 Gouge Marks on Face of Earth Impact Barrier Following T-16.

[Source: USAAVLABS TR 66-39]

Figures 2-27 and 2-34 show acceleration measurements recorded during the test.

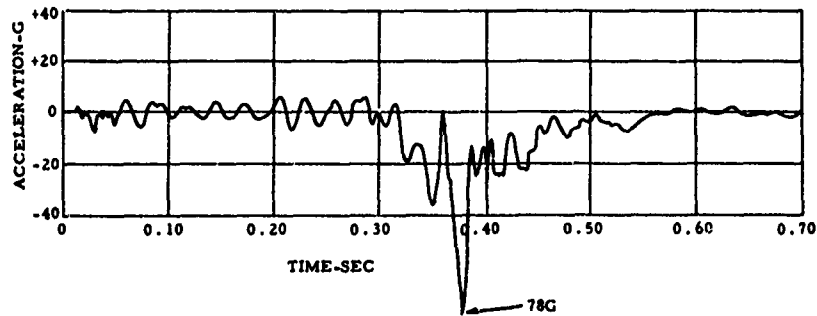


Figure 2-27. T-16 Cockpit Acceleration, Longitudinal.

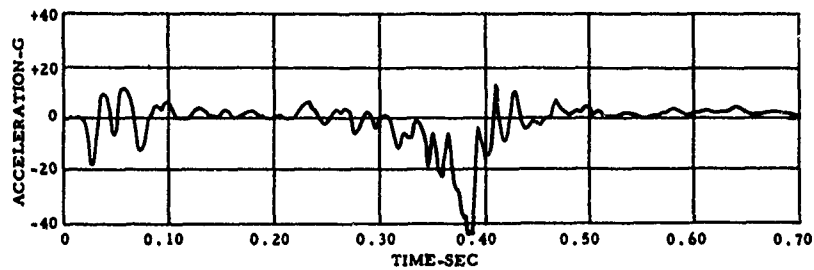


Figure 2-28. T-16 Cockpit Acceleration, Vertical.

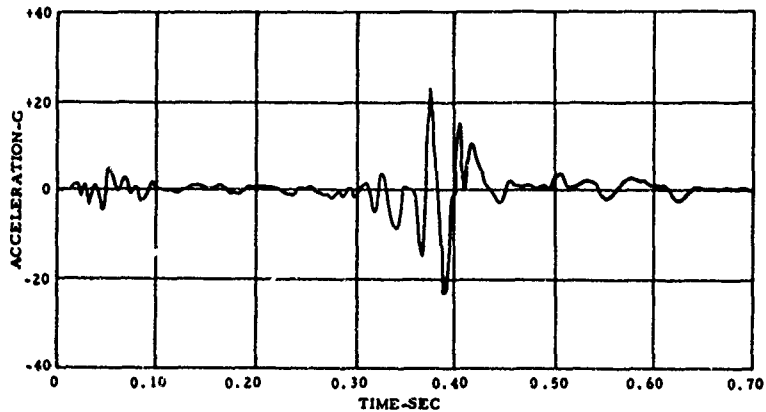


Figure 2-29. T-16 Cockpit Acceleration, Lateral.

[Source: USAAVLABS TR 66-39]

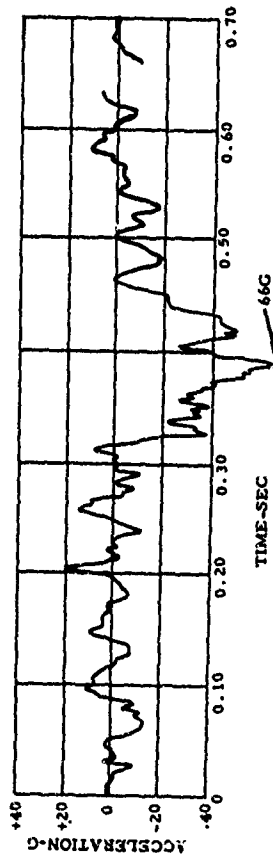


Figure 2-30 T-16 Mid-Cabin (c.g.) Acceleration, Longitudinal.

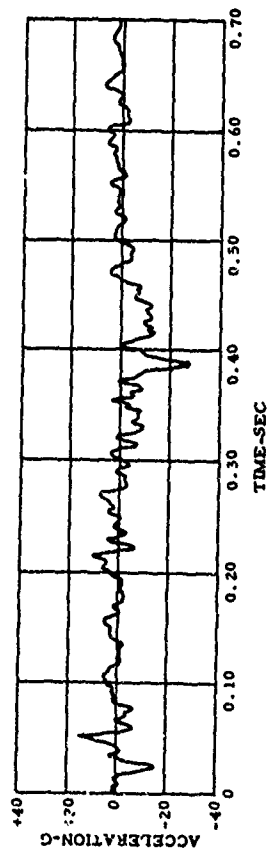


Figure 2-31 T-16 Mid-Cabin (c.g.) Acceleration, Vertical.

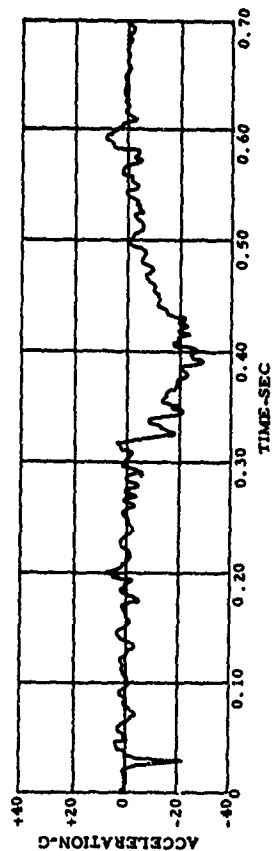


Figure 2-32 T-16 Aft-Cabin Acceleration, Longitudinal.

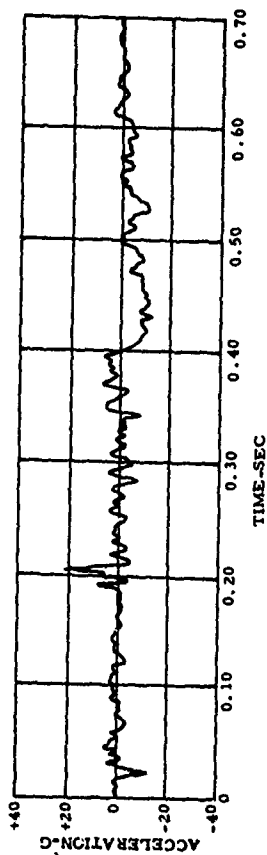


Figure 2-33 T-16 Aft-Cabin Acceleration, Vertical.

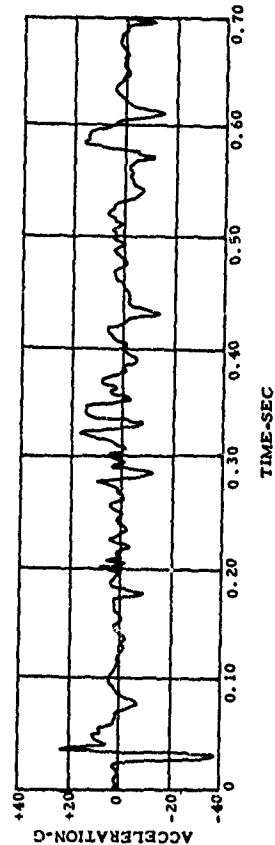


Figure 2-34 T-16 Aft-Cabin Acceleration, Lateral.

[Source: USAAVLABS TR 66-39]

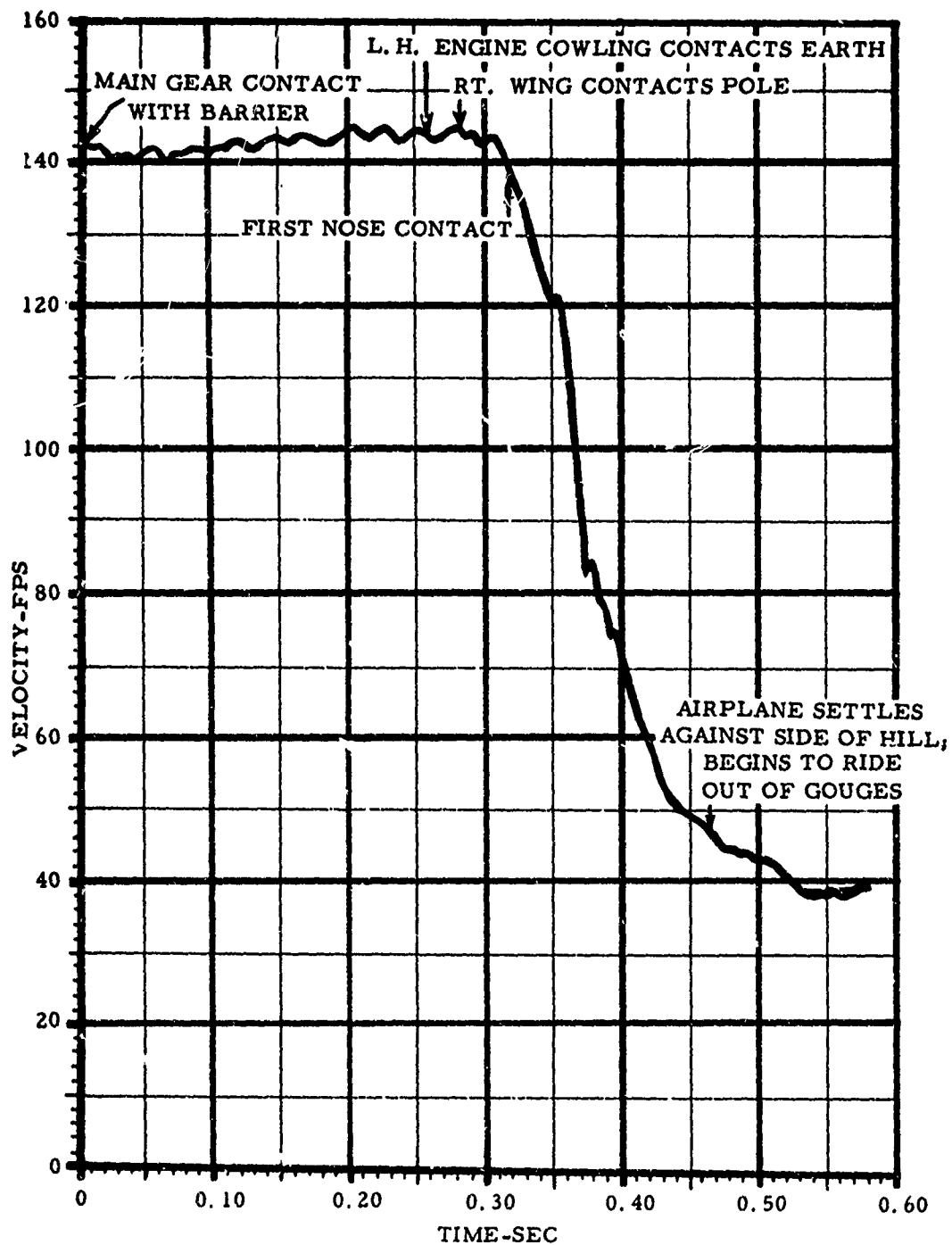


Figure 2-35. T-16 Longitudinal Velocity - Time Diagram.  
(Beginning at gear impact - cockpit accelerometer)

[Source: USAAVLABS TR 66-39]

### T-19 Test Objectives:

T-19 test conditions were the same as the T-16 test except the lower nose section structure was modified to prevent the "snap-in" type failure.

The modification of the nose structure consisted of reinforcing the nose formers at fuselage stations 19.88 and 29.12 and adding a partial bulkhead at station 38.38. See Figures 2-36 through 2-40 for details of installation.

Post crash investigation revealed the modifications were effective in preventing earth gouging. The lower nose structure was crushed to a flat surface. The nose did not "snap-in" nor did it dig into the ground appreciably.

During the test, the photographic equipment operated properly, but the electronic equipment failed. However, from the motion pictures taken, it was established that aircraft velocity decreased from 140 feet per second to 62 feet per second in 0.20-0.25 seconds. This occurred in the first impact. The T-16 test velocity change was from the initial 144 feet per second to 40 feet per second in 0.22 seconds. Therefore, the energy dissipated in T-19 test in the longitudinal direction for the primary impact pulse was less than for the T-16 test. The vertical impact force was the same for both tests.

One of the primary objectives of the tests was to determine the effectiveness of the modifications to the nose. The modified nose prevented earth scooping and reduced the energy levels experienced by the cockpit in the test crash.

### Analytical Methods:

In general, the objective of airframe crashworthiness is to provide the maximum feasible protection to the occupants. The airframe can serve this purpose in two ways. It can reduce or control the deceleration environment transmitted to the occupants, and can serve as a protective "shell".

The primary factors affecting occupant survival are:

- a. Velocity change in the major impact pulse.
- b. Occupant deceleration magnitude, duration, and onset during the major impact pulse.
- c. Direction of the applied deceleration force with respect to the occupant.

In accidents, velocity changes may be largely a function of fuselage collapse and movement or deformation of impacted objects. The energy balance is given by the following expression:



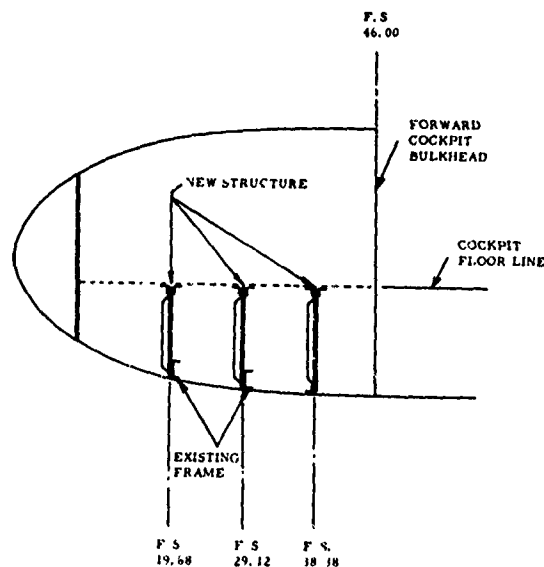


Figure 2-36. Sketch of Locations of Nose Structural Reinforcements (Side View).

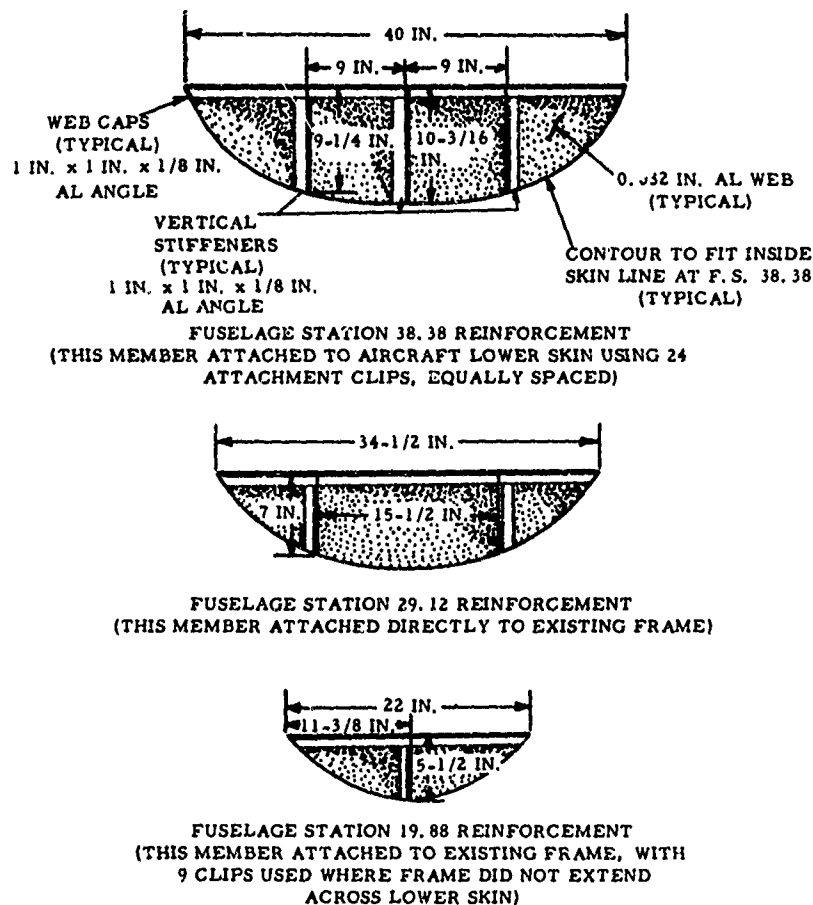


Figure 2-37. Sketches of Nose Structure Reinforcement Webs and Stiffeners.

[Source: USAAVLABS TR 66-39]

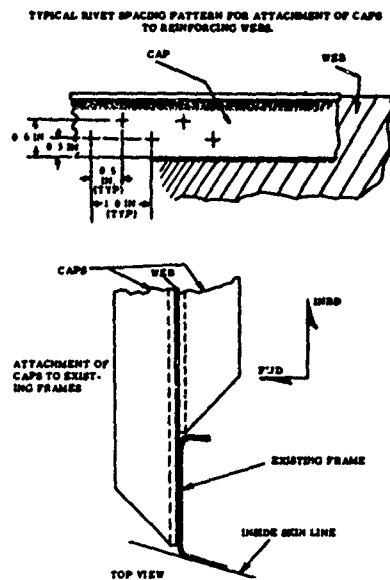


Figure 2-38. Attachment of Cap Angels to Webs and Existing Frames.

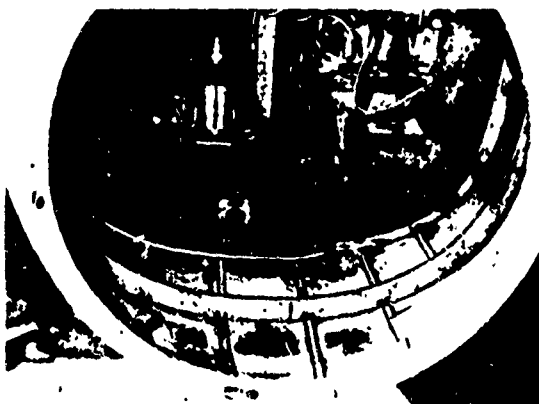


Figure 2-39. Nose Structure of a T-19 Airplane Prior to Modification.

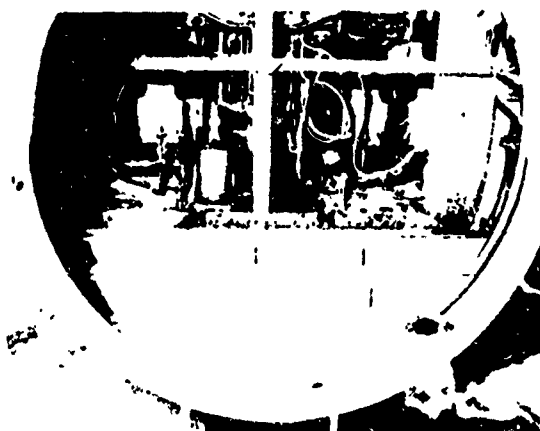


Figure 2-40. Nose Structure of T-19 Aircraft After Modification.  
[Source: USAAVLABS TR 66-39]

$$\frac{M_A (V_o^2 - V_f^2)}{2} = U_S + U_G \quad (1)$$

where:  $M_A$  = Mass of Aircraft  
 $V_o$  = Initial impact velocity of aircraft  
 $V_f$  = Velocity remaining after impact  
 $U_S$  = Energy Absorbed by Structural Collapse  
 $U_G$  = Energy dissipated in deformation or movement of impacted objects.

$U_S$  can be factored into the following equation:

$$U_S = P_{av} s + U_S' + U_C \quad (2)$$

where:  $P_{av}$  = Average force developed in collapse of structure between the cockpit/cabin and the outer extremities of the fuselage.

$s$  = Reduction in the dimension between the occupant and the original fuselage dimension.

$U_S'$  = Energy dissipated by deformation or shearing of airframe components other than the fuselage.

$U_C$  = Energy to be absorbed by the cockpit/cabin structure.

By substituting for  $U_S$  in equation (1), the cockpit/cabin deformation energy can be expressed by the following:

$$U_C = \frac{M_A (V_o^2 - V_f^2)}{2} - P_{av} s - U_S' - U_G \quad (3)$$

This equation is good for the cockpit/cabin deformation energy, only if conditions reach or exceed the critical point for cabin deformation. Therefore, the ideal objective of airframe design would be to obtain a cockpit/cabin structure whose critical deformation energy is greater than the impact conditions, or;

$$U_C \geq \frac{M_A (V_o^2 - V_f^2)}{2} - P_{av} s - U_S' - U_G \quad (4)$$

This would insure a protective shell, or crash cage, for the occupants. However, the ideal design may not always be practical.

In equation (3), the factors which may be controlled by design are  $P_{av}$ ,  $s$ ,  $U_S'$ . An increase in any one of these factors will reduce the energy necessary for the cockpit/cabin to absorb.

$P_{av}$  may be increased by providing structure which requires a uniform force throughout the mode of collapse, thereby reducing force peaks or a

steadily increasing force.  $P_{av}$  may also be increased by simply increasing the strength of the structure surrounding the cockpit/cabin. However, this method is limited. For example, if the maximum collapse force for nose structure exceeded the cockpit/cabin critical collapse force, then the cockpit/cabin would collapse before the nose section, and the desirable energy absorption characteristic of the nose section would be lost.

Another point to consider in increasing  $P_{av}$  is the deceleration transmitted to the occupants. If the maximum collapse force is increased, the airplane decelerations will rise faster to a higher magnitude, which adversely affects occupant deceleration. Hence, a compromise between increasing  $P_{av}$  and the detrimental effects of increasing the airplane deceleration must be considered.

Increasing the available deformation distance,  $s$ , provides a greater energy absorption capacity. This may be accomplished by adding collapsible structure exterior to the cockpit/cabin structure.

Increasing  $U_G'$  would reduce the energy that the fuselage structure must absorb. It is difficult to predict which portions of the airframe would be beneficial. However, deformation or shear energy absorbed by the wings when descending through trees would reduce the kinetic energy of the airplane at ground impact. Increasing the energy absorption capacity of the wings and tail sections may also be beneficial if these components are the primary cushion for the cockpit/cabin. The crash tests of the Lockheed Loadstar illustrated how the wing can provide a cushion for lateral impacts (reference Figure 2-11).

The second factor of the energy balance (equation (1)) to consider is  $U_G$ . Impact with the ground normally produces the primary deceleration pulse. Ground impact produces a number of observed phenomena. The two phenomena of primary concern are soil scooping and soil plowing.

Under certain conditions of impact attitude and terrain consistency, the forward sections of an impacting airplane deform to a scoop configuration. The scoop then picks up a mass of soil and drives it to the aircraft velocity in a very short time. This short time permits application of impulse and momentum principles. Accordingly, these principles provide the following relationship between the airplane mass and the effective soil mass:

$$M_A V_0 = (M_A + M_E) V \quad (5)$$

where:  $M_A$  = Mass of airplane

$M_E$  = Effective mass of accelerated soil

$V_0$  = Initial impact velocity

$V$  = Velocity of airplane soil system immediately after impact.

Solving for  $V$  in equation (5),

$$V = \left[ \frac{M_A}{M_A + M_E} \right] V_0 \quad (6)$$

An impulse-momentum relationship may be applied to the soil mass as a free body, to determine the interaction force involved in the momentum exchange as;

$$\int_0^t F dt = M_E V \quad (7)$$

where,  $F$  = Interaction force  
 $t$  = Time involved

also, by definition,

$$\int_0^t F dt = F_{av} t \quad (8)$$

by substitution;

$$F_{av} = \left[ \frac{M_A M_E}{M_A + M_E} \right] \frac{V_0}{t}$$

Since  $F_{av} = M_A a$ , the aircraft deceleration may be expressed as:

$$a_A = \frac{F_{av}}{M_A} = \left[ \frac{M_E}{M_A + M_E} \right] \frac{V_0}{t} \quad (9)$$

also,

$$M_E = QAV_0 t \quad (10)$$

where  $Q$  is the mass density of the soil and  $A$  is the cross-sectional area

Substituting for  $M_E$  in equation (9) gives,

$$a_A = \frac{KAV_0^2}{M_A + KAV_0 t} \quad (11)$$

Since the airplane deceleration varies with the square of the velocity, equation (11) shows that the scoop effect rapidly becomes more significant with increasing impact velocity.

Soil plowing is a phenomenon different from soil scooping. Soil plowing is an additional force associated with momentum exchange. It is brought about by soil penetration by projecting structure which upturns or moves the soil aside. The drag force generated by plowing is a steady-state force of a magnitude which depends on velocity, mechanical characteristics of the soil, and the area of interference. These variables are very unpredictable. However, the crash tests reported in USAAVLABS TR 66-39 have indicated that design improvements aimed at reducing scooping will also reduce the plowing effects.

CHAPTER II  
REFERENCES

1. Annual Review of U. S. General Aviation Accidents Occurring in Calendar Year 1968, Prepared and Published by National Transportation Safety Board, Department of Transportation, Washington, D. C., September 1969.
2. Preston, G. M., and Moser, J. G., NACA Conference on Airplane Crash-Impact Loads, Crash Injuries and Principles of Seat Design for Crash Worthiness, National Advisory Committee for Aeronautics, Lewis Flight Propulsion Laboratory, Cleveland, Ohio, April 17, 1956.
3. Eiband, A. M., Simpkinson, S. H. and Black, D. O., Accelerations and Passenger Harness Loads Measured in Full-Scale Light-Airplane Crashes, NACA TN 2991, August 1953.

## CHAPTER III

### INTERIOR

#### Seats

##### Introduction:

In considering aircraft interiors and furnishings, seats should be carefully evaluated. This is evident because seats will normally provide body support for occupants.

Although body support is the primary objective of seat design, the factors of utility and comfort should not be ignored. An uncomfortable seat can produce pilot fatigue, which is often an indirect cause of accidents.

##### Service Experience:

The service experience records for seats in light aircraft accidents are not extensive. However, there are indications that seats have failed in accidents in which the structural integrity, or living space, of the cabin was maintained. There are also a few cases on record where seats have failed while the pilot was performing some maneuver.

##### Seat Orientation Experience:

As discussed in Appendix A, experimental studies have shown that human tolerance is dependent on the contact area and the load direction with respect to the body. Therefore, seat orientation is an important factor.

For longitudinal impacts, rearward facing seats would provide the maximum body support for combined forward and vertical deceleration forces. However, the rearward facing seat would still be inadequate when major lateral deceleration is experienced. This could be counteracted by the use of a chest strap of much lighter weight than that required for other seat orientations.

In the case of seats which face forward, such as crew seats, protection can be provided by a restraint system.

Side-facing seats would provide the least protection for the majority of accidents. Even with shoulder harness, the tolerance to impact decelerations is low because of lateral spinal flexure. However, protection may also be

provided by any of the three methods specified by Amendment 23-7 to FAR 23 in Section 23.785(g).

#### Seat Parameters:

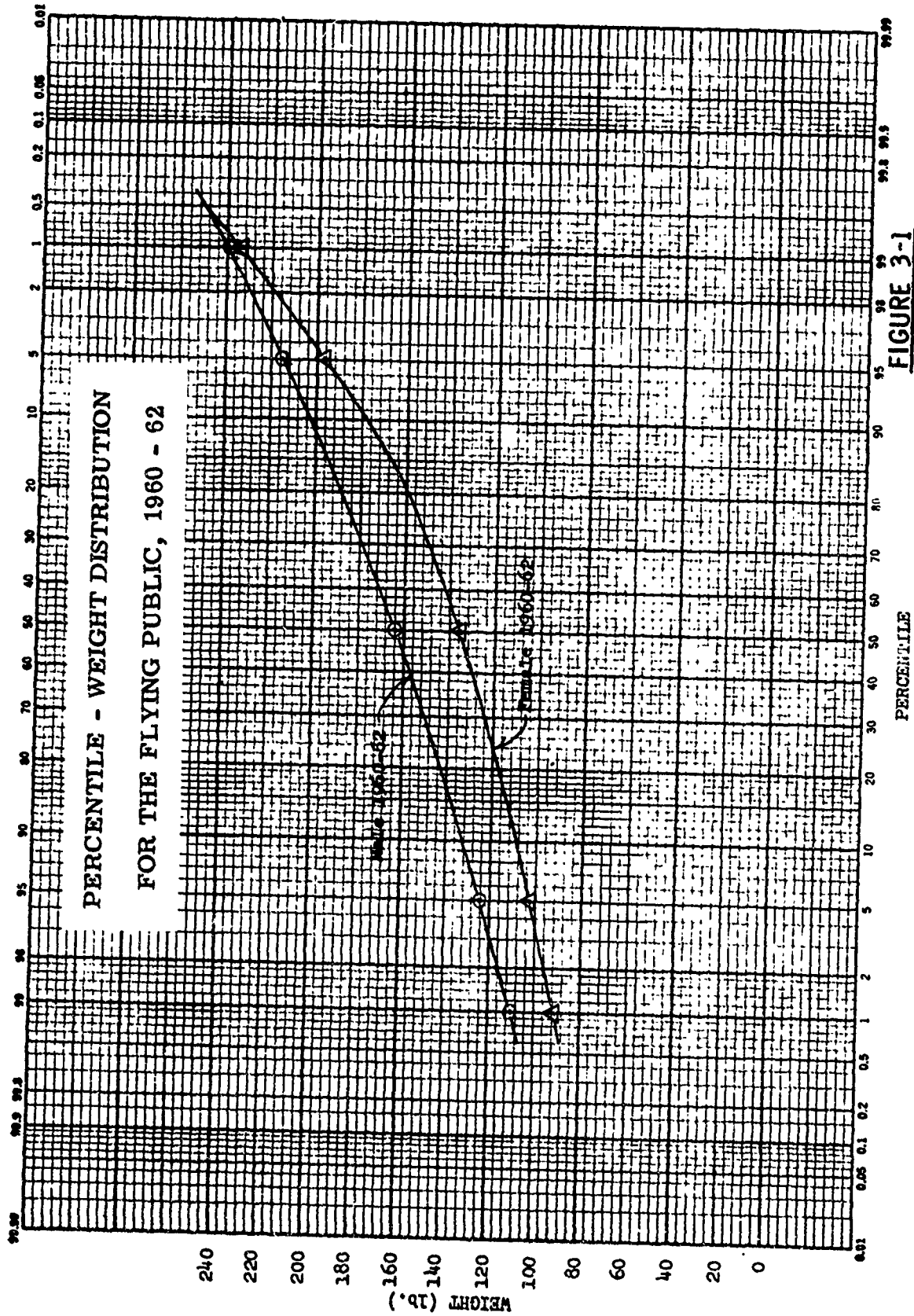
The inertia loads imposed on a seat in a crash situation are generated by the effective weight of the occupant plus the weight of the seat. The loads imposed by the occupant can vary, depending on whether the restraint system is anchored to the seat or to the airframe. Seat orientation also affects the stress magnitudes at various points in the seat structure.

The FAA has conducted an analysis of the available anthropometric data to provide an estimate of the weight distribution for the flying public. These distributions for male and female are shown in Figure 3-1. The most recent data used in Figure 3-1 were taken in 1962.

Due to restraint harness elasticity, the compressibility of the soft human tissue, and the relative movement of body parts, the occupant acquires a relative velocity with respect to the cabin floor under impact conditions. Depending on the magnitude and duration of the deceleration pulse, as well as the elastic characteristics of the restraint system, the maximum relative velocity may be significant. According to Reference (2), computer simulation and experimental observation show that the relative velocity can create deceleration factors of 1.2 to 2 times that of the floor deceleration. With this phenomenon, a load limited or energy absorbing seat may be practical from both the weight and safety aspects. Reference (2) provides a comparison of some typical load limiting devices. See Table 3-1.

The effect of not providing for relative seat leg-to-floor rotation is illustrated by Reference (2). The rear legs of a crew seat were attached to a base frame with castings as shown in Figure 3-2. The casting failed repeatedly in actual accidents as a result of combined axial and bending stresses acting at the region of stress concentration. With the slight modification to a pinned joint, the longitudinal load capacity was nearly doubled. It should be noted that the seat carried the seat belt and shoulder harness loads which is why the modified seat worked.



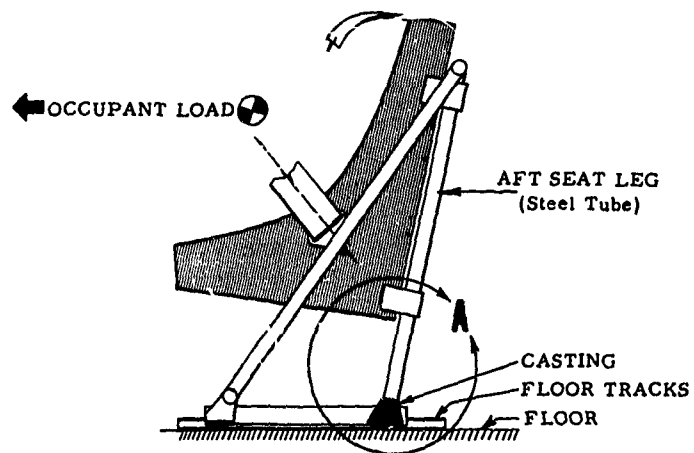


**FIGURE 3-1**

**TABLE 3-I.**  
**COMPARISON OF "ONE SHOT" LOAD-LIMITING**  
**DEVICES FOR 1000- TO 4000-POUND LOADS**

Device Description	Energy-Absorption Process	Operational Sketch	Tension or Compression	Specific Energy (ft-lb/lb)	Space Required	Long-Term Reliability	Ability To Sustain Rebound Loads	Potential Applications
Strap/Rod over Die or Roller	Metal Bending and Friction		T	Not Known	Average	Fair to Good	Poor	Cargo Restraint
Basic Metal Tube or Plate	Elongation of Metal		T	3400-4500	Minimum	Good to Excellent	Poor <sup>a</sup> to Fair	Forward or Lateral Seat Braces
Basic Stranded Cable <sup>b</sup>	Elongation of Stainless Steel		T	3000-4500	Minimum	Excellent	Zero	Cargo Restraint <sup>b</sup>
"S" Shaped Bar <sup>c</sup>	Bending and Shear		T	1600-2400	Good	Excellent	Poor	Seat Pan Downward Support, Cargo Restraint <sup>c</sup>
Rod Pull-Through Tube <sup>e</sup>	Hoop Tension and Friction		T and C	600 <sup>g</sup>	Minimum	Good	Good	Seat Legs or Braces <sup>e</sup>
Inversion Tube <sup>d</sup>	Hoop Tension/Compression and Bending		T and C	1200-2000	Average	Excellent	Excellent	Seat Legs or Braces <sup>d</sup>
Tube Flaring	Hoop Tension, Friction and Bending		C	30,000 <sup>h</sup>	Average	Good	Fair <sup>a</sup>	Seat Pan Downward Support
Honeycomb Compression <sup>f</sup>	Buckling of Membrane "Columns"		C	2500-3500	Average	Good	Poor <sup>a</sup> to Fair	Seat Legs or Landing Gears <sup>f</sup>
<p>(a) This device could be rated higher if an integral rebound device were incorporated into the design.</p> <p>(b) Currently being marketed by American Chain &amp; Cable Company.</p> <p>(c) Royal Netherlands Aircraft Factories Fokker did the initial development of this device in 1963.</p> <p>(d) Development conducted by General Motors Research Laboratories, Warren, Michigan.</p> <p>(e) A device utilizing a compressed tube rather than the expanding tube shown is being marketed by the Aerotherm Company, Bantam, Connecticut.</p> <p>(f) This device is being utilized by the Sikorsky Aircraft Company in their S-58, S-61, and S-62 helicopter landing gears.</p> <p>(g) This value is based on the compressed tube device tested. This value could be doubled in a more efficient design.</p> <p>(h) This maximum value does not consider end fitting weights; a value of 6000-8000 ft-lb/lb is comparable to the other devices.</p>								

[Source: USAAVLABS TR 70-22 (2)]



Aft Seat Lcg Casting Attachment.

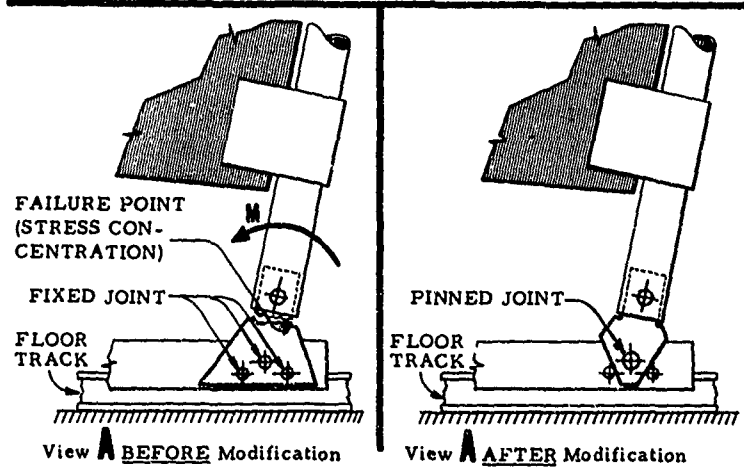


Figure 3-2. Aft Seat Leg Casting Attachment Modification.  
[Source: USAAVLABS TR 70-22 (2)]

## Structural Testing of Seats:

Structural tests are used by some manufacturers not only for seat performance verification but in seat performance design as well. The following discussion of a test program used in the development of an energy-absorbing seat is extracted directly from Reference (12), "An Energy-Absorbing Seat Design for Light Aircraft" by B. Underhill and B. McCullough of Piper Aircraft Corporation.

"Much effort has gone into the development of methods of protecting aircraft occupants from horizontal accelerations during accidents. These methods usually take the form of padded instrument panels, lap belts, and shoulder harnesses. However, very little has been done to protect the occupant from vertical accelerations.

The human body is far less resistant to vertical accelerations than it is to horizontal accelerations. Although most aircraft accidents result in higher horizontal than vertical loads, there is also much more crushing structure between the occupant and the point of impact in the horizontal direction than there is in the vertical direction. This means that although simple restraint systems are acceptable for horizontal accelerations, the lack of attenuating structure makes some type of energy-absorbing system necessary in the vertical plane. For this reason, when a new seat was required for the Piper Cherokee, it was determined that it should be designed to have energy-absorbing capabilities. In addition, it was necessary to consider weight, reliability, and cost, since no reduction in payload or cost increase would be acceptable to our customers.

It was determined that the development program required would consist of preliminary design, static testing to arrive at an acceptable product, and dynamic testing of final seats to make sure that dynamic behavior would correlate with the results of static test.

This program was begun in April 1971, and dynamic tests of the final seats were run in November 1971. We discussed the reasoning leading to the seat design, the testing processes used, the final results of these test, and the conclusions arrived at as a result of these tests.

### DESIGN OBJECTIVES

An aircraft flown at cruising speed (low angle of attack) has very little velocity component in the vertical plane (using body-oriented axes). Impacts with the ground at cruising speed or above are due to lack of visibility or loss of control, and these are rarely considered to be survivable. At lower airspeeds, however, the vertical velocity component as measured from the fuselage horizontal axis becomes large. An examination of geometry and airspeeds will show that, for high angles of attack, the possibility for vertical velocity components of 1500 ft/min (7.62 m/s) or more are possible even in light aircraft. At low

airspeeds it is not possible to reduce this rate of descent by raising the nose of the aircraft. Thus, with the fuselage in approximately a level flight attitude, an aircraft could impact a level surface with a large vertical velocity, and this velocity would be arrested almost instantaneously, without necessarily imposing a high horizontal acceleration. Many accidents of this nature have been reported.

The design requirement set up for the seat structure, therefore, was to arrest a downward velocity component of 1500 ft/min (7.62 m/s) or more in a distance of about 8 in (20.3 cm) without exceeding acceptable g loads.

#### ENERGY ABSORPTION

If it were possible to build a seat that would provide the same acceleration limits for occupants of all weights, the problem of limiting the maximum acceleration would be quite simple. It would only be necessary to pick the maximum tolerable acceleration and allow the seat to deflect at that point. A conventional seat structure, however, responds to force rather than to acceleration. In other words, 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. Theoretically, of course, it would be possible to design a seat whose energy-absorbing capacity could be adjusted to the weight of the passenger, either manually or automatically; but an examination of the problems involved in this approach led to abandoning it because of the increased weight and complexity that would characterize such a unit.

**LOAD PARAMETERS** - The next step was to see if it would be possible to make a reasonable compromise in load capacity, which would provide protection for the widest range of passenger weights.

Using a design acceleration level of 25 g, a nominal weight of 177 lb (53.1 kg) was established. This weight represents a woman of the 22nd percentile in weight, or a 2nd percentile man. Using an effective mass on the seat of 80% and an acting seat weight of 15 lb (6.8 kg), a design load of 2715 lb (1232 kg) was established for the seat.

To explore the effect that variations in weight would have on the accelerations experienced, a 200 lb (90.7 kg) occupant was investigated. With this weight the same design load results in an acceleration of 15.5 g. With a seat stroke of 8 in (20.3 cm), a vertical velocity of 1500 ft/min (7.62 m/s) could be dissipated before the travel limits of the seat were exceeded.

Table 1 shows the effect of weight extremes on accelerations and velocity limits, with an 8 in (20.3 cm) travel. It should be noted that a weight as low as 75 lb (34.0 kg) will still give an acceleration limit of 36 g or 34 ms with an initial velocity of 2365 ft/min

Table 1 - Acceleration and Weight Limits for Nominal 25 g Seat

Occupant weight		Acceleration		Max Allowable Impact Velocity		Time for Max Acceleration, ms
lb	kg	g	m/s <sup>2</sup>	ft/mi <sup>hr</sup>	m/s	
75	34.0	36.2	355	1365	12.0	34
105	47.6	27.4	269	2058	10.5	39
117	53.1	25	245	1965	10.0	41
200	90.7	15.5	152	1548	7.9	52
280	127.0	9.7	95	1224	6.2	65

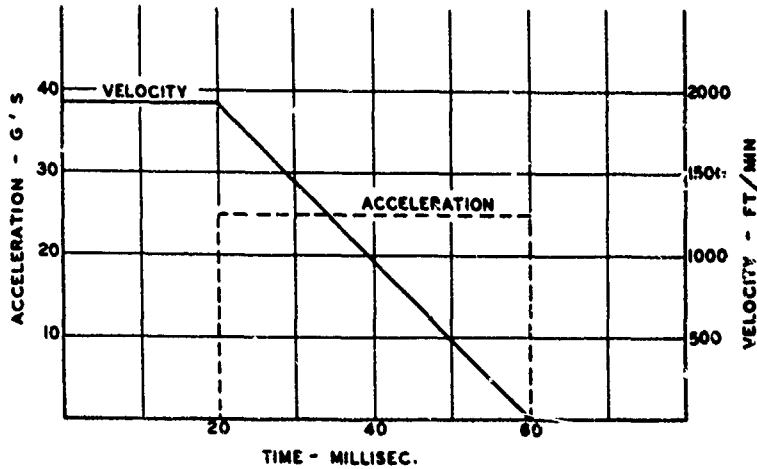


Fig. 1 - Acceleration and velocity for an ideal energy absorber

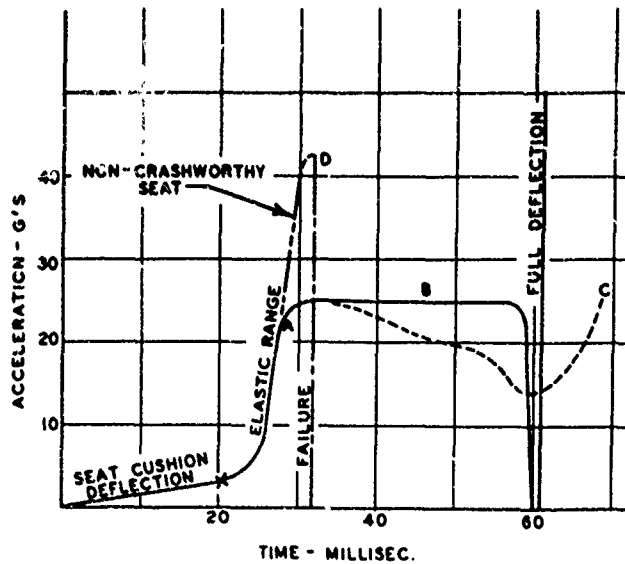


Fig. 2 - Typical seat acceleration time curves

(12.01 m/s). Even though this acceleration is close to the threshold of severe injury, it represents a much lower g load than if a rigid seat were used.

On the other end of the scale, a 280 lb (127 kg) individual would get a relatively soft ride of 9.7 g, but with a velocity limit of only 1224 ft/min (6.22 m/s) before bottoming out. Again, this is a definite improvement over the standard rigid seat or one that collapsed suddenly, without any appreciable energy absorption.

These calculations assume a rectangular acceleration pulse (Figure 1). The pulse shown represents the case where mass is accelerated at 25 g for 40 ms. Assuming an initial velocity of 1932 ft/min (9.81 m/s), this pulse would bring the man to rest in a distance of 8 in (20.3 cm) assuming that there was no energy absorption in other structural members of the aircraft. This picture, of course, does not represent a realistic situation, which would be more like that in Figure 2. Here, the initial load build up as the seat cushion begins to deflect and then as the seat structure deflects elastically. At point A, the seat structure begins to deform plastically, and energy is absorbed. If it were possible to continue this deformation at a constant load (curve B), the acceleration level would remain constant and the maximum amount of energy would be absorbed without exceeding the initial g load.

Curve C is more typical. In this case, the acceleration is reduced to lower levels as the deflection increases, and a longer stroke is required to absorb the full energy.

A third case is also shown, since it is typical of normal seat design. In the case (curve D), a higher load is required to start deformation; but failure, which occurs before appreciable energy is absorbed, allows the occupant to fall to the floor, where much greater accelerations are experienced.

#### DEVELOPMENT

Having established load criteria for the design of the seat, the next step was to determine a method of construction that would accomplish the desired objective and at the same time meet the normal seat requirements for light aircraft. Although an aircraft seat should contribute toward occupant protection, its basic function must be to provide firm support and comfort. It must perform this basic function satisfactorily to be acceptable for use in aircraft. Additional requirements were:

1. The seat should be adjustable on rails fore and aft.
2. It should not require any more maintenance than conventional seats.
3. It should be light in weight and inexpensive.

With these objectives in mind, a search of the literature was made to determine a suitable method of construction. Although several designs found were feasible for use in light aircraft, none appeared to meet all the requirements given, and so a new approach was taken. This was to try to use the seat leg material to absorb energy in bending as efficiently as possible. This would provide the greatest amount of energy absorption with the least amount of excess weight.

#### PRELIMINARY DESIGN

The method employed to absorb and dissipate energy had to be one that could be implemented without occupying much space. The area under the seat must remain open and free of obstructions, since this area would be utilized during the energy-absorbing action of the seat. This lack of space was the major factor leading to the utilization of the seat structure as the energy-absorbing vehicle. The energy would be dissipated through structural deformation.

The use of a mechanical energy-absorbing device was eliminated on the basis of complexity and lack of space. There then remained three types of structure with which Piper has manufacturing experience, namely: sheet metal, welded tubing, and a combination of the two. Since we were more familiar with seats constructed from welded tubing, this type of construction appeared to be the best approach. The problem then was to arrange the geometry of the seat 'legs' to function as energy absorbers.

Having chosen a type of construction and decided on a method to limit the vertical accelerations, it was also necessary to consider how the seat structure would react during horizontal accelerations. The lap belt and shoulder harness are anchored to the fuselage structure and not to the seat. Therefore, the seat accepts very little load during horizontal accelerations and the belts perform almost all the occupant restraining function.

The existing relation between the instrument panel, the control column, and the seat track established the required relation between the seat support rollers and the seat bottom. This put the aft rollers under the aft edge of the seat bottom and the front rollers approximately under the center of the seat bottom (Figure 3). Because the front legs were just forward of the occupant center of gravity, they would have to perform almost all the energy-absorbing function. Although the rear legs would also absorb some energy, they would serve primarily to stabilize the seat as it bent downward under load. The main problem, then, was how to design the front legs so that they would, under the required load, deform and dissipate energy at approximately a constant rate.

Tubing is normally used in tension or compression loading. In either case, however, the material fails by buckling or breaking after



its yield point is reached, without absorbing much energy. But if a tube is loaded in bending, it will deform over a considerable distance, absorbing energy at a more constant rate. Thus, we had to find a tube configuration that would distribute the load over a considerable length, deforming plastically without failing at any one point.

There are four factors that can be varied to get this equally distributed deformation. These are the magnitude of the load, the tubing material, the tubing size, and finally, the geometry. Once we had established the load requirement at 2715 (1232 kg), as discussed previously, the other parameters could be varied to arrive at a practical solution.

For material, 4130 normalized steel was chosen because it has the toughness needed to obtain the required amount of bending without fracturing; also, it is readily weldable and was available in stock in a variety of sizes.

The first geometrical configuration tried was a circular arc of large radius (Figure 3). In this configuration, failure would first occur in the center of the arc, where the distance is greatest from the line of applied load, but the bending would be spread over a length of the tube; as bending continued, the upper and lower sections would tend to pick up part of the load. The first development seat bottom was built of 0.5 x 0.035 in wall tubing for the basic frame, with the same size tubing for the front legs. This frame was designed to fit an existing production seat back assembly.

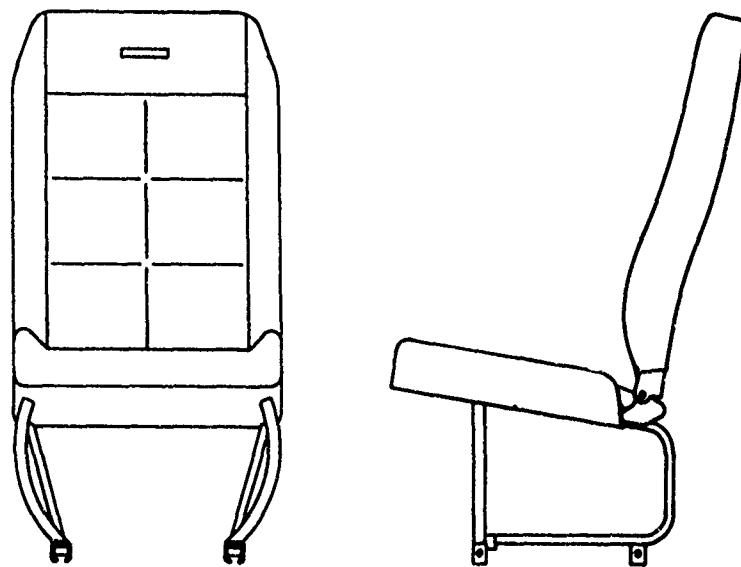


Fig. 3 - First seat design

## DEVELOPMENT TESTS

The major development tests were static load tests, using a hydraulic jack to load the seat vertically through a wooden load-distributing block; the standard nylon seat webbing and foam cushioning material served to carry the load to the seat frame.

TEST 1 - The first development seat, loaded as described, showed no permanent set as 3500 lb (1588 kg). This showed that the legs were much too strong in this configuration. It was felt that a smaller diameter tube would not have the required stability for good design, however, and therefore a new configuration was required.

As part of the development work, the required forward load was applied. This test showed that, under horizontal loading, the legs would bend until the load was transferred to the seat belt and shoulder harness. This was considered satisfactory, since the harnesses had recently been redesigned to take a full 25 g forward load.

The next configuration chosen for the front legs was a double arc (Figure 4). By going to two bows, we reasoned, the load in each bow would increase because the center of each bow is further from the

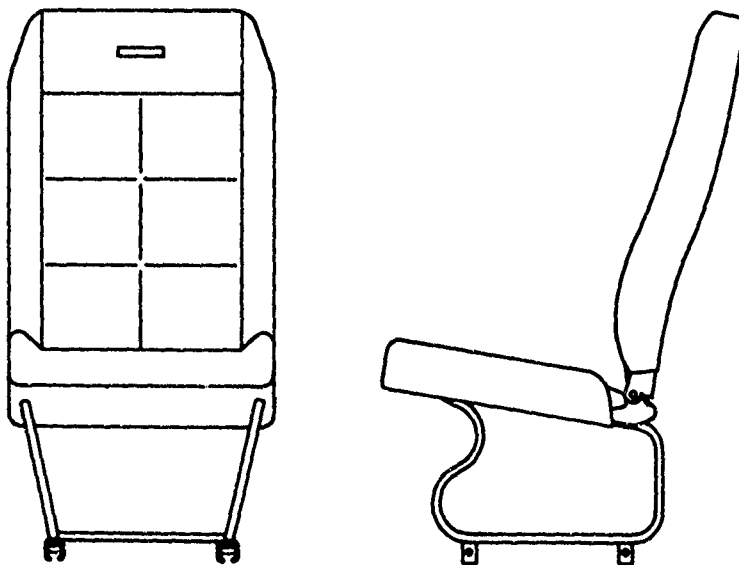


Fig. 4 - Second seat design

applied load. The deformation, however, would be spread over twice the length of tubing. In addition, the scissoring action of this configuration kept the distance from the bending areas to the point of load application more nearly constant for the full seat deflection.

The basic seat frame 0.5 x 0.035 in wall tubing appeared satisfactory and was retained. This became the final configuration and was used throughout the remainder of the tests.

TEST 2 - The second test had the following parameters: front leg tube size 3/8 x 0.035 in wall (double bow); load at which permanent deformation occurred, 1400 lb (635 kg).

After initial deformation had occurred on this test, the load decreased to 1200 lb (544 kg), and the load remained relatively constant as the seat was compressed. Even though the design load was not achieved, the seat, after the initial decrease of 200 lb (90.7 kg), showed good linear energy absorption. This indicated that the basic design was sound.

TEST 3 - The third test had the following parameters: front leg tube size, 3/8 x 0.083 in wall; load at which permanent deformation occurred, 1900 lb (862 kg).

After initial deformation, the load decreased to 1850 lb (839 kg) and held steady as the seat was compressed. In comparing tests 2 and 3, it was noted that, when the wall thickness was increased, the drop in load after initial deformation was less than that observed with the thinner wall tubing. Apparently this effect was due to the ability of the tubing to distribute the load over a greater length.

TEST 4 - The fourth test had the following parameters: tube size, 7/16 x 0.083 in wall; load at which permanent deformation occurred, 3300 lb (1497 kg).

Again, deformation was linear throughout the energy-absorbing stroke, even though the load was too high.

TEST 5 - The fifth test had the following parameters; tube size, 7/16 x 0.065 in wall; load at which permanent deformation occurred, 2600 lb (1179 kg).

Since the required load was bracketed by the last two tests, it appeared that wall thickness intermediate between 0.083 and 0.065 in would give us the required characteristics. At this point a conformity seat was constructed. Based on data derived from these tests, the front legs were fabricated from 7/16 x 0.072 in wall tubing.

FINAL STATIC TESTS - In order to meet the requirements of CAR Part 3, under which the Cherokee is approved, the loads listed in Table 2 must be supported by the seat, along with its belts and shoulder harness.

Table 2 - Loads Required by CAR Part 3

Direction	Ultimate Load, lb (kg)
Downward	1290 (585)
Upward	555 (252)
Sideward	277 (126)
Forward	1660 (753)
Rearward (pilot effort)	300 (136)

Table 3 - Dynamic Test Program

Test	Drop Height		Velocity		Dummy Weight		Acceleration	
	ft	m	ft/min	m/s	lb	kg	g's	m/s <sup>2</sup>
1	16	4.88	1840	9.35	200	90.7	41.3	373
2	11	3.35	1512	7.68	200	90.7	25.3	235
3	11	3.35	1510	7.67	200	90.7	26.4	245
4	11	3.35	1512	7.68	200	90.7	25.5	262
5	7	2.13	1197	6.08	200	90.7	-	-
6	7	2.13	1193	6.06	200	90.7	17.9	167
7	11	3.35	1500	7.62	105	47.6	27.9	274
8	16	4.88	1824	9.27	105	47.6	41.8	387
9	16	4.88	1829	9.29	105	47.6	39.1	370
10	16	4.88	1838	9.34	105	47.6	39.0	374

Table 4 - Dynamic Test Results

Test	Dummy Weight, lb	Impact Velocity, ft/min	Peak Carriage Acceleration, g's	Peak Pelvic Acceleration, g's	Seat Deformation	
					in	cm
1	200	1840	41.3	22.4	7.4	18.8
2	200	1512	25.3	22.4	3.3	8.4
3	200	1510	26.4	21.5	3.6	9.1
4	200	1512	25.5	22.3	3.0	7.6
5*	200	1197	-	-	0.5	1.3
6	200	1193	17.9	18.7	0.9	2.3
7	105	1500	27.9	37.4	0	0
8	105	1824	41.8	36.8	0.6	1.5
9	105	1829	39.1	36.9	1.0	2.5
10	105	1838	39.0	36.8	1.1	2.8

\*Data recordings lost on this run.

As a matter of policy, some higher loads were applied after the FAA requirements had been met. These were, in addition to the 2715 lb (1232 kg) down load, an upload of 1540 lb (699 kg), a side load of 777 lb (353 kg), and a forward load of 4250 lb (1928 kg). Although deflection and permanent set would be permitted for these overloads, no catastrophic failures were premitted.

Because of the critical nature of the down loads in relation to the new seat design, this test was run first. After the required F.A load was applied, the load was removed. No permanent set was found. The seat was then reloaded to obtain the overload condition.

At 2700 lb (1225 kg), obvious plastic deformation was noted. No higher load could be obtained and, as loading as continued, the resistive load gradually dropped off to about 2000 lb (900 kg). Because the actual dynamic loads were not known with any certainty, this load-deflection characteristic was considered acceptable, pending the results of the dynamic tests.

All the other static tests were completed without problems.

#### DYNAMIC TESTS

Because of their interest in the development of energy-absorbing seats, the FAA Civil Aeromedical Institute, under Dr. J. R. Dille, agreed to conduct dynamic tests of the final seat design.

A schedule of the test program appears in Table 3. The test sequence was arranged to obtain the greatest amount of data in the minimum time, within the limitations of the test facility. Other tests are planned to investigate the effect of different deceleration rates and impacts with rearward, as well as upward accelerations.

The results of the test program are summarized in Table 4. In general, these tests reveal that at lower accelerations, the dummy pelvis follows closely that of the carriage and even shows some amplification. At higher g levels, the pelvic acceleration levels off (Figure 5). This maximum acceleration is a function of dummy weight. The data indicate that, at lower accelerations, the seat is acting as a rigid member, but this rigid member action stops at the design load of the seat, and above this point energy is absorbed by seat deformation.

The most severe test from the standpoint of the seat was Test 1. On this test, the impact velocity was 1840 ft/min (9.35 m/s) with a stopping distance of approximately 8 in (20.3 cm). The input deceleration was a roughly triangular pulse with a peak of 41.3 g, and the pelvic acceleration measured was nearly trapezoidal, with an average peak of about 20 g for a duration of 35 ms (Figure 6). The short 25 g pulse (A) occurring after the main pulse is due to the seat bottoming out, which would not have occurred at lower impact velocity.

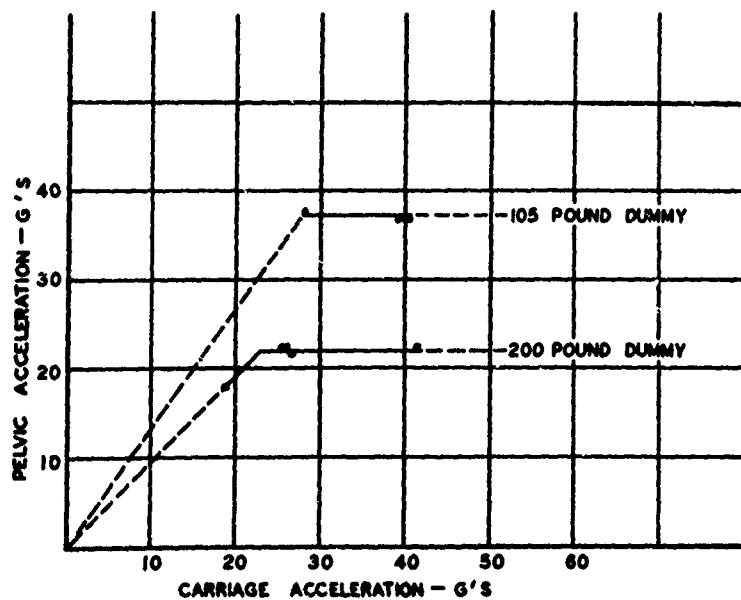


Fig. 5 - Maximum pelvic accelerations versus carriage accelerations

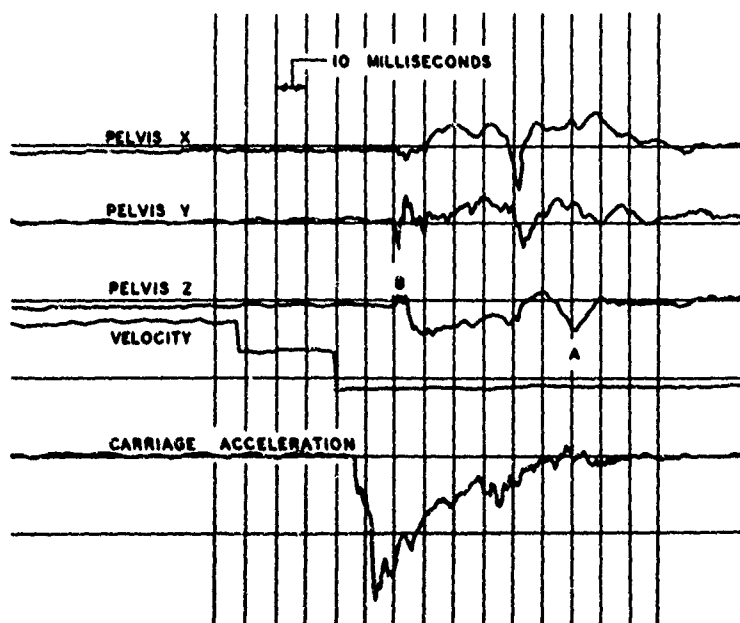


Fig. 6 - Oscillograph trace of dynamic test 1

It is interesting to note that there is a delay of 19 ms between the impact of the base platform and the start of acceleration in the pelvis. In this period of time, the carriage velocity has been reduced by approximately 10 ft/s (3 m/s), so that the dummy is effectively impacting the seat at this velocity while the seat itself is being decelerated at a rate of approximately 25 g. This delay period will increase the dummy deceleration pulse, since the allowable stopping time is decreased from 86 to 67 ms.

Although part of the delay time represents the softness of the seat cushioning material, part is also due to the limitations of the test method, in that the dummy and carriage are at nearly a zero g level before impact, rather than the normal one g condition. This allows the dummy to float, being held in place only by the seat belt and shoulder harness. This slack must be taken up after carriage deceleration begins.

The slight negative g area (point B, Figure 6) is also interesting. It may be due to the dummy's leg impacting the floor, causing a downward load on the pelvis, or it may be attributable to stored energy in the seat belts being returned to the system.

The most severe dummy acceleration pulse occurred in run 9, with the 105 lb (47.6 kg) dummy. This run, at a velocity of 1829 ft/min (9.29 m/s), gave a carriage acceleration of 39.1 g and a maximum dummy pelvic acceleration of 36.9 g. (Although a slightly higher peak acceleration is shown in run 7, the total pulse is less severe). This acceleration was considerably higher than the maximum experienced by the 200 lb (90.7 kg) dummy, but it was not as high as would be expected because of the weight difference.

Although the difference could not be fully explained, it may be due to the more compact configuration of the smaller dummy, resulting in a high percentage of total mass being effective in acting on the seat bottom. It is also possible that the somewhat different internal construction of the dummy could have an effect on the effective mass.

If the pelvic acceleration were approximated by a trapezoidal pulse shape, it would result in a pulse of 31 g for a duration of 24 ms. Although high, this deceleration is still below the severe injury level.

Comparing the actual acceleration values with those in Table 1, actual values are 35-45% higher than calculated, apparently because of an effective mass on the seat lower than the value used in calculation. If this difference in effective mass were characteristic of what would happen under actual impact conditions, it would indicate that the force levels used for design should be reduced, so that accelerations would be less severe. However, the calculations were based on a pulse having a waveshape different from that actually obtained in the dynamic tests, and this may account for some of the difference. In addition, part of

the difference may be due to the zero g level before impact; but the effect of the difference cannot be determined without comparative tests run with impact occurring at a one g level, or at least some means to simulate this condition. Another difference that may affect the test results is the dummy response, which is dissimilar to actual human response.

For these reasons and since the accelerations recorded were within acceptable limits for both the 200 lb (90.7 kg) and the 105 lb (47.6 kg) dummies, no further design changes are contemplated until additional dynamic tests can be completed.

## CONCLUSIONS

1. The seat described here is effective in reducing impact acceleration by energy absorption, particularly for high accelerations and heavier occupant weights.

2. This seat would be more effective for lighter weight occupants if it were less strong, but this would decrease its effectiveness for heavier occupants.

3. Increased seat height would increase its effectiveness at higher sink rates and accelerations.

4. Energy-absorbing seat padding would increase the effectiveness of the seat by giving some measurable deceleration level while the initial deflection was occurring.

5. Better correlation between dummy response and human response is needed, if the most effective energy-absorbing systems are to be developed.

6. If future seat designs are to be fully effective under the conditions described, further definition of actual acceleration histories during light aircraft accidents is badly needed. Although such histories are available for transport and military-type aircraft, the data are inapplicable to low-speed 4-6 passenger aircraft.

Reference (11) contains criteria being used by FAA in some dynamic seat tests including the design impulse data shown in Table 3-2. This data was suggested as arbitrary initial test impulse criteria until realistic experimental crash data from component or full scale testing of general aviation airplanes are available. These impulses are being applied to the floor structure.



TABLE 3-2

DESIGN PULSES FOR DYNAMIC SEAT TESTING

<u>DIRECTION</u>	<u>PEAK G</u>	(1) <u>PULSE TIME-(SECS.)</u>	<u>PULSE SHAPE</u>
LONGITUDINAL	20	$0.15 \pm 0.04$	TRIANGULAR
VERTICAL	25	$0.085 \pm 0.03$	TRIANGULAR
LATERAL	10	$0.125 \pm 0.05$	TRIANGULAR

(1) THE RISE TIME TO PEAK G MAY VARY BETWEEN  $\pm 0.2T$  FROM  $T/2$ .

[Source: Reference (11)]

## Restraint Systems.

### Introduction:

The prime function of the Restraint System is to protect the personnel in the event of a crash. There are passive and non-passive systems. A passive type would be air bags, padded interior or automatic mechanical systems which would not require any action on the part of the personnel for protection. The non-passive system is the type where the personnel must take some action to initiate this protection. This section is on the non-passive systems and is directed toward making them more comfortable and easier to use in order to encourage occupants to take the necessary action for adequate protection.

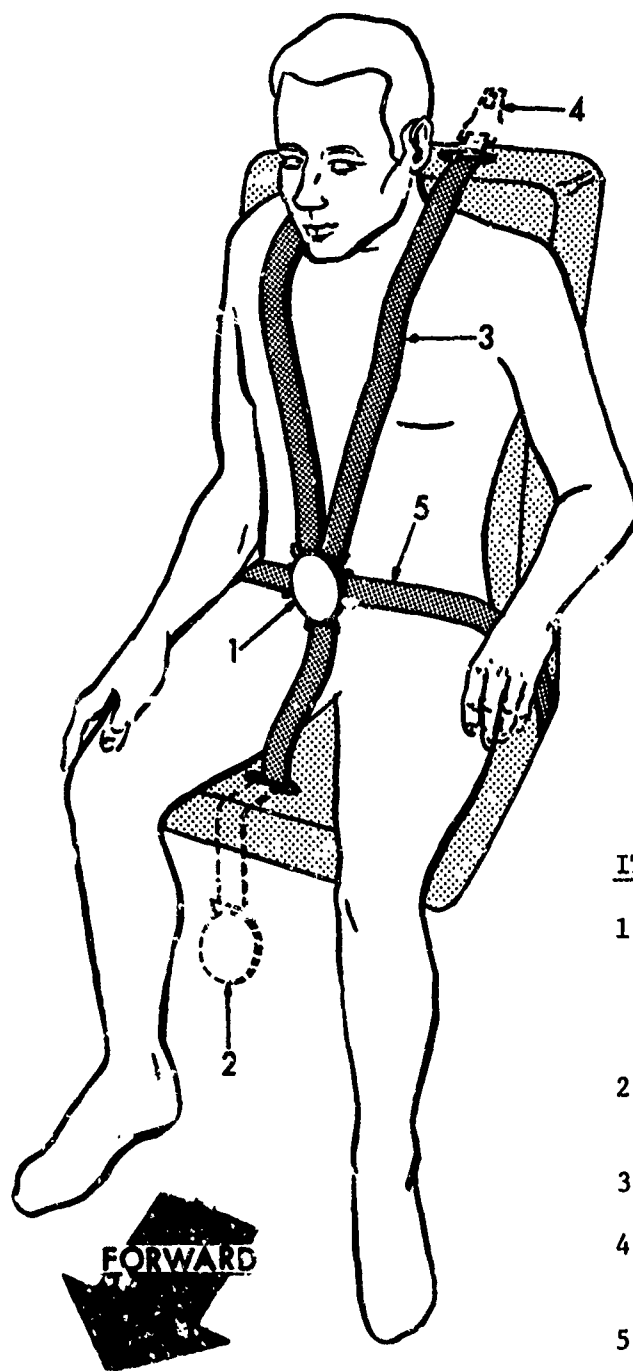
### Restraint System Service Experience:

In general, official accident records are not extensive regarding the performance of personnel restraint systems in general aviation aircraft. However, a few cases are on record where the standard lap belt configurations have failed, but causes of failure were unknown. Common points of failure were the lap belt anchors or the buckles. There are details that should have close attention.

Recent, on site accident studies by the FAA Civil Aeromedical Institute have provided data which indicate that lap belts usually provide adequate strength but do not provide the degree of body support obtained with a lap belt and shoulder harness. With only a lap belt, the occupants are subjected to a jackknifing action which may impact the head and upper torso on control wheels, instrument panels, and other objects directly in front of the occupant. Sometimes the occupant submarines under the lap belt, and subsequent decelerations then place the belt load in the upper abdominal area. This may cause injury to the lumbar spine.

### Restraint System Configuration:

The lap belt/shoulder harness configuration of occupant restraint presently used by the military is considered far superior to the lap-belt-only restraint system. The restraint system on the crew seats of most transport airplanes has been adapted from the military systems. (Ref. Figure 3-14). These systems are reasonably comfortable and have a single point buckling which aids the ease of putting on and removing the harness. With a load locking inertia reel, the harness permits freedom of movement in operating controls, and it provides much more body support in all directions than the lap-belt-only configuration.



#### ITEM IDENTITY

1. 5 point attach  
4 point release  
SINGLE ACTION RELEASE  
Buckle
2. Buckle fixed to  
Crotch Strap
3. Shoulder Strap
4. Shoulder Strap end  
fitting stowed
5. Lap Belt

Figure 3-14. Airline Transport System

# ITEM IDENTITY

1. Single point release for Lap Belt and Shoulder Strap
2. Shoulder Strap should always be above navel
3. Lap Belt
4. Inertia Reel and Lap Belt attachment located in structural seat.
5. (Alternate) Inertia Reel located on aircraft structure.
6. (Alternate) Lap Belt attachment located on aircraft structure

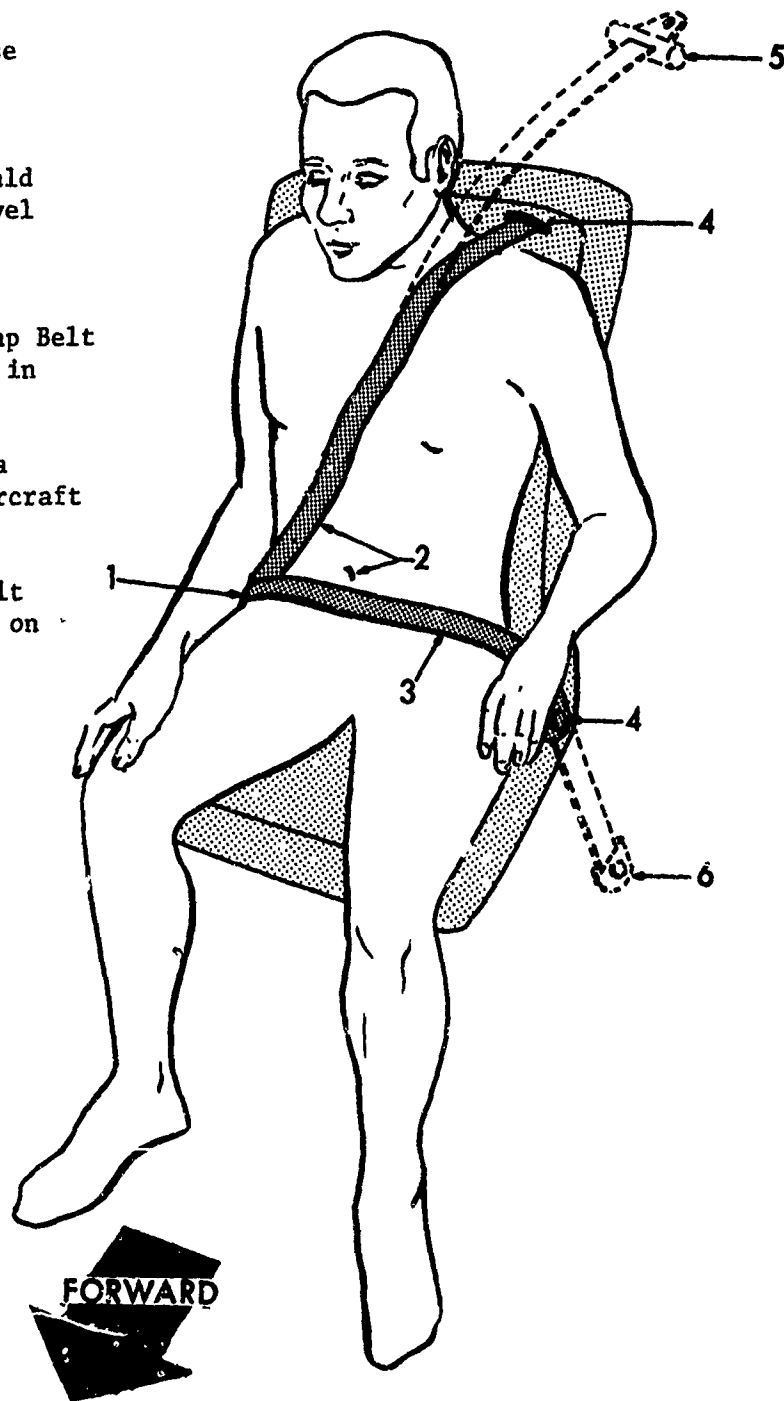


Figure 3-15. Single Diagonal Shoulder Strap and Lap Belt System

Note that the crotch strap should be located forward of the crotch so the large loads are taken on the lap belt. The purpose of the crotch strap is to hold the lap belt down so it will take the high crash loads into the large pelvic bone structure. If it is undesirable to use a crotch strap then the lap belt attach points may be moved forward two to four inches to react the shoulder harness forces which tend to pull the lap belt up.

Many of the systems per Figure 3-14 attach the buckle to the crotch strap permanently which keeps the buckle off of the floor and assures the use of the crotch strap.

In many installations it is necessary to compromise from the best restraint system to one that is easier to use and more comfortable. This led to the single diagonal strap system (Ref. Figure 3-15). It really is not a compromise if you can design a system which, because of comfort and convenience, is used 90% of the flying time versus the best restraint system which because of the comfort and difficulty in getting in and out of the system is used only about 30% of the flying time. It is desirable to make a good study of the human factors involved in arriving at a system that people will use. The airplane flown by professional pilots can be one type of a system and the airplanes flown by general public might need to be something different to get people to use the systems. Inertia reels on the shoulder harness are useful in improving comfort and providing freedom for reaching controls. For the back seats, the use of inertia reels reduces the objections that the majority of people have to being tied down or restrained from freedom of movement. If the restraint system is made as comfortable and easy to use as possible, it will be much easier for persons to get in the habit of using it.

In many instances, it is not practical to make a structural seat as shown in Figure 3-15. The existing aircraft structure can be utilized to anchor the shoulder and lap belt restraint system. When this is done, it is desirable to consider the effect of seat adjustment and possible seat deformation in a crash. These might make the restraint system ineffective and possibly a potential hazard.

Upper torso restraint on side facing seats is important to prevent head and back injuries.

#### Restraint System Design Parameters:

The restraint systems should resist as high a crash load as possible. The military systems normally restrain the occupant against a 40 g deceleration of the airplane. The value of utilizing general aviation restraint systems at this high a strength level is somewhat less because the physical fitness of the average pilot and passenger is not comparable to that of military personnel. There are several systems which will restrain a 170 lb. man against 25 g's, but to achieve levels above 25 g, consideration should be given to energy absorbing methods and materials.

Inertia reels are beneficial with the shoulder harness restraint configuration on crew seats. Crew members must be able to move and reach essential flight controls, especially during takeoff and landing. Of course, these are the most critical periods for wearing the shoulder harness. Inertia reels will permit this necessary movement and will also provide the restraint when needed in a crash. However, proper designs with fixed shoulder harnesses, providing equivalent comfort and ease of access to necessary controls, should be equally acceptable.

There are two types of shoulder harness and lap belt retractors in use on military, transport and general aviation aircraft.

1. Personnel sensitive locking inertia reel. This inertia reel senses the movement of the individual in any direction from the seat and is set to not lock when the individual moves quickly to operate an emergency control, but it will lock when the individual is thrown from his seat as he would be in a crash. This is done by so designing the inertia reel that it is sensitive to acceleration only and is set to lock at 3 g's ( $3 \times 32 \text{ ft/sec/sec}$ ) but will not lock at 2 g's ( $2 \times 32 \text{ ft/sec/sec}$ ). It should not be sensitive to velocity because this will make it a nuisance in that it can lock before you can touch the control you are reaching for. Velocity sensitive inertia reels have brought objections from airline pilots.

These inertia reels can be set at lower g settings but the installation must be considered. For example, in the flight engineer's seat on one of the Wide Body Transports where the engineer has to reach a long distance to operate the engine-controls, a low g setting or velocity sensitive reel has proven to be a nuisance. But in an Ag airplane, where only 6 to 8 inches of body movement is required to reach all controls, a lock at  $1 \frac{1}{2} \text{ g}$  and no lock at 1 g has proven to be satisfactory. One of the advantages of this type of inertia reel is that you can check to see if it will automatically lock by a sharp jerk on the shoulder strap.

2. The impact sensitive inertia reel. This inertia reel will not lock with a 2 g deceleration of the reel housing but will lock with a 3 g deceleration on the housing in a forward direction. The g's required to lock this type of reel increase as the direction of this load is changed. The way to check to see if this reel will automatically lock is to strike the housing a sharp blow. This type of a reel should be mounted on structure that will sense the airplane's deceleration before the man senses the deceleration or the man might start to extend the shoulder harness before it locks. A disadvantage of this type reel is if the crash forces are not in line with the g sensing mechanism, the g force required to lock the reel might be too high, and the man will be leaning too far out of the seat when the reel locks.

## Occupant Protection.

### Introduction:

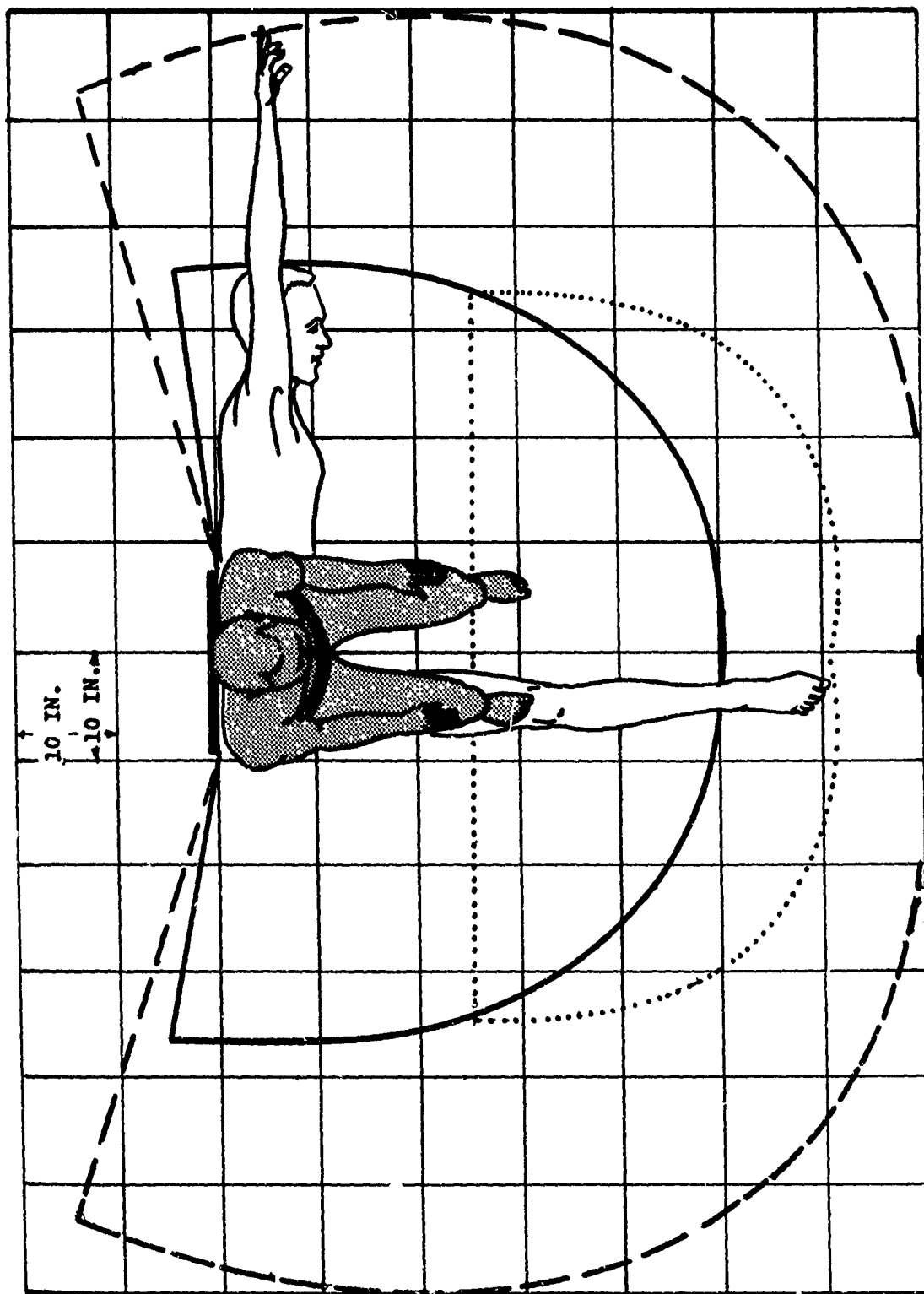
Protection of an occupant in the front seat(s) in a survivable accident depends primarily upon the occupant's use of a seat belt/shoulder harness restraint system. Fatal head and torso injuries can be greatly reduced by proper use of this type of restraint system. Means for providing protection from head and torso injury are desirable for the times that the occupant fails to use the shoulder harness portion of the restraint system. It is impractical to place occupants where they cannot strike the aircraft structure. Therefore, cabin interior design will be necessary to minimize injury to the flailing arms, legs, head and torso.

### Extremity Strike Envelope:

Figures 3-23 through 3-28 show the body extremity strike envelopes for a fully restrained occupant and an occupant restrained only by a seat belt. The strike envelopes are based on the following parameters:

- a. Ninety-fifth percentile U.S. Army personnel.  
(Note: The subjects are not typical of the civilian population.)
- b. Four g accelerations with human subjects; higher accelerations would change the strike envelopes slightly.
- c. Four inches of lower torso movement away from the seat both forward and laterally (an approximation based on crash test data).
- d. Four inches of upper torso movement away from the seat back both forward and laterally when restrained by seat belt and shoulder harness (an approximation based on crash test data).
- e. Head movement upward is a possibility in certain impact situations.

The dashed lines in the forward and sideward extremity envelopes show an approximate head movement for a situation of this type.



**Figure 3-23 Seat-Belt-Only Extremity Strike Envelope - Top View.**  
[Source: USAAVLABS TR 67-22 (5)]

[Source: USAAVLABS TR 67-22 (5)]



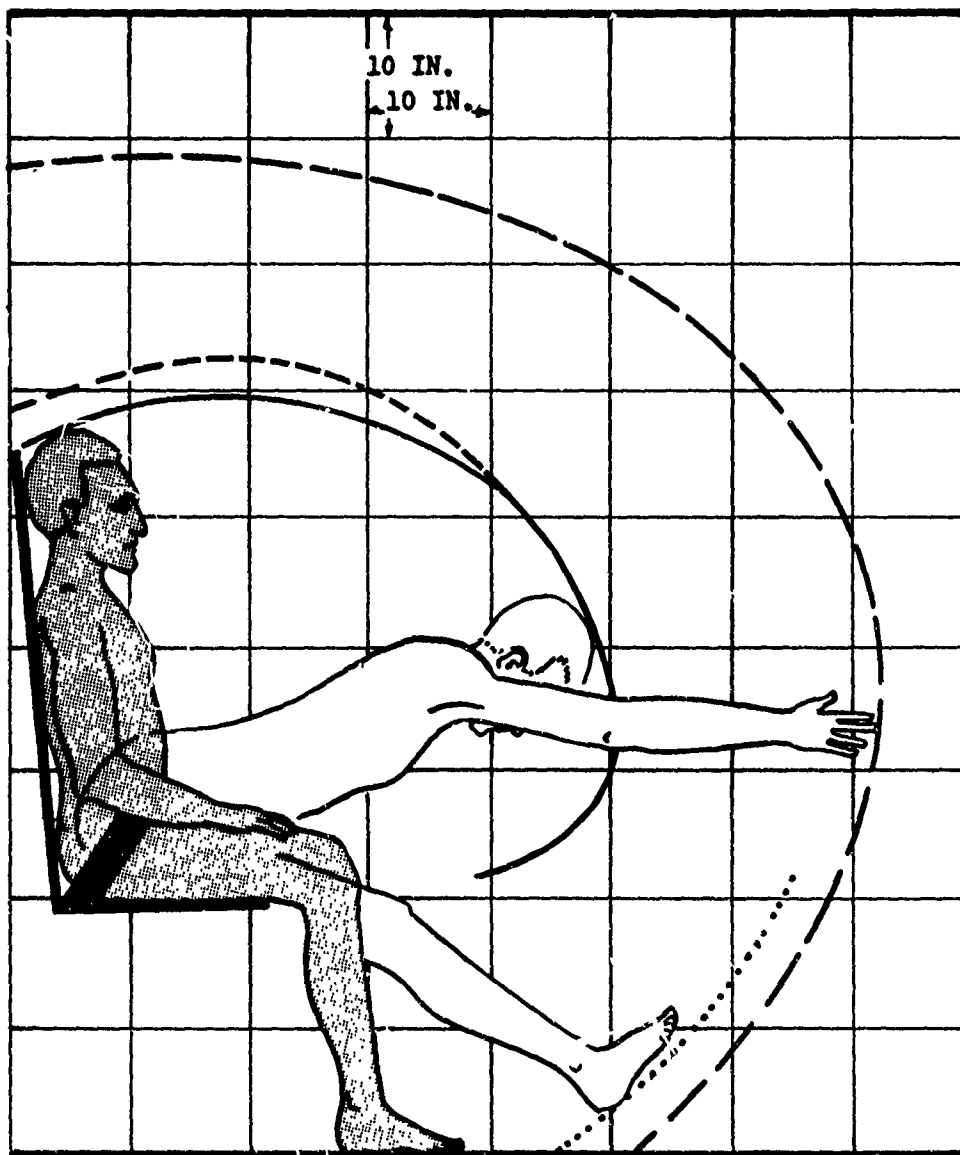


Figure 3-24. Seat-Belt-Only Extremity Strike Envelope - Side View.

[Source: USAAVLABS TR 67-22 (5)]

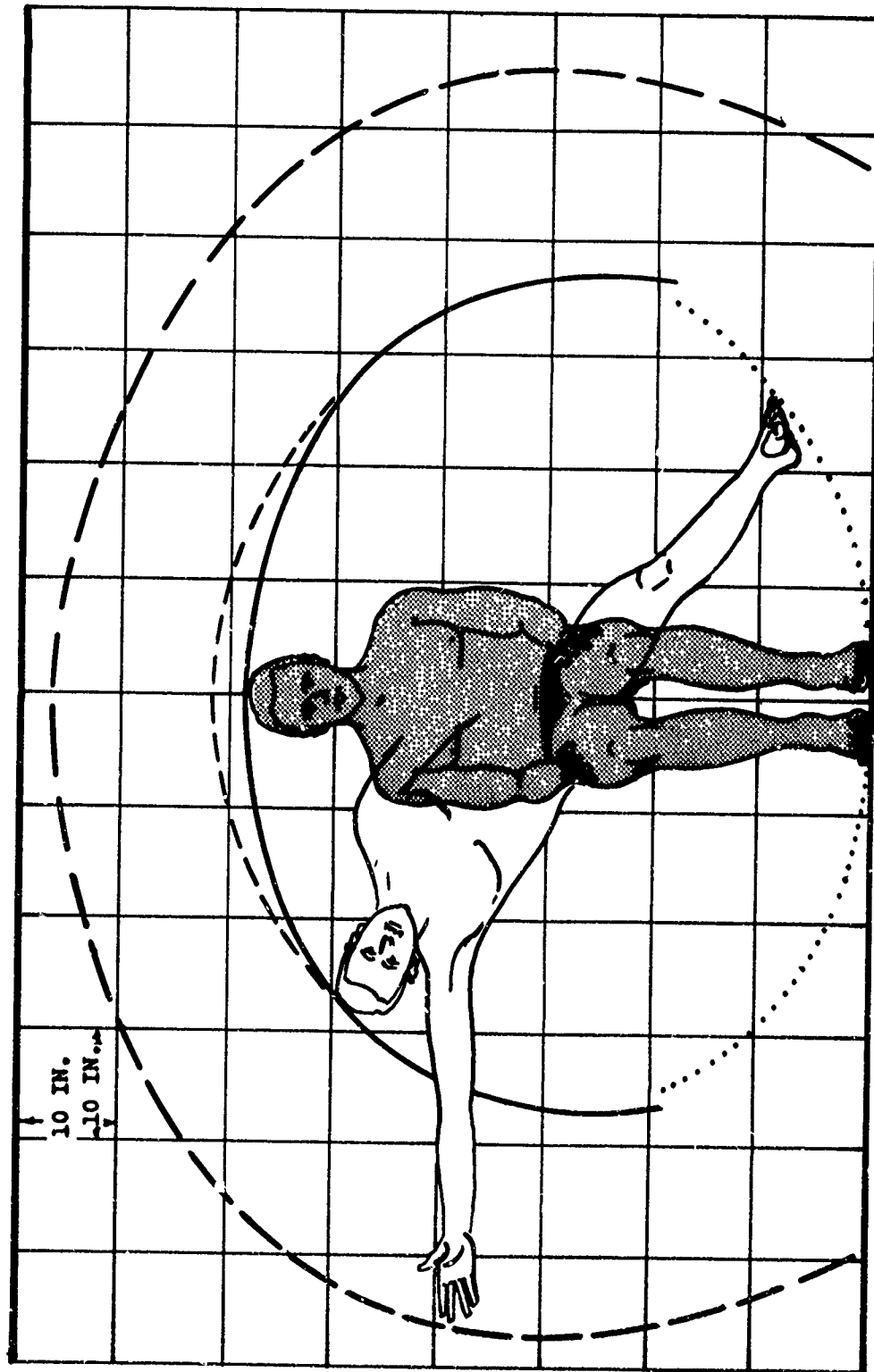


Figure 3-25. Seat-Belt-Only Extremity Strike Envelope - Front View.

[Source: USAAVLABS TR 67-22 (5)]

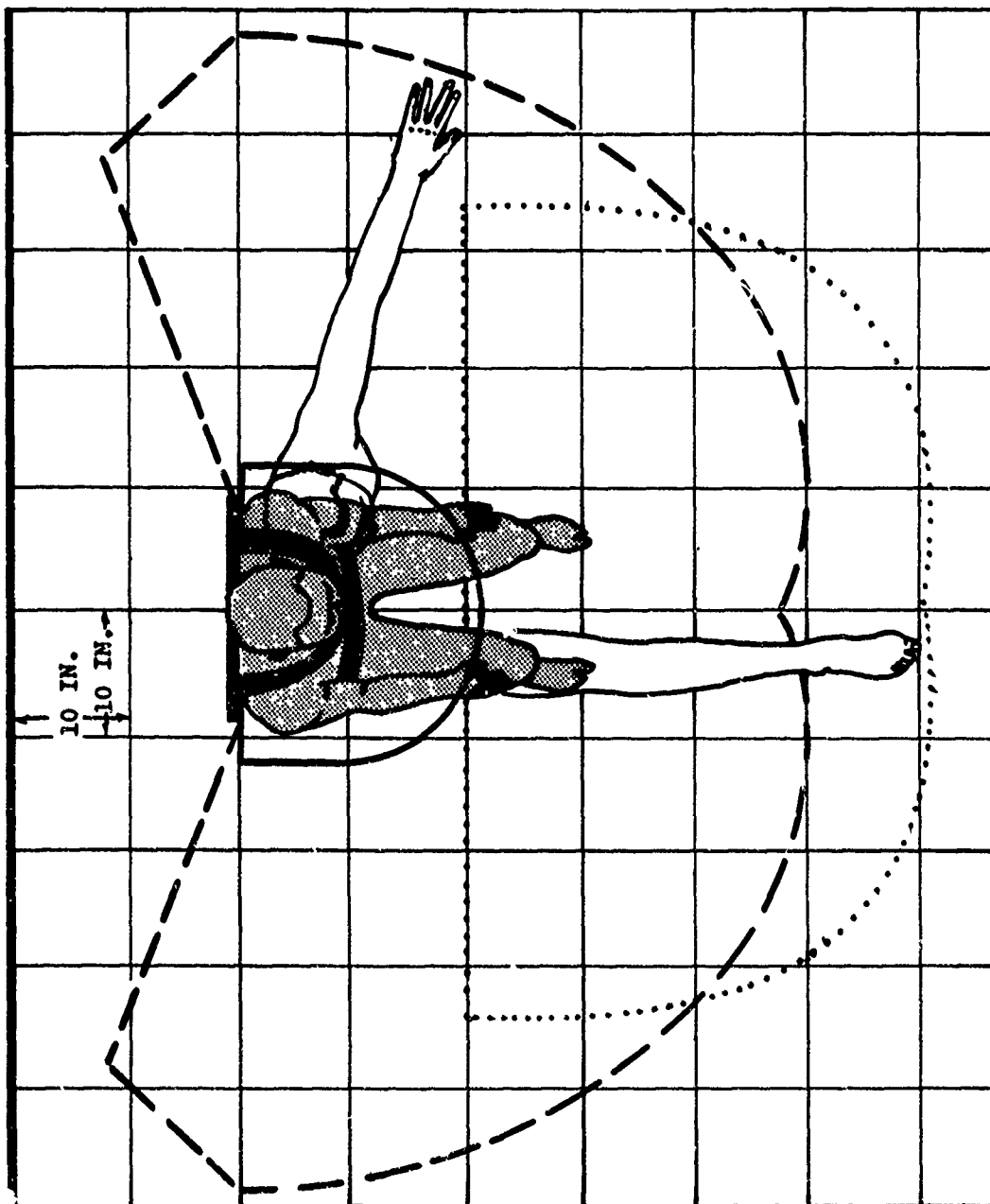


Figure 3-26. Full-Restraint Extremity Strike Envelope - Top View.  
[Source: USAAVLABS TR 67-22 (5)]

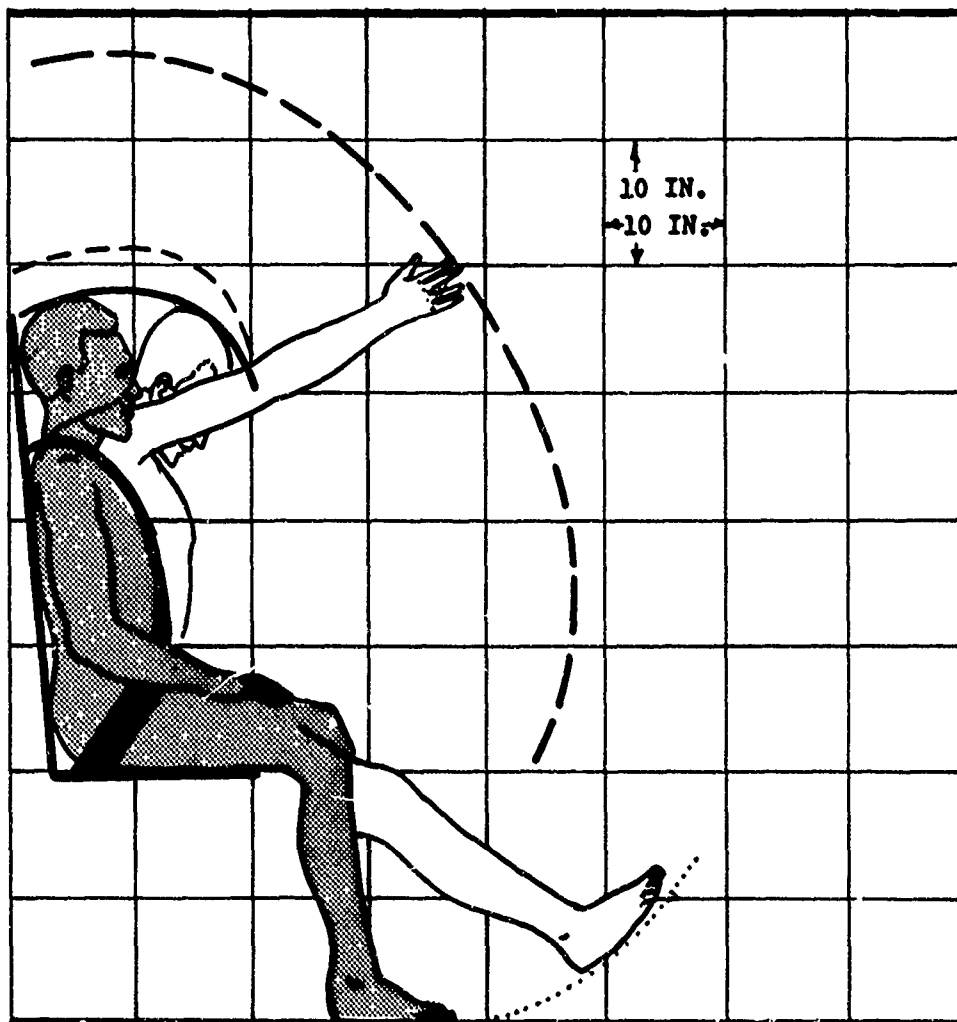


Figure 3-27. Full-Restraint Extremity Strike Envelope - Side View.

[Source: USAAVLABS TR 67-22 (5)]

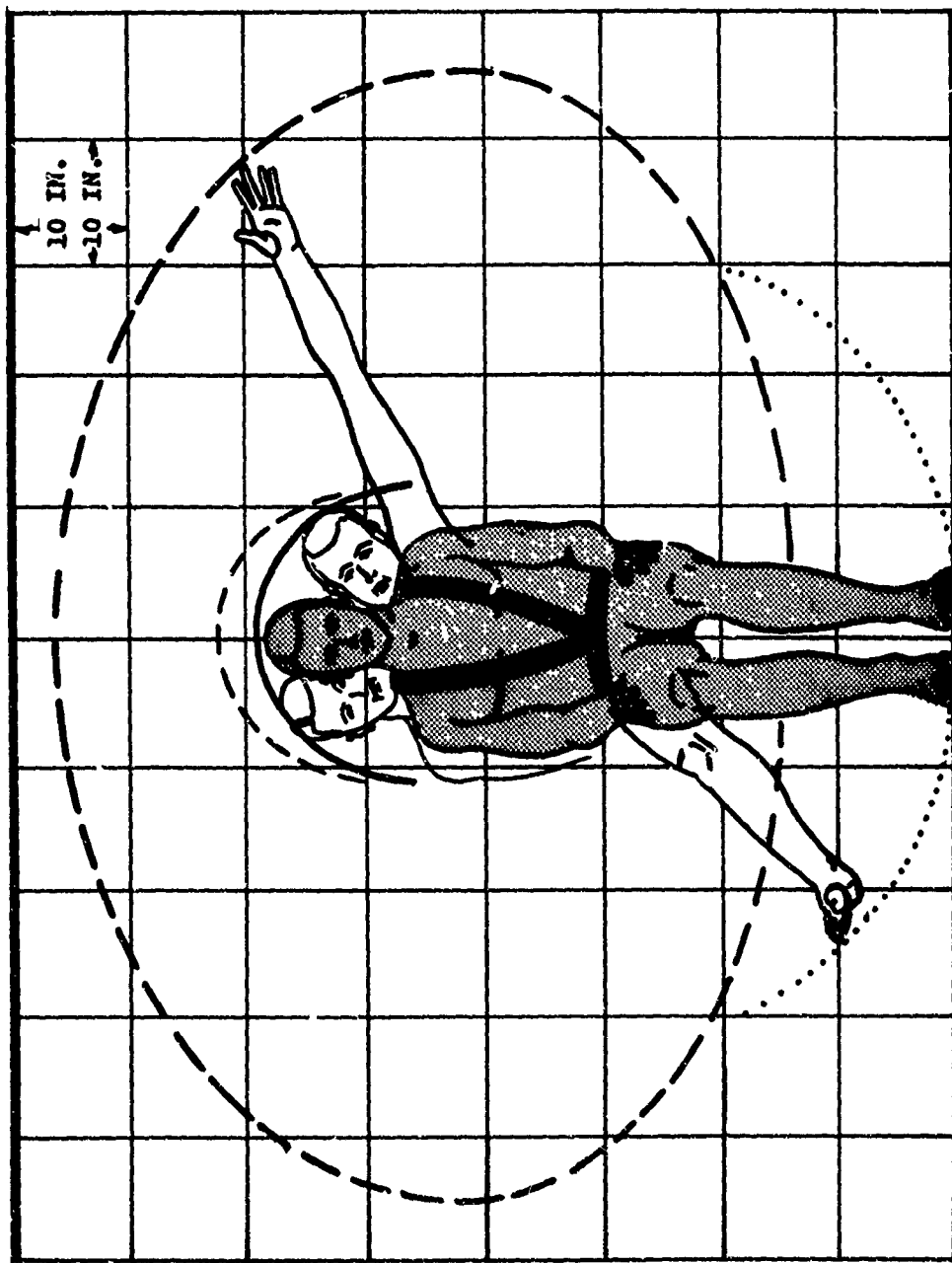


Figure 3-28. Full-Restraint Extremity Strike Envelope - Front View.  
[Source: USAAVLABS TR 67-22 (5)]

### Tolerance to Head Impacts:

Studies by AvSER and Wayne State University indicate that head impacts at more than 20 fps are not readily tolerated by humans unless the structure has been adequately covered with energy-absorbing material. However, ductile or deforming energy-absorbing structure or construction can be as effective as energy-absorbing padding provided that sharp corners and protrusions are eliminated and the structure/head contact area is large. When the design layout is free of sharp or small radiused corners, edges, and protrusions, attention can be given to design for controlling the magnitudes of the acceleration pulses to which the head may be subjected.

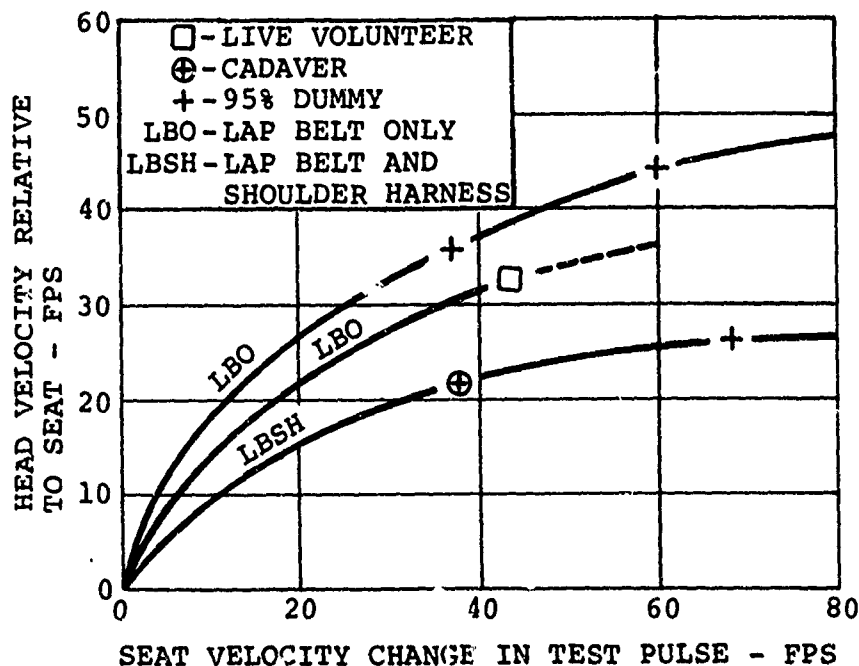


Figure 3-29. Measured Head Velocities in Sled Tests With Anthropomorphic Dummies and Cadavers.

[Source: USAAVLABS TR 70-22 (2)]

Head acceleration is a function primarily of (a) head striking velocity, (b) head/torso mass, and (c) stopping distance. Head striking velocity is a function of (a) body geometry, (b) method of restraint (lap belt only or both lap belt and shoulder harness), and (c) seat velocity change. Figure 3-29 shows typical head velocities relative to the seat as measured on anthropomorphic dummies, cadavers, and human volunteers in dynamic seat tests using (a) lap belts only, and (b) both lap belt and shoulder harness.

Figure 3-30 shows an approximate correlation between head impact velocity, crushable material thickness (stopping distance), and average acceleration. The material thickness given in this figure is based upon an assumed rectangular acceleration-time pulse and is, therefore, the minimum material thickness suitable under ideal conditions.

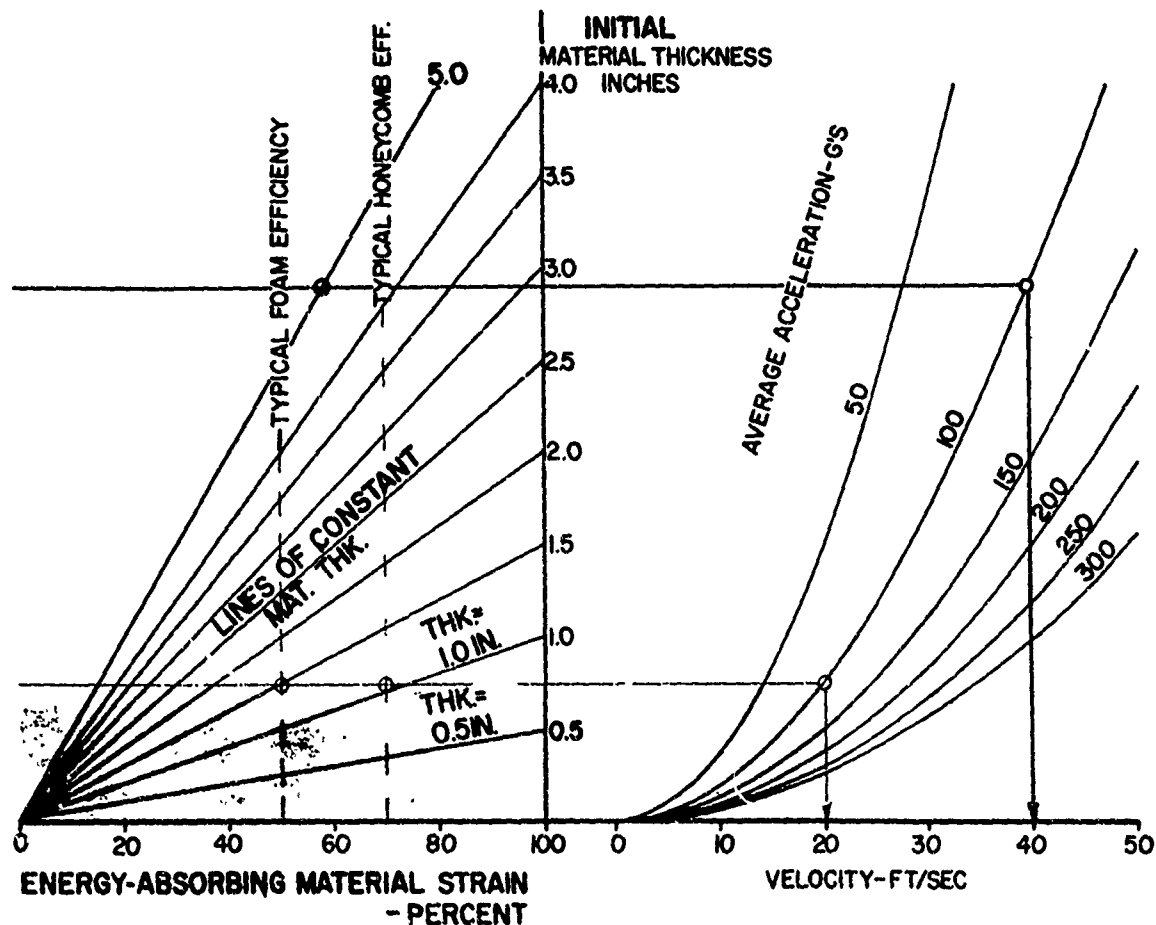


Figure 3-30. Crushable Material Thickness as a Function of Velocity Change and Acceleration Level.

[Source: USAAVLABS TR 65-44 (6)]

Figure 3-31 shows an acceleration-time plot of the average acceleration versus the total period of the impulse required to approach unconsciousness limits. This plot was reported by Dr. Gurdjian and others of Wayne State University after extensive experiments with cadavers and live animals in their work on skull fracture and concussion.

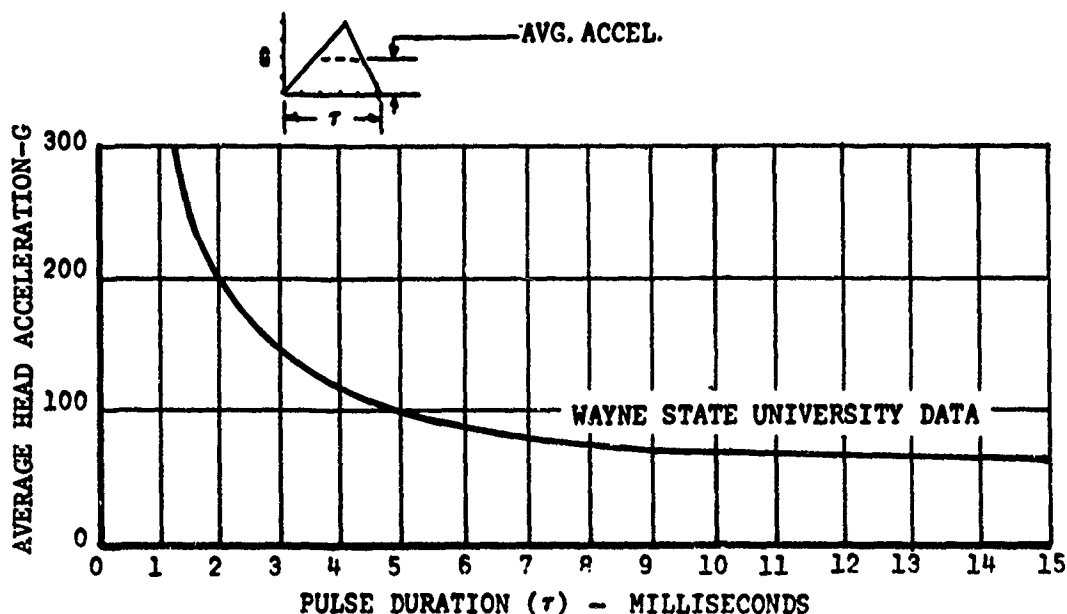


Figure 3-31. Head Tolerance to Impact as a Function of Pulse Duration as Published by Wayne State University.

[Source: USAAVLABS TR 70-22 (2)]

A designer may, by using the approximations and ranges of values for head velocities and impact tolerances of Figures 3-29 and 3-31, determine from Figure 3-30 approximate thickness of energy absorbing materials adequate for head protection. Lesser thicknesses would be adequate if installed on energy-absorbing structure.

#### Torso Impacts:

Figures 3-24 and 3-25 show the approximate flailing area for an occupant restrained only by a lap belt. Control wheels, control columns, pedestals and instrument panels are primary impact hazards to an unrestrained torso. Since the upper torso, particularly the head, is a most vulnerable part of the body, it is necessary that protection be provided within its strike envelope. Head impacts against local structure are a primary cause of serious injury. Protection for the head can be provided in the form of protective helmets and/or upper torso restraint and energy-absorbing structure in the occupant's immediate environment. Under certain conditions, even the forces incurred in minor crash impacts can cause serious or fatal injuries.



Figure 3-32 shows a 95th percentile male's forward flailing area superimposed on a scale drawing conglomerate of a number of late model light airplanes. Figure 3-32 also shows how a front seat occupant, restrained only by a seat belt, can contact an airplane's interior structure.

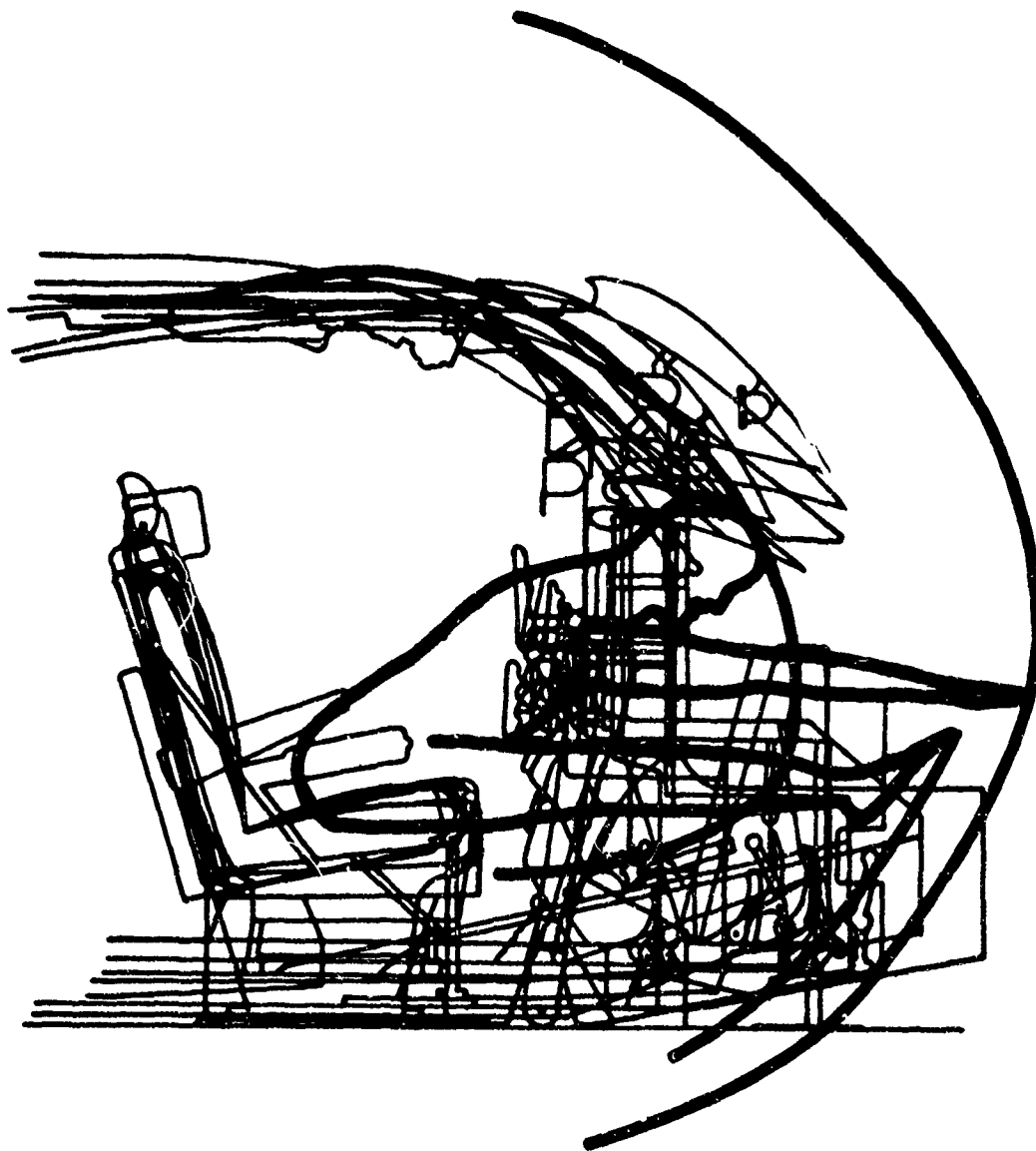


Figure 3-32.

[Source: CARI Report 62-13 (7)]

Control Columns and Wheels. A floor mounted control column can present a serious hazard if it fails within the torso/head flailing area. Such failure, especially if it is jagged or sharp, can cause serious injuries to an occupant thrown against it.

Horizontal, instrument panel mounted control columns are frequently the cause of serious or fatal injuries, especially if the column breaks or if the control wheel fails. Some horizontal, panel-mounted control columns have failed by bending over double to form a sharp projection in front of the occupant's chest.

The use of ductile rather than brittle materials will allow deflection of the control wheel structure under impact and prior to failure. Control wheels with provisions for as large a chest support area as practical even after failure will minimize fatalities due to chest penetration by the column. These were considerations used in the development of the control wheels in the aircraft shown in Figures 3-33 and 3-34.

Controls. Controls should be so designed as to minimize sharp edges. Where practicable, surfaces should be padded and controls should be either recessed or of a yielding design in order to minimize puncture hazards.

#### Hazards to Extremities.

The most serious injuries to the extremities are the debilitating fractures received by the ankles and lower legs. Assuming the occupant has not been thrown from his seat, leg injuries are caused by leg or knee impact against sharp or unyielding structure beneath and forward of the instrument panel or against the lower edge of the instrument panel. Figure 3-32 shows how the structures of a few contemporary airplanes present impact hazards to occupants' legs. It is not possible to eliminate structure within reach of the legs and feet.

Occupants of rear seats may be exposed to the rigid lower structure of the front seats.

Rudder Pedals. In certain crash attitudes, the pilot's feet will remain on the rudder pedals instead of flailing upward or outward. In these attitudes, pelvic rotation around the seat belt can occur. This pelvic rotation has the effect of forcing the pilot's feet hard against the rudder pedals, and can occur even if the lap belt is drawn up tightly. The tendency is aggravated by a loose or slack lap belt.

Protective Padding. Protective padding has reduced impact accelerations by absorbing a portion of the impact force, and has reduced high load concentrations by distributing the force over a large area. Report AM66-40 "Evaluation of Various Padding Materials for Crash Protection" by J. J. Swearingen gives the results of limited impact testing of various padding materials and thicknesses.

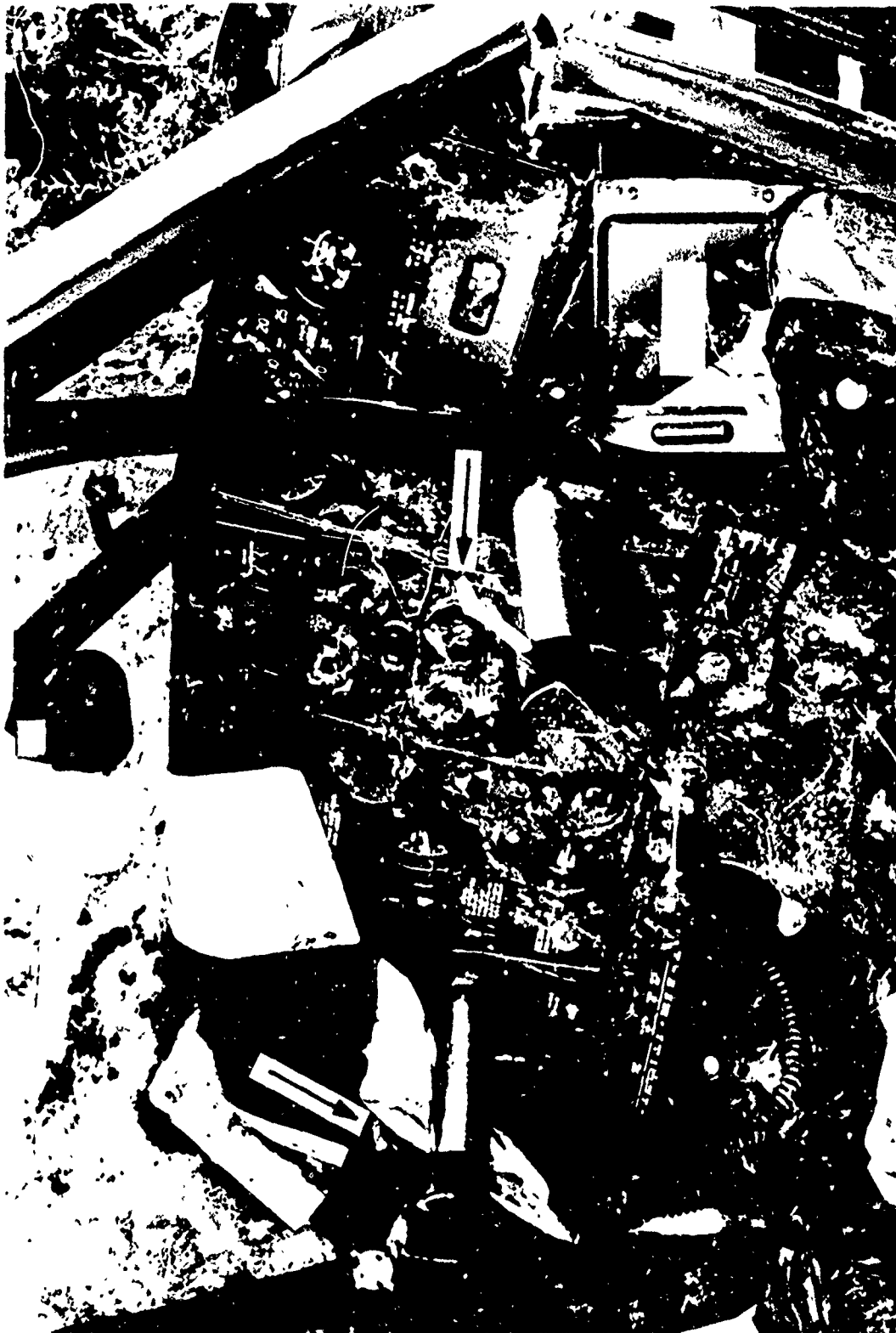


Figure 3-33  
Control Wheels Broken by Occupants During Emergency Landing

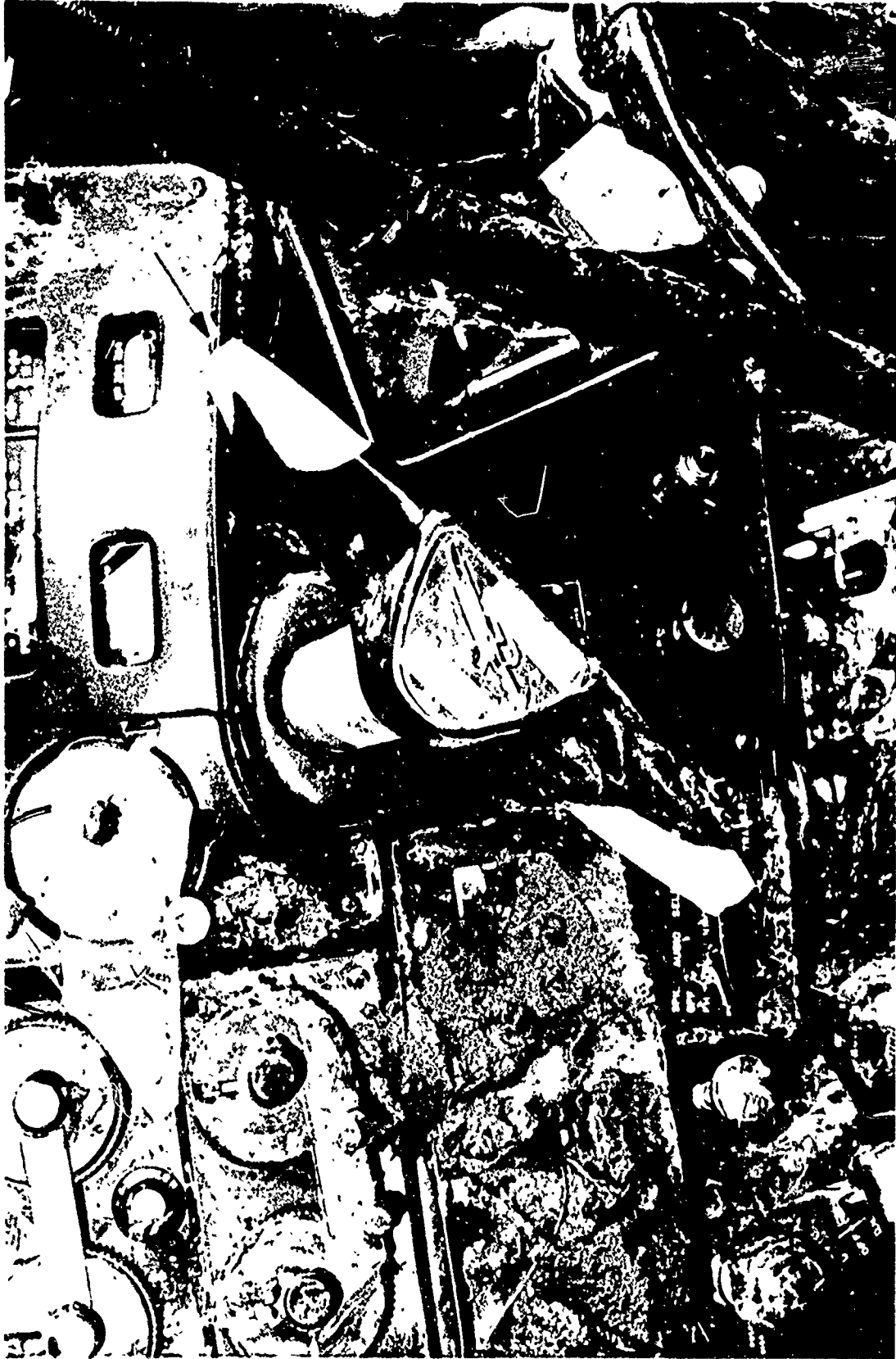


Figure 3-34  
Control Wheel Broken by Occupant During Emergency Landing

### Equipment.

In any accident, loose items or fixed equipment can become lethal missiles. Accidents have occurred in which occupants have been injured by loose equipment, some by direct injury and others by seat failure caused by the impact of equipment or baggage. Loose equipment and baggage can block or impede evacuation. It is, therefore, desirable that all items of equipment or baggage carried in the cabin (especially those items aft of the occupants) be installed or stored securely.

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## CHAPTER IV

### FAA TEST FACILITIES AND SYSTEMS RESEARCH AND DEVELOPMENT PROGRAMS

#### Introduction:

The FAA has certain test facilities suitable for different crashworthiness testing applications. These facilities are located at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey, and at the Civil Aeromedical Institute (CAMI) in Oklahoma City, Oklahoma. These facilities have been and will be made available to the aviation industry for their crashworthiness development or testing programs.

#### NAFEC Facilities:

The NAFEC facilities most suitable and currently in use for crashworthiness work are described below. Inquiries in regard to using the NAFEC facilities should be addressed to: Chief, Aircraft Safety Division, ANA-400, Department of Transportation, Federal Aviation Administration, NAFEC, Atlantic City, New Jersey 08405.

1. Drop Test Facility. This is an outdoor hoist assembly supported on two towers over a 70 x 30 foot concrete test pad or drop area. The facility is capable of drop testing a 30,000-pound load or swing testing a 6,000-pound load from maximum height of 35 feet. The only limitation on the physical size of an article to be drop tested is the distance between the two support towers, which is 40 feet. The tower height is 57 feet with a maximum effective or working drop height of 35 feet.
2. Catapult and Track Facility. A compressed air catapult is installed parallel to a 300-foot long track. It powers a 600 pound, 4 x 7 foot test car on the track through a pulley and cable arrangement. The catapult and track facility is capable of accelerating test articles weighing up to 6,300 pounds and to speeds up to 61 miles per hour. Maximum deceleration capability for a maximum weight load is approximately 15 g. The deceleration values attainable are dependent upon the method of arrestment which can reach values in excess of those capable of being resisted by current aircraft structures. Lighter weights can also be accelerated to higher velocities.
3. Static Test Facility. The indoor facility consists of a test stand, hydraulic system, and instrumentation system. The test stand bed is 7 x 12 feet. Working height above the bed is 6.5 feet and is adjustable. Two sets of three hydraulic cylinders each are available with combined capacities of 7,500 pounds pull and 2,400 pounds push for one set and 15,400 pounds pull and 24,000 pounds push for the other.

4. Instrument and Recording Equipment. Complete instrumentation capabilities are available for all three test facilities. Instrumentation systems include load dial indicators with remote switching; load, force, and deformation sensors; signal conditioning equipment; and oscillograph recorders. Motion picture cameras, 16 mm with adjustable film speed, and an event--marking system are also available.

#### CAMI Facilities:

The CAMI facilities currently in use for crashworthiness work are described below. Inquiries in regard to using the CAMI facilities should be addressed to: Chief, Protection and Survival Laboratory, AAC-119, Civil Aeromedical Institute, Department of Transportation, Federal Aviation Administration, Aeronautical Center, P. O. Box 25082, Oklahoma City, Oklahoma 73125

1. CAMI Test Track. The CAMI test track is an impact test device capable of producing a controlled deceleration pulse variables from 2 to 50 g's. The device consists of a wheeled test sled which moves along two horizontal rails, an accelerating device, and a sled braking device.

The sled is a flat topped vehicle upon which the test specimen is mounted. By use of adapters the test specimen may be mounted in a variety of orientations relative to the impact force vector. Test specimens from a simple, single seat and anthropometric test dummy to full-scale general aviation aircraft cabin sections with four test dummies may be readily accommodated on the sled.

Sled velocity is provided by a Newtonian acceleration system connected through a cable to the sled. This system accelerates the sled at a constant g level to the desired impact velocity over a maximum distance of 65 feet. The sled then coasts freely for 5 feet and is then decelerated by a metal deforming brake system. The deceleration force is produced when the sled contacts wires which pass over the rails and through brake units on either side of the rails. As the wires pass through the brake units, they are plastically deformed by being bent over a series of rollers.

The sled deceleration time history is controlled over a wide range of onset rates, g levels, and stopping distances by selection of the number and location of the decelerating wires in conjunction with control of slide velocity and weight. The maximum sled velocity for a 300-pound test specimen is 50 feet per second and for a 1200-pound test specimen is 40 feet per second.

#### Electronic Instrumentation.

The electronic instrumentation system of the CAMI test track is designed for maximum versatility and reliability under the deceleration forces encountered during impact tests. Special provisions have been



made for the use of bridge type transducers. This type transducer has proven to be useful and reliable for measuring strain, acceleration, pressure, force loading, and low frequency vibrations. A selection of these transducers is maintained at the facility to instrument a variety of test configurations.

Signals are transmitted from sled borne transducers to trackside signal conditioners through an umbilical cable which is attached at one end to the sled and which travels with the sled as it moves down the track. These signal conditioners provide excitation to the transducers (3-10 Vdc), amplify the signal, allow low-pass filtering when desired and provide a resistance shunt calibration for each transducer through the entire data recording system.

Outputs from the signal conditioners modulate subcarrier oscillators of a high frequency, constant band width multiplexer system. The composite output from the multiplexer system is recorded on wide band magnetic tape. The magnetic tape is reproduced through appropriate discriminators and displayed on an oscillograph recorder for quick look analysis. As required, portions of these data are then reproduced from the magnetic tape-discriminator combination into a high-speed, multi-channel, analogue-to-digital converter system and placed in a computer-compatible form on high density digital tape.

Routine reduction of the impact data provides tabular output and sealed plots versus time of acceleration, vector sum acceleration, velocity, and displacement for further analysis. Data may also be put into a program containing analytical injury prediction models. This program includes the ability to evaluate the maximum strain criteria (MSC), the dynamic response index (DRI), the Vienna Model, the SAE (Gadd) Severity Index, and the head injury criteria (HIC-Versache). Other specialized analyses can be programmed if required.

#### Photographic Coverage.

All CAMI sled tests are photographically recorded. This photographic coverage includes both technical documentary and instrumentation quality 16mm film from high-speed cameras located adjacent to the track in the impact area.

Various types of 16mm instrumentation cameras with unique timing devices are available to provide this coverage. Color film is routinely used in all cameras and adequate lighting is available to allow camera speeds of 1,000 fps.

Available 16mm cameras with film speeds from 500 to 5,000 fps include "Hycam" and "Wollensak" rotating prism cameras. Available 16mm cameras with film speeds to 500 fps (adequate for many impact events) include Milliken pin registered cameras. On-board photographic coverage is provided by "Fastair" and Photosonic cameras with nominal film speeds

up to 500 frames per second. A variety of lens types are available for each camera. An automatic, programmable camera and lighting control system is utilized for all impact tests. Equipment is available for quality on-site developing and processing of the color film collected for each impact test.

2. CAMI Drop Tower. The CAMI drop tower is a vertical deceleration device which produces a controlled deceleration pulse from 5 to 50 g's and a maximum velocity of 33 feet per second. Test specimen weights to 500 pounds may be accommodated in a variety of configurations.

Two basic carriage configurations are available upon which test specimens may be mounted and decelerated. Number One carriage has a flat platform 3 feet by 4 feet and provisions for elevated upper torso restraint attachments. Should the test specimen be an aircraft seat mounted to the platform, the g vector would be oriented  $90^\circ$  below an equivalent aircraft center line. Number Two carriage has a sloped platform 3 feet by 4-1/2 feet, allowing a g vector orientation  $30^\circ$  below and  $10^\circ$  to the left (or right) of an equivalent aircraft center line for a seat installed on the sloped floor.

Velocity is produced by lifting the carriage to a pre-determined height and allowing it to drop vertically, accelerated by the earth's gravitational field. Guide rails prevent rotation of the carriage during the free-fall phase. The deceleration profile is produced when wedges installed on the bottom of the test carriage are forced into a sand bed by the mass and velocity of the carriage and specimen. This deceleration profile is a reproducible reversed sawtooth (high onset rate, low offset rate) with duration dependent on carriage velocity and weight. Typical deceleration time durations are from 50 to 120 milliseconds with a nominal 9-inch deceleration distance.

Photographic and electronic instrumentation coverages are the same as those used on the CAMI test sled.

### Crashworthiness Systems Research and Development Programs:

The Crashworthiness Section in FAA's "Systems Research and Development Service" (SRDS) is responsible for coordinating FAA activities with respect to (a) requests for research and development efforts, (b) system requirements, and (c) exploiting advances in the state-of-the-art of aircraft crashworthiness, crash fire hazard and control, and crash survivability. The section is responsible for planning and coordinating agency resources and any contractual support required for the agency's crashworthiness research or development programs which may be assigned to the Airworthiness and Crashworthiness Branch.

Research projects dealing with crashworthiness which are contracted out at this time are the following:

1. Title: "Analysis of Aircraft Seating Systems Subjected to a Survivable Crash Environment"

Contract awarded to Dynamic Science.

The work outlined will develop a novel mathematical analysis program for application to the design and scientific analysis of aircraft seating systems. An analysis of general aviation seating systems during a survivable crash condition will be made, and promising design concepts and parameters will be identified. Associated penalties (such as cost or weight) will be investigated. Finally, a follow-on design, construction and testing program will be formulated to verify the analysis performed.

The three-dimensional mathematical model(s) sought would be capable of predicting forces and deflections of a forward or aft facing seat due to crash input, as well as the displacements, velocities, and accelerations of the occupants along the vertical, longitudinal, and lateral axes.

The model would be capable of evaluating the degree of severity of the calculated force and acceleration vectors applied to the occupant. This would be done in terms of the various available indices of human tolerance criteria, such as the Gadd Severity Index, and the Dynamic Response Index.

The model would allow for variations of the following parameters:

- (1) angles of roll and yaw,
- (2) shape, magnitude, direction, and duration of the crash input acceleration,
- (3) occupant dynamic response and anthropometric values,

- (4) type, configuration, and force-deflection characteristics of the occupant restraint system,
- (5) seat rigidity and force-deflection characteristics (including seat legs and seat cushions),
- (6) application of different types of load-limiting or controlled deformation devices.
- (7) various indices of human tolerance criteria, and
- (8) any other parameters required for accurate representation of the seat-restraint system - occupant system, or for design analysis of different systems.

The model would also be capable of coupled and uncoupled parametric studies.

2. Title: "Three Dimensional Inflatable Restraint System for General Aviation Aircraft"

Contract awarded to Beta Industries.

A research program recently completed by Beta Industries, Inc. for the FAA developed an inflatable restraint system concept for a general aviation aircraft. This concept provides protection for the occupant in both the vertical and longitudinal direction and also indicates the feasibility of using an inflatable restraint system in a general aviation aircraft. But while the feasibility (i.e., theoretical possibility) may have been shown, the practicality of an air cushion restraint system still needs to be determined. An inflatable restraint system is a highly complex and sophisticated mechanism, And to insure that it functions ideally in a general aviation crash environment requires that several practical questions be answered.

Future work on inflatable restraint systems is being contemplated to cover cabin overpressure, noise levels and gas toxicity.

Research projects which have not been contracted out but are being considered are the following:

1. Title: "General Aviation Aircraft Crashworthiness Design Criteria"

The objective of this project is to expand and refine analytical techniques for the accurate prediction of aircraft structural response to a design crash environment. To define crash-dynamics design criteria to improve occupant survivability using the updated analytical capability and applicable crash statistics and other related data. And to incorporate all criteria, analytical

development, and knowledge gained during hardware and testing phases into a crashworthiness design guide.

A contract will be awarded to expand and refine analytical techniques. Full-scale crash test aircraft will be instrumented and structural response data will be obtained and reported for correlation to analytical techniques to judge their accuracy.

2. Title: "Crash Resistant Fuel System Development"

This project will involve the development and testing of a lightweight, low cost, crash resistant fuel system which will prevent fuel spillage in small aircraft survivable accidents. The system will also be applicable to helicopters and larger aircraft types coming into the air-taxi market.

An industry contractor will design, construct and test components and a prototype system under simulated crash loads. Further contract work will supply a complete system and installation in a suitable airframe for actual crash test evaluation.

3. Title: "General Aviation Experimental Crashworthy Aircraft"

This project proposes the design and construction of an experimental crashworthy airplane through a design competition. The functional experimental airplane would demonstrate crashworthiness developments and principles which can be optimally integrated with cost considerations through a systems engineering approach.

A design competition will be held, limited to general aviation aircraft manufacturers. The principle design techniques, and criteria developed in previous R & D projects will be incorporated into an aircraft design through a systems approach to optimize crashworthiness, performance and costs.

## APPENDIX A

### HUMAN TOLERANCE TO IMPACT DECELERATION FORCES

#### Introduction:

One of the essential factors of crashworthiness design is a definition of human tolerance to an impact deceleration environment. But, what constitutes this definition of human tolerance?

Although it is generally recognized that actual aircraft crashes subject the occupants to a dynamic situation, human tolerance to deceleration force is predominately defined in terms of a static load vector. Even with this simple definition, there is disagreement among the tolerance limits suggested by various researchers and scientists. These disagreements emanate primarily from different assumptions and various degrees of simplification of a complex problem. However, some assumptions and simplifications were necessary due to a lack of information.

The complexity of defining human tolerance to a dynamic environment involves several interrelated factors. A substantial amount of research and experimentation has been conducted in efforts to determine the interrelationships among these factors. Experiments with human volunteers have necessarily been conducted at subcritical levels. Animals such as chimpanzees, monkeys, bears, pigs, and mice have been used in attempts to define critical deceleration levels. Human cadavers have also been used for this purpose.

In reviewing the data, it becomes apparent that little consistency existed in the test methods, the test apparatus, or the data recorded. Consequently, some researchers and scientists argue that the data is not complete, and that an accurate correlation of the interrelated factors to the limits of a live human is not possible. But, how valid is this argument when considering the limits of human tolerance for design purposes? This question can best be answered through an examination of the factors involved.

#### Factors Affecting Human Tolerance:

The various factors to consider when dealing with human tolerance to decelerative forces are diagrammed in Figure A-1. This diagram immediately illustrates the numerous variables, and thereby the complexity, of the overall system of human tolerance. Of the three subsystems illustrated, "Individual Physique" is probably the most complicated and the least understood.

Although no quantitative values have been established, "Individual Physique" has a decided effect on tolerance to decelerative forces. Qualitatively, an individual's weight and the distribution of that weight on his skeletal structure govern the force distribution on the various segments of bone-ligament structure. Concurrently, the force sustaining capabilities of bone-ligament structure differ between individuals. The bone-ligament structure is often related to stature; i.e., the larger person normally has larger bones and stronger ligaments. However, the force sustaining capabilities of bone vary with age. The bones of a younger person are normally more elastic and have higher failing stress levels. Therefore, the age of the bone-ligament structure would also affect an individual's tolerance.

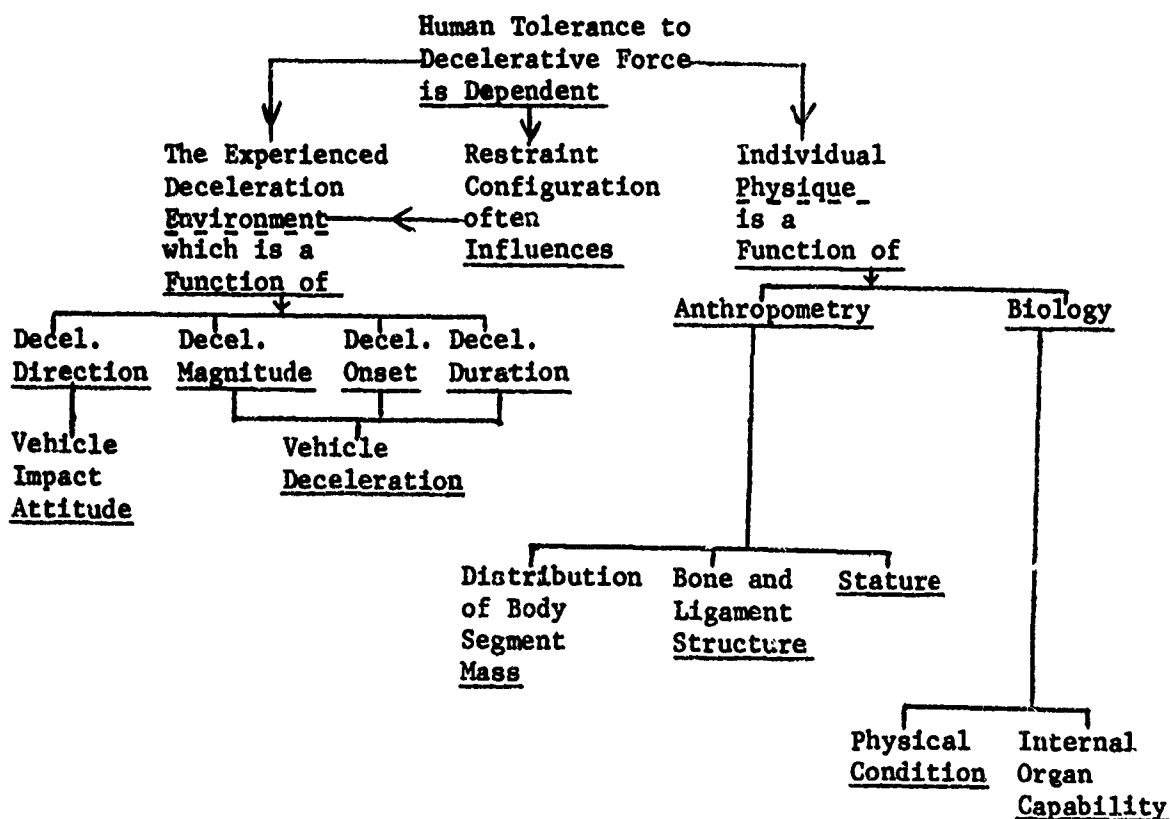


FIGURE A-1. Factors Affecting Human Tolerance to the Forces of Impact Deceleration

Body weight distribution and stature have another effect on human tolerance. These factors govern the body's center of gravity positions. When a mechanical restraint device is involved, body c.g. position can influence the response of various body segments to a given vehicle deceleration. This is particularly true where only a lap belt is used for restraint.

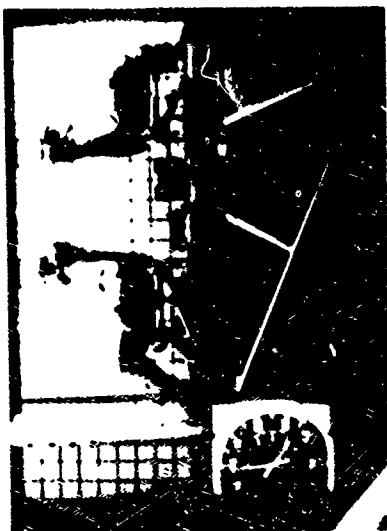
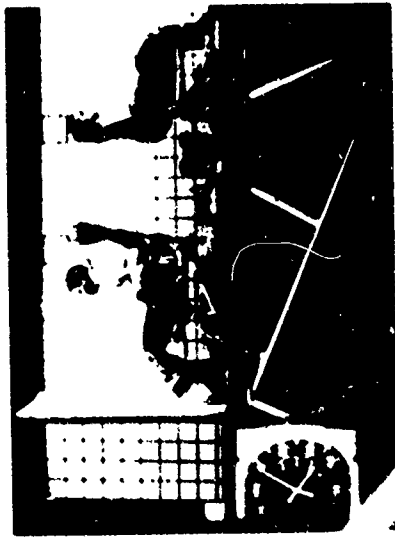
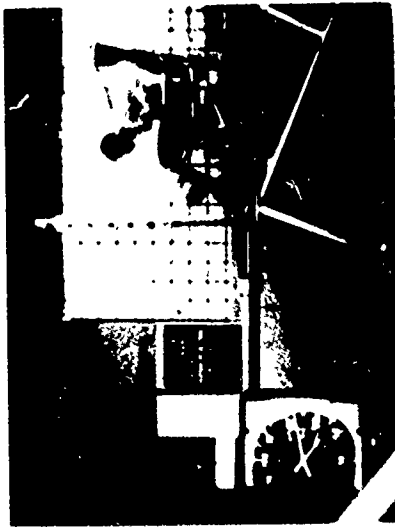
The biological aspects of an individual can also affect his tolerance to a given vehicle deceleration. To some extent, physical strength can provide self restraint against jack-knifing and arm and leg flailing. In this respect, the more physically fit individual would have a greater tolerance to deceleration.

The complexity of human tolerance to deceleration increases when the effects of the restraint systems are coupled with the effects of "Individual Physique." The experiments mentioned previously have produced some observed effects of "Restraint Configuration." Reference (2) reports the results of deceleration tests conducted with human volunteers. These tests were conducted in only the longitudinal direction to evaluate human reactions in forward and aft facing seats, with only a lap belt restraint configuration. Two test subjects were used, representing the 5th and 95th percentile individuals. Testing with human subjects was terminated with a vehicle deceleration of about 5g. The reason given for terminating testing at this low level was ". . . they were suspended at the 5g level due to the violent reaction of the forward facing occupant to this load. To continue past this level would greatly increase the risk of injury to the subject."

Although the tests reported in Reference (2) were terminated at sub-critical deceleration levels, they serve to illustrate the effects of different restraint systems. Figure A-2, taken from Reference (2), illustrates the jackknifing effects of the lap-belt-only restraint configuration under a forward directed deceleration. The aft facing subject had the benefit of nearly full body support, which prevented flailing and angular acceleration of the upper body torso. The angular acceleration attained by the forward facing subjects was not recorded, but it is apparent that contact of the head or chest with an obstacle would create a decelerative force additive to that created by the vehicle deceleration.

The deceleration traces corresponding to Figure A-2 are shown in Figure A-3. These traces illustrate the effects of restraint systems elasticity. The aft facing subject attained a considerably higher deceleration level at the hips than that attained by the forward facing subjects. Both subjects experienced deceleration greater than the vehicle deceleration. These different deceleration levels were produced by the elasticity of the different restraint systems. The seat cushions were made of latex foam sponge rubber. The lap belts were standard 2" wide nylon lap belts. The latex foam compressed, providing little resistance to deceleration. This permitted the occupant to experience a secondary impact with the rigid seat frame, which was additive to the vehicle deceleration.





95 percentile subject in forward position.  
Views from motion pictures

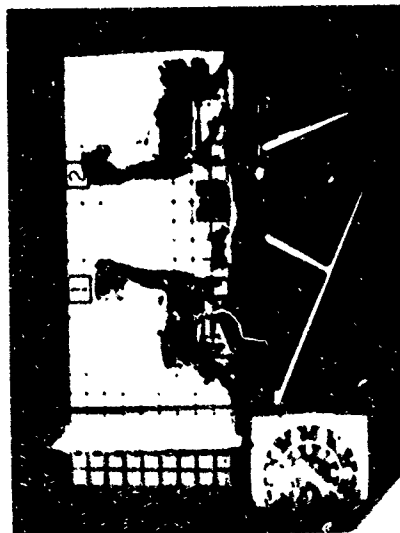
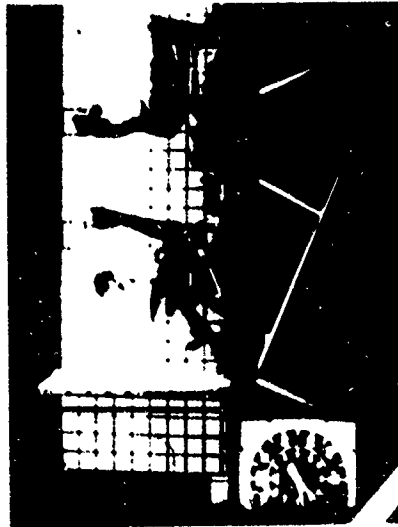
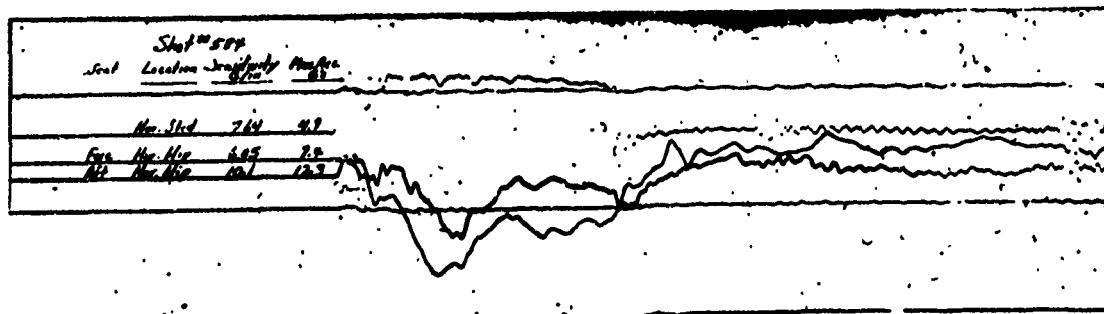
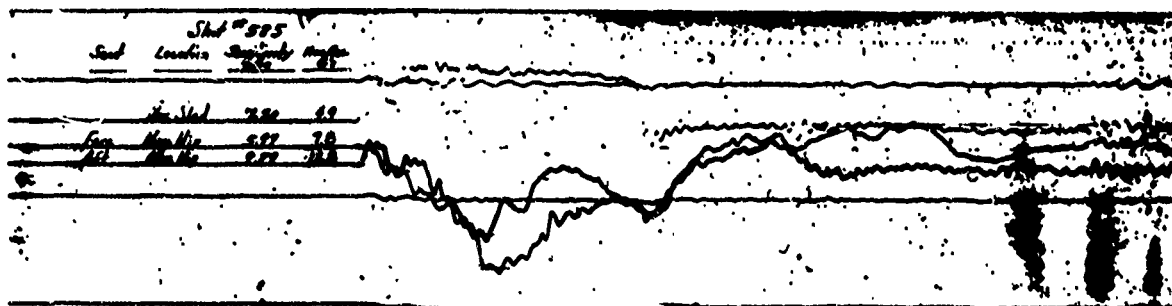


Figure A-2



## SUBJECT REACTIONS



## SUBJECT REACTIONS

Figure A-3

Deceleration Traces of Vehicle and Human Subjects  
corresponding to Figure A-2

[Source: Project TED NAM AE 6303.1(2)]

Note: The traces have been reduced in size to an  
unknown scale.

ation. The rigid seat frame provided a very short deceleration distance, and thereby produced the higher deceleration of the hip region. The stretch of the seat belt provided a longer secondary deceleration distance and, thereby, a lower total deceleration of the hip region for the forward facing subject. Hence, the restraint system elasticity, as well as the restraint configuration, can affect the deceleration environment experienced by the occupant.

Through early research and observation of accident consequences, researchers deduced that force and/or pressure distribution over the body was a predominant factor in human tolerance to deceleration. For example, humans have survived accidental falls which resulted in decelerations of about 200g. The individuals survived because they impacted the ground in a supine attitude which spread the impact force over the entire body structure. In contrast, aircraft accidents were observed where relatively low deceleration levels were indicated by minor structural damage; however, debilitating abdominal injuries and spinal fractures occurred due to concentrated loading at the seat belt. For this reason, the bulk of experimentation with human volunteers has been done with a restraint system which offered considerably more force distribution over the body than does the simple lap belt.

Of course there are practical limitations to the amount of confinement which should be imposed on an aircraft occupant. Therefore, most deceleration testing with human subjects has been done with various configurations of the lap belt-shoulder harness restraint system. Through this experimentation, it was learned that voluntary tolerance was increased when the decelerative force was distributed over subsurface bone structure, rather than over the fleshy areas of the body.

The third factor of human tolerance to examine is the "Deceleration Environment" experienced by the individual. The deceleration pulse experienced by the aircraft occupant will generally differ from that of the aircraft, unless the occupant is totally and rigidly anchored to the airframe. Rigid anchorage is virtually impossible because of restraint system elasticity and the viscoelastic nature of the human body. However, rigid anchorage is not particularly desirable at the higher g levels.

Experimental measurements (References (1), (4) and (5)) have shown that the deceleration level of the head and shoulder area can be as much as three times the deceleration of the vehicle floor. These measurements were taken in the forward direction, using a rigid seat and a tightly drawn lap belt-shoulder harness restraint configuration. However, the differences occurred only at levels above 3 to 5g (Reference (1)). It appears that an individual's physical condition permits some degree of self restraint at these low levels.

At deceleration levels above 3 to 5g, the body segment mass distribution seems to affect the amount that the head and shoulder area exceeds the floor deceleration. Therefore, an interrelationship between "Individual Physique" and the "Deceleration Environment" is apparent, but a quantitative correlation has not yet been established.

As mentioned previously, the "Deceleration Environment" experienced in an actual aircraft crash is a dynamic situation. The dynamic situation involves a changing deceleration magnitude with respect to time which is termed the deceleration pulse. The rate at which the deceleration increases or decreases is termed the onset or offset, respectively. Pulse duration can have different meanings, depending on which pulse shape is used. These meanings are illustrated in Figure A-4 by the various pulse shapes which have been commonly assumed for analysis purposes.

Obviously, the deceleration pulse transmitted through the adjacent airframe is the motivating factor in the response of an accident victim. What little crash testing that has been done with anthropometric dummies in small aircraft indicates that any of the pulse shapes of Figure A-4 would be a reasonable representation of the occupants "Deceleration Environment." The trapezoidal pulse was the one used for the majority of dynamic testing of human tolerance.

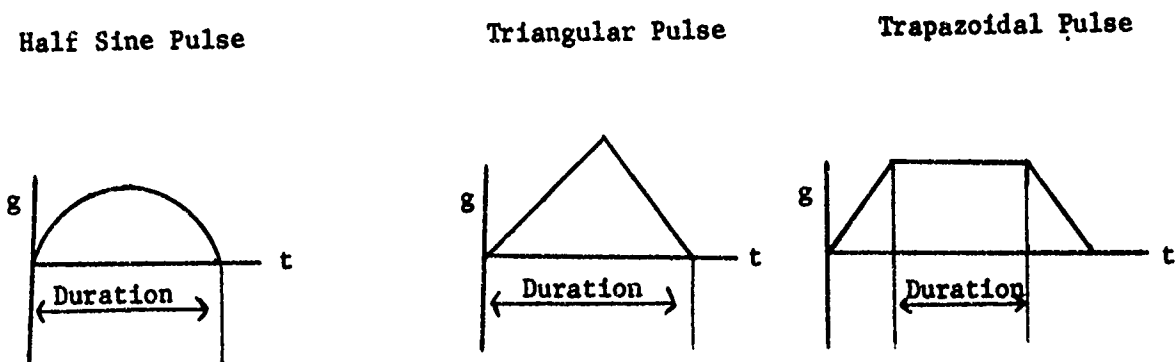


Figure A-4

Typical Deceleration Pulses Assumed for Analysis Purposes

Results of the dynamic tests with human volunteers indicate a voluntary tolerance for higher magnitude decelerations when either onset or duration is reduced. These tests also indicate that human tolerance to any set of deceleration parameters is dependent on the direction of the deceleration vector with respect to the body axis.

Deceleration vector orientation with respect to the body axis of a seated individual is illustrated in Figure A-5. If the individual is seated facing forward in an aircraft, spineward ( $-G_x$ ) would represent a forward deceleration, and headward ( $+G_z$ ) would represent a downward deceleration.

With equivalent deceleration onset and duration, tests have shown that individuals can generally tolerate the greatest magnitude in the longitudinal ( $\pm G_x$ ) direction, providing some form of upper torso restraint is used. Not enough data are available to fully assess the tolerance without upper torso restraint. However, the small amount of data that is available indicates a reduction in the tolerable magnitude by a factor of 1/2 to 2/3 in all directions. This is another factor related to "Individual Physique" and "Restraint Configuration."

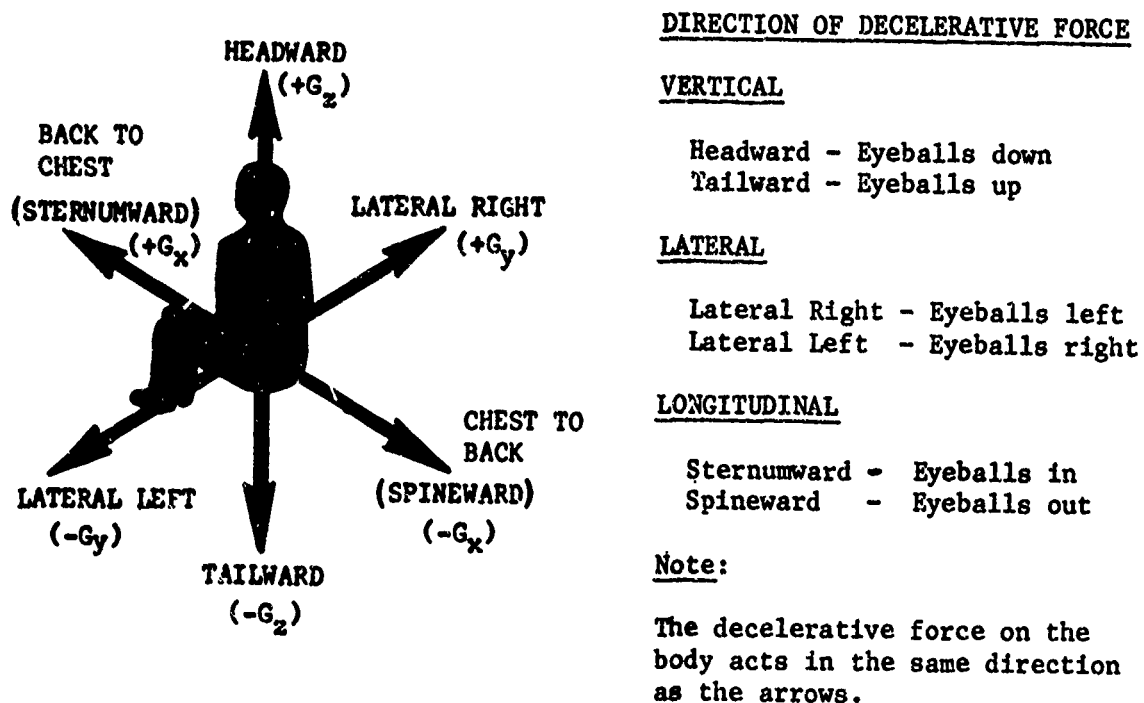


Figure A-5.

Deceleration Vector Orientation

[Source: USAAVLABS TR 70-22 (3)]

Obviously, the direction of the applied deceleration is dependent on the vehicle impact attitude. The decelerations developed in aircraft crashes are probably never unidirectional. They are normally complex resultants of either two or three of the directional components illustrated in Figure A-5. Since the direction of the resultant deceleration vector is unpredictable, crash test instrumentation has necessarily been oriented on the three axis system. These tests indicate that peak component magnitudes on the aircraft often occur simultaneously. Therefore, it is reasonable to assume that the component reactions of the occupants would also occur simultaneously, subjecting the individual to a complex loading condition. Data on human reactions and tolerances to complex decelerations are extremely scarce. This is one of the arguments some researchers and scientists offer against applying the present data to a definition of human tolerance.

Returning now to the question of "how valid are the arguments against the present data for design purposes?", it must be agreed that the inter-relationships of the discrete factors are not precisely defined by the data. However, with the number and complexity of the variables involved, there appears to be little justification for precise definitions for design applications. Since impact decelerations involve dynamically changing conditions, it would be more appropriate to define human tolerance in terms of an envelope. Parameters of this envelope would be the "Deceleration Environment," the "Restraint Configuration," and the "Individual Physique." This approach requires that the parameters be treated as integrated systems.

#### Test and Research Data:

The integrated system approach was used in practically all dynamic testing of human tolerance. Unfortunately, there was not much variation in the "Restraint Configuration" or "Individual Physique." As previously mentioned, the predominant restraint configuration consisted of lap belt-shoulder harness combinations. Also, the majority of human volunteers were young, physically fit, adult males. Therefore, the voluntary tolerance envelopes defined by the data are probably near the practical optimum. The envelopes described by the available data are shown in Figures A-6 through A-9 for the component directions.

Envelopes of potentially debilitating and lethal "Deceleration Environments" are also shown in Figures A-6 through A-9. These limits must presently be defined by data obtained with primates or other animals that were considered biophysically similar to humans. The weights of these animals were normally less than what would be expected for a typical adult. Therefore, the envelope of critical deceleration environment may be conservative.

FIGURE A-6A. - TOLERANCE TO SPINEWARD DECELERATION AS A FUNCTION OF MAGNITUDE AND DURATION OF IMPULSE  
[SOURCE: NASA MEMO 5-19-59E (1)]

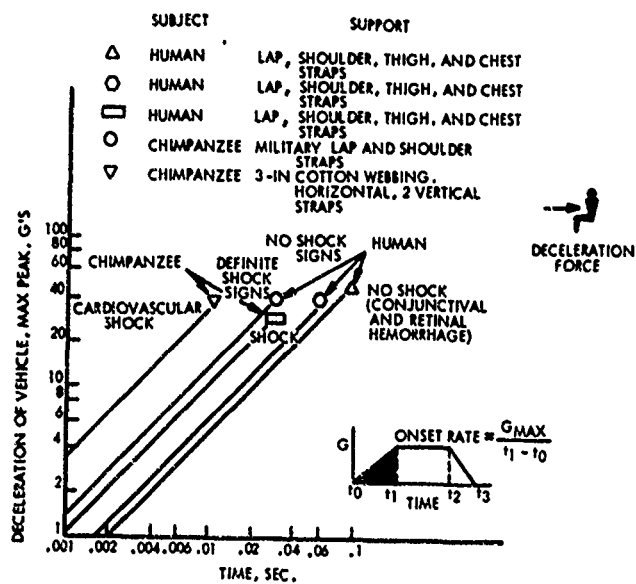
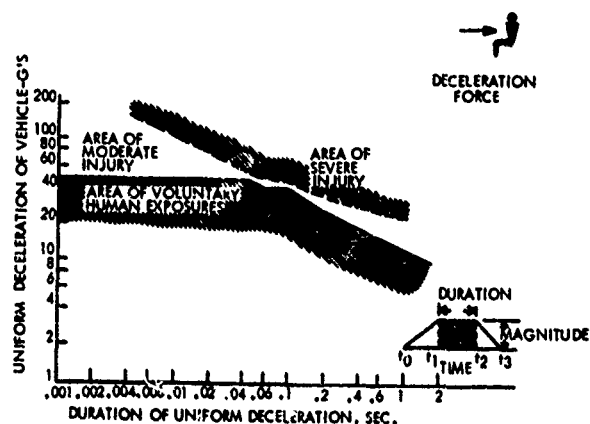


FIGURE A-6B. - EFFECT OF RATE OF ONSET ON SPINEWARD DECELERATION TOLERANCE  
[SOURCE: NASA MEMO 5-19-59E (1)]

FIGURE A-7A. - TOLERANCE TO STERNUMWARD DECELERATION AS A FUNCTION OF MAGNITUDE AND DURATION OF IMPULSE  
[SOURCE: NASA MEMO 5-19-59E (1)]

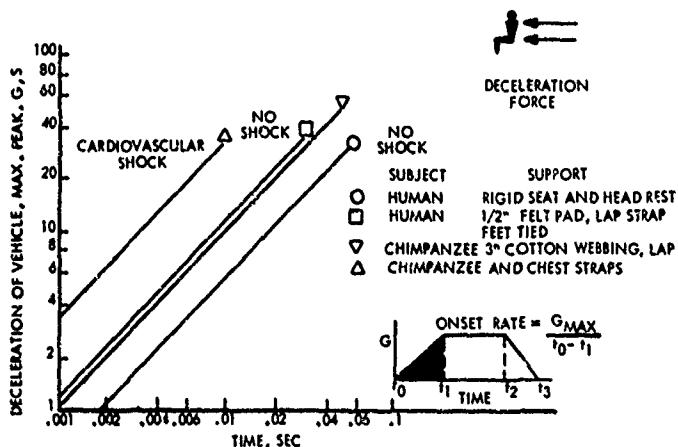
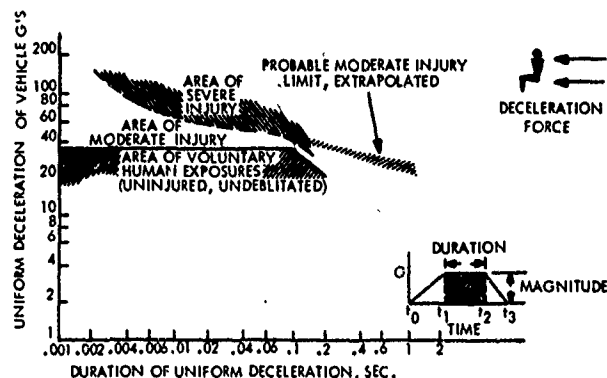
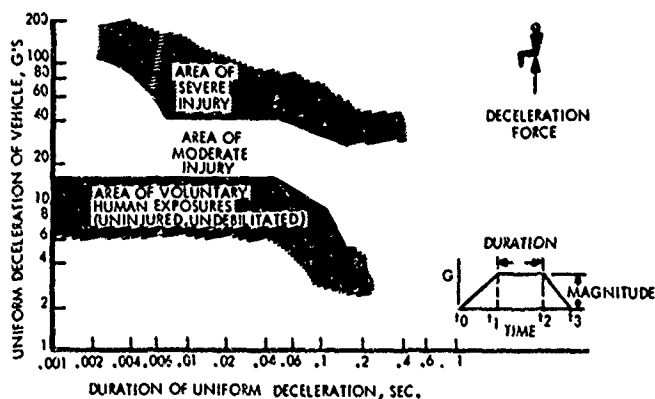


FIGURE A-7B. - EFFECT OF RATE ON ONSET ON SPINEWARD DECELERATION TOLERANCE  
[SOURCE: NASA MEMO 5-19-59E (1)]

FIGURE A-8A. - TOLERANCE TO HEADWARD DECELERATION AS A FUNCTION OF IMPULSE MAGNITUDE AND DURATION.  
[SOURCE: NASA MEMO 5-19-59E (1)]





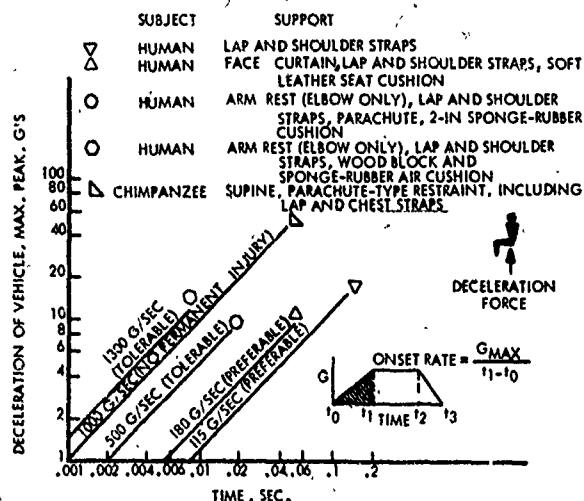


FIGURE A-8B. - EFFECT OF RATE OF ONSET ON HEADWARD DECELERATION TOLERANCE  
[SOURCE: NASA MEMO 5-19-59E (1)]

FIGURE A-9A. - TOLERANCE TO TAILWARD DECELERATION AS A FUNCTION OF IMPULSE MAGNITUDE AND DURATION  
[SOURCE: NASA MEMO 5-19-59E (1)]

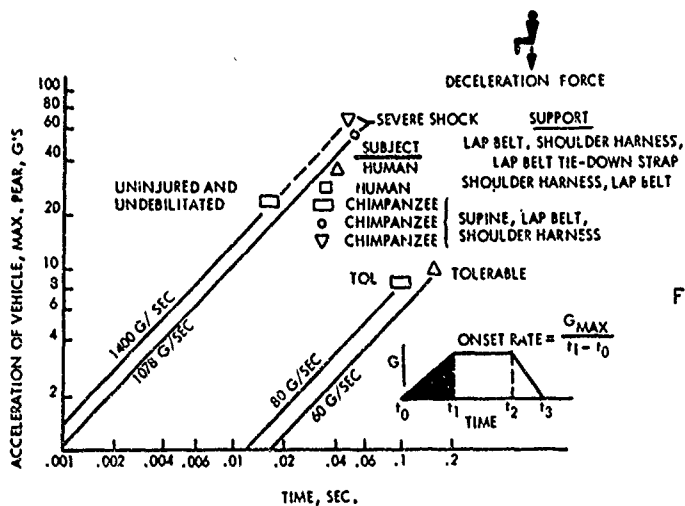
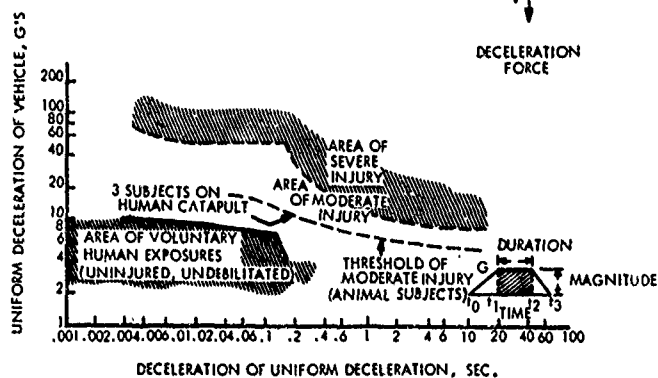


FIGURE A-9B. EFFECT OF RATE OF ONSET ON TAILWARD DECELERATION TOLERANCE  
[SOURCE: NASA MEMO 5-19-59E (1)]

Figures A-6 through A-9 are the results of an analysis of the available data by Eiband, Reference (1). This analysis involved a reduction of the various experimental test pulses to a trapezoidal pulse of equivalent energy level. The quantitative influence of deceleration onset is not clearly established. A lack of data prevents exact mathematical analysis of the influence of the total deceleration-time function. Separation of this function into a pulse of uniform onset and deceleration is not completely accurate. However, it provides the most useful analysis of the experimental data available. Therefore, deceleration onsets endured by various subjects are summarized separately for the different directions.

The data summarized in Figures A-6 through A-9 represent a conglomerate of measurements taken on either the decelerated vehicle, on the seat pan, or on the occupant's hip or chest area. For the analysis, it was assumed that decelerations were equivalent at all locations during each respective test run. This assumption may be questionable because the occupant's deceleration environment often differs from that of the vehicle unless he is rigidly anchored to the vehicle. However, with the laboratory conditions of ultra rigid seats and elaborate, tightly drawn restraint systems, the occupants were as rigidly anchored as possible. Therefore, the assumption of equivalent deceleration at the various locations is not unreasonable, when considering variations that will normally be caused by "Individual Physique" and differing impact conditions.

#### Survival Envelope:

Figures A-6 through A-9 show a basic definition of human tolerance to dynamic deceleration. As opposed to a static force vector, these figures illustrate the best available estimate of the effects of deceleration onset, duration, and direction. For the present, it must be assumed that tolerance does not vary appreciably with "Individual Physique." However, it is known that restraint configuration does have an appreciable effect. Therefore, Figures A-6 through A-9 are valid only when a lap belt-shoulder harness configuration is anticipated. A lack of data precludes any realistic definition of a dynamic survival envelope with lap-belt-only restraint.

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