ASD-TR-76-30

CARGO AIRCRAFT AND SPACECRAFT FORWARD RESTRAINT CRITERIA

DECEMBER 1977

TECHNICAL REPORT ASD-TR-76-30
Final Report for July 1976 – December 1977

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DEPUTY FOR ENGINEERING
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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Project Engineer

FOR THE COMMANDER

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This investigation was primarily conducted to review probability projections of crashes of Air Force cargo aircraft as developed in 1971. The 1971 effort resulted in considerable changes to the air cargo operations. This included a lowering of restraint criteria to 3Gs with an auxiliary 9G net system. The objective of this effort was to determine if further reductions could be made through removal of the auxiliary 9G net, in addition to both aircraft and spacecraft cargo restraint criteria. Restraint and aircraft modifications were

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also examined.

This effort viewed probabilities, based on the original data from January 1960 to July 1971, and an expanded base to July 1976 for a total of 40.4 million hours. Further, the original study viewed only major accidents; minor accidents have been added to this review.

Additionally, a review was made of previous efforts in this area to determine the origin and rationale for the various criteria levels.

This review showed that the current criteria is based on crash tests conducted on C-46 aircraft in 1949.

The probabilities developed in 1971 were conservative relative to actual occurrence over the past few years. Further, new probabilities were developed that show removal of the barrier net is feasible and appropriate changes are recommended to the current criteria. Commercial experience with barrier nets was also investigated and accidents where barriers were impacted are detailed.

FOREWORD

This report was prepared by Mr. Joseph L. Weingarten, of the Engineering Operations Office, Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson AFB, Ohio. The purpose is to update and validate data originally contained in AFFDL TR-71-139, "Air Cargo Restraint Criteria," and ASD TR-73-17, "Final Report - Air Cargo Restraint Criteria." This effort was accomplished to define forward restraint criteria for cargo aircraft and spacecraft, and to find origins and rationale for the criteria.

The effort originally viewed cargo aircraft only but was expanded at the request of the National Aeronautics and Space Administration to examine landing accidents in order to establish criteria for the space shuttle. The effort was further expanded to investigate aircraft Class II Modification installations.

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SECTION 1

INTRODUCTION

During World War II, a C-47 landed at Wright Field carrying a priority shipment of lead. An unloading crew climbed aboard as soon as the engines stopped. Seeing no tie-down straps, the unloading crew thanked the aircraft crew for removing them. The pilot commented, "We didn't use any, it's too heavy to move."

In the day of the C-47, restraint criteria was not a real concern. Cargo was secured to prevent shifting during flight and crash loads were basically not known. The cargo restraint criteria was not really developed until around 1950, yet to this day, the origin and rationale are unknown. Perhaps this report can provide a bit of insight into what was the intent in formulating this criteria.

While the exact origins of the criteria were not found, the basic origin was found and the history was traced back in the archives as far as possible with data available at Wright-Patterson AFB and the Air Force Museum. This trace has shown that the restraint level has gone up and down. The overall view has shown that war results in lowering the criteria while during peace time, the level has increased. While this review was primarily aimed at cargo operations, in essence, it has shown that a large spectrum of aircraft loads fall into the unknown rationale/origin category.

1. OBJECTIVE

This effort originally started as a review and validation of our current criteria as related to design problems on the Advanced Medium STOL Aircraft (AMST). This criteria was in part based on probabilities presented in AFFDL-TR-71-139, "Air Cargo Restraint Criteria" which was superseded by ASD-TR-73-17, "Final Report - Air Cargo Restraint Criteria". The final report contains the same data as the original effort, and was in an effect a printing with some expansion on implementation of recommendations of the first report. The remainder of the criteria came from an unknown source. To change criteria, the rationale should be known; yet in this case, it was not. An extensive literature search was undertaken to determine the origin of the criteria. While this was not totally successful, it has provided an insight into the background of where criteria most likely came from.

Further, the National Aeronautics and Sapce Administration (NASA) Space Shuttle Program was using Air Force structural design specifications and had a similar problem in defining system criteria for the cargo handling system and cargo to be carried on this vehicle. This effort was expanded to include the space vehicle.

Another area of concern that had been raised is Class II Modifications to our aircraft. These are temporary changes or alterations to an aircraft to support research, development, design change, and development and operational test and evaluation programs. Here too, the same type of review was accomplished.

2. APPROACH

During the 1971 study (AFFDL-TR-71-139), time did not permit the full literature search conducted for this effort. The search was conducted at the Wright-Patterson Technical Library, Air Force Museum, Deputy for Engineering files and through the Defense Documentation Center. The results of this effort are presented in Section II.

The re-examination of the 1971 study provided two opportunities; first, a validation of the original projections by viewing what has happened since various changes were enacted; second, a new set of probabilities can be computed by expanding the original data base of 1962 through June 1971 to July 1976. In view of this, the data presented in the report is being provided in both the original form and the expanded data base for comparison and convenience.

The 1971 - 1976 data will also be shown. The methods that were used in the 1971 study have been duplicated in developing the new overall data. Secondly, only in a case such as this where a study is reconducted, can you successfully use hindsight. The 1971 study viewed the probabilities relative to flight. However, in numerous situations; the definition as to what is a flight, time of a flight, and mission profile is truly not known. The intention of the use of flight as a base was to provide the probability on an average two hour flight of a crash. In view of change of average flight times, and other factors such as sorties and training times, the data presented within this report will follow the traditional method of presentation of this type of data, accidents per flying hours. Suggestions have also been made that the probabilities be viewed relative to sorties. While this data is available from 1966 through June 1976, it is not considered to be a usable data base. Sorties can consist of many landings and in training of many "touch and goes". It is not known which of these sorties are relative to training, cargo missions, and cargo and passenger missions. Using the accidents per flying hour will present the best data base and act as an equalizer. As a matter of information, the data on number of sorties will be provided. An addition to the study is the inclusion of minor accidents that underwent an unplanned forward G force but did not result in major damage or fatality. These are accidents that should have been included originally.

The data used for the accident review consisted of data collected during the 1971 study with updates to the present time frame and consisted of: computerized accident data summaries of all major and minor accidents of cargo type aircraft from 1962 to July 1976, from the Deputy Inspector General for Inspection and Safety, USAF, Norton AFB, California (IGDS); data on flying hours, landings and sorties from U.S. Air Force Accident Bulletins and IGDS files; data on mixed configuration flying hours for C-141 aircraft from Military Airlift Command files; major accident reports from late 1968 to February 1971 in Aeronautical Systems Division files, of 64 consecutive accidents; major and minor accident reports from mid-1973 to February 1976 in ASD files of 24 consecutive accidents, and C-130 accident data from a ten year time frame. The application of this data is discussed in Section IV.

3. OPERATIONAL CONSIDERATIONS

Several changes have been enacted based on a 1971 ASD/AFFDL study to restraint criteria. Further changes to the criteria were enacted as a result of mission needs. These actions are detailed in Section II. This has resulted in various documents with different values and confusion outside of the community directly involved in this subject. Further, the overall design and operational concept of the AMST and the space shuttle presents new problems related to the current design criteria. The changes and operation considerations are discussed in both Sections II and III.

SECTION II

HISTORY

Until this effort the best story as to the origin of cargo restraint criteria has been a rumor that in 1957, at the National Advisory Committee for Aeronautics (NACA) (forerunner to National Aeronautics and Space Administration (NASA)). Lewis Test Cite outside Cleveland, Ohio, a group of engineers crash tested some all metal aircraft in an attempt to develop a restraint criteria. That evening in a bar the criteria values were selected. We now know the names of some of the engineers, types of aircraft tested, and have some of the test data. This makes it doubtful the criteria was developed in the bar. The data developed is the same as values in current structures specifications and could have been its origin, but history shows it was only a confirmation of criteria developed a few years earlier. It is still unknown for certain where the basic criteria evolved. Information in this section will be provided in chronological order. Detail summaries of some of the source documents are provided as appendices.

1. THE FIRST TESTS

"From the earliest days the great dread of the aviator has been that of fire, a dread certainly not without foundation during the war, when a certain type of plane won the sobriquet of "Flaming Coffin" from the frequency with which it burst into flames in the air. Even now that airplanes rarely take fire in the air, the percentage of planes which burst into flames upon crashing is sufficient to cause the menace still to linger in the flyer's mind and it will continue to do so, until the possibility of such a disaster has been made practically non-existent." So began a report from the Engineering Division, Wilbur Wright Field to the Office Chief of Air Service in May 1925. The report was a preliminary document describing a series of 26 crash tests to determine the "exact cause of fire upon crashing of a plane." It was determined the best method was to run an airplane over a cliff. "A cliff hunt was engaged in, but acceptable cliffs seemed suddenly to have betaken themselves to parts unknown and when one was at last found, the expense involved made it out of the question." So the engineers proceeded to build their own cliff at Wright Field. The first crash was of a DH-4 aircraft with a 300 Wright engine on July 30, 1924 as shown in Figure 1. Unfortunately, the aircraft did not catch fire.

This effort was later expanded to where 83 crash tests were made from July 30, 1924 through September 30, 1926. This resulted in an Air Corps information circular "Aircraft Fire Prevention" published in 1927.

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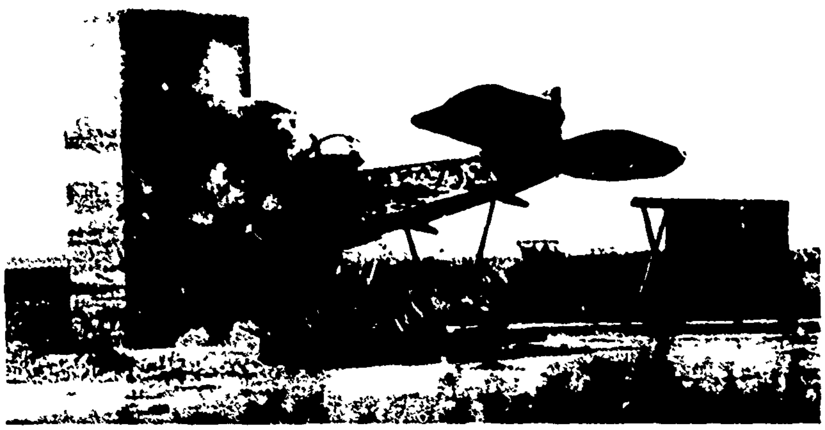


FIGURE 1

FIRST INTENTIONAL AIR CORP AIRCRAFT CRASH DH-4 WITH WRIGHT 300 ENGINE
1924

2. 1938 - 1950

The next document that was found was an Air Corps specification No. C-1803A. November 15, 1938. This document had an emergency load factor in forward direction of 8Gs. On 5 December 1941, the document was amended to where this value was changed to 6Gs forward. In the same time frame the ground loads handbook, ANC-2, October 15, 1941 was issued with the following load factors:

LIMIT EMERGENCY GROUND LOADS

2.W up 3W down

1.W aft 1.33W forward

1.W lateral

Factor of safety 1.5

The emergency ground load was defined as follows: "Emergency landing structures include those structural elements which are provided to protect the airplanes in the event of landings with a retracted landing gear and also the structural elements intended to protect the occupants of the airplane in the event of a 'turn-over'. Emergency landing structures extend into the airplane as far as emergency ground loads are critical."

The next document found was the Army Air Force Specification R-1803-4A, 22 October 1945 which specified the loads in accordance with Ground Loads Handbook; ANC-2. In Army Air Force Specification C-1803E, 2 April 1946, the requirement to meet ANC-2 was deleted. However, no load criteria was provided for transport aircraft but rather it indicated the load factors would be provided by the procuring activity as required.

The first report found in this technical area was published in 1943 by the Committee of Medical Research and Committee on Aviation Medicine of the National Research Council. This report was included in a comprehensive report number 440, dated July 9, 1945, also by the same committees. "The Relationship of Injuries to Structures in Survivable Aircraft Accidents." The report covers 110 aircraft accidents with fore and aft seating and 75 accidents with two abreast seating. These aircraft were high wing, 1000 to 1500 pound gross weight, basically built prior to World War II and did not utilize shoulder harness. During the twenty-eight month study period, there were 113 fatal accidents, 185 "survivable", 84 "serious" (where serious would be a minor accident today), and 343 minor accidents. If the minor and serious accidents were added together for 427 accidents, the ratios of minor to survivable to fatal now approach a trend very similar to those we find in the modern era as discussed in Section IV and shown here in Table I.

TABLE I

Percent Accident Ranges

TIME FRAME	MINOR	SURVIVABLE	FATAL
NRC REPORT 440	58.9%	25.5%	15.6%
ASD-TR-73-17	40.4%	26.2%	33.4%
1976 THIS REPORT	54.0%	12.5%	33.5%

The report indicates a large number of seat belt failures, as these were 5 to 6G systems. The report recommended an increase to 10 to 12G for both the belt and seat but this was not based on any real computation.

It becomes apparent that the G that should be used was not known. In a revision of Handbook ANC-2A, March 1, 1948 the load factors were deleted and they did not reappear until 1953 and will be discussed later. One additional factor must be recorded from these early documents, that of ditching loads. For example, in Army Air Force Specification No. C-1803E, "Stress Analysis Criteria", 2 April 1946 a limit load factor of 5.33 G is provided for water landing. The ultimate load factor would be the limit factor multiplied by the factor of safety of 1.5 or 5.33 x 1.5 = 7.995 or approximately 8Gs.

3. 1950's

The 1950's saw the first real efforts to develop restraint criteria. When the decade started, the military still did not have a firm criteria. The Civil Air Regulations, Part 4a, "Air Plane Airworthiness", 7 April 1950, required seats be installed to withstand 6Gs and the only reference to cargo stated "suitable means shall be provided to prevent the contents of mail and baggage compartments from shifting." Therefore no real criteria existed. By 1953 this document had undergone a major change. The seat criteria was changed to:

Upward	2.0G	Downward	4.5G
Forward	9.0G	Sideward	1.5G

With the attachment point of a seat or seat belt to be 1.33 times above this factor and that cargo should meet the requirements of the seat level. The current airworthiness standard (Part 25) of the Federal Aviation Regulation still contains the same criteria. It therefore appears that between 1950 and 1953 something resulted in development of civil requirements that are still in use today. It is possible that unpublished data from a NACA series of crash tests started in 1949 became the rationale for this change. This became extremely significant when another series of crash tests were conducted in 1957 using the same type of aircraft. Just as the first series of tests (1924-1926) were to determine causes of crash fires, so were these conducted from 1949 to 1952. The tests were conducted by the NACA on four C-46 and 13 C-82 aircraft to investigate fuel spill and resultant fires during a take-off accident without becoming airborne. Each test aircraft carried 1050 gallons of fuel and impacted at speeds ranging from 80-105 MPH. These tests are covered in NACA TR1133 "Mechanism of Start and Development Aircraft Crash Fires." However, the report does not provide any crash force data. Time velocity data, however, is provided and could have been used to determine force loads.

During the same time period as the crash fire tests Major John Stapp conducted a series of 53 experiments to determine human level of tolerance to G forces. This is the first significant effort to determine what loads should be to provide full protection to a human in a crash. While the effort did not provide final values to design against but basically indicated a level of 17G with a rate of onset of 1000G per second while using standard air force harness and 38G with a 1350G per second onset rate using an added inverted V-leg strap. The report further shows at a lower rate of onset higher G levels can be withstood. Further details are presented in Appendix A. This Appendix A data on basic levels of human tolerance together with tests on aircraft structural strengths provide a close relationship that may have resulted in the higher G levels. It further shows an attempt to provide protection to the highest possible level, based on human and aircraft tolerance.

In the August 28, 1953 issue of Specification MIL-A-8629 "Airplane Strength and Rigidity" loads criteria was once again referenced to ground loads handbook ANC-2. The October 1952 version of ANC-2 did not have any emergency loads listed. However, by December 1954 the military had established in Specification MIL-S-5705, "Structural Criteria, Piloted Airplanes Fuselage, Booms, Engine Mounts and Nacelles", a complete set of criteria for a variety of circumstances. These are listed in Table II.

TABLE II

MIL-S-5705 Structural Criteria Values

	Forward	Side	Up	Down
Cargo/No Passenger	3	1.5	2	4.5
Cargo/w Passenger	8	1.5	2	4.5
Fixed Equipment in Passenger				
Compartment	16	4	4	8
Fighter	32	4	4	8

Again, as with the civilian counterpart document we do not know how these numbers evolved. It is possible the 8G forward is related to ditching loads, or the 1949 crash tests. The 3G forward is most likely derived from the 1949 crash tests. A new factor is the 16G forward for fixed equipment. This is any equipment within the cargo compartment attached to the aircraft, for example a fire extinguisher would have to be restrained to this 16G level. A possible fallout of Major Stapp's effort.

Specification MIL-A-8421 "Air Transportability Requirements, General Specification For" was published in November 1955. This document provides the criteria for equipment to be transported on military aircraft with a 3G "taxi load" and an 8G "crash load". Taxi load was most probably a wrong terminology and should have been called landing crash loads. At this point in time, basically all documents were providing the same criteria with the only difference being the 8 and 9G between military and civilian requirements. In 1969, Specification MIL-A-8421 and in 1971, Specification MIL-A-8865 were changed to 9G to end this difference and achieve commonality.

We now enter a new phase, that of crash testing aircraft to determine the physics of a crash. It appears that the first crash tests related to crash dynamics occurred in 1953. These tests conducted by NACA were on three light aircraft with a maximum weight of 1220 pounds and are detailed in Appendix B. One interesting result of this test was the relationship of floor to seat loading. A dummy in the seat saw G loads ranging from 1.2 to 1.5 times higher than the aircraft floor directly below the seat. The loads on the dummy were 32G, 46G and 50 G with aircraft impact at 42, 47 and 60 MPH respectively.

The next effort is a study entitled "Seat Design for Crash Worthiness". This report provides an in-depth review of aircraft seat design relative to human survival and aircraft crashes. An interesting part of this report is a discussion of longitudinal deceleration of transport (C-46) and cargo (C-82) aircraft. This data most probably was developed as part of the fire tests conducted in 1949 as discussed in this section as no other crash tests had been conducted since those tests. Table III provides the data from the report. From this it appears that the changes to both civilian and military documentation in the early 1950's must have been based on these fire tests of C-82 and C-46 aircraft. While this data is presented, the main emphasis of that effort was on designing seats and the relationship of the seats to fuselage floor.

The aircraft seats are the structural links between the passengers and crew and fuselage floor. If a person were fastened rigidly to the seat and the seat rigidly to the floor, then the person, seat, floor and aircraft would move as a unit. However, this is not the case. The person is in reality a free moving body within the restraint system of the seat. Further, the seat is made of flexible members with some movement above the floor. The actual condition of the events are best explained by the model developed for the study which is quoted in Appendix C. Basically the human would undergo a deceleration after the aircraft deceleration when he impacts his restraint. "The peak passenger deceleration can be nearly 1.8 times the peak airplane deceleration". The more rigidly the person is fastened into the seat the lower this ratio. The reason for this ratio is dynamic overshoot of the person

TABLE III

Acceleration of Floor

Transport	Impact angle, deg	Impact velocity, mph	Impact point, distance from airplane nose, in.	Location of accelerometers, distance from airplane nose, in.	Accelerations: Longitudinal		Accelerations: Normal		Accelerations: Lateral		Acceleration corrected to 95-mph impact velocity		Average duration of pulse	
					Magnitude of peak, g	Time of peak, sec	Magnitude of peak, g	Time of peak, sec	Magnitude of peak, g	Time of peak, sec	Average longitudinal, g	Normal, g	Longitudinal, sec	Normal, sec
Low-wing pressurized	5	81	605	270	2.5	0.190	2.5	0.265			2.9	2.9	0.33	0.35
	15	93	80	250 360 485 680	10 11 7 9	0.120 .122 .125 .125	15 10 10 8	0.095 .075 .150 .170			9.3	15.3 10.2 10.2 8.2	0.22	0.18
	29	97	30	185 335 490 685	20 22 20 17	0.145 .145 .150 .155	25 18 12.5 10	0.105-0.175 .155 .160 .195			19.3	24.4 17.6 12.2 9.8	0.23	0.21
Low-wing unpressurized	12	87	108	243 312	3.5 3.5	0.265 .260	9 9	0.275 .275			3.8	9.9 9.9	0.12	0.09
		63	172	243 312	7 7	1.653 1.680	40 28	1.653 1.680	7 17	1.653 1.680	10.5	6.0 4.2	0.13	0.13
	16	109	72	243 312	15 13	0.195 .185	18 16	0.180 .215			12.2	15.7 14.0	0.25	0.22
High-wing unpressurized	4	95	156	Long 138, norm 140	6	0.150	12	0.030			6	12	0.17	0.17
	16	91	56	Long 340, norm 541	15	0.070	10	0.300			15.7	10.5	0.10	0.07

(NACATN 4158)

against the seat restraint resulting in an increasing delta velocity as the aircraft stops and the person continues forward until he impacts his restraint. This raises the question of relationship between fixed equipment, cargo and the seat in the aircraft. This could be the reason behind a 9G cargo system and 16G seat system (9 X 1.8 = 16.2) and raises questions of fixed equipment installation with G load requirements the same as seats.

Appendix D describes a series of tests conducted by NACA in 1957 on Navy FH-1 aircraft to determine level of restraint to protect the crew in a fighter. While we are discussing cargo aircraft, some of the data in this report is interesting in that the restraint results confirmed the 40G used in the military specification in the forward direction for the fighter aircraft. However, it also showed that the vertical G exceeds human tolerance levels with the 40G forward level. To a degree, it is further confirmed that dynamic overshoot of the man/seat versus aircraft structure is a valid theory.

Also in 1957 a series of crash tests were conducted on C-46, C-60A and C-82 aircraft, by NACA. The results of this effort are contained in NACA technical note 4158 "Accelerations in Transport Airplane Crashes". While I have stated that our criteria was based on the 1949 fire crash tests, it appears this effort using similar aircraft confirms the restraint criteria particularly when you view the average longitudinal G loads for low wing pressurized aircraft in Table III.

The data was obtained by crashing transport aircraft of three types. The tests were conducted to determine accelerations relative to landing/takeoff crashes to determine the survival limit. While the report does not indicate the number of tests conducted, it appears there were eight.

The longitudinal accelerations were measured on the fuselage floor at a station 270 inches from the nose of the pressurized transport during the 5° crash. The impact speed for this crash was 81 miles per hour. A maximum acceleration of only 2.5Gs was reached 0.190 second after nose impact. The pulse lasted about 0.3 second and produced a velocity change of 10 miles per hour.

Additional tests were also conducted on unpressurized aircraft. One test was to simulate a ground loop and other tests were the same as the first type test described above. Higher "G" loads were found in the crashes of unpressurized aircraft because of plowing into the ground. Table III contains a consolidation of the various crash data. This table also contains an item where the "G" loadings have been corrected to 95 MPH impact velocity. Again, it can be very clearly seen where the data contained in this corrected column for the low-wing pressurized transport corresponds to the values in civilian and military specifications and is presented in Table IV.

TABLE IV

Aircraft Acceleration Relationships

	G LOADS		
	"Ground Loads"	"Crash Loads"	"Aircraft Structural Limits"
*TN 4158 Crash Tests (Table III)	2.9	9.3	19.3
MIL-A-8865	3.0	8.0	20.0
MIL-A-008865 (After 1971)	3.0	9.0	20.0
Civilian Airworthiness Regulation	3.0	9.0	NONE

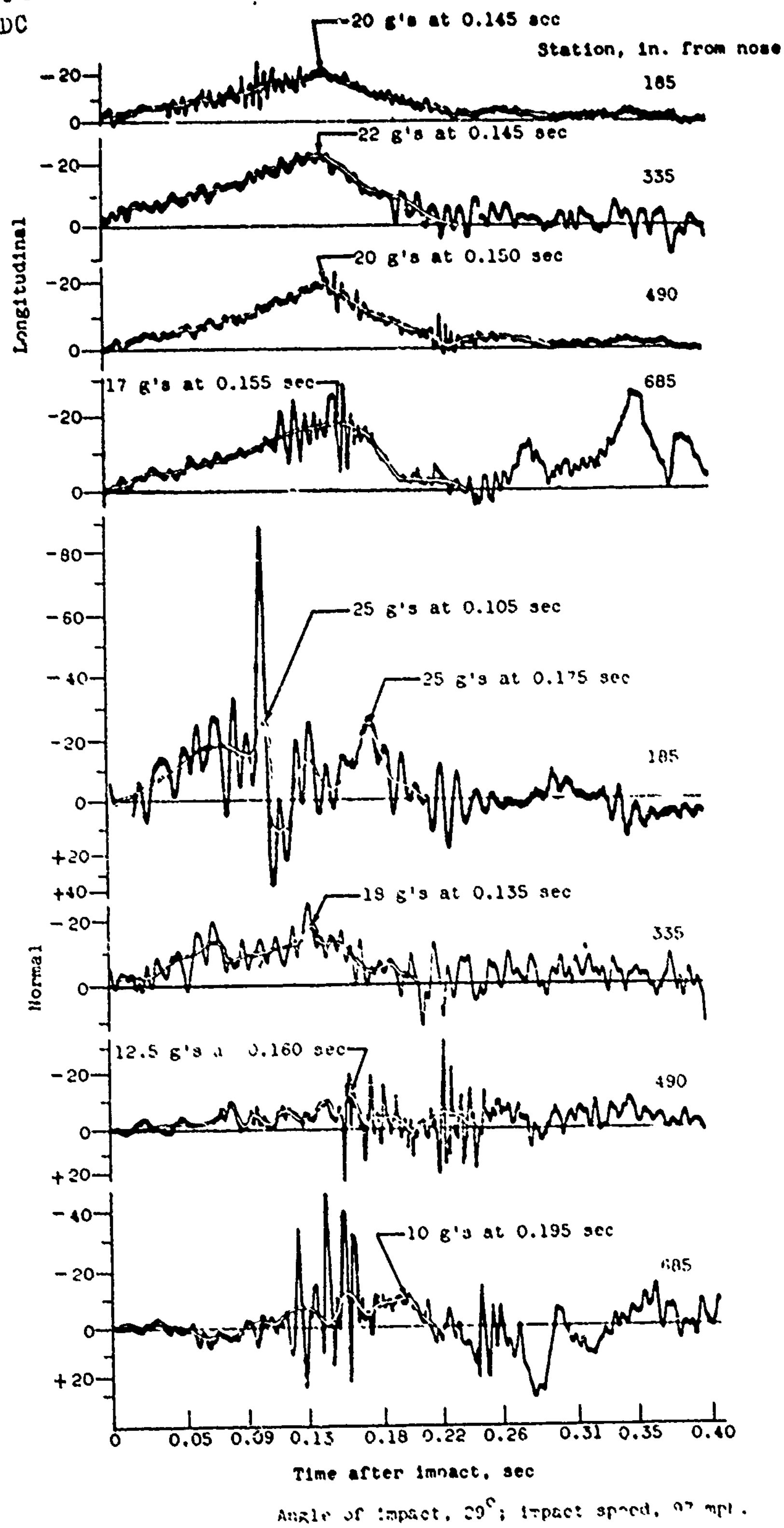
*CRASH TEST LOADS ARE ALSO BASED ON AN ANGLE OF IMPACT AS FOLLOWS:

5°/2.9G, 15°/9.3G, 29°/19.3G.

The NACA data in Table IV and throughout the report is based on a method to average the force loads. This was accomplished by drawing a line through the data trace as shown in Figure 2. This shows the degree of "averaging" done by NACA in development of the force levels. Peak forces were considered similar to noise and random vibrations that did not influence the overall aircraft structure.

4. 1960's

Two major events occurred in the sixties, crash testing of a Lockheed model 1649A, Super Constellation and a Douglas DC-7 both in 1965 (Appendix E and F). The tests were conducted to determine crash loading factors on "jet size" aircraft. The significant results were that the basic physics of the crash forces did not vary from those discussed by NACA covered in Appendix C. The cargo experiments in these aircraft experienced failure of instrumentation. However, some data was obtained. A closer look at the cargo experiments show the following. Two 3040 pound cargo pallets were placed in the aircraft as shown in Figure 3. The pallet's weight was 1040 pounds with a 2000 pound cargo load. Figure 4 provides the G loadings both fore and aft of the cargo loads on the aircraft floor and of both cargo loads.



Angle of impact, 29°; impact speed, 97 mph.

ACCELERATION MEASUREMENT

NACA TN 4158 FIGURE 2

L-1649 FUSELAGE INSTRUMENTATION & EXPERIMENTS

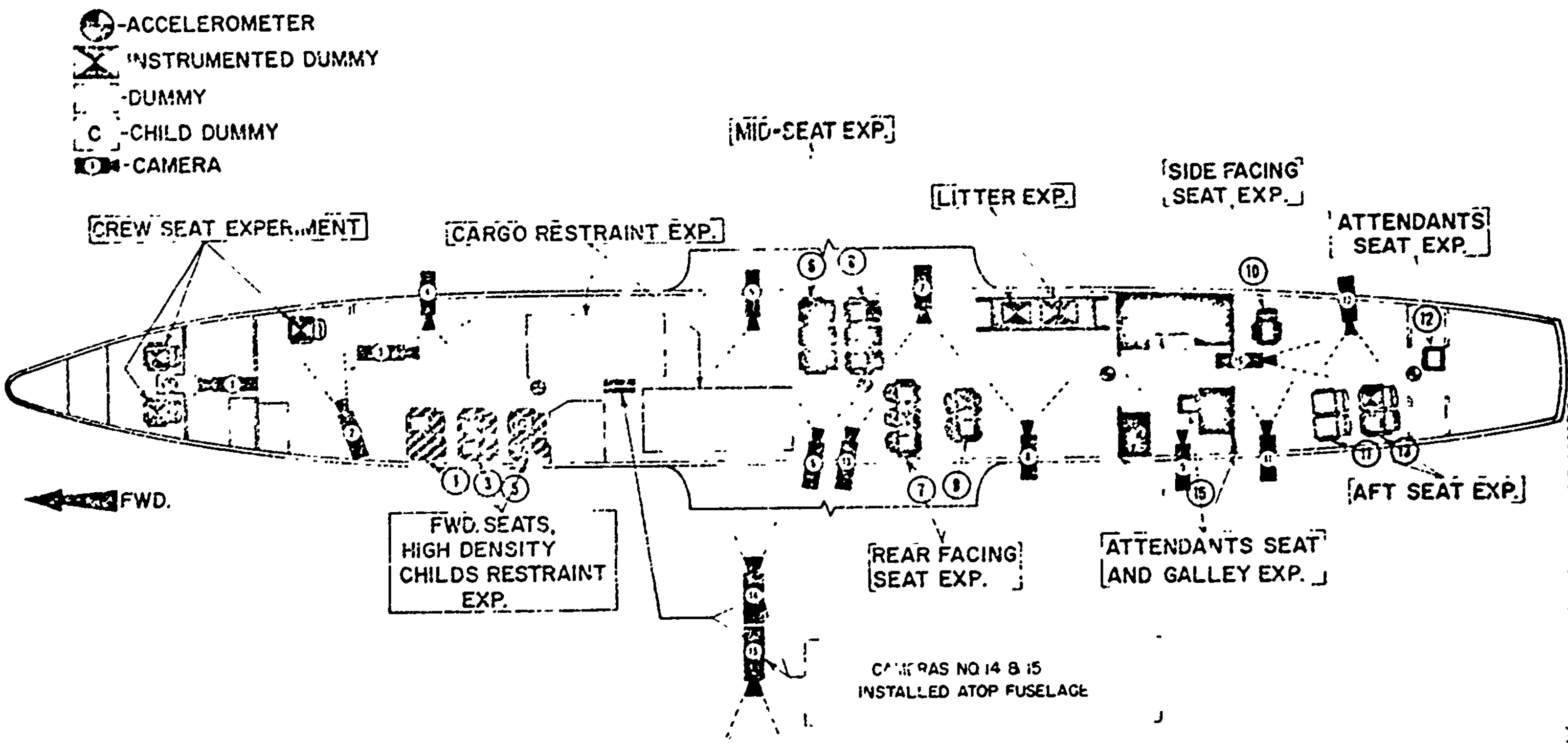


FIGURE 3 - ONBOARD EXPERIMENTS, CAMERAS AND FUSELAGE ACCELEROMETER LOCATIONS

(FAA-ADS-38)

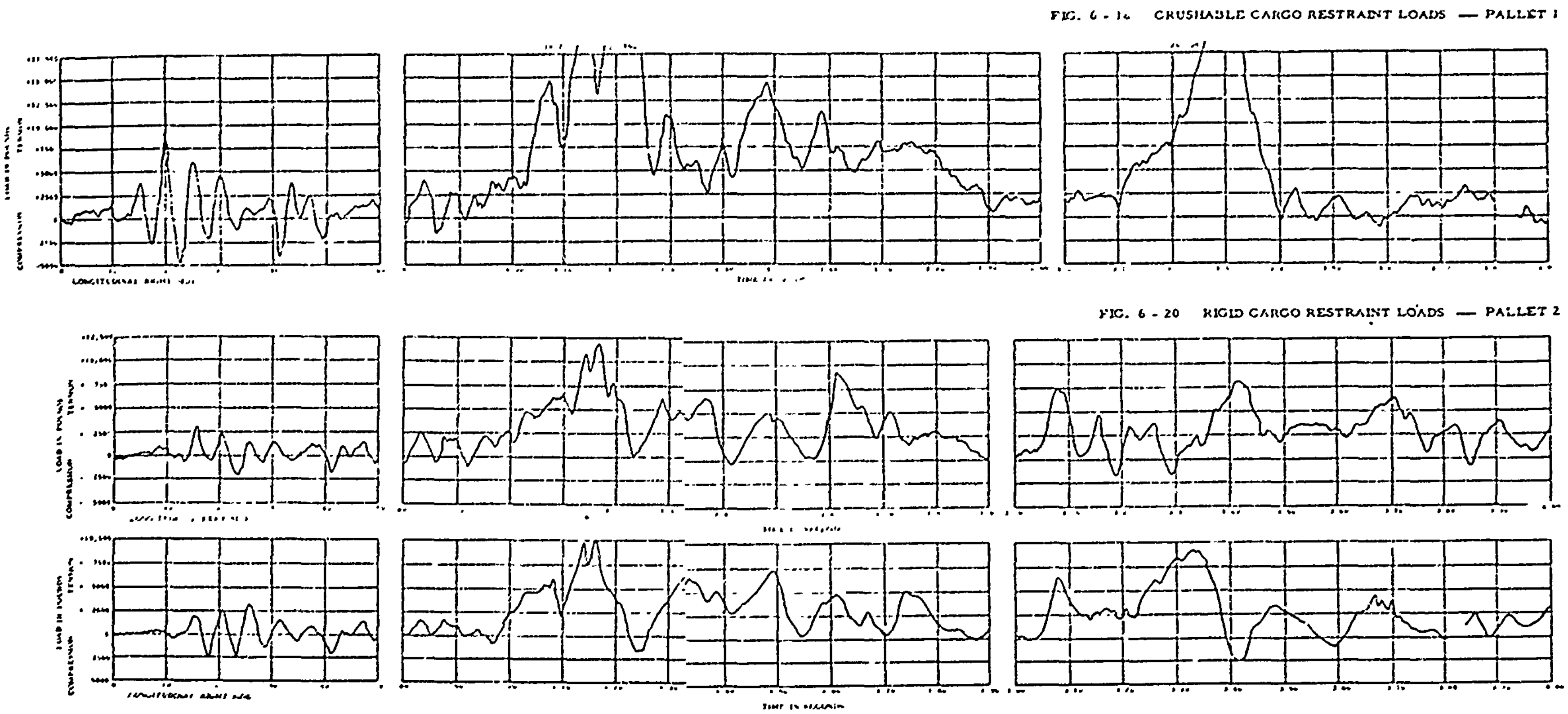


FIGURE 4

CRUSHABLE CARGO RESTRAINT LOADS, 3040 POUND PALLET

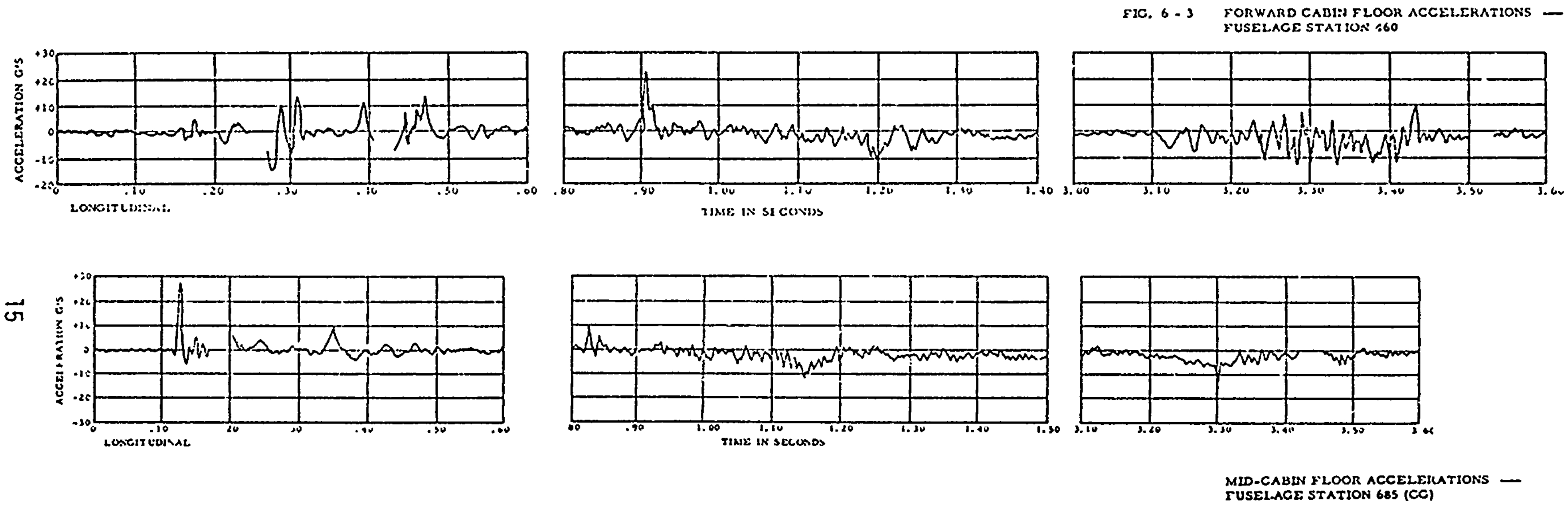


Figure 4 (Con't)- CRUSHABLE CARGO RESTRAINT LOADS-
3040 POUND PALLET,

Most of the continuing efforts of this decade are related to concepts of improving passenger and crew survivability. This resulted in reviews of all past data and in some cases even a view of selected civilian and military aircraft accidents. One of the problems found with this data is that they failed to view the entire spectrum of accidents. For example, a major effort by Haley, et. al. viewed only accidents described as "at least one person was injured in the accident to the extent that he was hospitalized for 24 hours and/or received bone fractures, excluding toes, fingers, and nose", and "at least one person did survive the accident, or at least conclusive evidence indicated that survival would have been possible if proper body restraint had been used. The fact that the fuselage structure was not crushed to the extent to preclude survival was taken as one indication that survival should have been possible. The severity of the accident, including estimated velocity change, impact angle and estimated G levels, provided further evidence of survival potential". The study did not view minor impact accidents, such as "landing gear failures after touchdown, or any other impacts in which the decelerative forces on the occupants do not exceed about 4G "or catastrophic impact forces". This resulted in viewing accidents only from approximately 4G to 20G. The civilian accidents came from a ten year time span, 1955 through 1964 and military from 1962 through 1965. This resulted in studying a total of 61 accidents. A crash loads environment study indicated that between 1959 through 1963 the total number of civilian accidents was 326. Of the 61 aircraft crashes, two-thirds had a fire that caused approximately one-half of all fatalities. It was also found that 58% of all the aircraft had a fuselage break and this increased to 68% for aircraft that impacted at 10 degrees or greater. However, the overall results of this effort must be very carefully utilized due to the severe tailoring of the data. One interesting G factor, was the use of average G force which is defined as one-half of the maximum level over a time frame.

Dr. John Avery in a 1965 study entitled "Cargo Restraint Concepts for Crash Resistance" viewed past history crashes with the special object of developing criteria for survivable crashes of helicopters and the C-7 aircraft. Based on prior crash data, a dynamic forward restraint diagram was proposed. This was a triangular shape with a peak of 25G with a rise from zero to peak in 0.125 seconds and same time for fall back to zero.

The report further views possible cargo nets for a C-7 type aircraft as a means to protect passengers. Four type of net systems are viewed including both direct restraint into aircraft attachments and use of load limiters built into net systems. The proposed restraint systems of this report were not adopted.

In 1966 another effort viewed the method for using load factors. This effort resulted in a report entitled "Aircraft Cargo Restraint System" which cites a "major fault" with current restraint systems and claims that to provide adequate restraint, 39Gs as a static force should apply. The report claims that 39G static force is equivalent to a 25G dynamic response. The report further shows how the tie-down would be accomplished on various Army loads to meet this "correct" criteria. The study also reviewed various designs on energy absorbing devices that could be added to restraint systems to allow higher G loads.

The 39G criteria proposed by the above report was not accepted for use. That same year a major change occurred in operational use of restraint criteria. The 8G criteria was causing problems during combat operations in South Vietnam, in extended turn around time. As a matter of operational expediency the restraint criteria was lowered to 4Gs. This corresponded to the 4G criteria that was used for airdrop with parachute recovery. While the airdrop load factor is another item whose origin is unknown, it is believed that this 4G forward factor is a fallout of securing cargo to platforms to withstand ground impact. The 8-9G criteria did not apply to these loads because they could be jettisoned prior to a crash. The 4G criteria realized risks involved, such as crash on take-off where jettison could not be accomplished relative to mission needs.

The criteria was lowered to 4G on combat missions or related exercises for aircraft such as C-130 and C-141 due to the jettison capability for all types of cargo. With time this filtered its way into a wide variety of aircraft missions. For example, many C-130s flew "tactical missions" and therefore used the 4G criteria, except with passengers on board.

Additional efforts in the sixties were related to consolidation of past efforts. One work of significance was published in 1967 entitled "Crash Survival Design Guide". It provides detail into human tolerance levels, relates to levels of survivability accidents and not occurrence, and is covered in Appendix G.

5. RECENT ACTIVITIES

In November 1969, Lockheed-Georgia Company conducted a study for Air Force Systems Command as part of the USAF Mobility Support Forces Study Program. The prime objective of this effort was to provide weight and costs incurred by the aircraft-installed material handling equipment under various conditions. The following aircraft were viewed: C-5, C-141, C-130, C-123, and C-7. Four levels of restraint were identified. The first group in Table V is that level of maximum acceleration that can be realized in the cargo compartment without being in a failure condition. Any level above these would be a crash condition as defined in this report. These levels for all the aircraft studied are listed in Table V. The other levels were those proposed for Boeing 747 and Lockheed 500, as well as basic military aircraft levels. These also have been presented in Table V.

The cost estimates from this effort are not included as they would be totally unrealistic in today's time frame. To provide a relationship, weights are provided for each aircraft system and restraint load factor in Table VI. In the C-141, two sets of data are presented. One is for a full face net across the entire aircraft fuselage. This is the type of net that would be required to meet full restraint requirements and is fully discussed in Section III. Basically, the cargo is secured at 3G with 9G protection provided by other means such as one of the barrier nets. The Van Zelm net in real use only covers the forward cargo load and does not prevent cargo from flying over the first load.

<u>TABLE V</u>

Aircraft Limit Load Factor

DIRECTION AIRCRAFT	C-5	C-141	C-130	C-123	C-7	ULTIMATE CRASH LOAD FACTOR		
						SPECIFICATIONS COMMERCIAL	C-5 TYPE 3G	OTHER 9G
Forward	1.2	1.05	.94	.99	1.0	1.5**	3.0**	9.0
Aft	.35	.46	.38	.64	.44	1.5	1.5	1.5
Up	1.3	3.1	1.36	1.5	2.8	2.5	2.5	2.5
Down	3.3	5.1	3.6	4.1	4.0	5.0	5.0*	5.0*
Side	.83	.72	1.0	1.0	.97	1.5	1.5	1.5

*Military system is 4.5 down

**Cargo compartment

(SCLAP-TR-69-63)

TABLE VI

Weights for Various Restraint Systems

AIRCRAFT	LOAD FACTOR FORWARD 1.5	3	9	
C-5	3103	3880		
C-141	964	1669	2449	Full Net Across Aircraft
C-141	589	1294	2079	Van Zelm Net Only Over Cargo
C-130	816	881	1077	
C-123	372	410	814	
C-7	575	585	598	

ALL WEIGHTS IN POUNDS (SCLAP-TR-69-63)

The Van Zelm design is also discussed in Section III. With the completion of this effort no challenge had been made to the original criteria. Until this point in time all effort seems to verify the criteria. Yet no one asked the question; how often does this crash condition occur, what are the risks involved in movement at various G loads? In 1971 a joint Aeronautical Systems Division/AF Flight Dynamics Laboratory study effort was started to define the various risk levels and resulted in Technical Reports AFFDL-TR-71-139 and ASD-TR-73-17.

"An aircraft accident can be termed an unlikely event; yet, through analysis of past accident history, predictions can be made of the occurrence of an accident and related events." Basically, the study followed this thesis. The data base covered the period from January 1960 to July 1971, and viewed the total flying time (33 million hours) of all AF cargo aircraft. During this period there was a total of 497 major accidents. Of these, 377 were crashes where the aircraft underwent an excessive "G" load or there was an in-flight accident. The accidents that were not included in the 377 were for such things as the landing gear being raised while the aircraft was on the ground, causing major damage.

The interesting thing was that the study results did follow a pattern and provided a distribution that could be used. For example, Table VII shows during which mission phase an accident occurs and the percentage of non-survivable accidents. Non-survivable accidents such as flying into mountains accounted for 84.1%, and 28.4% of the accidents occurred during flight (this comprises climb, cruise, and descent). On the other hand, look at the high amount of landing accidents and the very high survivability rate.

TABLE VII

Accidents Phase

Mission Phase	% of Accidents	% Non-survivable
Take-off	22.6	34.0
In-flight	28.4	84.1
Landing	44.9	8.6
Go-around	4.1	33.0

Landing accidents are usually at slower speeds, within an airport area, and even on the runway; as such the G loads encountered in these accidents are generally lower. When viewing the approximate G loadings, 40.4% were below 3G. Most of these accidents were during landings, 26.2% were within a range of 3G to approximately 20G (cargo aircraft non-survivable limit), and the remaining 33.4% of the accidents are non-survivable. It should be noted that this data differs from other reports relative to crash loads. The primary reason for this difference is selection of a data base. This report covered all crashes of USAF cargo aircraft; most other efforts have looked at selected accidents and will result in a significantly different result. A closer look showed that approximately 8.3% of the crashes occurred between 3 and 9G. Based on this and additional data, probabilities were that one crash would occur on an all cargo aircraft every 500,000 flights. If the flight was a mixed cargo/passenger mission, the possibility of crash was one in every 1,500,000 flights. Between 3 and 9G, the probabilities that a crash would occur on an all cargo aircraft is one in 1,500,000 flights. On a mixed cargo/passenger flight the possibility of crash is one in every 4,500,000 flights, again between 3 and 9G.

It became apparent we were operating under an extremely conservative criteria, and that a reduction could be effected without much risk. Based on this data, the Air Force, in December 1972, directed massive changes in the restraint criteria. The change was to 3G with some exceptions.

Why change? The overriding factor was the low risk and a large cost savings potential. For example, under the old system, equipment that was to be air transported, such as trucks, jeeps, AGE, etc., had to be built to a 9G level although they seldom were. This requirement is now 3G, with a restraint reduction in design and production cost of the item. It can also result in an item weight reduction. Another factor is that this now becomes a reasonable factor to design against. Tie-down on aircraft has also become simpler and another important facet is that now all three cargo aircraft (C-130, C-141, and C-5) are rated at 3G for cargo. Another important area is in design of future cargo aircraft. These aircraft will be built with a 3G rail onboard. In viewing the Advanced Medium STOL (first aircraft to be built under the new criteria), it has been estimated the savings will be 1000 pounds.

The most interesting factor found was the relationship between different Gs. At first glance that statement does not make sense. How can there be different Gs? It is a question that has been with us for 35 years. One should not talk in terms of Gs, but of force. During FAA crash tests, it was found that instrumentation on pallet loads and seats recorded different Gs at the same lateral location in the aircraft. This can be explained as follows: A seat is hard mounted to the aircraft floor while the pallet is free to move on rollers within the rail system. This freedom allows the absorption of energy as the pallet presses against the rail locks. Further, the shifting of cargo and give in the netting system acts in the same way. The result was that the cargo reacted to approximately one half the G force of the seat. Another fact is that the crushing of the aircraft itself has the same effect, where the tail would see a very low G force compared to the nose. An aircraft with 20G pilot seats, 16G passenger seats, and 9G cargo restraint, is in reality compatible.

Throughout the history of doing this study many people could not relate to a G load. The following is to provide a basic guide of loads incurred during various phases. In general, under a normal landing the G forces tend to be between 0.1 and 0.2G; under an assault landing condition it is a little higher. The maximum landing loads that the C-130, C-141, and C-5 can generate are 0.94, 1.05, and 1.20G, respectively. This is assuming full reverse thrust, full braking, and a loose dirt runway. For any load above these, the aircraft is in a crash condition as defined by this report. This can also be viewed as the distance required to stop these aircraft at various G loads. Table VIII provides this information for three different landing speeds. It is interesting to note that a C-5 with a touchdown speed of 130 knots would almost achieve a 3G level in its own length of 247 feet. While this assumes linear deceleration, it still indicates distance relationships.

TABLE VIII

Landing Forward G Forces

DISTANCE REQUIRED TO STOP (FEET)*

Speed at Touchdown (Knots)

G	130	110	90
1	731	520	349
2	365	260	175
3	244	173	116

* Source: Air Force Inspection and Safety Center

6. NUCLEAR

Before reviewing the implementation of the new criteria, it is necessary to have a short background of nuclear restraint criteria for air movement in cargo aircraft.

Nuclear weapons are restrained to 4G for movement. As with other restraint factors, the true origin of this is not fully known; however, it is believed this comes from loads incurred during ditching of an aircraft. The concept was that while the bomb could not go off, it would at least remain with the aircraft and could be recovered. On land, in a high G crash, it would break loose and be thrown away from the aircraft fuselage and the likely fire that would ensue. Again, the prime objective is to recover the bomb with least effects to the surrounding area. While it was proposed during the 1971 study that nuclear restraint be the same as other cargo, a determination was made not to accomplish that change but to review this on an ongoing basis. To date this change is still in review.

7. IMPLEMENTATION

ASD, in its recommendations, recognized that the equipment design factors to allow air movement were regulating the design of military equipment. This was a classic case of the tail wagging the dog. Wouldn't it be better to have part of the burden of air transport built into the aircraft rather than the equipment? This was based on a fleet of 1000 airplanes versus many times that in other military equipment. At the same time ASD recommended that 9G was a reasonable level of restraint for protection of passengers, yet it was recognized that it could not be achieved under all circumstances, particularly not in combat conditions. If air transportable equipment was built to 3G, it could not be secured to 9G. This resulted in adaptation of the method used by commercial airlines in their cargo operations - use of a net for high restraint where possible with a low G cargo system.

However, because of landing on dirt runways, and assault landings, ASD and AFFDL proposed to maintain a minimum of 3G restraint criteria. This was based on a landing mishap at 2G with a 1.5 safety factor. Further, based on the very low risk factors, it was felt the then current system was over protective.

To meet the above, the USAF issued the following:

"ALMAJCOM 1882/72

1. Air cargo forward restraint criteria, with the exception of nuclear weapons cargo, are lowered to a minimum of 3G. Nuclear weapons cargo will continue to be restrained to a minimum of 4G forward.

2. When passengers or nuclear weapons cargo are carried forward of general cargo, an HBU-8/A barrier net shall be positioned in front of the general cargo to achieve a minimum of 8G forward restraint.

3. Air transportability design requirements for items designed for air transport shall be revised to eliminate the 9G emergency forward restraint criteria. The 3G forward flight and taxi load air transportability design equipment remain unchanged."

Further, in July 1974 and December 1972 two actions were taken by the Chief of Staff that amended the original order as follows:

> "The supplementary 8G forward restraint requirement for cargo when personnel are seated in front of or alongside cargo, exclusive of missions carrying nuclear cargo, may be waived to 3G only during the deployment, employment or redeployment of US combat forces personnel and DOD civilians participating in combat, contingency, joint airborne/air transportability training or exercise operations directed by major command or higher authority. Only essential operations, direct support, and command and control personnel required to accompany the cargo on each aircraft will be transported under this waiver."

It should be noted one error exists in the study, only major accidents were examined. A large number of minor accidents occurred during the period covered by the study and these should have been included. The difference between a minor and major accident is basically related to man-hours to repair the aircraft or damaged beyond repair. For example, if man-hours of repair was less than 900 hours for a C-130, C-141, or C-5 but more than 150 hours, it would be a minor accident, above the 900 hour level, a major accident. An example of a possible minor accident is landing with the gear up. Since most of these accidents are in the low G range it adds a conservative value to the original predictions. The review in Section IV has included all accidents.

8. SUMMARY

We assume from past reports that the 9G restraint criteria was based on the degree of protection afforded passengers in the crash of an aircraft (C-46) at approximately 95 MPH, that the survivable limit is approximately 20G, that a relationship exists between the passenger and fuselage, and fuselage and cargo in the ratios of 1.2 - 1.8 to 1 and 1 to 0.5 respectively. Also a more compact fuselage such as a fighter can withstand higher G loads and afford a much higher degree of protection than a larger cargo aircraft.

Finally restraint criteria in the past was based on providing maximum possible protection without any relationship to occurrences of crashes.

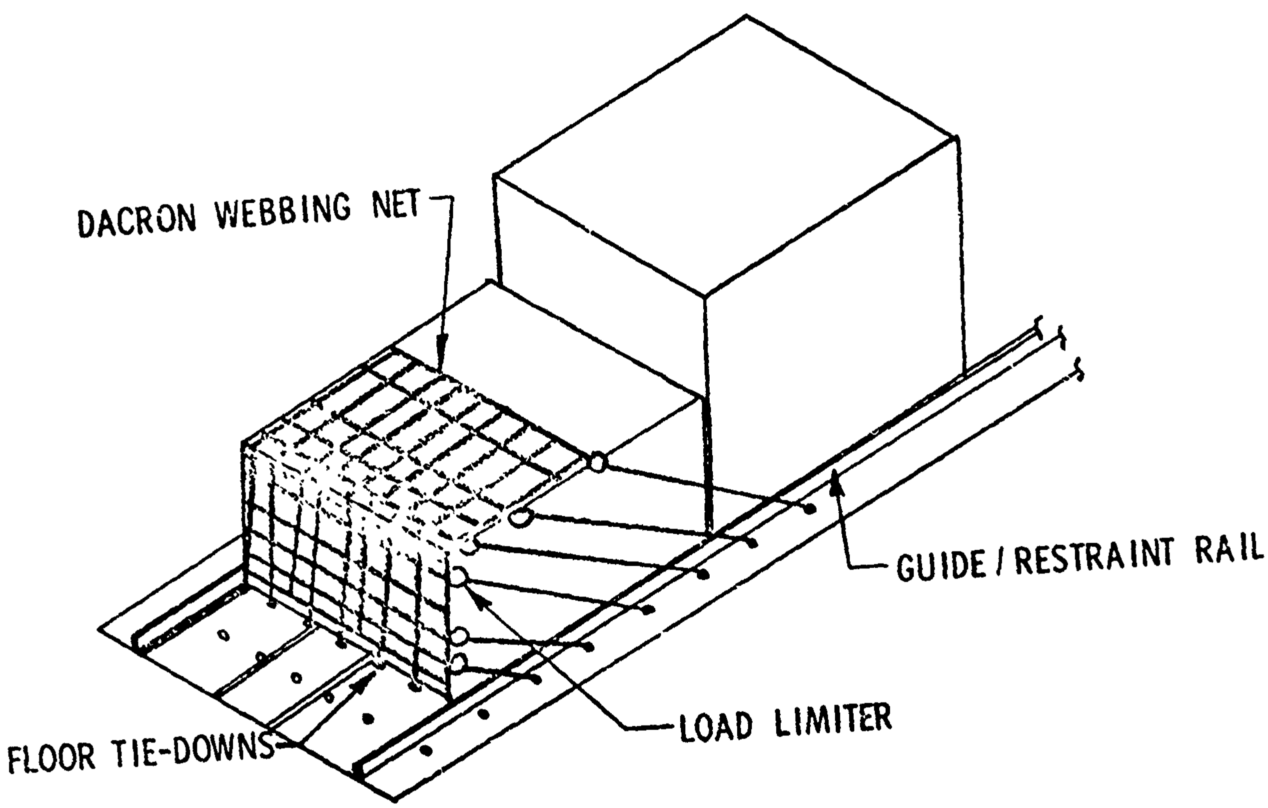


FIGURE 5 - VAN ZELM BARRIER NET

SECTION III

OPERATIONAL CONSIDERATIONS

The development of a criteria must also consider the real world operational concepts and limitations.

1. CURRENT OPERATIONS

Currently all equipment that is designated air transportable is built to meet the requirements of Specification MIL-A-8421, "Air Transportability Requirements", general specification for which requires 3G in the forward direction. This is in accordance with the Chief of Staff direction. This equipment is moved in military aircraft and secured at 3G. As stated in Section II a barrier net is required to provide 8G protection when passengers are seated or when nuclear weapons are forward of general cargo. The barrier net currently in use is called the Van Zelm net (Figure 5) and it provides a limited degree of protection. The net as shown in Figure 5 is placed over the first cargo load if the first pallet is low profile; cargo in the rear with a higher profile can go over the top of the net in a crash condition. Therefore, the net would provide very limited protection. Even if the net were erected on a high profile load, during a crash some cargo could come around the sides of the net. Figure 6 shows the interior of a C-141 that underwent an explosive decompression. A Van Zelm net was installed over a low profile load; under a high G crash condition the cargo could have come over the top of the first load. When is the net needed? It is used mainly on routine traffic missions. Military Airlift Command records show these currently account for approximately 10-12% of the C-141 hours. In 1969 and 1970 this mixed load was approximately 2% of the total flying hours of the C-141. On the C-130, from September 1976 to January 1977, approximately 10.5% of the flying hours were in the mixed mode.

Air Force aircraft are built to meet Military Specification MIL-A-00856, "Airplane Strength and Rigidity Miscellaneous Loads". The current specification for cargo aircraft requires that cargo systems be designed for 3Gs. However, where cargo and passengers can be collocated, and passengers are seated adjacent to or forward of the cargo, the restraint shall be supplemented with a net-type restraint

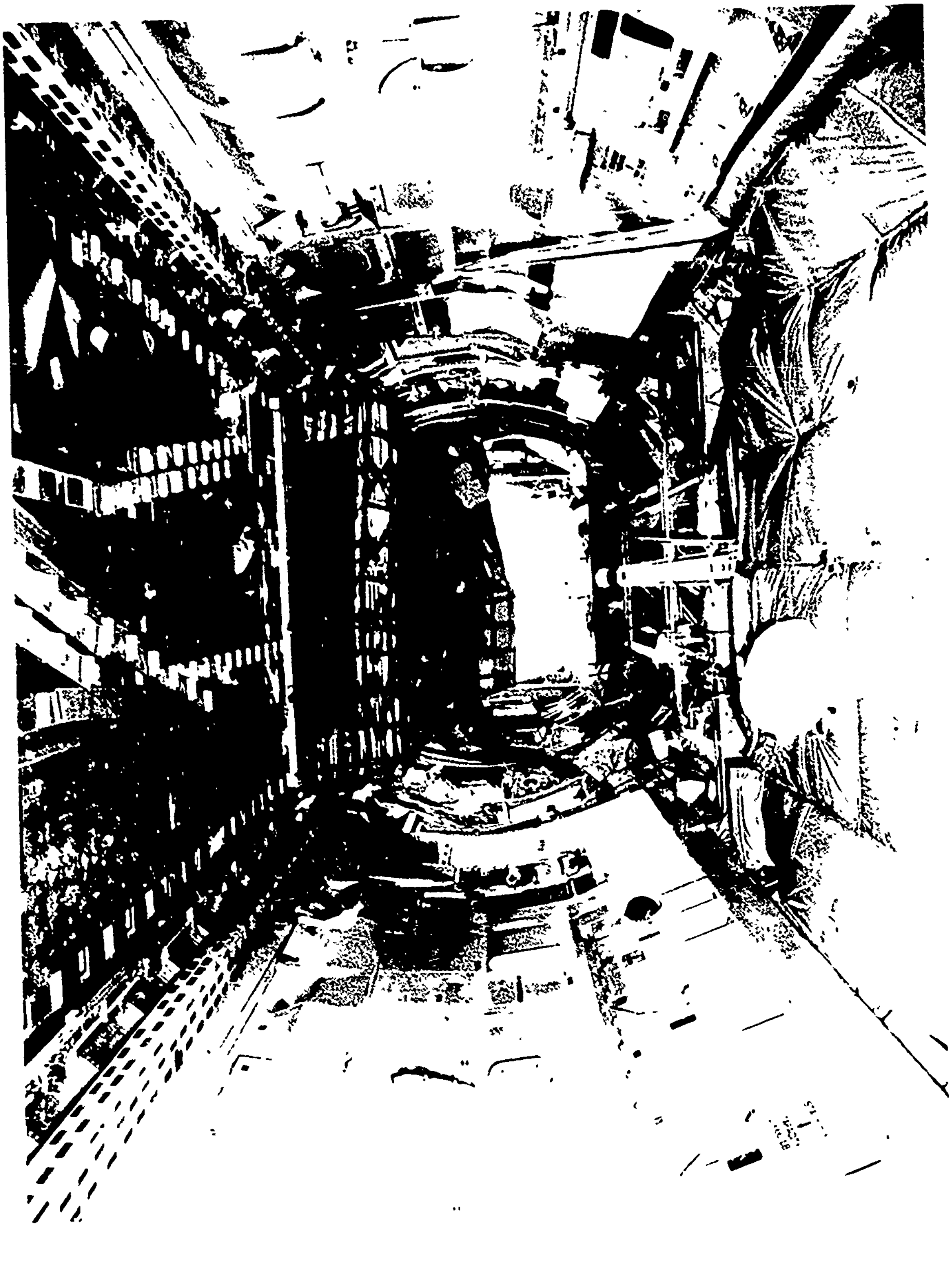


FIGURE 6
C-141 INTERIOR AFTER EXPLOSIVE DECOMPRESSION

system, so that an 8G system is provided. This follows procedures used by commercial airplines where cargo is secured to 1-1/2G or 3G and a 9G barrier net is installed for crew protection in accordance with Part 25 of Federal Aviation Administration Regulations. In designing a new aircraft it would require a full face barrier net built into the structure of the aircraft to meet this specification. Figure 7 provides a view of such a net. This is reviewed in more detail in the discussion on the Advanced Medium Stol Aircraft.

This specification also required that when any equipment is intalled in a manner "wherein failure could result in injury to personnel or prevent egress, or are collocated with passengers, their respective airframe attachments and carry-through structures shall be designed to be commensurate with the seat installation load factors, the airplane design load factors or the following minimum load factors or the following minimum load factors acting separately, whichever are greater:

Longitudinal	16.0 forward, 16 aft
Lateral	8.0 right and left
Vertical	16.0 down, 8.0 up"

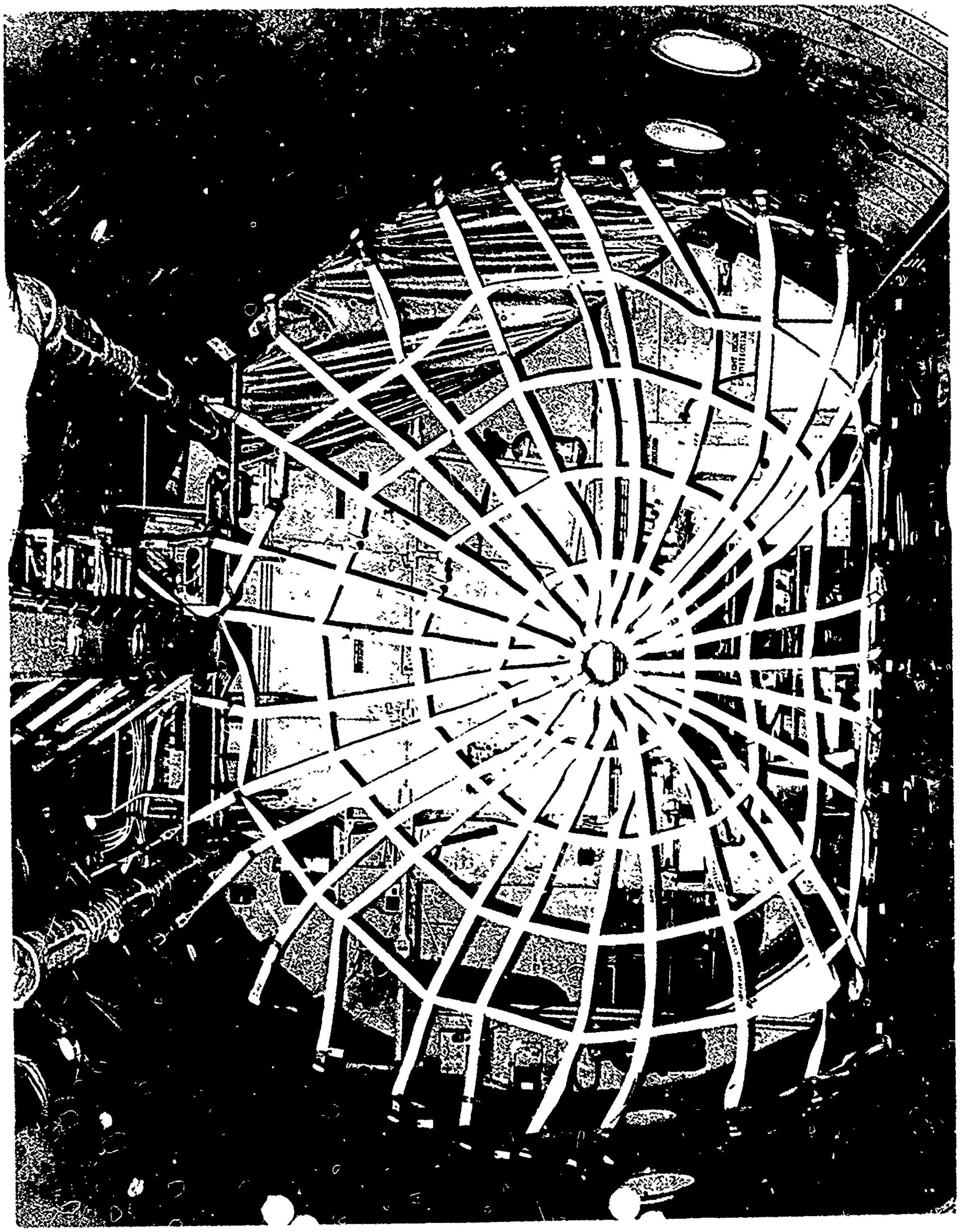
This has presented problems in installation of Class II modification. A Class II modification is a temporary modification to an aircraft for testing purposes. In some cases, for example, it would consist of a test console. This console would have to be installed at 16.0Gs on a cargo aircraft, while on a fighter it would be installed at 40.0Gs where failure could result in injury to personnel. These load factors are basically at the same installation level as required for seats, yet we have previously discussed the relationship of dynamic overshoot of a person relative to fixed equipment within an aircraft. Current criteria would result in Class II modified equipment to be installed at a seat installation level which is higher than the surrounding standard equipment. In most cases, these factors were not applied to the actual aircraft installation.

2. FORCE LEVELS

The following is a list of forces and the application of these factors as related to both the Air Force and civilian cargo aircraft. Each is G value used for the forward direction.

1-1/2G - The value used to secure cargo in most commerical air cargo aircraft where a barrier net is used to protect the crew. Where the crew is seated above the cargo deck, no additional restraint is required.

3G - All military equipment designated air transportable is built and secured in aircraft at this level. Further, aircraft cargo handling systems will be built to this level on future aircraft. An 8 or 9G barrier net must be erected between the passengers and cargo. This does not apply to crew members, personnel alongside cargo, or in combat or training exercises to simulate combat. Cargo to be airdropped is secured to this level. Equipment mounted on the aircraft where the failure



FIGUFE 7 - FULL SIZE BARRIER NET

will not result in injury or block egress to passengers or crew may be installed at this level.

4G - All nuclear weapons are secured to this level for air movement.

8G - The C-130 aircraft cargo handling system is built to this load factor. Until the advent of the C-141 aircraft, this was the primary restraint factor. The 463L cargo pallets are also built to this level. New pallets will be built to 3G.

9G - The C-141 aircraft cargo handling system was built to this load factor to obtain civil aircraft certification. This level of protection is also required for passengers seated forward of cargo. This is the required level for any barrier net system. In commercial aircraft, passenger and crew seats are secured to this factor as required by the Federal Aviation Administration.

10G - Stowable and side facing troop seats are required to meet this level.

16G - All fixed and removable miscellaneous equipment, which in the event of a crash can insure personnel, must be secured to meet this level. Many passenger seats are built to this level for military use.

20G - If no seat specification is called for in the aircraft specification, such as the 16G seat, this load factor must apply, as well as the level used for Air Force crew seats. This is generally considered the non-survivable limit crash load factor for cargo type aircraft.

40G - For aircraft other than cargo type aircraft where no seat specification is stipulated, the seat must be capable of withstanding this force level. This is considered the limit of human tolerance and a person could survive a crash up to this level.

3. ADVANCED MEDIUM STOL AIRCRAFT (AMST)

The AMST presents a new problem relative to movement of personnel and cargo. This wide body aircraft is configured to carry passengers along the sides facing inward with cargo down the center of the aircraft (Figure 8). Under some conditions, passengers may also be seated forward of cargo as is currently done on the C-130 and C-141.

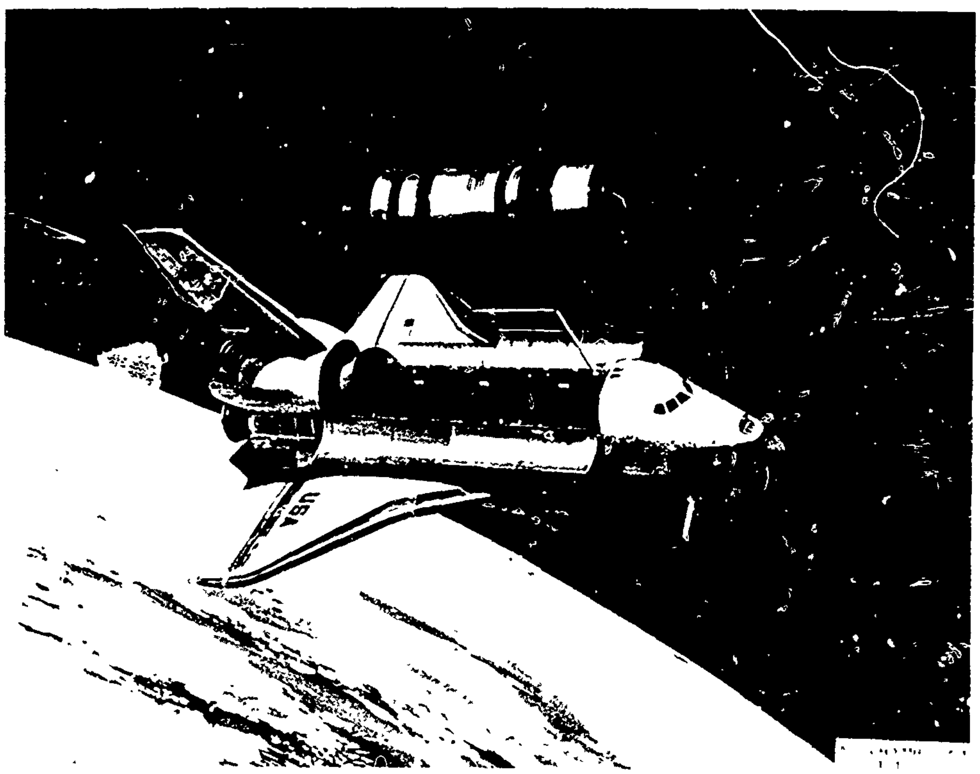
To meet both the current operational requirements and the military specification lowers the utilization of this aircraft. If cargo were to be carried over the full length of the cargo compartment, no passenger could be seated alongside the cargo. Further, if only a partial cargo load was placed in the aircraft, a full net would be required. All seats aft of the load position cannot be used and three feet forward of the net cannot be used. This is to allow the net to move in a crash mode. Because of the various load configurations, a series of net positions would be required. This would result in needing three tie-ins and a full face net for a weight increase of approximately 1000 pounds. This does not include the dead weight from seats that cannot be used.

AMST INTERIOR TROOPS SEATED ALONGSIDE CARGO

FIGURE 8

4. SPACE SHUTTLE

The Space Shuttle, as shown in Figure 9, presents a new set of circumstances. It is a cargo spacecraft with a basically unpowered landing approach similar to that of a lifting body. It is possible the shuttle would be required to return cargo to earth. To what level should both the cargo and cargo restraining system be built? The only guidance available to NASA was the structural military specifications and FAA airworthiness requirements. This resulted in a 9G criteria for the shuttle. In viewing the return portion of flight, any failure outside the landing phase would be catastrophic. In view of high landing speeds, to stop the spacecraft to a level of 9G, a linear deceleration would require a stopping distance of approximately 210 feet or about its own length. At the same time, the 3G criteria was also unrealistic since the rockets have an actual thrust factor of 3.3Gs, requiring restraint to at least this level. In view of this, landing accidents and acceleration ranges will be viewed in Section IV, paragraph 7.



SPACE SHUTTLE

FIGURE 9

SECTION IV

AIRCRAFT ACCIDENT DATA AND PREDICTIONS

In the original study AFFDL-TR-71-130, it was stated "an aircraft accident can be termed an unlikely event; yet, through analysis of past accident history, predictions can be made of the occurrence of an accident and related events". It appears that the predictions made in the 1971 study were conservative in that the number and type of accidents have remained within projected crash limits.

1. OBJECTIVE AND SCOPE

This re-examination of the same subject provides two opportunities, first to validate the projections provided in the original effort and second to broaden and correct the study base.

First, let us review the original effort from the viewpoint of any needed corrections. In the original effort, minor accidents were not included, those that underwent excessive forward G loadings should have been included to provide an overall viewpoint. While this has been done in this effort the effect will be to add a degree of conservatism to the data base since accidents of this type are in the low G range. Another area of concern has been the presentation of probabilities of related flights. An attempt was made to provide a more reasonable factor rather than flying hours. Several comments have been made to relate accident probabilities to sorties. However, this would be even less accurate than use of landings, since a sortie is made up of an unknown number of landings. Since many accidents occur during landings and touch and goes, it is not possible to form a consistent base for all of the data, all probabilities will be presented in terms of flying hours. The data from the original study will be converted back into flying hours to provide a basis for comparison.

2. DATA REFERENCE

The data used includes the original set of data used in AFFDL-TR-71-139 and later on-going data to provide this update. The overall base is as follows:

All major and minor accident data of Air Force Type C and T-29 aircraft from 1962 to July 1976 contained in the computerized accident data system maintained by the Deputy Inspector General for Inspection and Safety, USAF, Norton Air Force Base, California (IGDS) were used in the following analysis. Total flying hours, landings and sorties were also obtained from this system. Accident reports available at ASD were 64 consecutive major accident reports from late 1968 to February 1971 and 24 consecutive major and minor accidents from mid 1973 to July 1976.

3. AIRCRAFT ACCIDENTS

Air Force data is provided on all aircraft accidents and not crashes. For the purpose of this study a crash is defined as an excessive G force in the forward direction. Within this data base the accidents are listed as either major or minor with the difference being the number of hours required to repair the damage. The number of hours that set the category limit also vary according to the aircraft type. An accident can further vary to an aircraft sitting in a hangar where an earthquake resulted in light fixtures falling on the airplane causing minor damage or a mid-air collision resulting in total loss of the aircraft where no ground crash occurred; i.e., break up in air. These accidents have one item in common; they did not undergo any excessive forward G force. The total number of accidents from 1962 to July 1976 was 799 and of these, 461 were crashes. The following shows a relationship of these accidents to crashes from the different studies conducted and explained in the report.

	ACCIDENTS	CRASHES
Major 1962 - July 1971	415	315
Major July 1971 - July 1976	61	55
Minor 1962 - July 1976	323	91
Total 1962 - July 1976	799	461

It can be seen, particularly in the minor accident category, far fewer of the accidents were crashes than in the major category. The time period covered includes both peacetime and combat operations and covers 34,990,250 flying hours and 20,886,468 landings. The yearly totals are provided in Table IX developed from AFISC data.

4. ACCIDENT DATA ANALYSIS

Within this paragraph data from the original study will be provided for comparison. Since that data was based on major accidents, the information will also be presented in both this manner and for total accidents.

USAF CARGO AIRCRAFT OPERATIONAL AND ACCIDENT DATA											
YEAR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Flying Hours	2782448	2704753	2560735	2547584	2679931	2746575	2154969	2949422	3571259	3138024	2752801
Landings	1259322	1232249	1219465	1312710	1390809	1392426	1741231	1903264	1987126	1648590	1807739
Sorties	NA	NA	NA	NA	NA	NA	937555	1139561	1403169	1597158	1055293
Major Accidents	41	40	47	38	46	47	60	55	49	36	27
Minor Accidents			25	9	11	7	9	7	15	15	15
Major Accident Rate/Per 100000 Hr	1.47	1.47	1.84	1.49	1.71	1.71	1.90	1.36	1.37	1.14	.98
Major or Minor Rate Per 100000 Hours			2.81	1.84	2.12	1.96	2.18	2.10	1.79	1.63	1.52
YEAR	1971	1972	1973	1974	1975	First Half 1976		1962-1Jul76 TOTAL	1960-1Jul76		
Flying Hours	2349821	2080675	1623855	1380627	1181631	267741		34990250	40477451		
Landings	1735111	1344942	1183395	1095812	903461	220387		20886468	23378039		
Sorties	841535	624486	497411	472195	392855	94723					
Major Accidents	18	17	6	13	10	2					
Minor Accidents	10	14	10	11	5	0					
Major Accidents Rate Per 100000 Hrs	.76	.81	.36	.94	.84	.74					
Major and Minor Rate Per 100000 Hrs	1.19	1.48	.98	1.73	1.26	.74					

TABLE IX

a. Crashes per 100,000 hours:

Major Accidents	1960-1970	1.17
Major Accidents	1971-1976	.71
Major/Minor Accidents	1962-1976	1.32

b. Accident by Mission Phase:

The 799 accidents were analyzed according to mission phase type for both the total ˙ ˙dent spectrum and for nonsurvivable accidents for all three time fram. .ategories as shown in Table X and summarized below:

Mission Phase	% Accidents			% Nonsurvivable Accidents		
	1962-July 1971 Major	6/71-6/76 Major	62-6/76 Total	62-6/71	6/71-6/76	62-6/76
Takeoff	22.6	17.7	19.6	34.0	18.2	16.6
In-Flight	28.4	30.6	31.3	84.1	76.4	36.3*
Landing	44.9	35.5	44.1	8.6	13.3	5.8
Go-Around	4.1	16.1	5.0	33.0	40.0	31.0

*The inclusion of minor accidents in this category includes, for example, bird strikes, weather damage, or loss of a panel where the aircraft can make an uneventful landing. If we were to remove these types of accidents, this value increases to 61.7%.

With the exception of a higher number of go-arounds, the data is basically the same. In the 1971 effort, 57 accident reports were reviewed to determine ranges of G landings. These ranges were 0 to 3G, 3G to nonsurvivable (N/S), and those that were nonsurvivable. Where nonsurvivable is basically defined at the 20G level, loss of life due to fire was not considered in determining the level of nonsurvivability. If persons on board survived the impact and later died due to fire, the crash was considered survivable for purposes of this study. The G ranges are approximations based on average decelerations. This is very similar to determinations computed by NACA in formulation of the original criteria. A review was accomplished of ASD files currently available. A total of 24 accidents were reviewed where the aircraft involved underwent an unusual forward G force. These accidents occurred from 1974 to June 1976. The forward G loadings were also broken down for 3-9 and 9-N/S levels for the 1976 data, as follows:

TIME FRAME	0-3		3-NS		NS
1971 Study	40.4%		26.2%		33.4%
1976 Study	54%		12.5%		33.5%
	0-3	3-9	9-NS	NS	
1976 Study	54%	8.3%	4.2%	33.5%	

The 1976 data includes minor accidents while the 1971 does not. A total of 76 major and minor accidents that occurred from July 1971 to 1976 were reviewed from the summaries in the IDGS data. This was also accomplished for ninety C-130 accidents in the original effort and a total summary is provided below.

CRASH FORCE ESTIMATES

	0 to 3G	3G to N/S	N/S
1971 Cargo Aircraft Accident Reports	40.4%	26.2%	33.4%
C-130 Accidents	48.4%	25.8%	25.8%
1976 Cargo Aircraft Accident Reports	54.0%	12.5%	33.5%
Combined Estimates	49.0%	14.0%	36.0%

Crash force estimates were not computed for the C-141 or C-5 aircraft as the frequency of crash is too low to provide a data base.

Of the 64 aircraft in the 1971 study, 20 had cargo on board and six had a mix of cargo and passengers. Of the 24 aircraft in this review group, (1974-1976) four had cargo on board and two had a mix of cargo and passengers. This resulted in a total of 88 accidents where 24 (27%) had cargo on board and 8 (9%) a mixture of cargo and passengers.

5. JULY 1971-1976 VALIDATION

The 1971 study provided probabilities of crash under various conditions in the major accident category. The data was provided on a flight basis as shown below with a flight having a duration of two hours.

Event	Projected No. of Occurrences	Probability Per Flight	No. of Flight For 1 Occurrence
Cargo Aircraft Crash	35	0.000023	43,500
Crash at 3G to N/S Level	35 x 2.62 = 9	0.000006	168,000
Crash at 3G to N/s Level with Cargo on Board	9 x .27 = 3	0.000002	500,000
Crash at 3G to N/S Level with Cargo and Passengers	9 x .09 = 1	0.00000066	1,500,000

For the Jan 1971-July 1976 time period, the number of flying hours was 8,884,350 hours with 6,483,108 landings for an average flight of 1.37 hours. This is a shorter average flight than the two hours for 1962-1971 time frame. Therefore, the above chart is converted for comparison of hours to the 1971-76 time frame. From the full data available, it was not possible to project the actual final two categories. It was not known if passengers or cargo were on these aircraft. However, in the table below, it is clearly shown that the projections of crash were conservative relative to the actual number of crashes. During the time frame, 55 cargo aircraft crashed, and five of these were estimated to be in the 3 to 20G range. The actual hours from July 1971 to July 1976 is 7,709,439 hours and was used for determining the number of hours for an occurrence in that time frame.

MAJOR ACCIDENTS

Event	1962-July 1971 Probability Hours For One Occurrence	July 1971-76 Actual Occurrence
Cargo Aircraft	87,000	140,172
Crash at 3G to N/S Level	336,000	1,541,888
Crash at 3G to N/S Level with Cargo on Board	1,000,000	N.A.
Crash at 3G to N/S Level with Cargo and Passengers	3,000,000	N.A.

Of the 24 accidents in the range below the N/S level no injuries or fatalities were recorded as a result of moving cargo. The Air Force Inspection and Safety Center, in a review of C-130 aircraft, found that in a 1972 crash a loadmaster was injured from shifted cargo and in a 1975 crash a loadmaster received major injuries when equipment broke loose.

6. CRASH PROBABILITIES

The occurrence level has shown the probabilities were conservative in the major accident range. As stated previously, the minor accidents were also deleted from the original study. The probabilities presented here combine major and minor accidents and view the time frame from 1962 to July 1976. One of the reasons for the conservatism in the probabilities is due to the decline in the number of accidents per 100,000 hours as shown in Table IX. This has been the result of better aircraft systems and Air Force Flight Safety Programs.

The accident rate for both minor and major accidents since 1962 have been 1.32 accidents/100,000 flying hours. This equates to one accident in every 75,750 hours of flying operations. This relates to the entire spectrum of crashes. Both the catastrophic (N/S) and the less than 3G crashes are not within the risk analysis as these areas are not under question. The 3G to N/S level accounts for approximately 21% of aircraft crashes. This can be further broken down into mission of the aircraft to where 27% of cargo flights had cargo on board and 9%, a mixture of passengers and cargo.

$$\text{Probability} = \frac{\text{No. of Occurrence}}{\text{No. of Flying Hours}}$$

Where number of occurrences is 1.32/100,000 hours.

Event	Projected No Occurrance/ 100,000 Hours	Probability Per Hours Operation	No Hours Flying For One Occurrence
Cargo Aircraft Crash	1.32	0.0000132	75,750
Crash 3G to N/S Level	0.28	0.0000028	357,143
Crash at 3G to N/S Level with Cargo On Board	0.076	0.00000076	1,315,789
Crash at 3G to N/S Level with Cargo and Passenger	0.025	0.00000025	4,000,000

While the probability data shows the risk of an occurrence for a crash at the 3G to N/S level as being very small, other factors must also be considered. The data base, crashes with exact G levels, is not large enough to provide projections ..om 3G to 9G and 9G to N/S level. Since 1972, the C-141 has flown a mixed cargo/passenger mission under the current requirement for a net. This mission accounts for approximately 12% of the C-141 flying hours and from July 1971 to July 1976, it is 1.7% of the Air Force cargo aircraft mission. Both of these factors would tend to increase significantly the number of flying hours for one occurrence. For example, if these factors are used the following results. Of the 24 accidents in the 1974 to July 1976 time frame, 8.3% were between 3-9G and 37.7% from 9 to N/S level. This would result in a crash potential of one in 4,347,826 hours of operation for a crash between 3G and 9G with cargo on board. In this same crash level, but with a mix of cargo and passengers, the crash potential becomes one in 21,008,403 hours of flying.

The Air Force Inspection and Safety Center also accomplished a review of C-130 accidents over a ten year time frame. These accidents were of destroyed aircraft from 1967 through 1976, for a total of 33 occurrences. This data only related to destroyed aircraft and is not comparable to the data presented elsewhere in this study. Of these aircraft, four had G forces below 3G, 19 between 3 and 20Gs, and ten over 20Gs.

If the above data were viewed with the Military Airlift Command's approximate 10% passenger/cargo mix for the C-130, the number of flying hours for one occurrence is one in 2,900,000 hours of operation. This aircraft is a good example when viewing the tactical type of cargo aircraft.

In examining the AMST, several assumptions can be made to determine potential crash in which a barrier net would be used. The trend for aircraft crashes has been decreasing and we can assume the AMST being a more advanced aircraft with improved flying qualities and slower landing speeds would have a good safety record. The trend of accident rates has been downward as shown in Figure 10. For this projection of a crash level of one per 100,000 hours is assumed. While the current projected usage of the aircraft does not include routine channel traffic, it must be assumed it would be used in this configuration in the future and at the same level as the C-141 or 10%. The net is of value only for the 3G to 9G level, to add conservation to the projection. The crash force level of 3G to N/S level is used and at a 20% of all crash rate. This results in a probability of occurrance of one crash per 5,000,000 flying hours, with cargo and passengers mixed in the routine channel traffic mission.

7. LANDING ACCIDENTS

Using the data from July 1971 to July 1976, a review was made of all landing accidents to determine G ranges. During this time period, a total of 29 crashes occurred. Of these, 26 were less than 3Gs while the remaining three were in the N/S range. Most landing crashes are of a nature where the gear failed or a belling landing occurred. This results in the aircraft skidding down the runway for a considerable distance with a low forward G factor.

8. ACCIDENT TRENDS

The accident level relative to flying hours has, to a degree, decreased over the past few years as shown in Figure 10. This level is approximately one-half of the level in the 1960's. In viewing the overall

CARGO ACCIDENT RATE

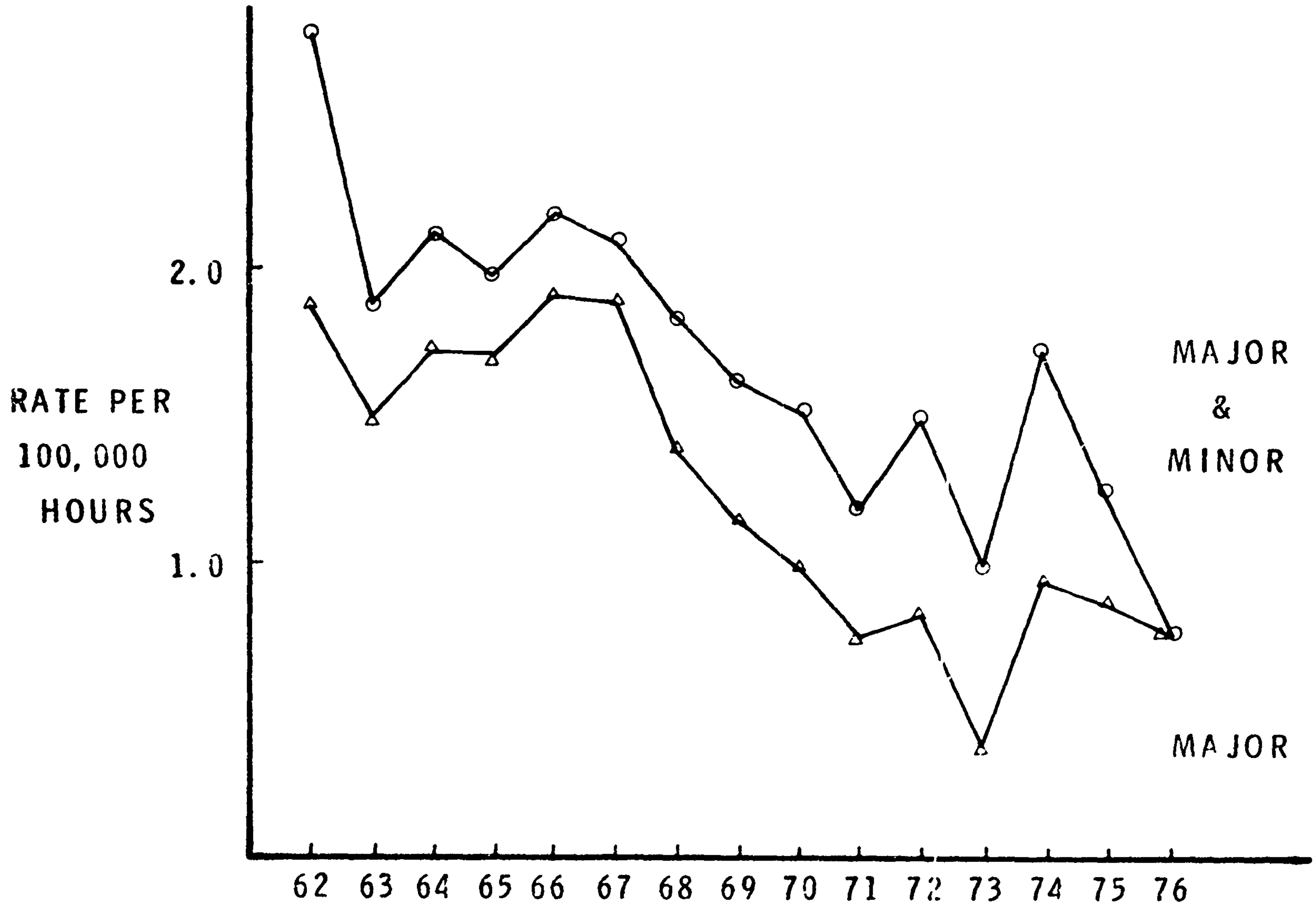
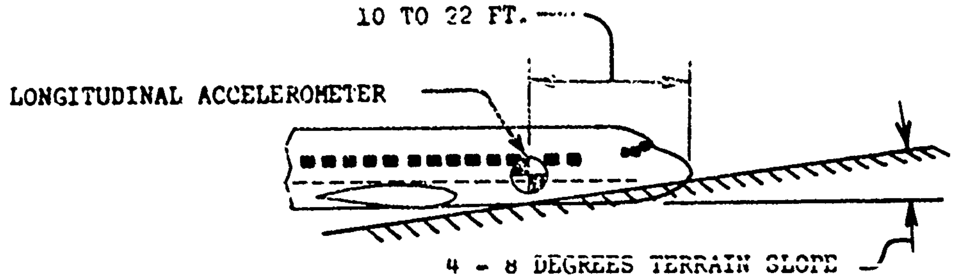


FIGURE 10

DATA SOURCE AFSIC

accident trend, most crashes occur either below 3Gs or in the nonsurvivable range. The area in between has a very low incident rate. This is due to impact speed and angle of impact to meet this range. For example, as shown in Figure 11 for a 4 to 8 degree angle of impact, a 3-9"G" crash occurs between 70 and 105 knots. Had the angle of impact been different with the same airspeeds, the crash force would be different. If an aircraft crashed at an angle of 1 degree on a runway (belly landing), the "G" loadings would be extremely low; yet if the angle of impact was 90 degrees, the



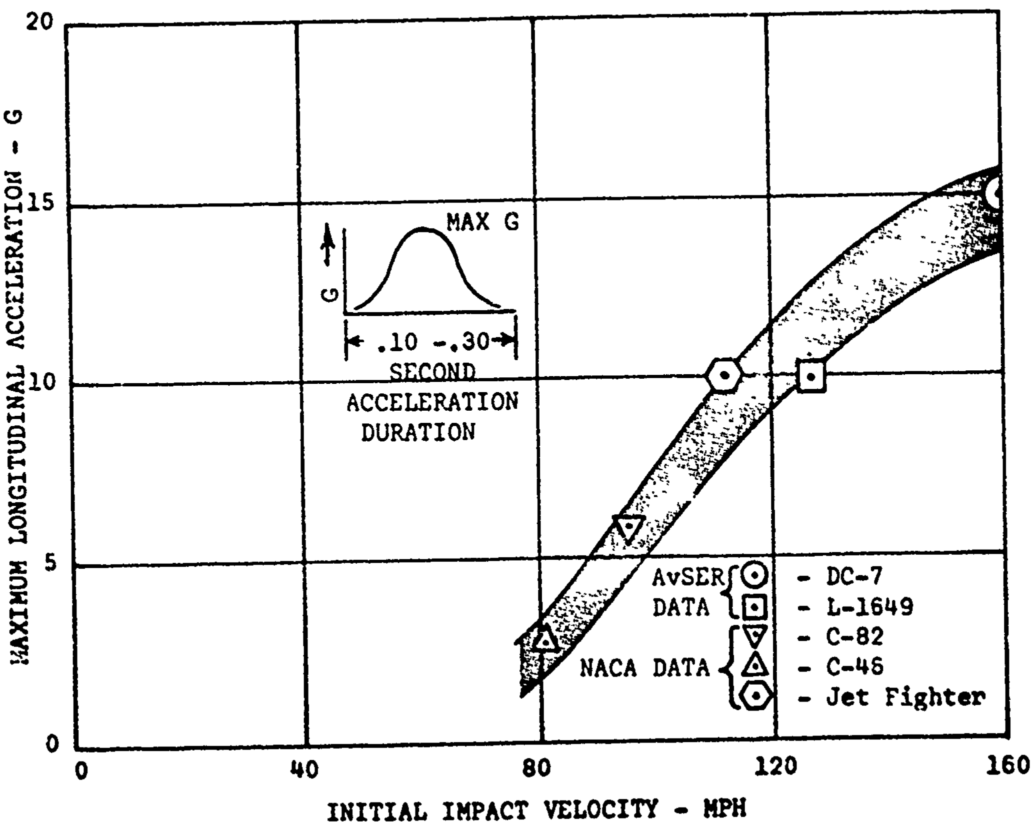


FIGURE 11 - FORWARD FUSELAGE LONGITUDINAL ACCELERATION MEASUREMENTS IN LOW ANGLE IMPACTS (USAAVLABS TR 67-16)

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ACCIDENT CODE

Phase	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	YY	98	TOTAL
10					5						2		10						1	18
20																		1		1
21					8			2			8		5		1			1		25
22					1			3			7		3						1	15
23											2		1					1		4
30									1											1
31	17				4			1	1		5		2					6	3	39
32			3	1	1				2/1	35/14	3	5/3		8/1	4	1		4	1	68/19
33													1	2				1	2	6
41			3		1				10/3	40/31	4/2	1/1		15/1	25/7	2		7	3/1	111/46
42															1					1
43									1	2/2				3	8/1			2		16/3
44									6/4	1		1		1	6	1		3		19/4
45														1						1
47									1	11/3	2	1/1		1/1				1		17/5
48										7/7				2	6/1			2		17/8
50									1											1
51	1		20	2	3	22/2			3/1	19/9	1	3/2		4	1			1	1	81/4
52	1	2/1	2	17	2	30	1	1		10	1	2				1			1	71/1
53	29	1	4	1	32		8	1	1		14		1		1			2	8	103
61	2/1		2						1	4/3		2/1		2/1				:	1	15/6
62	2/1					1	1			6	1/1	3/1								14/3
71					13			18			25		28		7		5	19	17	132
72					3			3		1	5				2					14
73					2						2		2							6
74								1		1/1	1									3/1
TOTAL	52/2	3/1	34	21	75	53/2	10	30	28/9	137/70	83/3	18/9	53	39/1	62/9	5	5	52	39/1	799/110

TABLE X

ACCIDENTS BY PHASE/TYPE (DATA SOURCE AFISC)

LEGEND FOR TABLE X, EXPLANATION OF
"PHASE OF OPERATION" COLUMN
IGDM-127-1

Codes 10 through 62 are used to record phase of operation for all accidents/incidents occurring in flight, or where there was intent for flight. Codes in the 70 series are used for accidents/incidents where there was no intent for flight.

10 - ENGINES RUNNING, NOT TAXIING - Includes accidents while making power checks or starting engines.

20 - TAXIING - Anytime aircraft is in motion under power with intent for flight.

21 - To takeoff

22 - From landing

23 - Other areas

30 - TAKEOFF

31 - Roll

32 - Initial climb within five miles of takeoff airport

33 - Discontinued - All attempts to stop the takeoff run or climb by reducing power and/or using brakes or other deceleration equipment.

40 - IN-FLIGHT

41 - Normal

42 - Acrobatics - Includes intentional maneuvers of abrupt change in direction, speed, or altitude.

43 - Climb prolonged - To cruising altitude change of altitude. etc. (See 32 above).

44 - Refueling

45 - Air-to-ground ordnance delivery

46 - Air-to-air ordnance delivery

47 - Low-level flight - Prolonged in accordance with directed mission requirements.

48 - Descent - Prolonged, jet penetration, letdown, etc.

49 - Other

50 - LANDING

51 - Approach - All legs in landing pattern. GCA and ILS included

52 - Flareout

53 - Roll - Ends with application of power for touch-and-go or go-around (see 60 below) or slows to taxi speed for turn off runway.

54 - Other

60 - GO-AROUND - Aircraft will be considered on go-around until sufficient altitude and speed have been attained so that power can be reduced and the aircraft can maneuver freely.

61 - Premeditated go-around. Touch-and-go.

62 - Unpremeditated go-around. Full stop landing was originally intended

70 - NONFLIGHT ACCIDENTS (No intent for flight)

71 - Parked

72 - Towed

73 - Taxiing

74 - Stolen aircraft, whether or not aircraft became airborne.

LEGEND FOR TABLE X, EXPLANATION OF
"TYPE OF ACCIDENT" COLUMN
IGDM-127-1

Up to three accident types may be coded for one mishap.

01 - Loss of Directional Control - Loss of directional control or sudden swerve while on ground or water. Ground loops and running off side of runway during taxi, takeoff, or landing.

02 - Wingtip Landing - All cases in which an aircraft is landed on a wingtip or drags a wingtip. Include such cases as above involving tip tanks instead of wingtips.

03 - Wheels-up Landing - All landings in which the landing gear could not be or was not lowered and locked prior to contact with the ground. Excludes cases where collapse occurs during landing roll after initial landing contact has been made).

04 - Hard Landing - Stalling in or flying into the runway or other intended landing space while landing.

05 - Collapse or Retraction of Landing Gear - All retractions and collapses which occur on the ground except those defined as wheels-up landings. Either personnel errors or material failures can be the cause of this type accident.

06 - Undershoot - Landing short of runway or other intended landing space.

07 - Overshoot - Landing too fast or too far down the landing area, resulting in:

a. Running off the end of the runway.

b. Groundlooping, nosing up, or retracting the gear to prevent running off the end.

c. Landing beyond the runways end.

08 - Aircraft Collision on the Ground - Collisions between aircraft when one or both of the primary aircraft involved are on the ground and are not on the takeoff and landing roll.

09 - Aircraft Collision in the Air - Collisions between aircraft when both of the primary aircraft involved are flying. Aircraft on the takeoff or landing roll are considered to be flying for purposes of this definition.

10 - Collision with Ground or Water - Includes collisions with mountains, hills, flying into ground or water, etc. Excludes collisions preceded by stall, spin or spiral, explosion, airframe or engine failure.

11 - <u>Other Collisions</u> - Collisions with any object other than planes or ground or water. (1) Aircraft in flight collides with power lines, trees, tow targets, birds, etc; (2) Aircraft is engaged in taxiing, takeoff roll, or landing roll, and collides with any object other than aircraft, such as poles, buildings, fences, etc.

12 - <u>Spin or Stall</u> - Mishaps in which the aircraft spins or stalls into the ground or water. Excludes hard landings and those stalls which occur above the landing space during the leveling-off process.

13 - <u>Fire and/or Explosion on Ground</u> - Mishaps resulting from and caused by fire and/or explosion on the ground.

14 - <u>Fire and/or Explosion in the Air</u> - Mishaps resulting from and caused by fire and/or explosion in the air.

15 - <u>Airframe Failure</u> - Mishaps resulting from failure of any part of the airframe, such as wingspars, empennage, hinges and fuselage skin. Includes structural failure where safe landing was effected with no further damage. Includes cases where the canopy or hatches come off in flight and are not caused by the action or inaction of person(s).

16 - <u>Abandoned Aircraft</u> - Aircraft abandoned in flight by all personnel capable of piloting aircraft.

17 - <u>Propeller or Jet Mishap on Ground</u> - Mishaps in which a person suffers injury from contact with a rotating propeller or from a turbojet-engine intake. Also used for mishaps caused by prop or jet blast resulting in injury to personnel or damage to any equipment, building, etc.

YY - <u>Not Applicable</u> - Enter this code where no other type of Accident is used.

98 - <u>Type of Accident</u> - Not determined.

loading would be extremely high. One effect of airspeed is that initial impact velocity relates to peak accelerations. Generally, increasing the impact velocity causes higher peak accelerations at an earlier time after impact. However, NACA in its crash analysis work has stated that these peak acclerations are not significant as the aircraft structure has a damping effect on these peak loads. In viewing the 4 to 8 degree impact, a speed exceeding 120 mph would be above 9G level.

The narrow band in which 3 to 9G accidents occur does not normally occur in a crash condition.

FIGURE 12

AIR CANADA DC-8F AFTER CRASH
LOOKING IN ENTRY DOOR

9. COMMERCIAL EXPERIENCE

This study has used as its data base the total military cargo aircraft operations for a 14-year period. A comparative study of commercial environment would be extremely difficult since the data is not available within the confines of one organization. In view of this, the approach taken was to obtain information of any cargo transport crash where a barrier net was impacted. The three major airframe manufacturers, Lockheed-Georgia Co., Boeing Co., and McDonnell Douglas Co., were queried to determine if any of the aircraft they had built were involved in this type of accident. The accident data files of the National Transportation Safety Board and Federal Aviation Administration were also used as a source. In addition, the members of the Society of Automotive Engineers, Aerospace Equipment Division, Air Cargo and Aircraft Ground Equipment and Systems Committee, were asked to determine if any such accidents had occurred within the organizations they represented. This committee, through its cargo restraint panel, represents the aerospace industry in this technical area. It was through this committee that most of the data in this area was obtained. Representatives of the following airlines were contracted for information relative to this study:

The Flying Tiger Line, Inc.
American Airlines, Inc.
Trans World Airlines, Inc.
Air France
Alitalia Italian Airlines
Lufthansa German Airlines
Pan American World Airways
Iberia Airlines
Seaboard World Airlines

One of the major problems is that US manufactured aircraft are operated outside of the United States and in many cases, the operational data from these aircraft are not classified by type of mission of aircraft, i.e., cargo. Further, this data is not kept by aircraft type but rather by carrier. It is reasonable to assume that commercial operations are at least similar in comparison to the military system in terms of flying hours when viewing this on a world wide basis.

Both Boeing and Lockheed were unable to identify any use of a barrier net for its intended purpose on crashes involving their civilian aircraft. It was found that in some cases cargo was not restrained and this cargo shifted into the barrier on landing.

The following is a summary of aircraft accidents where the barrier net was impacted.

a. A Douglas DC-8-63F crashed on approach to Naha Air Base on July 27, 1970. The aircraft struck the water approximately 2,000 feet from the runway threshold breaking off the tail section, the nose section just aft of the cargo door, the wing sections, engine pods, the nose gear, and other portions. The barrier net is located aft of the door and as the cargo impacted the net, the loading may have been responsible for separation of the cockpit from the fuselage. After separation, additional cargo went out the front end of the aircraft. The cargo was restrained to 1 1/2Gs. The barrier net forward movement prevented the cargo door from opening. Three of the crew members that survived the crash were trapped in the cockpit, which was in 5-8 feet of water, and subsequently died of drowning.

b. An Air Canada DC-8F was involved in an accident after the pilot aborted takeoff just after beginning rotation. The aircraft had six pallets of cargo forward of passenger seating. The following is from a letter report from Douglas Aircraft Company dated 11 November 1977.

> "The airplane overran the end of the runway, slid 1,400 feet in a nose-down attitude through soft mud 6-8 inches deep, hit a ditch six feet wide and six feet deep (forcing the landing gear aft), and slid another 700 feet on its belly to a stop.
>
> The cargo system was designed for 1.5G forward load and retained control of the load with no appreciable load imposed on the forward barrier net, as can be seen in the enclosed Photo 1." (Figure 12)

c. There have recently been some instances of accidents involving aircraft and the movement of livestock. Two recent cases involve a Japan Airlines DC-8 and a Convair 880. While the final accident reports have not been issued in these accidents, preliminary reports indicate in both cases that the cattle on board the aircraft were not really restrained. For example, a Convair 880 went to the end of the runway in Miami, Florida, in December 1976. Just past the runway end, the aircraft slowly rolled into a drainage ditch where it came to rest nose down. The cattle all died and impacted a 9G barrier bulkhead. The crew survived.

The movement of livestock presents different hazards beyond the normal cargo movement and in essence should not be used to determine what restraint levels could have been used. If the livestock could be properly restrained to 1 1/2 or 3G, it is possible they would not have impacted the barrier in these crashes.

In viewing the commercial activities, only one accident, the Flying Tiger DC-8F, can be correlated to the types of accidents viewed where a barrier net was effective. But even in this accident the crew did not survive. The rescue teams could not use power tools to free the crew due to jet fuel on the water from break up of the aircraft. It may be assumed that if this accident had occurred on land, there would have been a post crash fire.

SECTION V

SUMMARY

Historically, restraint criteria has been based on the structural limit of a pressurized fuselage. This is an approximate 9G level. The reasoning was to provide protection to passengers to the level available from the surrounding aircraft. It was also well known that the human could survive much higher loads and studies into the dynamics of seats in the crash resulted in a higher, but compatible, restraint for passengers and crew. This data has also shown inconsistencies within structural design specifications.

One factor that appears to have been overlooked is that the envelope of speed and angle of impact to crash between 3 and 9G is very small. It became evident in researching crash loads factors to develop probabilities that very few accidents occur in this range. The actual crash condition is the same for either cargo aircraft or spacecraft, in landing mode as used by the space shuttle, and they will react in the same basic manner. The external forces against the air vehicle during a crash will be basically the same. The forces internally will vary based on vehicle design.

The crash event itself is rare, occurring on the average of once every 75,750 hours of flight. Upon narrowing this to a particular load range and operation, 3 to 9G with passengers and cargo mixed, for tactical aircraft the value at a 10% mix is 2,900,000 hours. For all cargo aircraft, it becomes an extremely rare event of one possible occurrence per 4,000,000 hours of operation. The level of risk becomes acceptable especially when considering the only time 9G protection is required today is on routine flights. This only accounts for approximately 2% of the Air Force mission, and approximately 10-12% on C-130 and C-141 aircraft. The probabilities developed within this report have shown a conservative trend from the data in the 1971 effort. Several factors can account for this; the most significant is the type of aircraft currently being used by the military. Each new generation of aircraft has shown higher safety records with corresponding reductions in number of accidents. Another factor has been the inclusion of minor accidents to provide a full picture of the crash spectrum.

The most significant factor of this study has been a complete validation of data and predictions made in the 1971 study using the data from the end of that study to July 1976. This adds another degree of confidence to the decision making process.

Further reviews by the three prime United States commercial air frame manufacturers and commercial carriers have had the same basic experience of crashes within the 3-9G range, as shown by use of the barrier net. There has been only one true occurrence when viewing a fixed cargo system. This effort was aimed at examining military operations. The data within this report has been used by both the Aeronautical Systems Division and NASA to change various criteria as listed below. The civilian fleet can also use the data in determining what design criteria to utilize. For example, either a 3G positive locking rail system or a 3G net in conjunction with current 1 1/2G rail system would provide an adequate system rather than the 9G system in use today.

As a result of this effort, the following actions were taken:

1. MIL-A-008865 has been revised.

a. Eliminate the need for auxiliary restraint systems above the 3G cargo handling systems. Trade studies should be performed to determine risk factors and level of restraint required.

b. Reduce restraint criteria for fixed installations to a load factor equal to aircraft structural load factors and not seat installation factors within structural design documentation for both new aircraft and Class II modifications.

2. NASA has established that restraint factors for spacecraft and payload be based on operational load factors with safety factor (current safety factor is 1.4).

APPENDIX A

HUMAN EXPOSURES TO LINEAR DECELERATION
Part 2, AIR FORCE TECHNICAL REPORT 5915
by
Major John Paul Stapp, USAF (MC) Dec 1951

Fifty-three experiments are reported in which twelve healthy male human volunteers were exposed to linear deceleration at right angles to the long axis of the body. For comparison, the subject was seated facing backward in two cases. The range of deceleration from 10G at 575G per second rate of change deceleration configurations increasing by about 5G increments. A second group of six runs provided a range of deceleration of 14.0G at 281G per second to 45.4G at 493G per second. Duration of deceleration ranged from .15 to .35 seconds for all experiments. Measurement of harness loading during deceleration by means of bonded strain gauge tensiometers attached to a symmetrical half of the harness allowed comparison of loadings for three harness configurations and served as a check on accelerometer data in twenty-two experiments. The weight of the subject multiplied by the deceleration reading at the chest was compared with the total loading of the harness measured simultaneously by the tensiometers, with good agreement. The limited number of channels confined measurements during a run to physical factors, so that physiological and clinical data consisted of such measurements before and after runs as electrocardiogram, X-rays when indicated, opthalmoscopic examination, testing of reflexes, urinalysis and dye excretion tests, pulse, respiration, temperature and blood pressure, and detailed interrogation for subjective data. In all cases were subjects were adequately restrained, findings were essentially negative below the level of 30G, with due allowance for mild abrasions, contusions, and transient effects due to excitement and exertion. At the 30 to 35G plateau, slight signs of shock such as palor, sweating, falling blood pressure, and rising pulse were occasionally present with rate of change of deceleration above 1000G per second. In two runs above 38G at more than 1300G per second rate of change of deceleration, definite shock levels of blood pressure, pulse, and respiration occurred, with near syncope in one case and with two brief episodes of syncope in the other. At the same 38G level but with rate of change of 330G per second, and at 45.4G at 493G per second, blood pressures were elevated and pulse and respiration increased to exertion levels but there was no sign of shock. Venous pressure in the veinules of the eyes evidently exceeded 80mm.Hg. in this last run since mild retinal hemorrhage and bulbar conjunctival petechiae were produced.

Subjectively, limits of voluntary tolerance were approached at 17.0G at 1000G per second rate of onset with the standard Air Force harness configuration, at 38.0G at 1350G per second with the inverted V leg strap added to the shoulder straps and lap belt assembly, and at about 46.0G with rate of change of deceleration of about 500G per second, using the latter configuration. Much higher levels can be survived, although reversible injurious effects may intervene. Of eight harness configurations tested, including the standard AF design, the minimum modification to provide adequate restraint up to the maximum exposure to deceleration in this period of experiements is the addition of the inverted V leg strap. The principles of crash harness design and requirements for adequate protection are discussed.

This effort is considered a major step forward in development of seat/aircraft restraint systems in that basic levels of human limits were defined.

APPENDIX B

"ACCELERATIONS AND PASSENGER HARNESS LOADS MEASURED IN FULL-SCALE LIGHT-AIRPLANE CRASHES" by A. MARTIN EBAND, SCOTT H. SIMPKINSON, AND DONALD D. BLACK, NACA TN 2991 August 1953

Three light aircraft (steel-tube, fabric covered, tandem, two-seat) were crashed at impact speeds from 42 to 60 MPH into a 55 degree slope earthen wall. The wall was oriented 66 degrees to the line of aircraft travel. Only deceleration values were obtained for the rear seat of this aircraft. Data was collected for the front seat because "collapse of the front portion of the cabin is often fatal to the front passenger (pilot)".

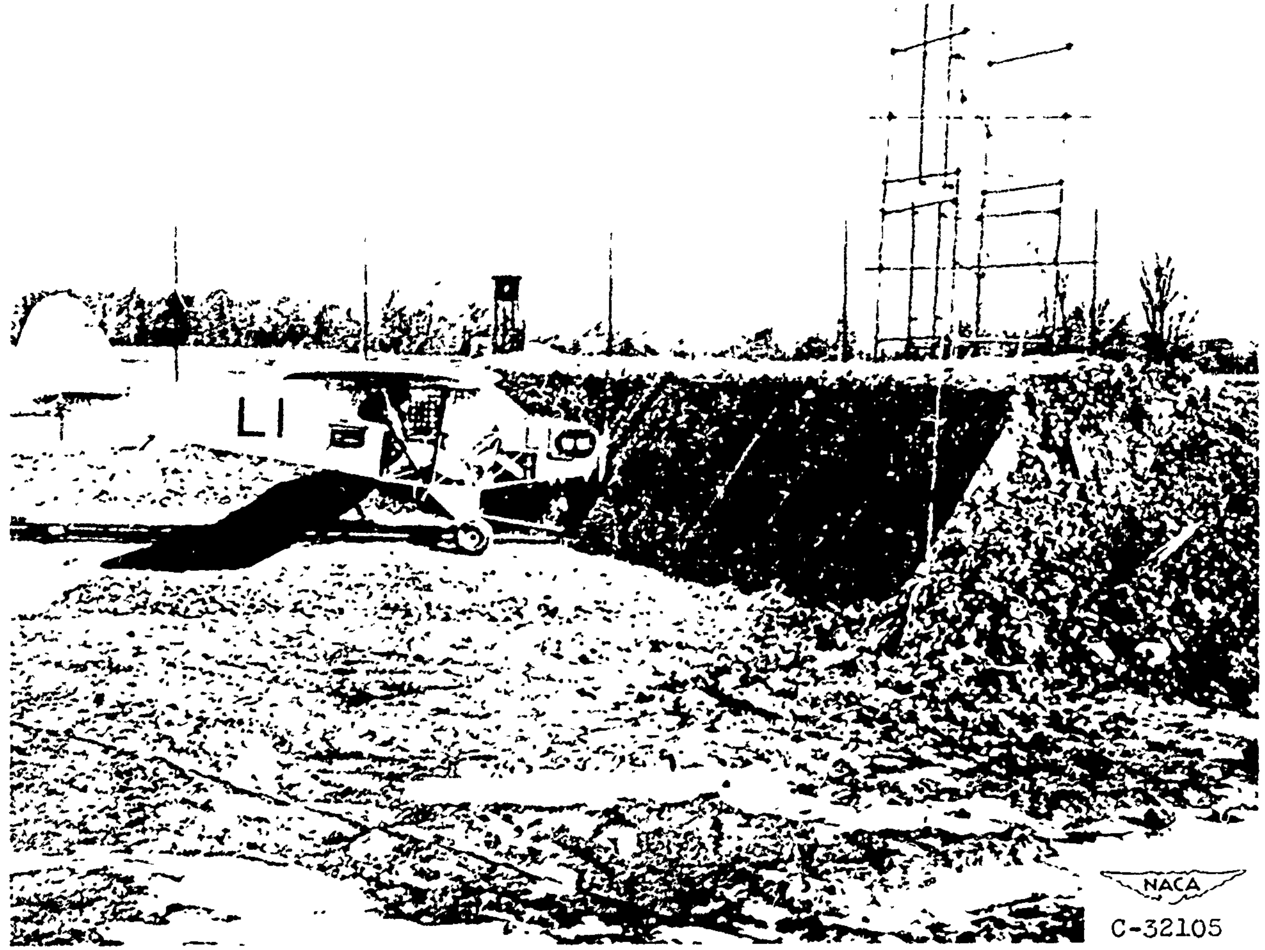
In the 47 MPH test a commercial type seat belt was used while in the other tests shoulder harness were used. The peak loads from the tests are contained in Table B-1, extracted from the Appendix B report. The deceleration loads show that loads imposed on the dummy exceed the fuselage loads and ranged from 1.2 to 1.5 times the fuselage load. This is explained in Appendix D.

Figure B-1 shows the test set up.

DECELERATION LOADS

TABLE B-1

Speed at impact with barrier, MPH	Maximum longitudinal engine deceleration, G	Maximum longitudinal deceleration of chest of rear dummy, G	Maximum longitudinal deceleration of fuselage under rear seat, B	Duration of maximum peak longitudinal deceleration of fuselage at rear seat, SEC	Peak total restraining force, rear dummy, LB	Aircraft Gross Weight LB
42	32.5	32	26.5	0.023	3680	1200
47	46.0	46	32.5	.038	4400	1013
60	62.0	50	33.5	.070	5800	1261



(a) Photograph of two-seat tandem airplane used in investigation, showing relation of airplane engine and left wing to front edge of earthen crash barrier.

FIGURE B-1 - MECHANISM FOR LIGHT-AIRPLANE CRASH INVESTIGATION

APPENDIX C

NACA TR 1332 AND NACA TN 3777

SEAT DESIGN FOR CRASH WORTHINESS

BY

I. Irving Pinkel and Edmond G. Rosenberg

TR June 25, 1956, TN October 1956

(THIS REPORT CARRIES TWO NUMBER DESIGNATIONS)

These reports provide an in-depth review of aircraft seat design relative to human survival and aircraft crashes. This report is broken into two parts, the first part shows the relation of aircraft deceleration and the seat, with the second part showing how to design seats. In this review only the part relative to aircraft deceleration is reviewed.

The aircraft seat is a structural link between the passenger and fuselage floor (the term passenger can also apply to the crew). If the passenger were fastened rigidly to the seat and the seat rigidly to the floor, then the passenger, seat and floor would move as a unit. However, this is not the case. The passenger is a free moving body within the restraint system of the seat; further, the seat is made of flexible members with some movement above the floor. The actual condition of the events are best explained by the model developed for this report which is quoted herein:

"MODEL OF DECELERATION PULSE FOR SEAT DESIGN"

"Since the rate of rise of the airplane deceleration proved to be an important quality, it is necessary to describe the airplane deceleration more accurately. The model used for the deceleration pulse must include a description of the rate of rise as well as the magnitude and duration. The half-sine pulse does not allow an independent specification of these factors.

A proposed model for the airplane deceleration that better approximates actual deceleration measurements is shown in Figure C-1. The base deceleration pulse is divided into three time zones: a rise time during which the airplane deceleration grows to maximum value, a dwell during which the deceleration has a constant value, and a decay time taken equal to the rise time. It is recognized that there is no necessary relation between the rise and decay times. However, peak seat decelerations will most likely occur during the dwell. For this reason, the decay time is not as important as the rise time. Very little is lost by the convenience gained by equating the rise and decay times.

As before, secondary pulses are superimposed on the base pulse. The secondary pulse may vary considerably in shape. A half-sine pulse represents a reasonable approximation for the secondary pulses which are of short duration compared with the base pulse. Secondary pulses may appear anywhere on the base pulse and may attain peak magnitudes greater than that of the base pulse.

The importance of the dwell in the base pulse in determining maximum seat deceleration is illustrated schematically in Figure C-2 (a). The base deceleration pulse is given by the curve ABDEF. Shown also is a half-sine pulse ABHJC having the same rise time and peak magnitude. The maximum seat decelerations obtained with each pulse, which differ only because of the dwell time, are compared.

Consider first the seat response to the half-sine pulse. Assume that the seat deceleration lags the airplane deceleration appreciably. The seat deceleration develops along the curve AKJ (Figure C-2 (a)). The area between the half-sine airplane deceleration pulse and the seat deceleration curve, Area 1, represents the relative velocity acquired by the seat. This velocity carries the seat deceleration beyond point J until Area 2 between the seat deceleration curve and the airplane deceleration pulse is equal to Area 1, in accordance with the earlier discussion. Maximum seat deceleration is attained at point L where the seat deceleration has about the same value as the peak airplane deceleration for the case shown.

The seat response to the long-duration airplane deceleration pulse ABDEF, which has the same rise time and peak magnitude as the half-sine pulse, develops initially along the line AK. Because the long-duration pulse maintains the peak deceleration beyond Point B, the seat deceleration follows curve AKHD beyond Point K. The seat velocity relative to the airplane grows continuously up to Point D. After Point D the seat deceleration continues to grow by virtue of this relative velocity and attains values greater than the airplane deceleration. The seat deceleration grows until Area 3, between the seat deceleration curve and the

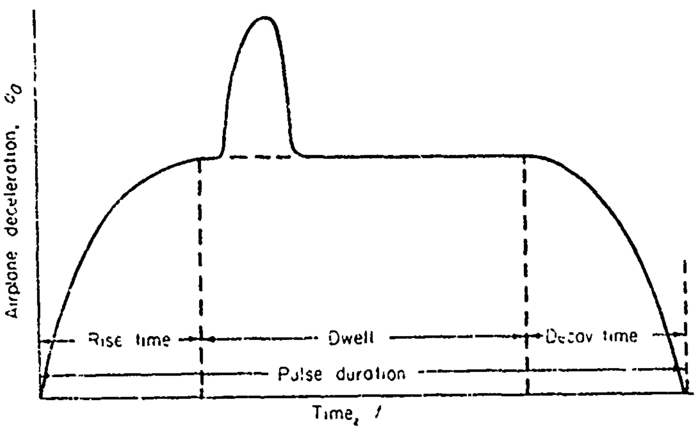
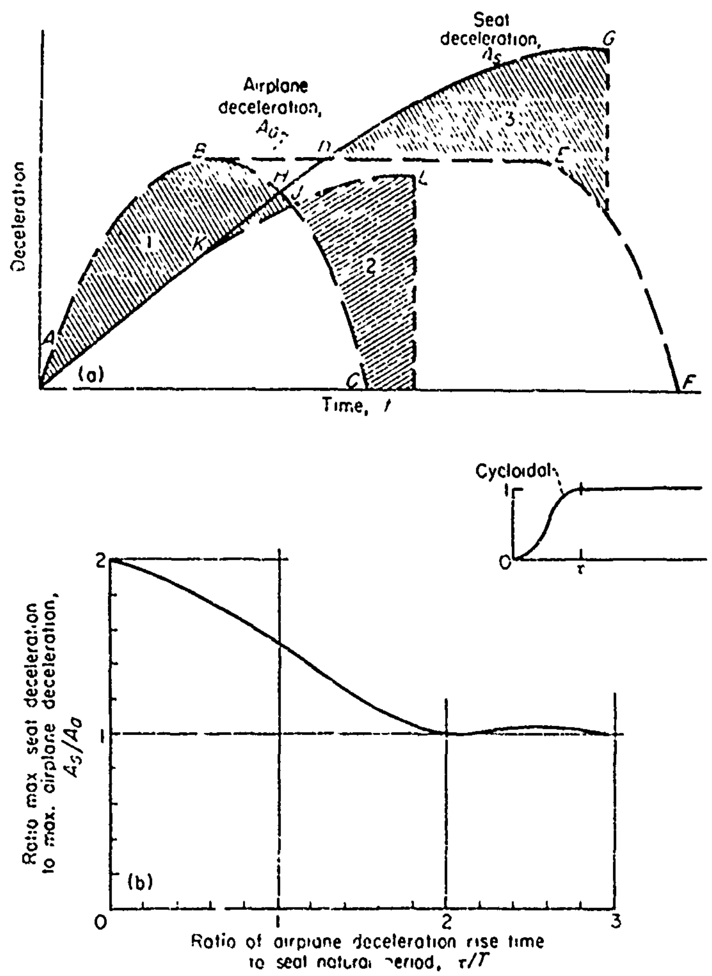


FIGURE C-1 - Deceleration pulse components.

airplane deceleration curve, is equal to that before Point D (approximately equal to Area 1). Since the airplane deceleation dwells at its maximum value, the seat deceleration must climb to Point G in order to develop this area. This dwell is responsible for the seat deceleration attaining a maximum value at Point G significantly greater than its value at Point L in response to a half-sine pulse.



(a) Schematic interpretation of response.
(b) Ratio of maximum seat deceleration to maximum airplane deceleration (ref 1) $T = 1/f_n$.

FIGURE C-2 - SEAT RESPONSE; PROLONGED DECELERATION PULSE

The ratio of maximum seat deceleration to maximum airplane deceleration for a base deceleration pulse having a dwell time appreciably longer than the rise time is given to a useful approximation in this problem in Figure C-2 (b). The values A_s/A_a in this figure are computed on the assumption that the rise time portion of the airplane deceleration pulse has the cycloidal shape shown on the figure. In view of the variety of possible shapes for this curve that may actually appear in crashes, further refinement in the definition of the rise time curve is not justified. In Figure C-2 (b), $_t$ is the airplane deceleration rise time and T is the period of the natural seat oscillation; T is related to the seat natural frequency through the expression.

$$T=1/f_n$$

According to Figure C-2 (b), the peak seat deceleration can be equal to twice the peak airplane deceleration when the period of the seat natural oscillation is large compared to the rise time for the airplane deceleration. When the ratio t/T is greater than 2, the airplane and seat deceleration peaks are about the same.

Since the ratio t/T increases with seat stiffness for a given airplane deceleration rise time, stiff seats will give lower seat decelerations than flexible seats of low natural frequency."

A proposed description of the second deceleration is shown in "Table C-1" for airplanes having a landing speed of 180 feet per second. The residual stiffness should be high enough to serve in a second deceleration whose primary and secondary pulse amplitudes have the values shown in the appropriate columns. The pulse durations and rise times should be the same for the first and second decelerations. For the case where Δ V is equal to 180 feet per second in the first deceleration, no second deceleration will occur since the airplane will have come to rest.

The report defines transport as a low or middle wing aircraft (C-46) and cargo as a high wing aircraft (C-82).

Deep seat-pan cushions introduce the same objectionable slack in a vertical direction. The use of extra seat cushioning, sometimes practiced in aircraft, increases the danger of back injuries in a vertical deceleration pulse. A proper seat-pan cushion should compress completely under the weight of the occupant and bring his buttocks in substantial contact with the seat pan. The illusion of greater protection provided by deep cushioning comes from sensations of comfort experienced when forces equal to the weight of the occupant are exerted. When these forces grow to 10 and 20 times the occupants' weight in a deceleration pulse, the protection afforded by the deep cushion no longer exists. Instead, the detrimental effects of slack appear as the occupant compresses the cushion and acquires velocity with respect to the seat pan he will ultimately strike.

It appears that most of our current seat criteria for transports and cargo aircraft have come from Table C-1 of the 1956 report as contained below.

	First deceleration							
	Transport				Cargo			
Change in airplane velocity, ΔV, ft/sec...	50	80	130	180	50	80	130	180
Primary								
Maximum g's ...	12	18	20	20	5	8	10	10
Pulse duration, sec	0.2[illegible]	0.20	0.25	0.30	0.50	0.38	0.46	0.58
Rise time, sec	Sine	0.06	0.045	0.03	Sine	0.10	0.08	0.06
Secondary								
Maximum g's..............	10	15	20	25	7	10	12	15
Pulse duration, sec........	0.02	0.03	0.04	0.03	0.06	0.04	0.04	0.03
Second deceleration (landing speed, 180 ft/sec)								
Primary pulse magnitude, g's.	9	9	7	1	4	4	3	1
Secondary pulse magnitude, g's..................	8	7	7	1	6	5	4	1

TABLE C-1 - DESIGN VALUES OF LONGITUDINAL AIRPLANE DECELERATION PULSES

The question that must be addressed is, what is the upper level of Point G relative to Point D of Figure C-2 (a)? The report provides an analysis to show that "the peak passenger deceleration can be nearly 1.8 times the peak airplane deceleration."

Another factor that can cause this deceleration factor to increase to a higher level is through deformation of the aircraft structure, which is common during a crash condition. 'Current practice of fastening the seat to the airplane fuselage wall and the floor exposed the seat to possible failures when the airplane structure between the fastening points distorts in a crash and shortens the distance between them. Even unoccupied seats may be lost when this happens.

Seat faste.ings must be able to support the seat design load and must engage airplane structure that will not flex or break under this load. A floor structure that flexes can seriously modify the effective seat natural frequency and reduce the ability of the seat to support the passenger."

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The same effect is true when considering passengers in aft-facing seats or in the vertical direction. Cushioning provided for comfort is in conflict with the ability of the seat to hold in a crash. To cover the resultant "G" on the passenger some of the cushioning may have to be comprised. For example: In an aft-facing seat the body would undergo a higher G force due to the travel into the cushion which will result in a larger relative velocity in comparison to the decelerating aircraft.

APPENDIX D

ACCELERATIONS IN FIGHTER AIRPLANE CRASHES

by

Loren W. Acker, Duglad O. Black, and Jacob C. Moser
November 4, 1957, NACA RESEARCH MEMORANDUM E57G11

Crash tests of five FH-1 aircraft to determine level of restraint to protect crew. These crashes simulated three unflared landings, angles of 18°, 22° and 27° angles of impact, a cart-wheel and a ground-loop crash. In the three unflared landings, human tolerance to normal (vertical) accelerations was exceeded in all these cases. All crashes occurred at 112 MPH.

ACCELERATIONS:

Longitudinal Unflared Crashes.

Location	13°	22°	27°
Rear Nose	18	18	18
Cockpit Floor	20	30	140
Cockpit Rear	20/35	35/50	40/160
CG 6 ft aft of cockpit	30	30	60

"From the preceding data, it can be seen that incipient failure of the cockpit occurred at a longitudinal acceleration of 35Gs and complete failure occurred at 40Gs. Since this cockpit structure was able to withstand loads up to 40Gs, the military services' division to design their fighter-pilot's restraining equipment for 40Gs is realistic in this instance."

In a ground loop crash, the aircraft had a maximum longitudinal acceleration of 9G for 0.1 sec at a point 2.33 seconds after impact. Initial impact was 4G with the level at 3G until it hit a second mound which resulted in the maximum loading. During a cart wheel crash, the acceleration levels encountered were less than 10G.

The report also reviewed loads of the dummy relative to the aircraft structure as follows:

The acceleration of the pilot is determined by the acceleration of the structure to which he is attached, the load elongation characteristics of his restraining harness, and the resiliency of his own body and clothing.

Body resiliency acts like a harness stretch in permitting body movement relative to the airplane. The effective stretch in the man-restraining-harness combination is the sum of the harness stretch and the body deformation. If the pilot's harness stretches under load, that part of his body restrained by the harness acquires a velocity relative to the airplane, the pilot's body will experience a deceleration equal to that of the airplane plus the additional deceleration required to bring the pilot's body back to the speed of the airplane. If the airplane deceleration declines while the harness is still stretching, his peak deceleration may not attain the peak airplane deceleration. Otherwise, the pilot's deceleration may exceed that of the airplane. If the pilot is attached rigidly to the structure, he will undergo the same deceleration as the structure to which he is attached.

The anthropomorphic dummy used in this study could not be expected to duplicate exactly the resiliency of a human; therefore, the response of the dummy to accelerations may be somewhat different from that of a human. However, the data obtained with this dummy should give some indication of the accelerations a human might experience.

The restraining harness used in this study was attached directly to the bulkhead at the rear of the cockpit. The seat, therefore, was not involved in the support of the dummy in the longitudinal direction.

For example, in the 13° unflared crash the dummy saw an acceleration path of 45G as compared with 35G with the rear bulkhead. The following conclusion is quoted "in some crashes the normal accelerations measured on the dummy's hip were as much as twice those measured on the cockpit floor."

With respect to vertical accelerations, the report indicates the level of human tolerance is 20 to 25G before injuries to the spine, this is almost 1/2 of the longitudinal direction (40G). In these crashes it was found that while it is concedable that a man can withstand the longitudinal forces the normal forces far exceeded the survivable limit. For example, in the 22° unflared crash the initial G loading was 35G on cockpit floor and 50G on dummy's hips. During a second impact the loadings were 55G on the floor and approximately 120G at the dummy's hips. This high G force was a result of the seat failure.

In the 4° ground loop initial G loadings on the dummy's hips were 5Gs. When the aircraft skidded over a bank and fell approximately five to six feet, the normal acceleration on the dummy's hips was 18Gs. This would have been the only survivable crash conducted during this program.

APPENDIX E

FULL-SCALE DYNAMIC CRASH TEST OF A LOCKHEED CONSTELLATION MODEL 1649 AIRCRAFT

by

W.H. Reed, S.H. Robertson,
L.W. T Weinberg, L.H. Tyndall,
FAA-ADS-38

This report covers a crash test of a Lockheed Constellation with an initial speed of 112 knots. Initial impact was designed to remove landing gears, the left wing was to contact an earth mound, with the right wing hitting a barrier of two telephone poles. Located beyond these barriers was a +6 degree slope extending 175 feet. The hill then dropped away for 75 feet and rose again at a 20 degree angle. From the gear barrier to the top of the 20 degree slope was a straight-line distance of approximately 500 feet. The following is a sequence of events from initial impact to aircraft rest. Figures E-1 and E-2 of this appendix illustrate velocity-time and velocity-distance histories.

At initial impact, both main landing gears were broken off. The left gear pulled the No. 2 engine nacelle downward as it failed, causing that engine to roll under the left wing. The right gear bounced upward into the path of the right-hand horizontal stabilizer, severing the right vertical fin. The No. 2 propeller was sheared off by the landing gear barrier just prior to contact between the left main gear and the barrier. Nos. 1, 3 and 4 engines and propellers were intact throughout the gear barrier impact sequence, with the exception of one blade of the number 3 engine propeller which was sheared off by the right main gear barrier.

The rail guide shoe, used to direct the aircraft down the guide rail, was broken off on impact with the nose gear barrier and was imbedded in the dirt mound at the end of the rail. The gear strut was forced backward and upward into the forward fuselage, where it remained as the aircraft impacted the two slopes.

After passing through the gear barriers, the aircraft dropped in a slightly nose-down attitude. Propellers on Nos. 1, 3 and 4 engines struck the earth, which resulted in disintegration of the blades. At this point, visible rupture of the wing structure adjacent to the engine nacelles began. The aircraft continued on into the wing barriers. The left wing struck the earthen barrier and commenced to separate from the fuselage at the wing root. The right wing impacted the pole barriers which opened up the wing about 25 feet from the tip and between engines No. 3 and 4.

The nose of the airplane contacted the ground at the foot of the +6 degree slope and slid into the hill. No major breakup of fuselage structure occurred during this impact.

After passing the crest of the +6 degree slope, the airplane rotated to a slightly nose down attitude before impacting the 20 degree slope. Impact with the 20 degree slope produced two fuselage breaks; aft of the cockpit between fuselage stations 370 and 380, and aft of the galley between fuselage stations 1020 and 1030.

Small fires occurred, had the aircraft crashed under normal conditions. With regular fuel on board, this crash would have resulted in fire of the entire aircraft.

Basically the crash would be considered a 20G crash condition.

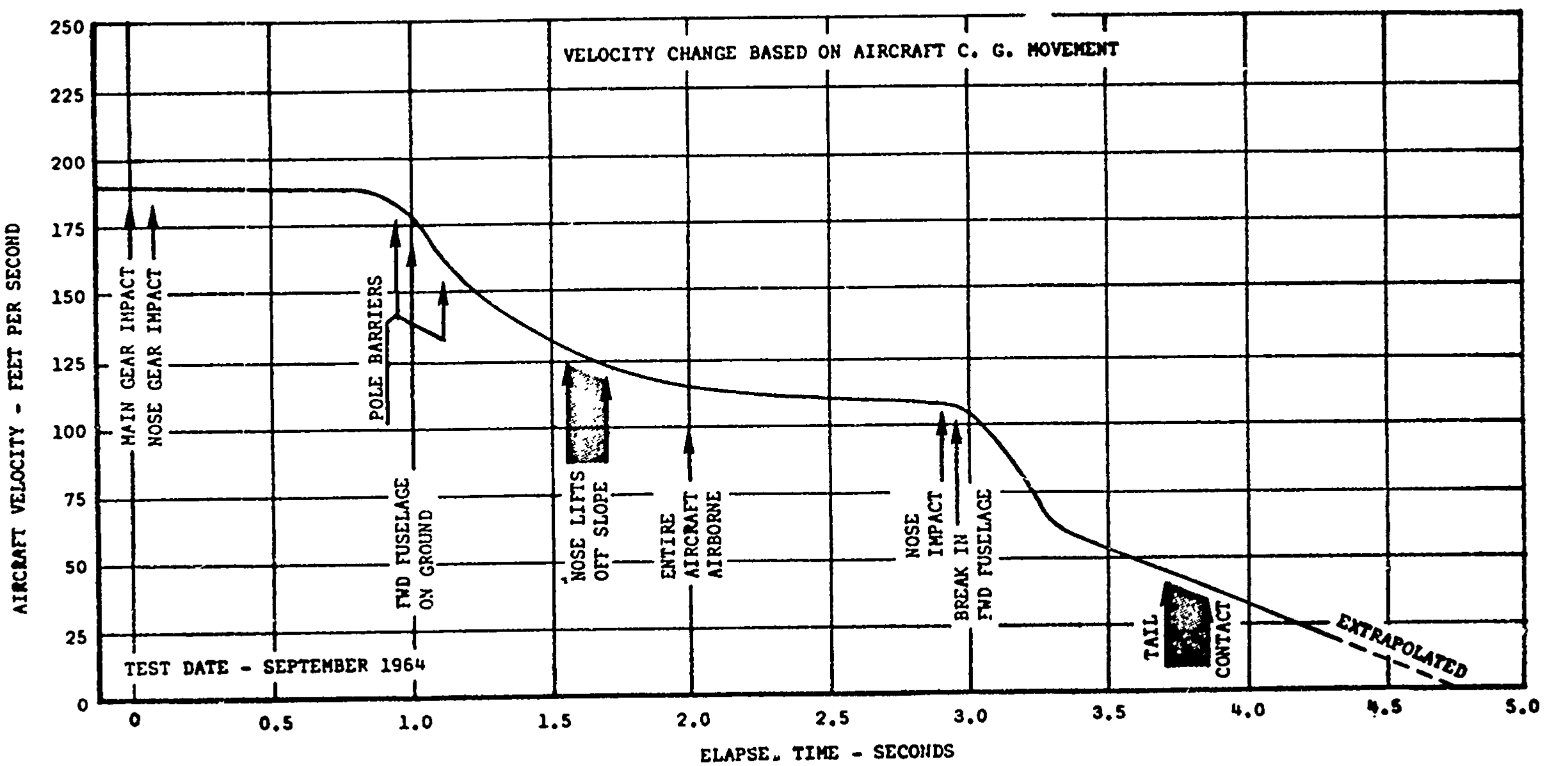


FIGURE E-1 L-1649 CRASH TEST VELOCITY-TIME HISTORY

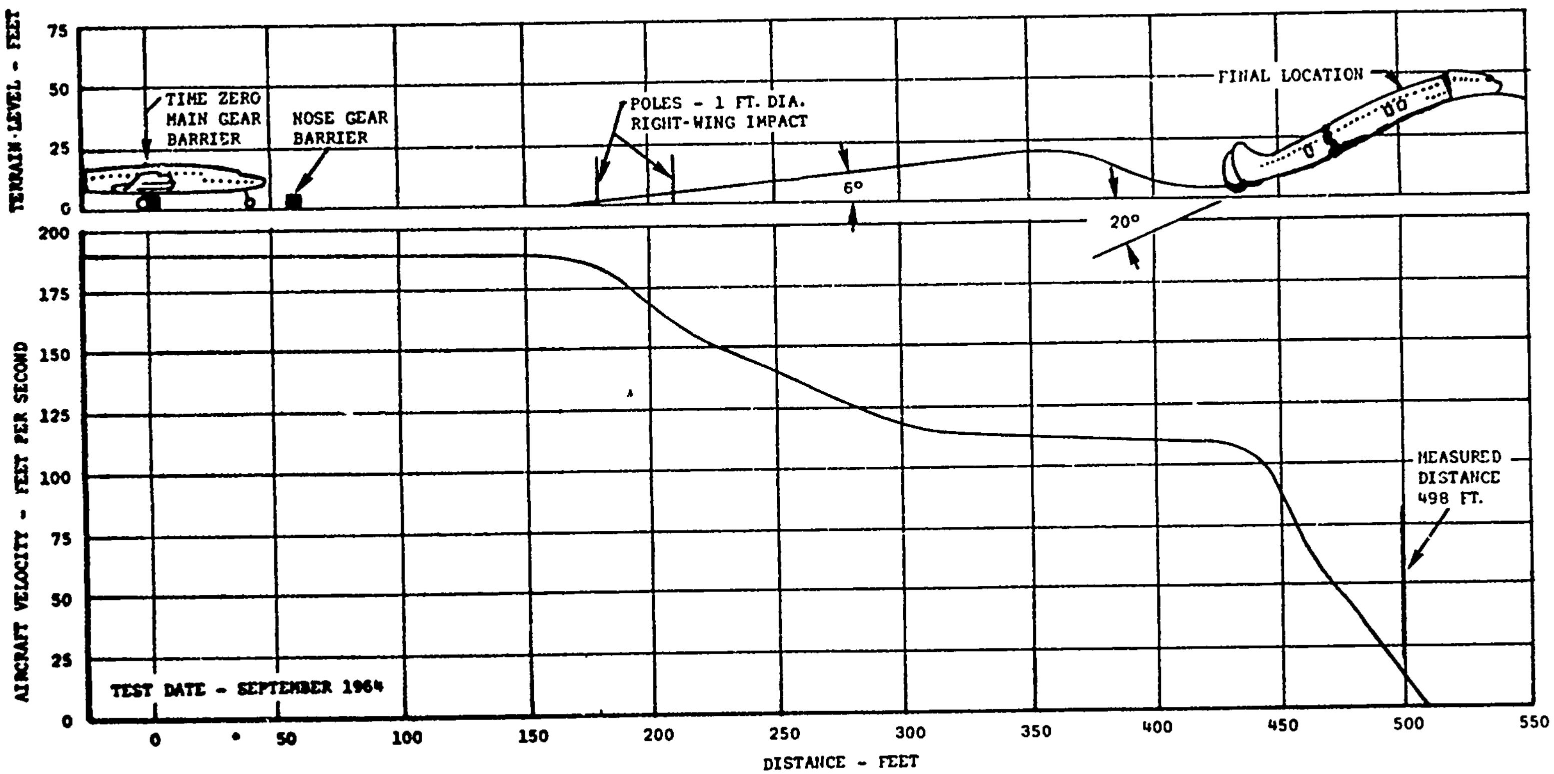


FIGURE E-2 - L-1649 CRASH TEST VELOCITY-DISTANCE HISTORY

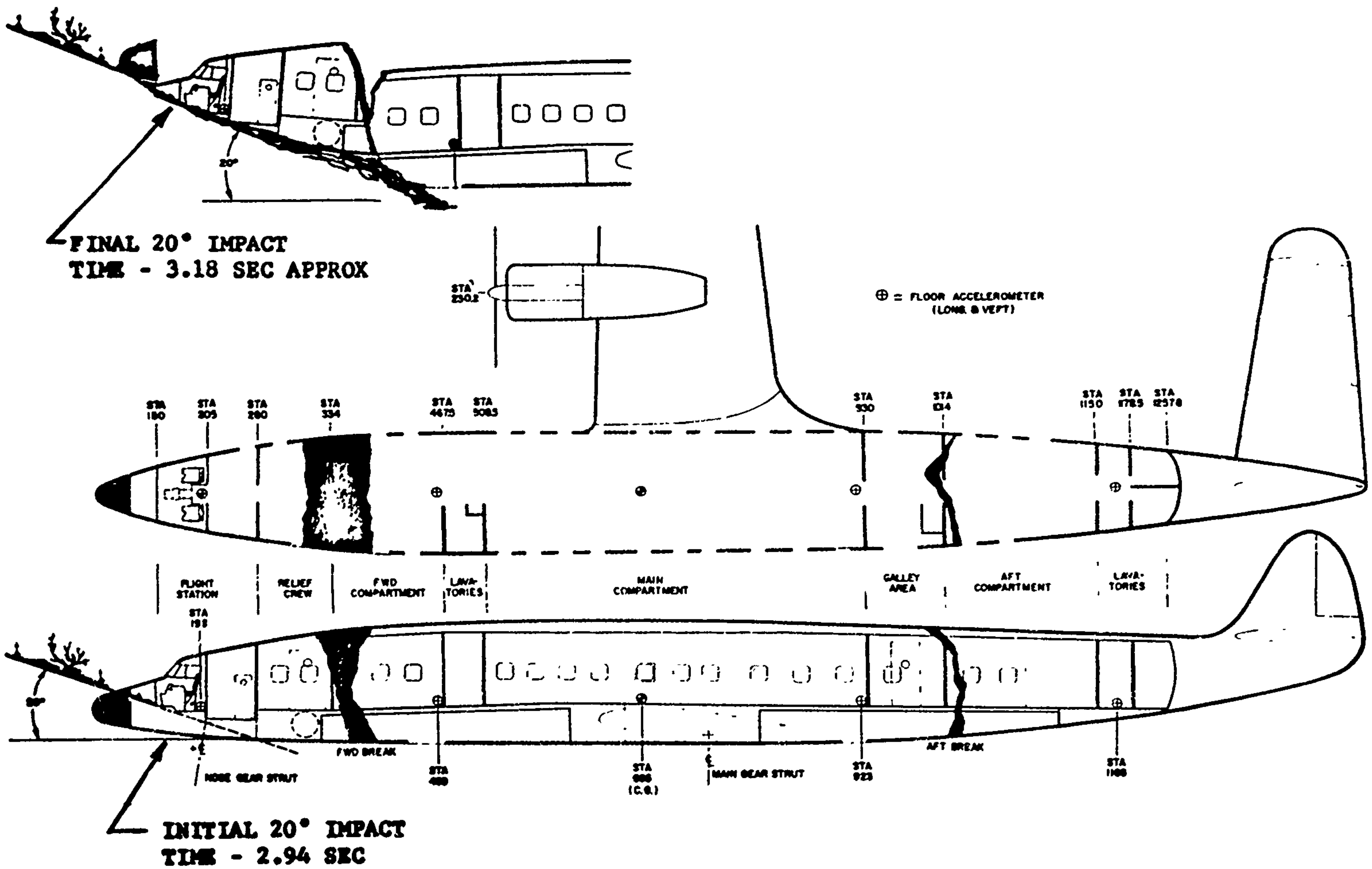


FIGURE E-3 LOCATION OF FLOOR LEVEL ACCELEROMETERS FOR X, Y AND Z RECORDINGS, L1649

APPENDIX F

FULL-SCALE DYNAMIC CRASH TEST OF A
DOUGLAS DC-7 AIRCRAFT
by
W.H. Reed, S.H. Robertson, L.W.T. Weinberg,
and L.H. Tyndall, FAA-ADS-37, April 1965

This report provides data on a DC-7 crash test conducted by the Flight Safety Foundation for the Federal Aviation Agency. In the test the aircraft was accelerated to 139 knots, landing gear was removed by impacting special barriers at which time the aircraft becam airborne until it impacted the following barrers:

First, the left wing impacted against an earthen mound to simulate a low-wing accident. At the same time the right wing impacted telephone poles to simulate trees. Next, the fuselage was to impact against a +8 degree slope, go over the slope and become airborne again and then impact a +20 degree slope.

A voltage control regulator failed in the on-board data system resulting in loss of all data except that in the cockpit. The cockpit floor showed longitudinal acceleration ranging from 23G at initial impact to 27G on the 8 degree slope and 47G on the 20 degree slope. While the pilot and co-pilot could have survived, the impact on the +8 degree slope, they would not have survived the 20 degree impact deceleration forces. A review of vertical accelerations also shows the pilot and co-pilot could not have survived this crash. Figure F-1 of this appendix illustrates the velocity-time history.

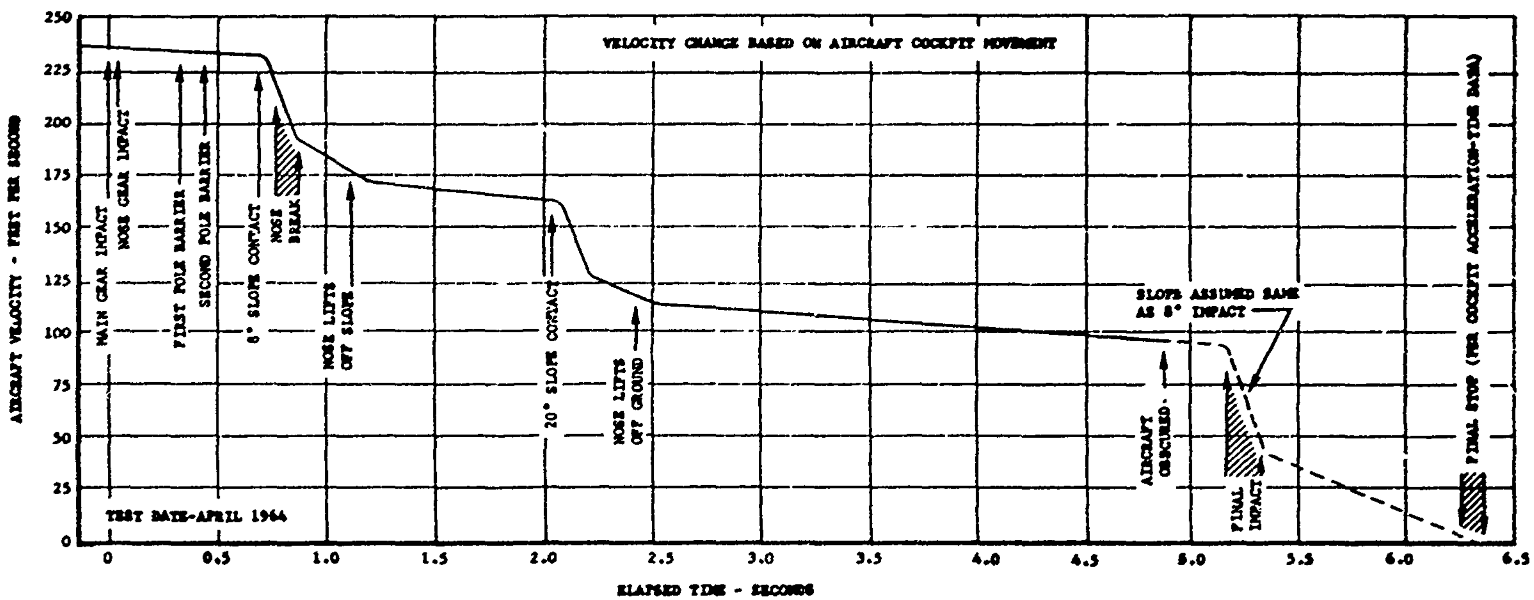


FIGURE F-1 DC-7 TRANSPORT CRASH TEST VELOCITY-TIME HISTORY

APPENDIX G

CRASH SURVIVAL DESIGN GUIDE

by

J.W. Turnbow, D.F. Carron, J.L. Haley,
S.H. Robertson, USAAVCABS TR-70-22,
U.S Army Aviation Material Laboratories

This guide is an excellent guide to levels of human tolerance and provides extensive guidance on designing aircraft and seats to survive crashes. Again this guide relates to survivable accidents and not frequency of crash occurrence.

The overall problem of defining human limits can be found by reviewing this guide. Human tolerance is not just based on a set G level but is variable, dependent on duration of the pulse. For example, a 45G force can be tolerated for less than 0.044 second but if the duration is increased to 0.2 seconds the magnitude is reduced to about 25G. Figures G-1 and G-2 provide duration and magnitude in the longitudinal and vertical direction. Figure G-3 shows how G on-set rates can also affect the limits.

The method of restraint also affects survivable limit of the passenger or crew member. When restrained only by a seat belt, the occupant's tolerance to abrupt acceleration is relatively low. In forward-facing seats, a longitudinal impact will cause a rotation of the upper torso over the belt, a whipping action of the head, and often impact of the upper torso on the legs, resulting in chest injuries. Head injuries due to impacts with the surrounding environment are also very common for occupants restrained only with seat belts. When longitudinal forces are combined with a vertical component, there is a tendency for the occupant to slip under the belt to some degree. This can place the belt up over the abdomen. The longitudinal component of the pulse then causes the upper torso to flex over the belt, with the restraining force concentrated at some point on the spine and not on the pelvic girdle. In this configuration, tolerance is extremely low.

The standard seat belt and shoulder harness configuration greatly reduces injuries from head impacts and helps to maintain proper spinal alignment for strictly vertical impact forces.

This standard configuration is unsatisfactory, however, for impacts with both vertical and longitudinal components. Pressure by the upper torso against the shoulder straps causes these straps to pull the lap belt up into the abdomen against the lower margin of the rib cage. This movement of the lap belt allows the pelvis to move forward under the lap belt, causing severe flexing of the spinal column. In this flexed position the vertebrae are very susceptible to anterior compression fractures. A lap belt tiedown strap prevents raising of the lap belt by the shoulder harness and nearly doubles the tolerance to impact forces.

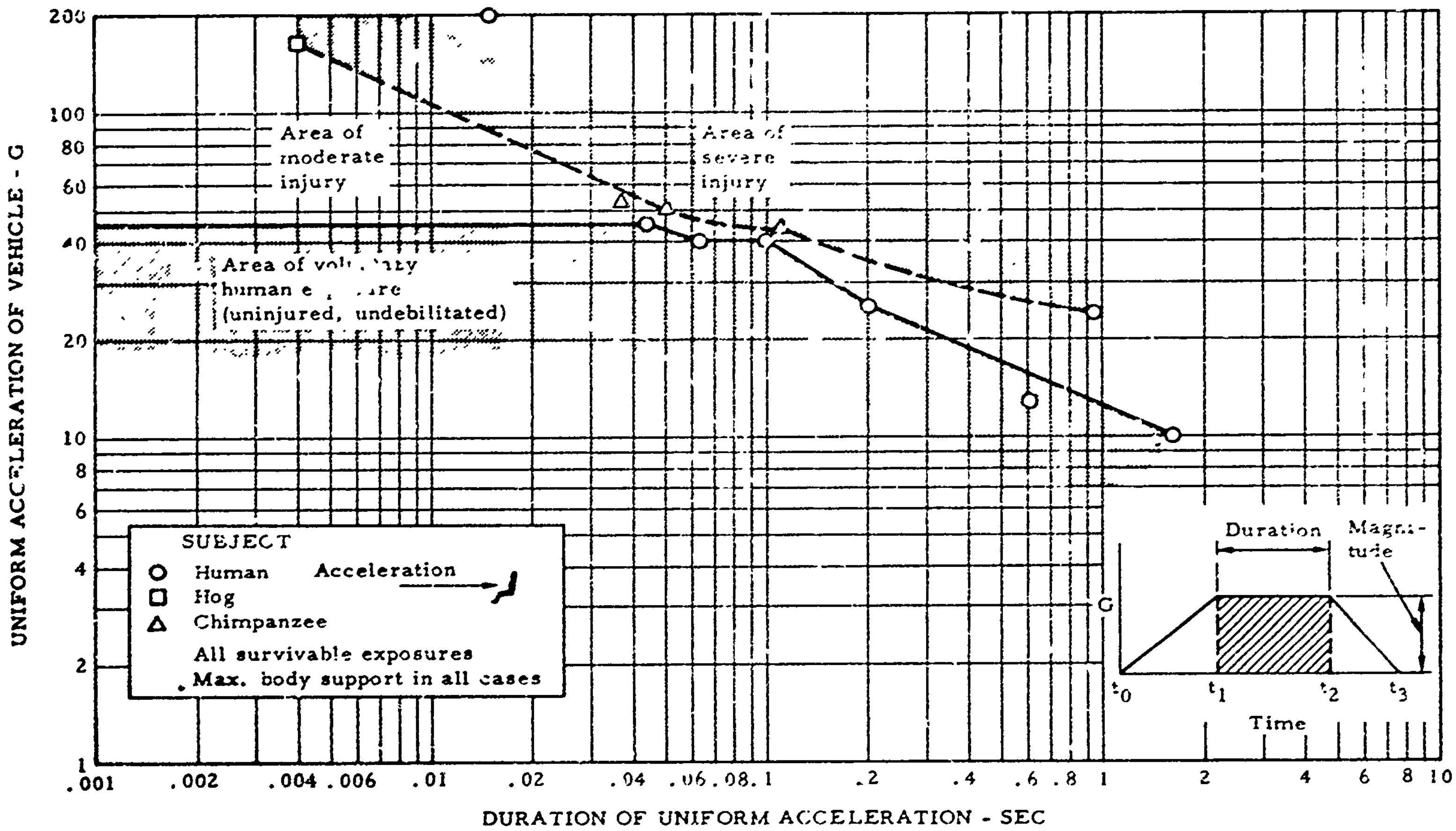


FIGURE G-1 DURATION AND MAGNITUDE OF SPINEWARD ACCELERATION ENDURED BY VARIOUS SUBJECTS (TAKEN FROM REFERENCE 3).

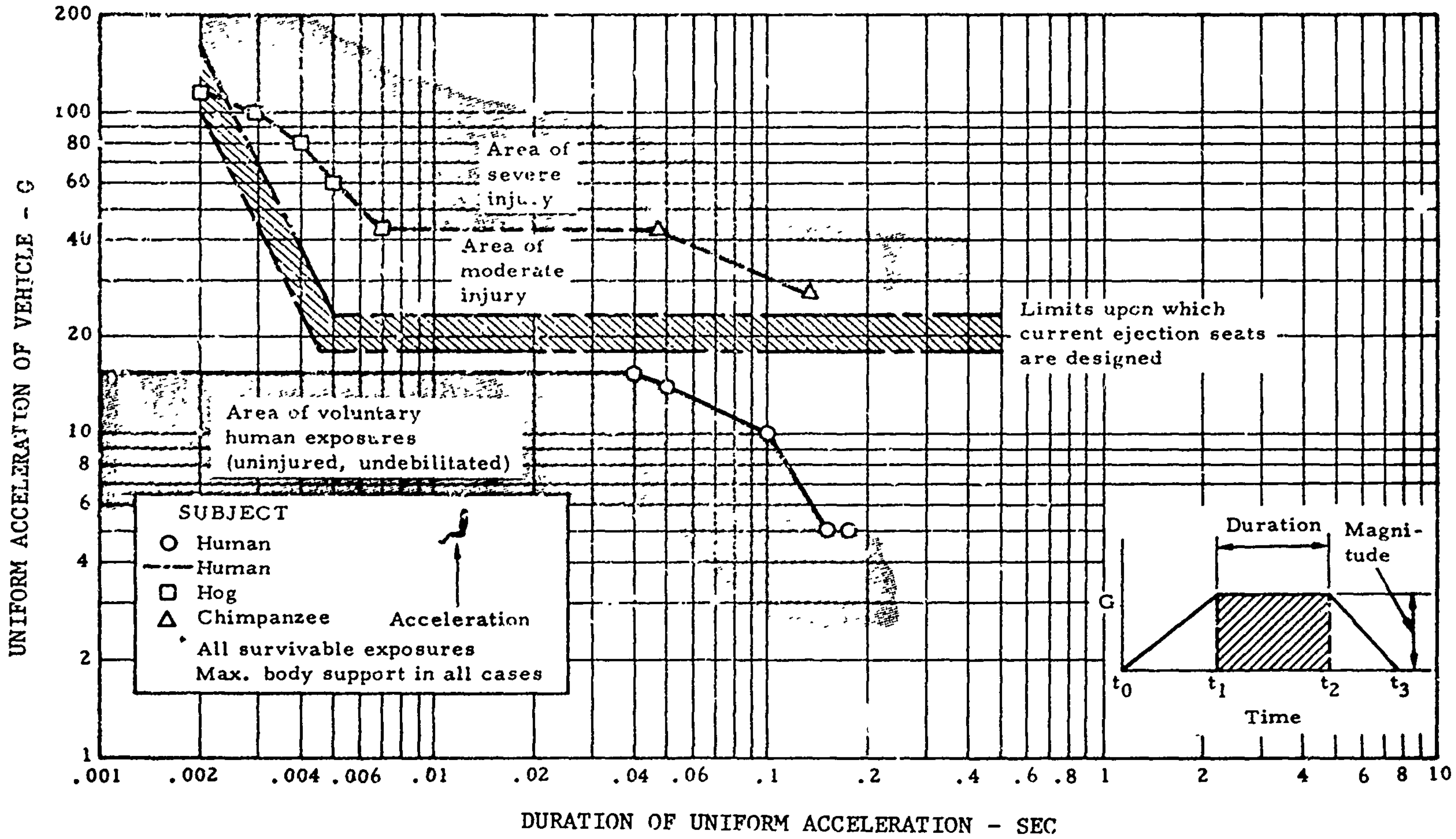


FIGURE G-2 DURATION AND MAGNITUDE OF HEADWARD ACCELERATION ENDURED BY VARIOUS SUBJECTS (TAKEN FROM REFERENCE 3)

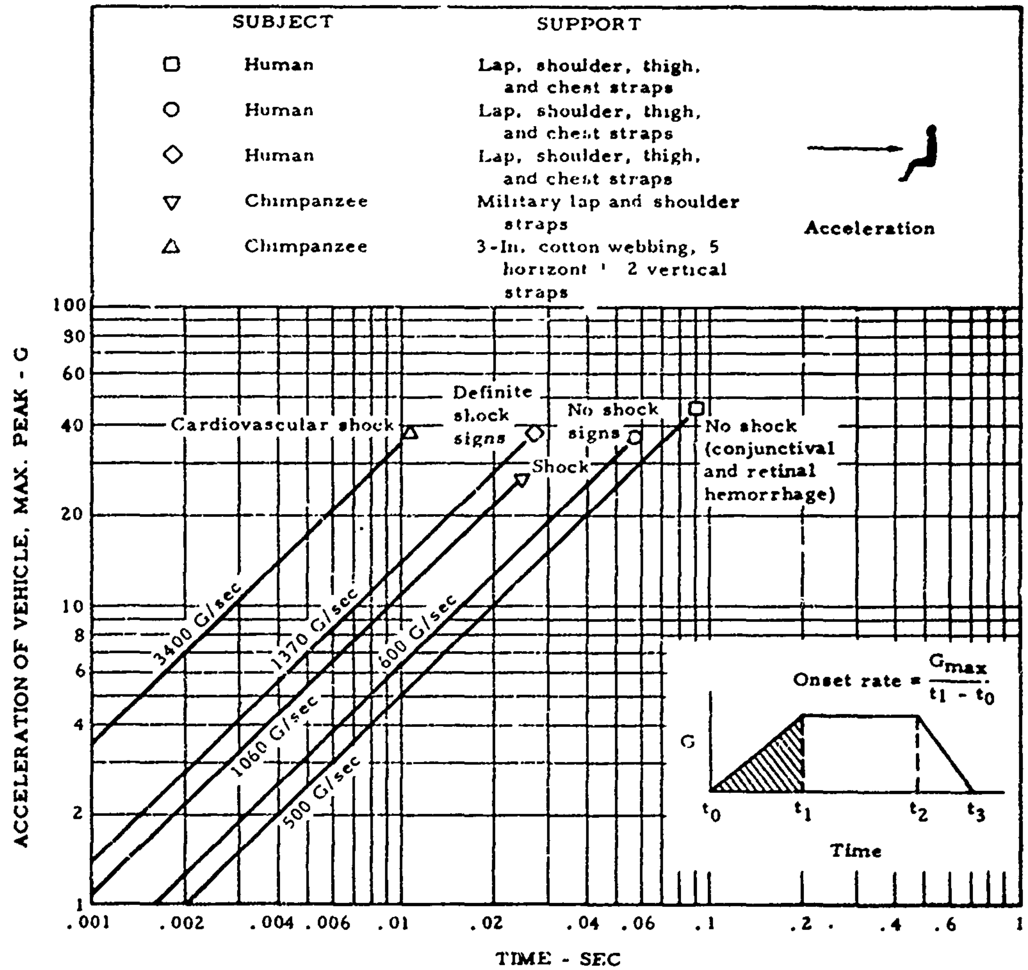


FIGURE G-3 INITIAL RATE OF CHANGE OF SPINEWARD ACCELERATION ENDURED ΒY VARIOUS SUBJECTS (TAKEN FROM REFERENCE 3)

The amount of slack in the restraint system can affect tolerance to a given input acceleration pulse. In general, the more rigid the link between the occupant and the seat, the greater the occupants' tolerance to an abrupt acceleration. A loose restraint system can result in the occupant's receiving a magnification of the accelerative force applied to the seat. This applied force will accelerate the seat over a certain distance. The inertia of the occupant will cause him to maintain a near constant velocity, independant of the decreasing velocity of the seat, until the slack in the restraint system is taken up. As this point is reached, the velocity of the occupant is abruptly reduced to that of the seat at relatively high G levels, even exceeding that of the seat. This is often referred to as "dynamic overshoot" which is a complex phenomenon involving the elasticity, geometry, and mass distribution of the occupant restraint and seat system.

Acceleration Forces on the Body (Figure G-4) apply to the following:

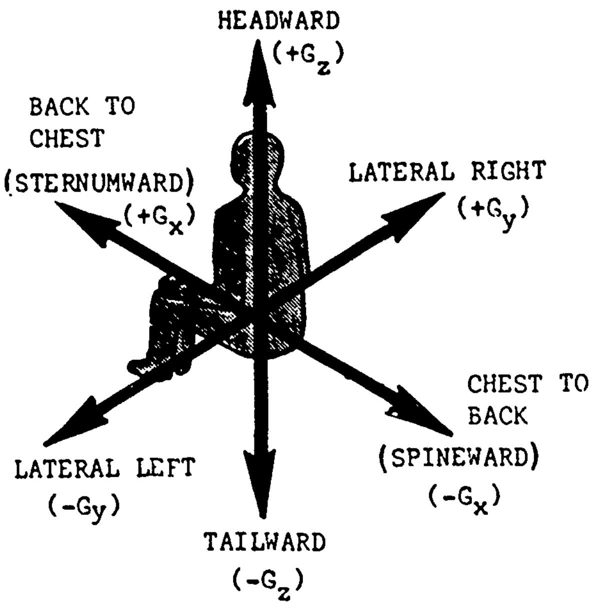
<u>Tolerance Limits to Headward Acceleration</u>: The human tolerance limit for headward, eyeballs-down ($+G_Z$) acceleration is a pulse of approximately 25G maintained for approximately 0.1 second. Injuries, primarily compression fractures of spinal vertebrae, do, on occasion, occur at this level. However, these fractures are not necessarily of the nature to incapacitate the occupant, and his ability to extricate himself from wreckage should not be seriously impaired. The 25G tolerance figure is based on experimental testing of the strength of human vertebrae and studies involved in the development and testing of various ejection seat systems and escape capsule landing systems.

Tolerance to vertical impact loads is greatly reduced when the spinal column is in a flexed position or is misaligned laterally. For this reason, a tight shoulder harness to hold the occupant's shoulders tightly against the seat back is an important factor in tolerance to headward accelerations.

<u>Tolerance Limits to Tailward Acceleration</u>: The human tolerance limit for tailward, eyeballs-up ($-G_Z$) acceleration is approximately 15G for a duration of 0.1 second. The shoulder harness/seat-belt restraint has been used in all human testing with tailward accelerations. Most experiments have also included a seat belt tiedown strap, and the 15G tolerance limit is based on this latter configuration.

<u>Tolerance Limits to Spineward Acceleration</u>: The human tolerance limit for spineward, eyeballs-out ($-G_X$) acceleration is approximately 45G for a duration of 0.1 second or 25G for a duration of 0.2 second. Restraint in the experiments establishing these limits was by means of a double-thickness, 3-inch wide shoulder harness; a seat belt with thigh straps, and a chest belt. With less optimum restraint systems, some debilitation and injuries will occur at this force level.

<u>Tolerance Limits to Sternumward Acceleration</u>: The human tolerance limit for sternumward, eyeballs-in ($+G_X$) acceleration has not been accurately established. Due to the high degree of restraint provided by full-



<u>DIRECTION OF DECELERATIVE FORCE</u>

<u>VERTICAL</u>

Headward - Eyeballs down
Tailward - Eyeballs up

<u>TRANSVERSE</u>

Lateral Right - Eyeballs left
Lateral Left - Eyeballs right
Back to Chest - Eyeballs in
Chest to Back - Eyeballs out

<u>Note:</u>

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

FIGURE G-4 DECELERATIVE FORCES ON THE BODY length seat back in this configuration, it can be safely assumed that tolerance is greater than for spineward acceleration. A maximum of 83G with a base duration of 0.04 second was experienced on one run in a backward-facing seat. However, the subject was extremely debilitated, went into shock following the test, and required on-the-scene medical treatment. Human tolerance to sternumward acceleration, therefore, probably falls somewhere between this figure of 83G for 0.04 second and 45G for 0.1 second, which is the accepted end point for the $-G_x$ (eyeballs-out) case.

Tolerance Limits to Lateral Acceleration: Very little research has been conducted on human tolerance to lateral (G_y) accelerations. Two studies, one involving restraint by a lap belt alone and the other involving restraint by the seat belt/shoulder-harness configuration, provide the principal available data. With restraint by the seat belt alone, volunteers were able to withstand a pulse with an average peak of approximately 9G for a duration of approximately 0.1 second. At this level, the tests were discontinued due to increasing danger from lateral spinal flexion. In the experiments with restraint by seat belt and shoulder harness, volunteers were able to withstand a pulse with an average G of approximately 11.5 for a duration of approximately 0.1 second and suffered no permanent physiological changes. Tests were discontinued at this level due to possible cardiovascular involvement experienced by one of the two subjects tested. No end points for human tolerance to lateral impacts were proposed in the reports of these experiments. The only reasonable conclusions from these data at this time are that a pulse of 11.5G with a duration of 0.1 second is readily sustained by subjects restrained by a seat belt and shoulder harness and that the human survival limit is at some point beyond this level, probably at least 20G for 0.1 second.

It should be noted the above limits are based on shoulder harness and in some cases additional restraint devices. Only in one test series was only a lap belt used. This should result in caution in use of this data.

The guide further defines a dynamic triangular pulse based on time and accelerations. Typical proposed design rules are shown in the table below for 95th percentile survivable crashes.

IMPACT DIRECTION	AV_{fps}	PEAK G	AVERAGE G	PULSE T SEC
Light Fixed-Wing				
Longitudinal Cockpit	50	30	15	.104
Longitudinal Passenger	50	24	12	.130
Vertical	42	48	24	.054
Lateral	25	16	8	.097
Fixed Wing Transport				
Longitudinal Cockpit	64	26	13	.153
Longitudinal Passenger	64	20	10	.200
Vertical	35	36	18	.060
Lateral Cockpit	30	20	10	.093
Lateral Passenger	30	16	8	.116

Airframe crash worthiness is a major area of discussion. What can be done in the area of designing an airframe to lower effective Gs in a crash? For example, if the forward fuselage were to deform on impact and form a scoop it will plow into the earth. The plowing will result in higher G forces than skidding. Therefore, a crash on a concrete surface would not have plowing and a lower G force. The fuselage can also be built to better withstand these forces. Additionally, seats as well as cargo restraint systems can be designed to absorb some of these forces and various designs are shown.

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