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AIR CARGO RESTRAINT CRITERIA

Joseph L. Weingarten, et al

Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio

April 1973

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ASD-TR-73-17

FINAL REPORT-AIR CARGO RESTRAINT CRITERIA

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FOREWORD

This report was prepared jointly by the Deputy for Engineering, Aeronautical System Division (ASD), and the Air Force Flight Dynamics Laboratory (AFFDL), Air Force System Command, Wright-Patterson Air Force Base, Ohio. The initial work effort was accomplished under AFFDL project 1367, "Structural Design Criteria for Military Aerospace Vehicles," and Task 136702, "Aerospace Vehicle Airframe Design Criteria." This effort resulted in AFFDL-TR-71-139, "Air Cargo Restraint Criteria" which has been abridged and incorporated in this report as Appendix 1. The abridgment relates only to specific aircraft accidents and dates which have been deleted.

This report was accomplished under ASD Project USAD 0034, Air Cargo Restraint Criteria.

This document has been reviewed and is approved.

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13. ABSTRACT A major change in Air Force air cargo restraint criteria has been enacted. The revised criteria, which are based on technical report AFFDL-TR-71-139, <u>Air Cargo Restraint Criteria</u> , and their implementation are presented. An extract of AFFDL-TR-71-139 is included as Appendix 1. The initial investigation was conducted to determine probabilities of encountering various forward crash load factors; to determine if cargo restraint procedures could be improved for better operational capability. Safety and cost factors were viewed in relation to current air transportability requirements. In determining the probabilities, data from January 1960 to July 1971, covering all major USAF cargo aircraft accidents with a total flying time in excess of 31 million hours, was used. The results showed that the risk to passengers on cargo flight is statistically rare and that a change in air cargo restraint procedures would provide a safer system than previously available with an overall cost savings to the military services.		

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ABSTRACT

A major change in Air Force air cargo restraint criteria has been enacted. The revised criteria, which are based on technical report AFFDL-TR-71-139, Air Cargo Restraint Criteria, and their implementation are presented. An extract of AFFDL-TR-71-139 is included as Appendix 1.

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SECTION I
INTRODUCTION

AFFDL Technical Report 71-139, "Air Cargo Restraint Criteria," was published for Air Force use in January 1973. The report has been abridged to allow its reproduction as Appendix I by deleting specific aircraft accident data and related dates. The removal of the accident data does not affect the presentation or conclusions of the report.

The report recommended a revision to Air Force restraint criteria. The then current aircraft cargo handling systems and cargo designated air transportable are built to a 9G forward loading capability to withstand crash loads. The proposed changes would require that air transportable equipment and aircraft cargo handling systems be designed to an operational 3G forward load and that aircraft barrier nets be utilized to provide a 9G forward capability for personnel protection. This change in restraint technique would lower equipment costs and provide a safer overall system. Nuclear cargo movement was not examined in the initial work effort; current transportability requirements for nuclear cargo will be maintained pending a full review of the area.

The adoption of the recommended cargo restraint revisions by the Air Force in December 1972 resulted in the approval of the following actions:

- a. The operational 4G requirement for cargo tie-down without passengers seated forward of general cargo will be lowered to 3G. Nuclear cargo will continue to be restrained to its current 4G level.

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b. Air Force Systems Command will investigate improved/alternative methods of nuclear cargo transport.

c. Passengers or nuclear cargo carried forward of general cargo will be protected by a barrier net positioned in front of the general cargo. Nets will be positioned to achieve a minimum 8G forward restraint or to the structural limitations of the fuselage, whichever is greater.

d. An investigation will be conducted by ASD to determine the feasibility of installing an integral barrier net in the C-130 and C-141 aircraft. The restraint capability to be provided will equal the structural limitations of the fuselage.

e. Specification MIL-A-008865A, "Airplane Strength and Rigidity Miscellaneous Loads," will be revised to establish a 3G cargo restraint system in conjunction with a 9G auxiliary net restraint system to be used when passengers are seated forward of cargo on the same deck level.

f. Specification MIL-A-8421, "General Specification for Air Transportability Requirements," will be revised by deleting the 9G crash load requirements. Action will be initiated to coordinate the revised specification with all services.

g. A program will be established to define the additional data required of Air Force cargo aircraft accident investigations applicable to the development of criteria relating to airframe crash worthiness, cargo restraint, seat design, and personnel survivability.

SECTION II

IMPACT

The implementation of the approved actions presented in Section I will have a far ranging influence on future Air Force operations, aircraft design, and equipment design.

1. Air Force Operations - Cargo movement will be simplified by permitting all general cargo to be secured to a 3G restraint level. Previously, several different G factors were allowed (Table I and II, Appendix I) depending on the aircraft and its cargo/passenger configuration for a particular mission. Although variable factors were allowed, standard practice required that pallet loads be restrained to the maximum required restraint level; the aircraft to be utilized initially, aircraft changes in route, and cargo/passenger configurations are not only variable but often unknown at the time that a pallet is loaded. In conjunction with the 3G pallet restraint, the Van Zelm net (shown in Figure 1) will be required on flights where passengers or nuclear cargo are placed forward of the general cargo to provide a minimum 8G level of restraint. The Van Zelm nets are currently available and being used by the operational Commands. The net does, however, require additional effort to install and readjustments prior to each flight. The additional cargo loading complexity does somewhat affect the advantages of using a 3G pallet restraint but this will be a temporary disadvantage.

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An integral barrier net restraint system and related installation requirements for C-130 and C-141 aircraft have recently evolved from an Air Force preliminary design study. This barrier net system is intended to overcome the using commands' objections to the complexity of the Van Zelm net and the restricted movements imposed by the commercial (see Figure 2) barrier net system. The new net system provides installation flexibility and allows inflight movement of personnel along the length of the cargo compartment. The prototype concept provides the necessary flexibility through a ceiling suspension trolley system which allows the net to be positioned at any point within the cargo compartment. Its restraint is provided in a manner similar to that of the Van Zelm net, which ties directly to existing floor rings. The ceiling supports do not provide restraint (see Figure 3); however, the ceiling suspension system does insure that the net will appropriately envelope the cargo should it exceed its 3G restraint level and move forward during crash impact. Aerial delivery loads are also affected and have been reduced from 4G to 3G.

2. Aircraft Design - Amendments issued to MIL-A-008865A will provide future cargo aircraft with a 3G (2.0G x 1.5F.S.) forward cargo restraint system to react the low G operational contingencies of an emergency nature in conjunction with an integral barrier net system providing an overall 3G level of protection for passengers when circumstances warrant.

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A measure of the impact that this new concept will have can be obtained by comparing the results of a study conducted by the McDonnell-Douglas Corporation for the Deputy for Advanced Planning, Aeronautical Systems Division. The analysis considered the cost and weight variations for a medium STOL type airplane incorporating the above 3G/9G system and a conventional 9G cargo restraint system. The study showed a potential cost reduction of 1.2 percent and an empty weight reduction of 1.6 percent for each aircraft. Considering the two medium STOL airplanes currently being procured under the prototype concept at a projected cost of five million dollars each, the cost savings on a production buy of 200 airplanes would be 12 million dollars ($5 \times 10^6 \times 200 \times 0.012$). Additional dollar savings would also be obtained over the life of the airplanes through the improved operational efficiencies that would result from a lower airframe weight.

3. Equipment Design - The potential for cost savings is greatest in the area of air transportable equipment design. Each military service has equipment designated air transportable and is governed by a common design specification, MIL-C-8421, "Air Transportability Requirements." This equipment includes, for example, most combat ground vehicles used by each service, Air Force ACE, containers and vans, artillery pieces, mobile bridges and related Corps of Engineering equipment. Air Force Base Base equipment requirements are even more extensive in scope. This concept considers only a cleared land area of sufficient size to support tactical

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aircraft operations, without physical facilities or natural resources other than a usable runway, taxiways, parking areas, and a source of water. These basic resources are then transferred to an operational Tactical Air Force Base in a matter of days. All equipment is flown in, including outsized equipment, and all of it is designated air transportable. Previously, vehicles and equipment considered air transportable had to remain intact following a 9G forward load and operate following a 3G forward load. The removal of the 9G load factor design requirement will not affect current equipment inventories but will have a significant effect on all future procurements.

4. 463L Equipment - Future pallet and net procurements for the 463L systems will be directly affected by the lower restraint requirements. The reduction in allowable strength will permit the use of lighter nets and tie-down rings on the pallets and extruded rails in pallet construction.
5. Cost Savings - The cost savings to be accrued by the reduced restraint requirement for general and aerial delivery cargo cannot be estimated as accurately for air transportable equipment, cargo handling equipment, or changes in operational procedures as they can for the previously cited airplane design example. Many variables must be considered in addition to the overall scope of the operation. Many influences, although small, are very significant when the total number of repetitive events is considered. Hence, the increased rapidity of loading permitted by a reduction in total restraint, the reduction in required tie-down equipment

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and related weights savings, the associated savings in manpower, man-hour reductions in equipment design and testing, lower manufacturing costs and improved cargo airplane turn-around times, will all contribute to the significant savings anticipated as a result of the restraint reduction for cargo. In addition, greater protection will be afforded passengers on mixed cargo/passenger flights as discussed in Sections V and VI of the Appendix.

SECTION III

SUMMARY

Actions taken within the Air Force will provide, upon complete implementation, a cargo restraint system that is safer than the one currently in use. The most significant safety improvement will be the design and installation of an integral barrier net system in the C-130 and C-141 aircraft.

Considerable cost savings will accrue in all military services as new equipment is designed. The Air Force will also benefit from simplified procedures in tying down both cargo and airdrop loads. Future aircraft will be lighter in weight, resulting in a cost savings when procured and throughout its lifetime.

The previously discussed changes in air cargo restraint requirements were based on a study of data from USAF cargo aircraft accidents over a ten year period. It was apparent during the study that additional data could be included in the accident reports which would be valuable in developing future cargo and personnel restraint system criteria. Understandably, current accident report requirements concentrate on the causes of accidents and recommendations for actions to prevent recurrence. Minimum detailed data is included on what happened to seat, cargo, fuel, and other items on the aircraft during the crash. Procedures are being developed to obtain additional data from accidents which can be used to improve design requirements and emergency procedures to enhance personnel survivability in the aircraft crash environment.

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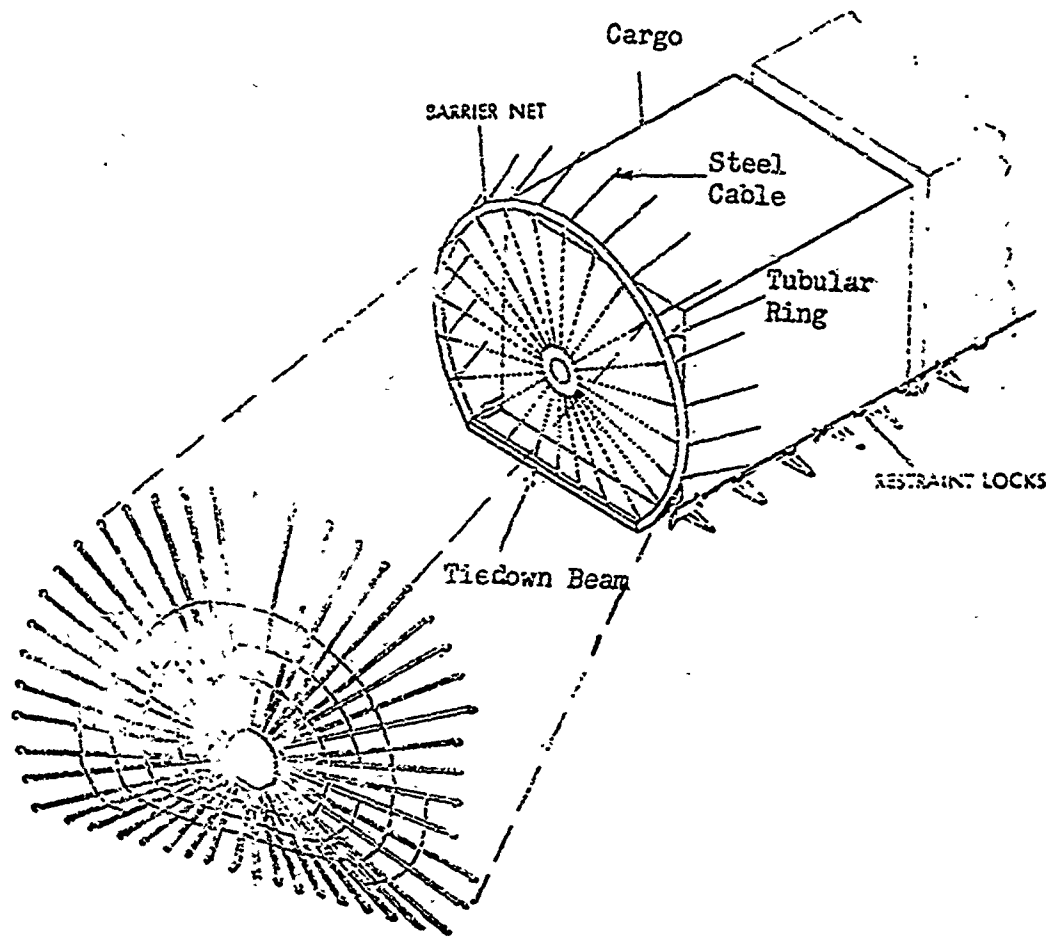


Figure 1 - Commercial Barrier Net

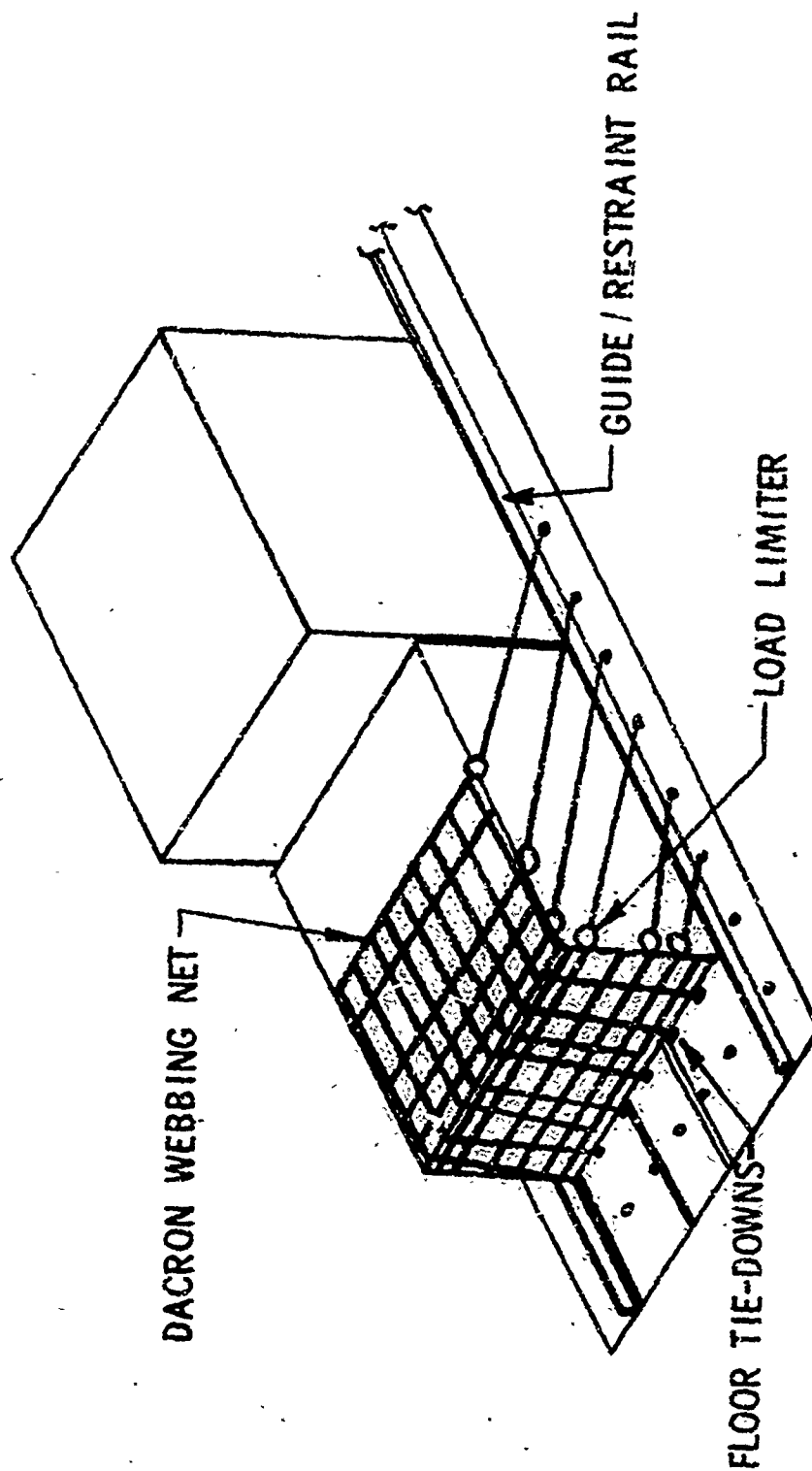


Figure 2. Van Zelm Barrier Net

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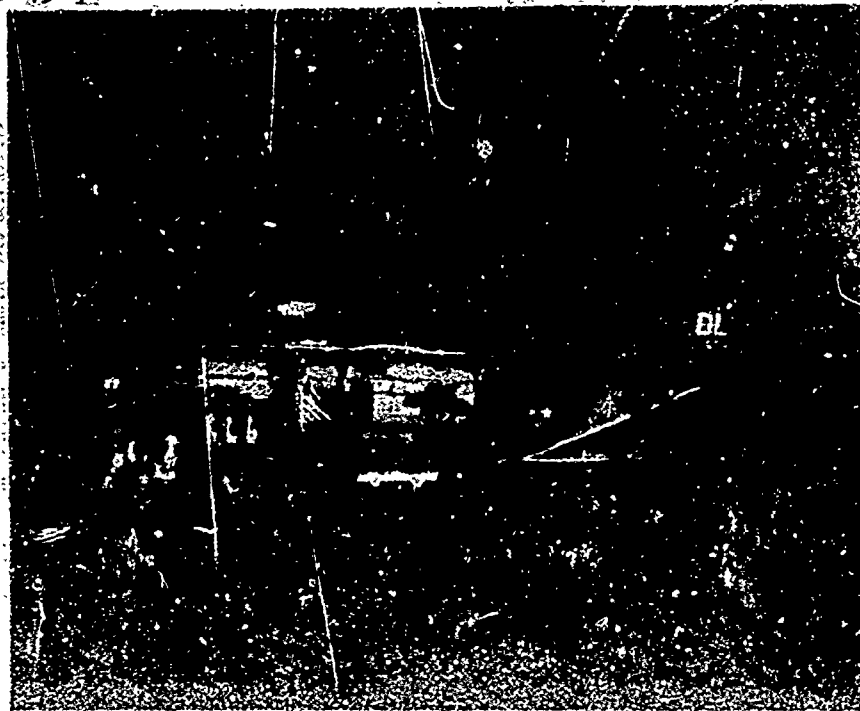


Figure 3 - C-130/C-141 Integral Barrier Net

APPENDIX I

SECTION I

INTRODUCTION

1. SCOPE

This investigation examined the load factor criteria used in air-cargo-restraint system design and operation in light of the latest Air Force cargo aircraft accident data and available information on the acceleration environment encountered in cargo aircraft crashes. The objectives were to: (1) develop the probabilities of encountering various magnitudes of load factors, and (2) assess the potential of personnel injury associated with designing and operating cargo restraint systems at different load factor levels. The results are intended to be used as a guide in making decisions on the levels of restraint that will be required in future air cargo operations and equipment design.

The currently published USAF load factor requirements related to the air cargo restraint system are summarized in Table I. Note that these criteria are specifically applicable to: (1) the airframe attachments with associated carry-through structure, and (2) any equipment which is to be air transported. The link between the airframe and the transported equipment is the tie-down equipment and the procedure is to make the strength of this link equivalent to the load requirements shown in Table I.

The application of the load factors shown in Table I, as well as those required by previous editions of the noted specifications, has a significant impact on the design and use of air cargo handling equipment.

The validity of the magnitudes of the load factors has frequently been questioned and was one of the reasons for initiating this study.

Table II permits comparison of current load factor requirements (Table I) with the load factors used to design airframe attachments and basic cargo handling systems for the primary aircraft in the USAF cargo transport fleet.

2. BACKGROUND

As previously noted, the load factor criteria used to design restraint systems for cargo being transported by military aircraft has a significant effect on flight safety, cargo aircraft and cargo handling equipment design, and the effectiveness of air cargo operations. The primary factors affected are the safety of the aircrews and passengers; the weight, cost, and complexity of the basic airframe, and the cargo handling equipment; and the manpower and time required to accomplish the air cargo mission.

Advances in air cargo handling equipment and procedures such as the palletized cargo system, and, more recently, the proposed use of airlift containers has focused additional attention on the need for realistic air cargo restraint criteria. These criteria must include the loads resulting from the accelerations which can be encountered during all phases of the air cargo transport mission. The accelerations associated with normal takeoffs, air turbulence, maneuvers, and landings are predictable and pose no serious problems. It is the least predictable emergency situation or, more specifically, the acceleration environment

encountered in aircraft accidents, which is the key to air cargo restraint criteria. Cargo aircraft accidents ranging from hard landings to catastrophic crashes provide the data base from which the limits for the load factors specified in air cargo restraint criteria must be developed.

It should be remembered that the load factors associated with the crash acceleration environment (regardless of whether the criteria applies to restraint of cargo, personnel, or miscellaneous equipment) are essentially empirical values based on past experience and supported only by a limited amount of full scale aircraft crash test results. The prime factor in determining the limits for air cargo restraint is personnel safety. This is reflected in the higher load factors currently required (reference Table I) when there is a potential of injury to the aircraft crew and/or passengers.

3. OPERATIONAL CONSIDERATIONS

Three aircraft systems are of primary concern. These are C-130, C-141, and C-5. The current forward restraint load factors vary as shown below:

Current Restraint Load Factors

<u>Aircraft</u>	<u>Operational Cargo Only</u>	<u>Cargo/Pax Mix</u>
C-130	4	8
C-141	4	9
C-5	3	*

*Passengers are seated above the cargo compartments.

The variation in load factors between aircraft types has caused concern in two areas. First, transfer of one load from one air vehicle to another may require additional restraint. Secondly, many items carried on aircraft cannot be restrained to the 8 and 9 load factor level. For example, a US Army 2-1/2 ton truck weighs 19,785 pounds. Even when secured by a 9-G restraint system, the attachment points on the vehicle will fail at 6 G's forward. The effective strength of the fittings are further reduced to 4.5 G's when the downward components of the restraint tie-downs are introduced (Reference 1). The battery, windshield, and other components of the truck will begin to separate from the body and frame to become lethal missiles at approximately 2 G's forward. Similarly, the new air-land-sea container, which is expected to enter the air cargo system in the near future, cannot be directly restrained to 9-G levels without an auxiliary restraint system. Container restraint is a matter of concern and one of the factors which established this study.

4. APPROACH

The limited time period scheduled to accomplish this investigation required the application of readily available data pertinent to the problem area. Two primary sources of data were used. The first was Air Force cargo aircraft operational data with special emphasis on cargo aircraft accident information for the period from January 1960 to July 1971. The results of the analysis of this data are presented in Section II.

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The second source of data is analyses which have been conducted of transport aircraft accidents and full scale aircraft crash tests to define the crash acceleration environment. The application of these data is discussed in Section III.

SECTION II

AIRCRAFT ACCIDENT ANALYSIS AND PREDICTIONS

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.

1. DATA REFERENCE

Three sets of interrelated data were used in this study to formulate the probabilities of an accident and its relation to cargo transport. The Deputy Inspector General for Inspection and Safety, USAF, Norton Air Force Base, California (IGDS), maintains records and published reports on all Air Force aircraft accidents. The documents utilized were US Air Force Accident Bulletins from 1960 through 1969, which provided overall statistical data on all accidents. To obtain additional detailed accident data, a request was submitted to IGDS and they applied the computerized accident data system to provide information on all (415 cases) major cargo accidents from January 1962 to July 1971. This provided data on the cause of accident, phase of operation, and personnel injuries for each aircraft. To provide details that were not available in the accident bulletins or the computerized accident information, 64 consecutive major accident reports available in ASD files from late 1968 to February 1971 were reviewed. The cross correlation of these three sets of data provided a more complete view of the major accidents than could be obtained from any one set.

Time did not permit the use of actual accident reports other than those noted, nor were additional reports readily available. A more accurate accounting of crash force estimates, occupant injuries, and cargo interactions could have been made if the actual accident reports had been available and if time had permitted such an extensive review.

2. AIRCRAFT ACCIDENTS

The data available is based on major accidents and not aircraft crashes. Major accidents are defined by the Air Force as those aircraft accidents where there is loss of life and/or where an aircraft receives at least substantial damage. This includes accidents where a parked aircraft catches fire during refueling, as has happened numerous times, or the times the landing gear was retracted on a parked aircraft. For the purpose of this study, a crash is defined as an accident where the aircraft underwent excessive "G" loadings during any mission phase, except in-flight accidents where a successful landing was accomplished. From January 1962 to July 1971 there were 415 major accidents. Of these, 315 fit the above crash definition; 76 percent of the accidents are therefore considered crashes for this study. This same relationship was applied to two other time periods where only accident information was available, with the following results:

<u>Time Frame</u>	<u>Accidents</u>	<u>Crashes</u>
January 1962 to July 1971	415	315
January 1960 to July 1970	486	369
January 1960 to July 1971	497	377

The accidents analyzed include worldwide military cargo transport missions in both combat and noncombat zones. They did not include aircraft which were lost as a direct result of hostile action. Available data on Southeast Asia aircraft losses show that for the period from February 1962 through February 1971, approximately 66 cargo aircraft were destroyed due to hostile action and an additional 85 were destroyed due to accidents. Data on the combat losses were not available for inclusion in this study; however, the 85 accident cases are included in the IGDS data.

3. ACCIDENT DATA ANALYSIS

Table III lists data on USAF cargo aircraft flying hours, major accidents, and landings per year where available. The landings per year data for the 1960 through 1966 time period were divided into the corresponding years flying hours and this provides an average flight duration of two hours and one minute. The total flying hours and number of crashes for the 1960 through 1970 time period were used to calculate a crash rate as follows:

$$\frac{369 \times 100,000}{31,445,869} = 1.17 \text{ crashes/100,000 hours}$$

The 415 major accidents were analyzed and grouped by mission phase and type of accident and the results are shown in Table IV. It is

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evident that the chance of survival is dependent on the mission phase as shown below:

<u>Mission Phase</u>	<u>% of Accidents</u>	<u>% Nonsurvivable</u>
Takeoff	22.6	34.0
In-flight	28.4	84.1
Landing	44.9	8.6
Go-around	4.1	33.0

Landing accidents are generally the least severe due to the lower aircraft speed, comparatively unobstructed crash terrains, and lower impact angles. In-flight accidents include flying into mountains, collisions with other aircraft, and equipment or structural failure leading to high speed impacts with terrain.

To determine a range of "G" forces in relation to crashes, estimates were based on the more detailed data contained within the 64 accident reports in current Aeronautical System Division files. Fifty-seven of these reports were descriptive enough to allow crash force estimates to be made. The general guidelines used in Reference 2 were followed when establishing crash force estimates from the accident report data. The guidelines are discussed in Section III and the cumulative distribution of the crash forces is shown in Figure 1. The crashes in Reference 2 generally fall into a 3-G to a nonsurvivable crash category. The crash force estimates for the 57 crashes evaluated were grouped as shown below to coincide with the data in Reference 2, and allow correlation with the crash force and injury data in Section III.

<u>0 to 3 G</u>	<u>3 G to Nonsurvivable (N/S)</u>	<u>Nonsurvivable (N/S)</u>
40.4%	26.2%	33.4%

Of the 64 aircraft, only 20 (31%) had cargo on board and 6 (9.4%) of these had mixed cargo and passenger loads. This reflects the fact that cargo transports are also used as tankers, attack, reconnaissance, electronic warfare, weather, rescue, and command post aircraft. Considerable additional flying time is used for update training. This is reflected in utilization factors of the above cargo.

In an effort to check the estimates of crash force levels developed from the accident report review, the ninety C-130 aircraft major accidents summaries in the IGDS data from January 1962 to July 1971 were examined in more detail and estimates made of the crash force levels (See Appendix I). The result was a similar crash force level distribution pattern as shown in the following comparison:

	<u>Crash Force Estimates</u>		
	<u>0 to 3 G</u>	<u>3 G to N/S</u>	<u>N/S</u>
Cargo acft accident reports	40.4%	26.2%	33.4%
C-130 Accidents	48.4%	25.8%	25.8%

A comparison of C-141 crash force estimates was not computed due to the low frequency of crash. From January 1962 to July 1971, eight C-141 accidents occurred but only three of these were crashes.

4. CRASH PROBABILITIES

To determine the probability of an aircraft crashing with cargo on board or a mix of cargo and passengers in any year, a standard year was

projected to be 3 million flying hours (see Table III), with an average flight lasting two hours. The projected number of cargo aircraft flying hours per year, together with the crash rate previously computed, were used to predict the number of aircraft crashes per year.

$$\text{Flying Hrs/Yr} \times \text{Crash Rate}/100,000 \text{ Hrs} = \text{Crashes/Yr}$$

$$3,000,000 \times \frac{1.17}{100,000} = 35 \text{ Crashes/Yr}$$

These 35 crashes were grouped into the crash force levels using the percentage distribution developed from the accident report review. The grouping is as follows:

<u>Fwd Crash Force Level</u>	<u>Percent at Level</u>		<u>Total No. Crashes</u>	<u>No. Crashes at Level</u>
0 to 3 G	40.4	x	35	14.1 or 14
3 G to N/S	26.2	x	35	9.2 or 9
N/S	33.4	x	35	11.6 or 12

The risk factors developed are for the 3-G to N/S level only, since there is no question of reducing air cargo load factors below 3 G and the load factors used have no significance in catastrophic (N/S) cases. Cargo loading conditions for the 9 cases at the 3-G to N/S level were determined using the percentages previously determined from the accident report review as follows:

$$\text{Cargo on board} = 31\% \times 9 \text{ cases} = 2.79 \text{ or } 3$$

$$\text{Mixed cargo and passengers} = 9.4\% \times 9 \text{ cases} = .84 \text{ or } 1$$

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Since it was desired to present the risk factors as the probability of occurrence per flight, the projected 3 million flying hours per year was divided by the average 2-hour flight duration to provide the 1.5 million flights per year used in the following calculations:

$$\text{Probability} = \frac{\text{No. of Occurrences/Yr}}{\text{No. of Flights/Yr}}$$

<u>Event</u>	<u>Projected No. of Occurrences</u>	<u>Prob. Per Flight</u>	<u>No. of Flights For i Occurrence</u>
Cargo acft crash	35	.000023	43,500
Crash at 3-G to N/S level	9	.000006	168,000
Crash at 3-G to N/S level with cargo on board	3	.000002	500,000
Crash at 3-G to N/S level with cargo and passengers	1	.00000066	1,500,000

The probability data shows that the projected risk of encountering a crash in the 3-G to N/S level where cargo is a hazard to crews or passengers is low. This low projected risk is supported by available accident injury data which is discussed in the subsequent paragraph.

5. CARGO-INFLICTED INJURY DATA

The IGDS cargo aircraft accident data includes a Life Sciences Section which provided personnel injury data for the 415 major accidents for the 1962 to July 1971 period. In the data, personnel injuries are related to cause factors and one of these factors is "Equipment or cargo, dislodged/unattached." Three of the major accidents cited this factor as the cause of injury to a total of five persons. Available

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Information on these three cases, two C-130's and one C-133, follows:

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6. CARGO AIRCRAFT ACCIDENT TRENDS

Since the accident rate for USAF cargo aircraft has been decreasing (see Figure 2), the number of personnel injuries should be proportionally reduced. The 1970 major accident rate for Air Force cargo aircraft is down to 0.98 per 100,000 flying hours. As previously noted, the crash rate is less than the major accident rate; consequently, the average 1.17 crash rate per 100,000 flying hours used in this study to project risks may be considered a conservative value.

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The 1970 major accident rates for the C-130 and C-141 aircraft were 0.6 and 0.2 per 100,000 flying hours respectively. The C-141 mission is considered similar to that of the civil air carriers and IGDS points out (Reference 3) that for a civilian fleet equivalent to the C-141, the accident rate was 0.815 per 100,000 flying hours in 1970.

SECTION III
CRASH FORCES AND INJURIES

1. CRASH FORCE DATA

Accident reports and related accident information are available as discussed in the previous section. Crash force data, however, are not normally generated during the course of an accident investigation. Crash force estimates have been developed by analysis of civil and military aircraft accidents and are documented in Reference 2. The referenced analysis covered accidents involving "moderate to severe impact forces" and only accidents meeting the following criteria were used:

- (1.) Aircraft weight was greater than 20,000 pounds
- (2.) Aircraft was multi-engined
- (3.) At least one person was injured
- (4.) At least one person did survive the accident, or that conclusive evidence indicated survival would have been possible if proper body restraint had been used.

As evident from this criteria, the accidents included in the study are in the "survivable" accident, or crash, category. Sixty-one survivable civil and military aircraft crashes extending over a 10-year period were selected for the data base. The data derived includes average horizontal, vertical, and lateral G forces; and impact angle, velocity, and the velocity change in the major impact.

With regard to the injuries and fatality data in the study, Reference 2 concludes that nearly half of the fatalities and serious injuries could probably have been prevented by the use of an improved personnel restraint system. The reduction of post crash fires would have reduced the fatality and injury rate still further. Also of interest is that out of the 61 crashes, there was one case noting "passengers probably crushed or trapped by cargo." This is the 18 September 1965 C-130A crash discussed in Section II, paragraph E.

Several disparities in the data base for this section, which is taken from Reference 2, and the data base used in Section II are noted. First, the Reference 2 data cover the 1955 to 1964 period, while the data in Section II cover the 1960 to July 1971 time period. Secondly, 70% of the crashes used in Reference 2 are civil aircraft and only 30% military, whereas Section II involves military aircraft only. Thirdly, the Reference 2 data do not include crashes in the low G range (less than 4) unless at least one person was injured, while the Section II data include all crashes regardless of personnel injury.

While the disparities in data bases are noted, they are not considered of sufficient significance to prevent Reference 2 data from being used to correlate crash forces and injuries.

2. ACCUMULATIVE DISTRIBUTION OF CRASH FORCES

The average horizontal crash forces estimated in Reference 2 were given as a range of values (i.e., 5 to 10 G's) due to the uncertainties involved when using accident report data to estimate the crash forces.

For this study, where a range of estimated crash forces was given, the mean value was used and rounded off to the next whole number G value (i.e., 5 to 10 G's = 8 G's). The resulting crash force distribution is shown in Figure 3. In Reference 2 the largest G value for each range was used. A comparison of the different accumulative percentages vs average horizontal crash force distributions obtained by the two methods shown in Figure 4.

When those crashes involving a fatality are separated from the total crashes, the distribution is as shown in Figure 5. Note that the distribution for fatal crashes closely approximates that for all crashes reflecting that fatalities occur throughout the G range and are not confined to the high G values.

In this study it is desired to examine the injury potential to crews and passengers due to crash forces. To accomplish this the data in Reference 2 was applied to develop distributions of fatal and serious injuries with respect to crash forces. Since the study is not concerned with fatalities due to post crash fires, these fatalities were re-distributed between the serious and minor or no injury categories according to the Reference 2 notations concerning potential survivors.

3. ACCUMULATIVE DISTRIBUTION OF CRASH INJURIES

When an aircraft crashes, the primary interest is to determine the extent of injury of the personnel on board. Since a crash event was defined in Section II as an aircraft undergoing excessive G loading, the distribution of occupant injuries will also be shown in relation to G forces.

While a crash can be viewed as an entity, the number of occupants can vary. For example, 18 military crashes were listed in Reference 2, with a total of 125 fatalities and, of these, 78 occurred in one crash.

The data was therefore normalized to show the cumulative distribution and the associated risk or probability that crash injuries will occur at a value less than or equal to a specific G level as shown in Figures 6 and 7. Similarly, the probability function or noncumulative values could be tabulated to show the "exact" probabilities (based on the data used) of an injury occurring at a specific G level given that a crash at that level occurred; however, the crash force data is limited and the selective nature of the available data in Reference 2 could provide inaccurate results or lead to a misapplication of the data when applied in such a detailed form. Instead, injury distributions based on the data trends in Section 11 and Reference 2 were formulated to give a visual representation of the injuries which can occur with respect to a range of crash force levels. These distributions are shown in Figures 8 and 9. For any G level, the three categories of injuries total 100%. It must be remembered that both figures are only approximate trends (not probabilities) that assume 100% fatalities for a crash force of 20 G's. However, for any single crash, regardless of its severity, there will be exceptions regarding occupant safety and survival. Individuals will receive fatal injuries in minor crashes and survive catastrophic crashes because of the extenuating circumstances unique to each crash. These occurrences are exceptions which cannot be considered within the scope of available data.

Although the injury mix blends at a variable rate, the seriousness of the injuries increases, as a whole, with increasing G. The distributions of the serious injuries peak near the mid-G range and are bell shaped. Fatal injuries rapidly replace the serious injuries as the G's increase beyond mid-range. Note that the injury trends are generally more severe with respect to the crew injuries and that the trend curves collectively cross at approximately the 9-G level. The crew members incur a greater percentage of fatal injuries below 9 G's than passengers. Above 9 G's the trend reverses slightly. These trends are indicative of the fact that the crews are exposed to greater structural distortion during initial impact while passengers are relatively better protected in the central portion of the fuselage. However, as the severity of a crash increases above 8 G's the fuselage tends to distort and rupture, resulting in an increase in passenger fatalities. The mid to high-G crash range, therefore, offers the greatest opportunity for improving occupant safety through better crash protection.

A more accurate and possibly more useful set of data for injury correlation can be obtained by closely analyzing the data in Section 11 to provide additional crash force relationships as found in Reference 2. An extensive analysis of the original accident report data would be required, however, and it could not be accomplished during this effort.

SECTION IV
AIR CARGO SYSTEM

The assessment of an air cargo system requires, in addition to personnel safety as related in Sections II and III, an assessment of the systems utilization and related costs. Personnel safety, systems utilization and costs all interact. This interaction can best be demonstrated by viewing a newly proposed materials handling system, the intermodal container, and its effect on the life cycle of cargo aircraft. The material handling system and the aircraft form a single entity, the air cargo system. The levels of cargo restraint incorporated into the system influence both its utilization and cost and becomes an important adjunct in its assessment. Conversely, cost and utilization are a consideration of this investigation.

Variations to the current 9-G level of restraint could include a reduction to a lower level, an increase to a higher level, or a combination utilizing a low G rail restraint (operational) and a high G auxiliary restraint (emergency) system. To determine a definitive cost savings or increase for these variations to the present restraint level is an impossibility. Describing interactions between the systems is possible, but only on a very limited scale, because the current system is too vast. It consists of all cargo aircraft, present and proposed, and all Army, Navy, Marine Corp, and Air Force combat vehicles and equipment designated air transportable. At the same time there is an impending shift in the basic air cargo mission through the introduction of the jumbo type cargo jet (C-5 and B-747F) and the intermodal container.

1. CURRENT SYSTEM

The Air Force operates one of the world's largest air cargo operations. The 463L materials handling system is the mainstay of Air Force operations. Under this concept, cargo is received at a terminal and loaded on special netted pallets. Specialized equipment is utilized to load or unload the aircraft, and place the pallet on a special rail system within the aircraft. The entire system revolves around the pallet dimensions (88 inches long x 108 inches wide). Vehicles and other rolling stock can also be restrained to tie-downs on the floor of the aircraft. Loads longer than 88 inches are straddled over more than one pallet, which requires considerable manpower to accomplish.

The commercial airline industry uses the same basic concepts. But the other three transportation modes (truck, rail, and ship) have moved into a new concept of intermodal containers. These containers are 8 feet wide x 8 feet high x 10, 20, 30, or 40 feet long nominal size and designed for land-sea compatibility with approximately 70% being 20 feet (Reference 5). The era of containerization started in October 1957 when the first container ship, Gateway City, started regular service. Since that time the world container population has grown to 340,000 units.

Two motivating factors can be found for viewing this large scale change to containers. First is economics, the cost to a steamship company is largest in the area of loading and unloading. This is reflected in steadily increasing wages paid to longshoremen without any increase in productivity. The container provided the means in which

mechanization could be applied and therefore increase productivity. It is apparent from the vast growth of the container industry, that containerization has resulted in a cost savings. The second factor is in the source to user concept. The object being that cargo moves from factory to consumer with the least amount of handling. The ability to transfer these containers from one mode of transport to another, without repacking, and with decreased pilferage and greater protection from damage has made the source to user concept a reality.

A review of logistics support in the Vietnam era emphasized both the importance and the possible effect of containers during the conflict. Containers were used in limited quantities and found to be extremely successful. In a review of "Logistics Support in the Vietnam Era" it was found that in 1968, if Vietnam operations had been fully containerized, a total of 82,100 containers would have been required to sustain cargo operations. This would represent a total movement of 394,100 container loads, for approximately 7 1/2 million tons. If containerization had been in effect from 1965 to 1968 between CONUS and SEA there would have been a potential cost savings of \$881,300,000, as shown in Table 5 (Reference 6). These factors are the motivating forces behind the DOD movement into the container field. At the present time the U. S. Army is in an initial procurement of 6700 land-sea containers (8 feet x 8 feet x 20 feet). These containers undoubtedly will move into the airlift system.

2. AIR CARGO

In determining any restraint criteria, a basic review should be made of future air cargo. If it were assumed that DOD has converted to full containerization, to move cargo at the 1968 level would require an ownership of containers amounting to 82,100 units to support an SEA-type effort. This would only include movement of cargo to SEA, and represents only one-third of the total DOD shipments in 1968. Therefore overall container loads could be as high as one million units. The number of containers required, however, would only double due to the lower turn around time to Europe as opposed to Asia. It can be assumed that a fully containerized effort in 1968 would utilize as many as 160,000 containers (8 feet x 8 feet x 20 feet).

Again this still does not represent all items moved, but would amount to approximately 80% of all DOD cargo.

At the present Air Force logistic support level of 4% to the Army, it is possible that 40,000 of these container loads would move by air in any year, yet it is estimated that by 1980 this support level would double. In case of a deployment, during initial phases, the support level could be as high as 100%.

3. POTENTIAL COST SAVINGS

Under today's USAF air transportability requirements, all Army, Navy, Marine Corp, and Air Force equipment designated "air transportable" must be built to remain intact but not necessarily function after being subjected to a load factor of 9 G's. If this load factor could be

lowered to 3 G's, all equipment could be built to a lower level consistent with its functional requirements. This reduction in strength would result in significant cost savings (or cost avoidance) to all military services and result in a weight reduction on this equipment. Such a reduction can be accomplished by using barrier nets as an auxiliary restraint system to provide a 9-G level of personnel safety on mixed cargo/passenger flights.

If the 160,000 containers needed for DOD worldwide shipping should be required to meet a 9-G forward load factor, a standard commercial land/sea container would require additional aluminum weighing 362 pounds (Reference 7). Since the cost of fabricated aluminum is approximately \$1.15 per pound, the 160,000-container modification would cost \$66,608,000. The added slave pallet cost to carry commercial containers on Air Force aircraft would be the same at either restraint level and therefore is not shown. However, at the 3-G level, barrier nets would be needed if passengers are forward of the load. If present barrier nets are used, one net would be required for each C-130 and two nets for each C-141, totaling approximately 1100 nets at \$900 each or a total requirement amounting to \$990,000. In the case of containers only, this lower restraint level would result in a savings of \$65,618,000. This does not include all other air-transportable equipment, and airdrop loads.

Another savings would be in tare weight. In the above case, a net for the container weighs 238 pounds vs 362 pounds additional weight of the container. The total amount of added weight to the containers would be 28,960 tons. This would be reflected in added costs of shipping this extra tare weight for each container movement.

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This basic argument can be used with any of the military equipment designated air-transportable.

In addition to equipment savings on future aircraft, a 3-G rail and 9-G net system would result in an added cost and weight savings in relation to the present 9-G rail restraint system.

SECTION V
AIRFRAME/RESTRAINT SYSTEM

There are generally two aspects to crash survival. One is related to the airframe capability to remain intact, and the other is related to the occupant/seat-strength/restraint-system capability. Since the imposed crash forces are dependent upon the velocity changes that occur and the related deceleration forces, it is possible to present the limits of structural/restraint capability in these terms. Similarly, the occupant has deceleration tolerances beyond where he sustains injury.

1. HUMAN TOLERANCE

The accelerated pace of research in the field of human survival has revised the train of thought regarding human tolerance to the airplane crash environment. The human is quite tolerant of the crash environment and the survival rate should be higher. This fact poses a number of new considerations for the airframe designer. Existing crash requirements are decidedly concerned with occupant safety and survival but only within the framework of existing airframe strength. Relatively new research has shown that survival potential can be greatly increased with minimal airframe weight and cost penalties.

An Aviation Week magazine article, published in 1956, stated that "death and severe injury can be prevented in any crash unless it is violent enough to disintegrate the cabin structure. Sound detail design in the cabin is the preventive.

"The tacit assumption of the hopelessness of designing for crash survival gradually is being replaced by the realization that the anatomy of man is rugged enough to withstand impact greater than any which can be transmitted through the structure of a current airplane. The key to improving survival chances is in designing the tie-down of passengers and loose equipment up to the ultimate load factor of the airframe."

The article also noted that even though the "airframe structure is stronger than the human body, it is also much heavier and usually subjected to more pounds of decelerative force. A deceleration which is within human G tolerance will destroy an airplane."

2. AIRFRAME STRENGTH

The interacting facets of crash survival, cargo restraint, and structural design require further clarification. When integrated, the common denominator of the interacting facets becomes the crash strength of the airframe. Once the protective "shell" provided by the airframe ruptures or the occupiable volume is encroached, survivable conditions rapidly deteriorate and efforts to improve survivability by improving the restraint system become futile.

An absolute definition of airframe crash strength is elusive. Many variables are involved. References 8 and 9 both tend to verify the fact that the strength level of a current-day pressurized fuselage is approximately 8 to 9 G's longitudinally. A typical fuselage will tend to rupture when the longitudinal acceleration buildup reaches an average 8 or 9-G level. Higher accelerations can be tolerated if the duration

is sufficiently short. Full-scale crash tests of transport-type aircraft show average deceleration levels ranging from 5 to 9 G's. Much higher accelerations are experienced locally and can range upward to about 40 G's for durations of generally less than 0.2 second. The actual values depend in part on the impact velocity and impact angle. The dynamics of the airframe contribute to the overall response and generally cause the very high localized responses noted during instrumented crash tests.

The higher acceleration levels are generally associated with the crew compartment near the nose and account for the 40-G crew seat installation criteria. Accelerations are generally less in the cabin area and the criteria vary with the type of seat they are applied to; a load of 16 to 20 G's is the nominal installation level. Current criteria do not associate these installation factors with a time duration; all specified crash factors are applied statically.

3. LEVELS OF RESTRAINT

The design strength requirements for fixed equipment and tie-down fitting carry-through structure have been defined by the average 8 or 9-G levels associated with the fuselage breaking strength since the fuselage ceases to provide maximum occupant protection following rupture. This acceleration level can be considered as a reasonable compromise, partly because of the practical limits associated with the restraint of cargo for occupant protection, but primarily for the following reasons: cargo is seldom "rigidly" tied down as are seats and the relative motion of the cargo allows the restraint system to absorb the higher magnitude short duration loads; cargo restraint systems are generally more

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redundant in terms of connecting load paths than are seat installations; restrained cargo provides interference for loose cargo; partial failures in a cargo tie-down "chain" are not as direct a threat as a partial seat failure would be to the occupant.

In light of recent findings concerning human tolerance, current structural specifications (see Table I) have increased restraint requirements for miscellaneous equipment and cargo tie-down hard points to be consistent with seat installation requirements. The intended objective is to provide a more equal measure of protection consistent with human tolerance. While the magnitude of the revised factors is appropriate, the requirement should be stipulated as a dynamic rather than a static requirement to be more consistent with the crash environment and the response of restrained cargo to that environment.

Structural specifications also recognize circumstances when occupants would not be in any direct danger from loose equipment or cargo during a crash and the design requirements are considerably less. Nonhazardous restraint requirements are 3 G (2.0 G x 1.5 F.S.) in the forward longitudinal direction. The lower 3-G factors are still considered "crash" load restraint factors, but they are more consistent with low G operational contingencies of an emergency nature. The 3-G level provides restraint for airplane decelerations associated with maximum braking combined with full thrust reversal, landing short, landing overruns, skidding off runways, tire blowouts and gear collapse. The 3-G level affords protection to the airplane and the cargo by minimizing damage to both during such emergencies.

4. OPERATIONAL RESTRAINT

Operational restraint problems invariably concern the level of restraint required for cargo tie-down because of the inappropriate separation of two distinct requirements. One is the airframe design requirement to provide a level of crash protection; the other is the operational requirement to secure cargo to specified levels of restraint. A conflict arises when the maximum structural design requirements are applied as fixed operational cargo restraint requirements. The two are compatible, but they are not necessarily interchangeable under all circumstances. Operational requirements can vary considerably depending on the cargo and the mission, especially in combat, and they should not be stereotyped.

Both operational and structural design requirements have a basic concern for occupant safety. The choice between providing a structural level of safety or measure of protection commensurate with the occupants' ability to withstand the nonfatal physical forces, and providing a level of safety consistent with certain operational requirements, can result in equally unsatisfactory alternatives. Structural requirements attempt to provide a realistic compromise by providing a cargo tie-down strength level consistent with the basic airframe strength, but not necessarily consistent with the upper level of human tolerance. Similarly, operational tie-down requirements are variable and the level of occupant safety that can be provided is often mission dependent.

The using commands find it is impractical to tie cargo down to structural design limits in many instances. Cargo tie-down requirements are tempered by definite operational limitations which must be considered.

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For example, certain types of cargo are known to break apart at very low G levels; the cargo may be so massive that impractical amounts of chain and cable would be required to restrain it to high G levels; combat conditions may not allow time to secure cargo as positively as would otherwise be desired; the cargo may cover the majority of the available tie-down fittings, leaving too few exposed for adequate restraint. As difficult as the operator's problem is, the circumstances provide no direct justification for the structural designer to lower the design requirements below a reasonably safe level. Adequate structure must be provided for occupant safety for the many circumstances which do allow its use. As shown in Table II, the problem has been alleviated to some degree by allowing lower cargo restraint levels on the C-130 and C-141 aircraft when passengers are not seated forward of the cargo.

5. RESTRAINT FLEXIBILITY

Although in an engineering sense, an occupant can be reasonably well protected and restrained to almost any G level within human tolerance, there are operational circumstances which require restraint flexibility and appropriate options should be provided. For example, many decisions arise that are of a tactical nature based upon immediate circumstances. If absolute tie-down safety with respect to cargo cannot be provided to passengers utilizing an available restraint system, it must be recognized that in a crash environment the risk to passengers increases as the level of restraint provided for the cargo decreases. If it is impractical or impossible to restrain cargo to crash level loads, the additional risk must either be accepted or the passengers should not be carried, or the passengers must be separated from or placed behind the

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cargo, or the flight must be postponed or delayed until better circumstances prevail.

The required operational flexibility can be at least partially achieved by a portable restraint net of the type recently developed by the Air Force. The portable net can be used as an auxiliary restraint system to more reliably contain cargo to a 9-G level or higher depending on the mass contained. If a sufficient number of nets were made available to each cargo transport, the desired level of restraint could be provided when circumstances require added protection. The portable net system, however, is limited by its size and its dependence upon floor attachment points. It must literally envelope the cargo to be effective and a sufficient number of tie-down points must be accessible. Although desirable for interim use, the portable system is not as efficient a system as desired for new aircraft. A preferable auxiliary system would be composed of a removable net that could be attached circumferentially to permanent installation fittings in the fuselage similar to nets currently used on commercial cargo aircraft. Such a system will provide maximum protection and efficiency.

Certain odd size cargo of high density, such as pipe, gun barrels, and tow booms have excessive penetrating power when decelerated and cannot be effectively restrained by a conventional net or chain or cable restraint system. Special packaging should be required for items that cannot be net restrained.

6. NET RESTRAINT

Reference 4 divides restraint requirements into two groups: Net restraint and cable, rope, or chain restraint. The latter group presents a higher hazard since it represents a "rigid" type of restraint system which is more susceptible to shock loading breakage and requires higher factors of safety in design. A well designed net restraint system minimizes the dynamic overshoot problem and provides more protection by "containing" the cargo in an efficient manner. Net restrained cargo therefore provides the safer environment for mixed cargo/passenger loads.

Failure in the various elements composing a cable or nylon restraint net can be tolerated since it normally requires a series of such failures to release the cargo. Any one element or net can be readily overloaded by slack in other system elements, but the other elements or nets are available and can pick up the load or block the motion of loosened cargo. The elements of a net system inherently yield to a great degree before rupture and allow the forces within the net to redistribute and equalize, thereby retarding rupture. Net restraint systems, then, can conceivably be designed to lower deceleration peaks since the hazard to the occupants is a function of series of failures (rather than a single failure) and is therefore a less direct hazard than, say, a seat failure. On the other hand, a restraint system cannot be designed to too low a deceleration peak since it must retain an overall level of integrity when subjected to the normally expected crash pulses. Except for the "rigid" restraint system having low ductility, Reference 10 notes that the very short duration peak G "spikes" have only a minor effect on the performance of a cargo restraint system. In most cases, a minimum of only 0.01

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second is required for loads to reach maximum value within the relatively rigid airframe and the influence of short duration peaks should be assessed for each restraint system.

For bulk cargo the 9-G requirement has served adequately as an upper restraint limit. Cargo generally does not respond to the high frequency, high G crash pulse as do small items and more rigid installations. This low response of cargo can be noted in the crashes discussed in References 11 and 12. Undocumented occurrences have also noted that cargo has not significantly shifted even in crashes where occupants seated near the cargo have received fatal injuries from side lap-belt restraint.

SECTION VI

DISCUSSION

Human survival in the crash environment can only result through the combined efforts of the related design disciplines. Each discipline, although related to crash survival, is concerned with a different design problem and each seems to have its own terminology, design philosophy, design goals, and acceptable design compromises. Coordination, therefore, between airframe designers, air mobility/cargo handling designers, and airplane operators becomes exceedingly important.

The overall perspective to be gained from the data in Sections II and III can take two basically different, but related approaches. The crash event itself is relatively rare, occurring once per 43,500 flights. On the other hand, in any given crash, the risk of injury to occupants is very high. If crashes are considered only with respect to airplanes carrying a mix of passengers and cargo, the combined probability of a crash occurring during any one flight is very remote - one per 1,500,000 flights. Consequently, because of the rarity of the event, extensive passenger protection seems academic. Yet, based on the individual accident, it can be shown that in many cases an increase in current levels of restraint protection could increase occupant survival. These two perspectives were reflected in Section I and have been applied to the specifications in Table I.

The injury statistics in Section III describe what is frequently called the "survival" crash range. This range includes those crashes

severe enough to cause injury, but not severe enough to prevent survival. Minor crashes and nonsurvivable crashes have been eliminated from the "survivable" accident range. The majority of these "survivable" crashes occur between 3 and 10 G's (Figure 3). Injuries to crew and passengers follow similar trends, in that both the number and severity of the injuries increase with increasing G level. Fatalities increase sharply above 9 G's.

The crashes discussed in Section III were originally selected and categorized for survival potential rather than for a specific crash force (G) level, hence the term "survivable" crash. If we consider the survivable circumstances surrounding this select group of crashes, which excludes the fully survivable and the nonsurvivable crashes, we can qualitatively evaluate the relative hazards to which the crew and passengers are exposed with respect to cargo. A qualitative evaluation is necessary because of the low incident rate of cargo inflicted injuries (Section II).

Since the majority of the crashes in this select group occur above 3 G's, cargo restrained to an operational load level of 3 G's can be expected to break its restraints to some degree in almost every crash. The risk of cargo injury would normally be greater to passengers than to crew because the passengers are in closer proximity to the cargo when all are on the same basic deck level. Considering the current inventory, these circumstances would apply primarily to the C-130 and C-141 airplanes. With respect to crew protection, both of these airplanes separate the crew and cargo compartments by a bulkhead which provides some additional protection, although this is not its intended

purpose. Conversely, the crew are generally in greater jeopardy from impact forces than passengers because the crew are in closer proximity to the initial impact region and the greater distortion of the forward fuselage. Passengers are therefore generally better protected by the airframe in a crash than the crew and loose cargo imposes a more direct hazard and a proportionally higher risk to passengers.

Available crash statistics show that crew safety is not greatly affected by cargo regardless of the restraint level. Approximately four years of operational experience has been accumulated at the reduced, 4-G, restraint level. There are no discernible differences in the crash statistics regarding injuries during this four-year period than in the previous six years of the data sample when cargo was restrained to 8 G's.

Obviously, passenger safety is more directly influenced by cargo and its level of restraint. In lieu of sufficient statistical data relating cargo and passenger injuries, passenger risk with respect to cargo should be considered directly proportional to the level of cargo restraint when passengers are seated in front of the cargo and not separated by a suitable barrier. Although mixed passenger/cargo flights are statistically rare, auxiliary restraint devices having a minimum 9-G restraint capability for the protection of passengers seated forward of the cargo should be retained if a 3-G operational restraint level is adopted.

The structural criteria generally provide a level of restraint potential consistent with the crash environment; it is up to the user to decide on a restraint technique and the level of restraint consistent with his mission objectives and the amount of risk to which the occupants must be exposed. It is possible to restrain cargo to the same level as the troops or passengers sitting next to it; however, the weight and complexity of a restraint system capable of keeping a maximum cargo load in place at seat installation load levels would be high (Reference 4). The structural criteria already provide a design compromise between seat attachment structure and cargo tie-down fitting structure that is reasonably consistent with levels of human tolerance, fuselage strength, and cargo response to the crash force. No perfect solution to the dilemma exists beyond the design compromises noted and possible operational restrictions imposed by the user if the risk to personnel is not acceptable.

Statistically, a statically designed 9-G auxiliary cargo restraint system provides adequate passenger protection. Properly restrained cargo provides a less direct hazard to occupants as opposed to seats and personnel restraint systems, because cargo is less responsive to high deceleration peaks and less likely to fail its restraints. Seat failures and fixed miscellaneous equipment support failures pose a very direct hazard, since seats and equipment respond readily to the imposed crash forces and are directly in contact with or in close proximity to the occupants.

The current 9-G level of operational restraint cannot always be achieved as noted in Section V and illustrated by the example of the

2 1/2 ton truck in Section I. Yet, various items of bulk cargo that cannot be fully restrained are carried behind passengers. In effect, a valid 9-G restraint system does not exist and passengers do not receive appropriate protection. An auxiliary barrier system would greatly improve passenger safety and, if used in conjunction with a 3-G operational restraint level, would provide compatibility between all USAF cargo transport airplanes.

The barrier-net concept could be readily implemented and would be cost effective. Although greater cost savings and operational flexibility can be shown when a barrier system is utilized in a new airplane system, its application to the C-130 and C-141 would provide immediate benefits. A 3-G operational restraint system using a 9-G net for auxiliary protection will provide passenger safety and a cost avoidance for future air-transportable equipment through uniform restraint requirements.

To minimize future design interactions and to retain a standardized air cargo system, a consistent Air Force design/safety philosophy concerning the upper level of cargo restraint for the protection of passengers should be established. Maximum protection is desirable but practical limitations do exist (as noted in Section V). Although airframe and restraint systems strength can be increased, its value is limited if the increased strength is never used operationally. Available statistics concerning cargo/passenger aircraft crashes, deceleration, and cargo related injuries, in conjunction with operational limitations and air-transportability costs data, can be used to reach an appropriate compromise between design levels, cost, and risk of passenger injury in

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a crash. A compromise acceptable to all Commands would seem to be the only appropriate solution.

Early in this study it became obvious that an analysis similar to that in Reference 2 in regard to 61 military and civilian accidents, should have been accomplished for accidents which occurred between 1960 and July 1971. Such a study would have provided an excellent basis for this or any related studies. The larger sample, reflecting Air Force missions and operating environments, would increase the confidence that can be placed on projections developed from the basic data. The basic data would be applicable to studies requiring the definition of crash load criteria for seating and restraint systems, miscellaneous equipment tie-down, and air cargo restraint. It would also provide additional information applicable to studies concerned with the reduction of post crash fires and personnel evacuation.

Communication with IGDS during this study confirms the fact that comprehensive accident data are available; however, as IGDS points out, they are not staffed to extract detailed data and conduct analyses which would, for example, provide an estimate of the accelerations associated with each cargo aircraft crash.

SECTION VII

CONCLUSIONS

1. Occupant survival becomes acute in the 3-G to nonsurvivable crash force range. The serious injuries which occur in this range occur most frequently between 3 and 10 G's. Fatalities increase sharply above 9 G's.
2. The probability of a crash occurring between 3 G's and the non-survivable range with cargo or with a mix of cargo and passengers is one in 500,000 flights, and one in 1,500,000 flights, respectively.
3. Since a mixed cargo/passenger crash event is rare, little data exists and the probability of cargo inflicted injuries cannot be established. Passengers seated ahead of the cargo are generally in greater danger from cargo than crew members in the cockpit with respect to cargo when all are on the same deck level.
4. With respect to crew safety, the current 4-G operational restraint level for cargo on all cargo flights has apparently been satisfactory. Statistically, a reduction in the operational restraint factor from 4 to 3 G's for general and aerial delivery cargo will not appreciably alter the level of protection provided to the crew. Neither level provides true major crash protection with respect to survivable crash conditions.
5. An operational restraint level of 3 G's for all-cargo flights would require, when passengers are seated forward of the cargo, an auxiliary restraint system or the continual use of current 9-G cargo restraint levels to maintain the current level of passenger protection.
6. A reduction in the 9-G design requirement for air-transportable equipment to 3 G's will result in a significant cost savings (or cost avoidance) and in a weight reduction for this equipment.

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7. Air transportability requirements and airframe structural design requirements affecting cargo restraint with respect to occupant protection are following divergent design philosophies (Table 1) which will complicate the establishment of design requirements for future airplane systems.

8. The accident data available from IGDS covers a broad range; however, it does not include detailed information pertinent to this study, such as: what cargo, if any, was on board and its condition and position after the crash; type of restraint; an estimate of the acceleration forces encountered in aircraft crashes; and accurate descriptions of cargo-inflicted injuries.

SECTION VIII
RECOMMENDATIONS

1. That the operational 4-G requirement for cargo tie-down without passengers in front of the cargo be lowered to 3 G's.
2. That cargo restraint for the C-130 and C-141 be lowered to 3 G's for complete compatibility between these aircraft and the C-5, and that passengers be required to sit aft of the cargo or be protected by an auxiliary barrier system capable of restraining the cargo to a 9-G forward crash level.
3. That an investigation be conducted to determine if an integral commercial type net modification can be made to the C-130 and C-141 aircraft.
4. That future cargo aircraft system design give first priority to provisions which easily accommodate locating passengers aft of cargo for mixed loads. When this is not practical, incorporate integral auxiliary restraint systems to provide a minimum of 9 G's forward crash protection, in conjunction with a 3-G cargo restraint system, for passengers seated forward of cargo on the same deck level.
5. That air-transportability requirements be lowered from 9 to 3 G's forward upon acceptance of the above recommendations 1, 2, and 4.
6. That current difference in the upper G level for cargo-transportability requirements and airframe design requirements be resolved with the establishment of an upper level of operational restraint for mixed cargo passenger loads, acceptable to all Commands, and selected on a risk of injury versus G basis.

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7. That a program be accomplished to analyze existing Air Force cargo aircraft accident reports to provide estimates of the crash forces and related data which can be used in future studies of crash load restraint criteria and related efforts to enhance personnel survivability in the crash environment.

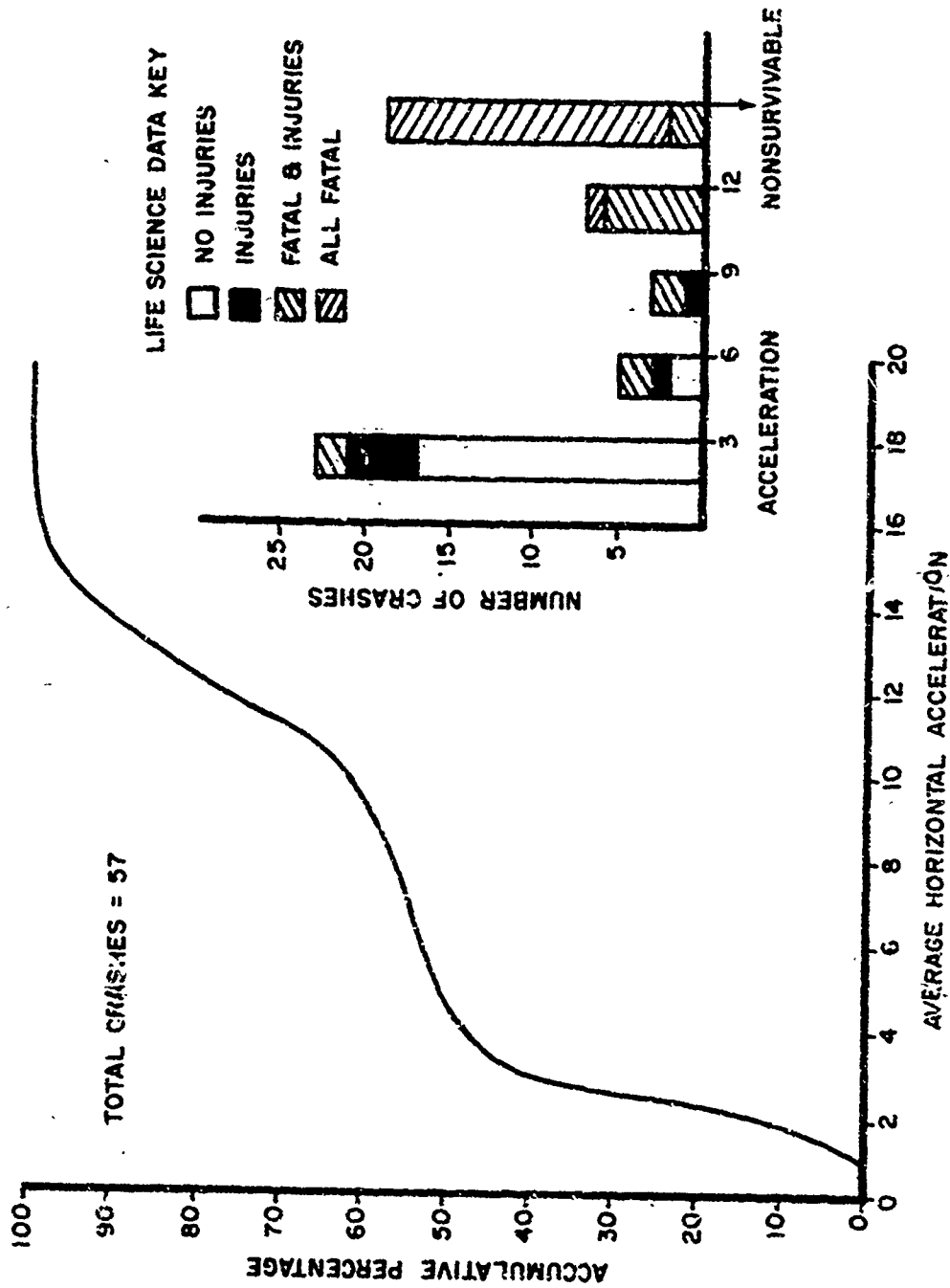


Figure 1. Estimated Forward Load Factor Levels for USAF Cargo Aircraft Crashes

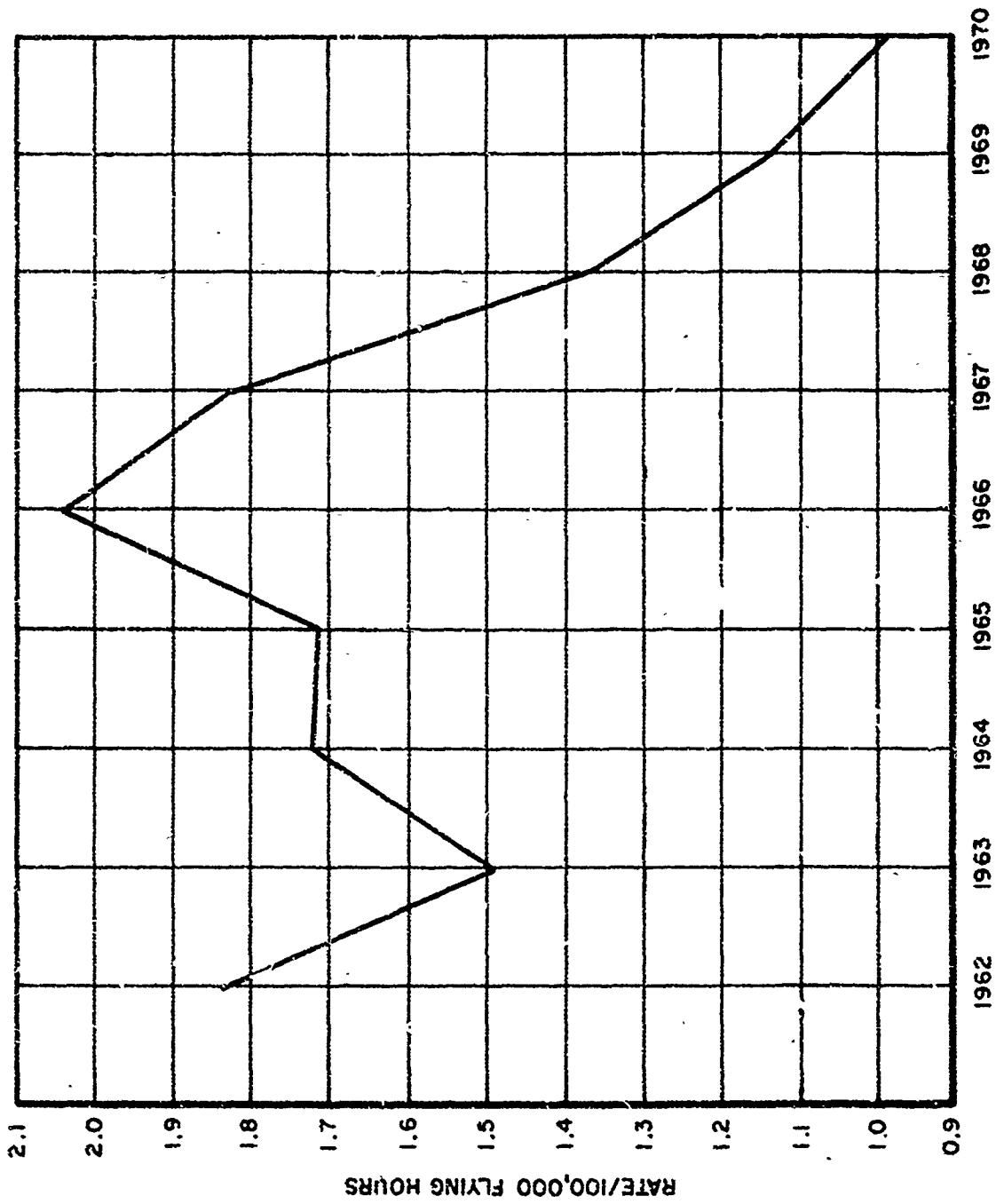


Figure 2. Major Accident Rates USAF Cargo Aircraft

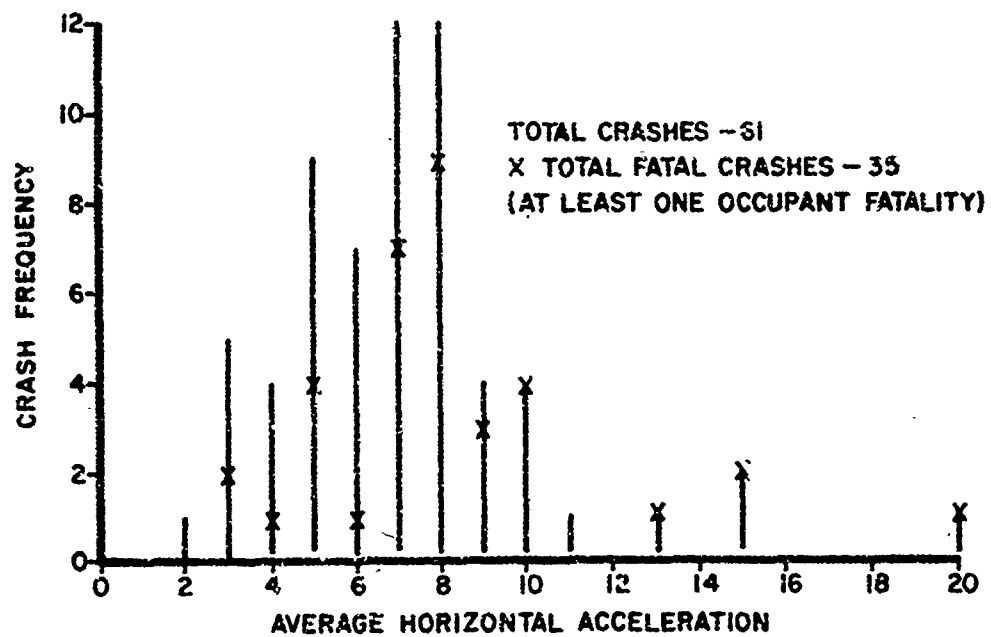


Figure 3. Distribution of Survivable Crashes

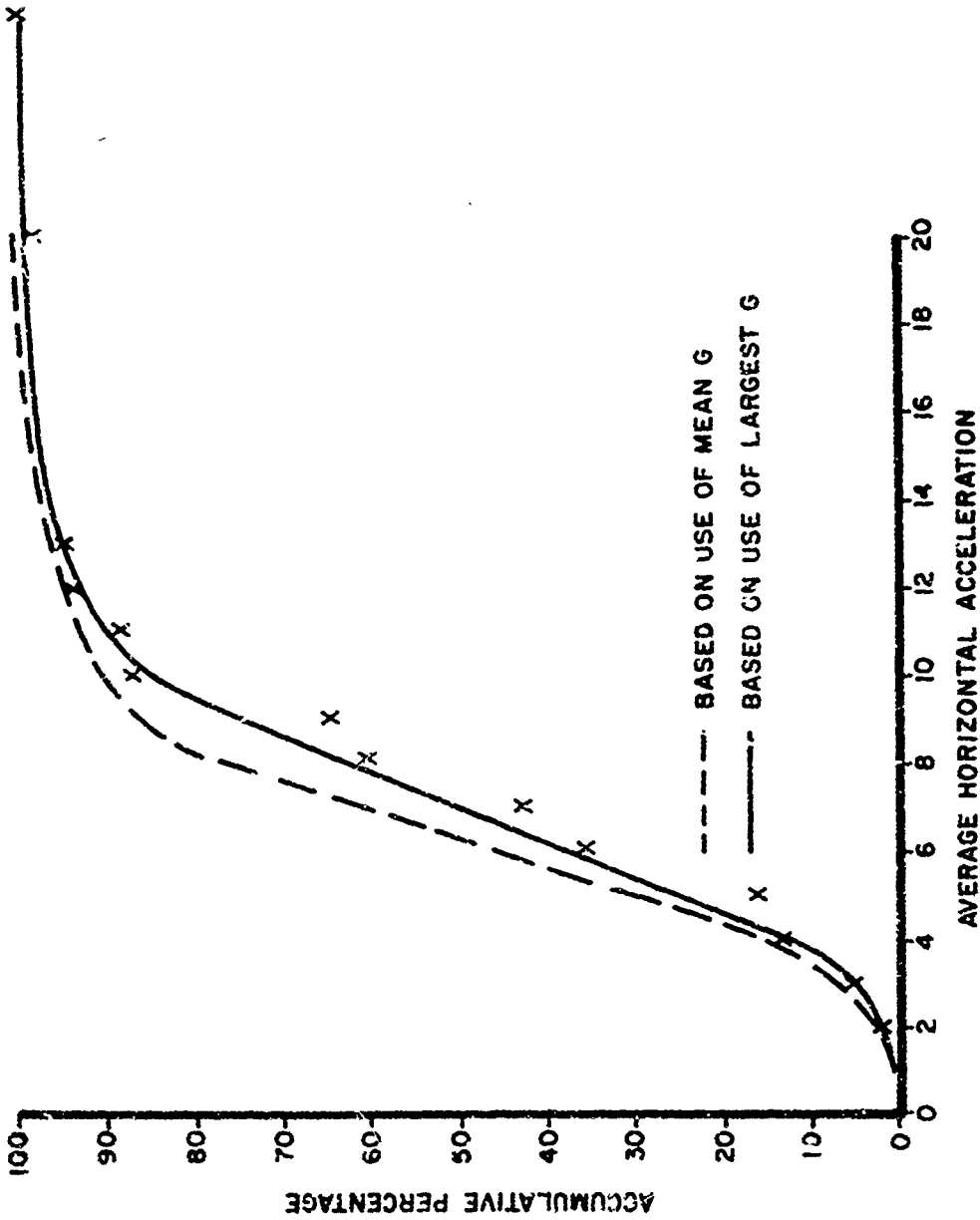


Figure 4. Horizontal Acceleration Distribution of Survivable Crashes

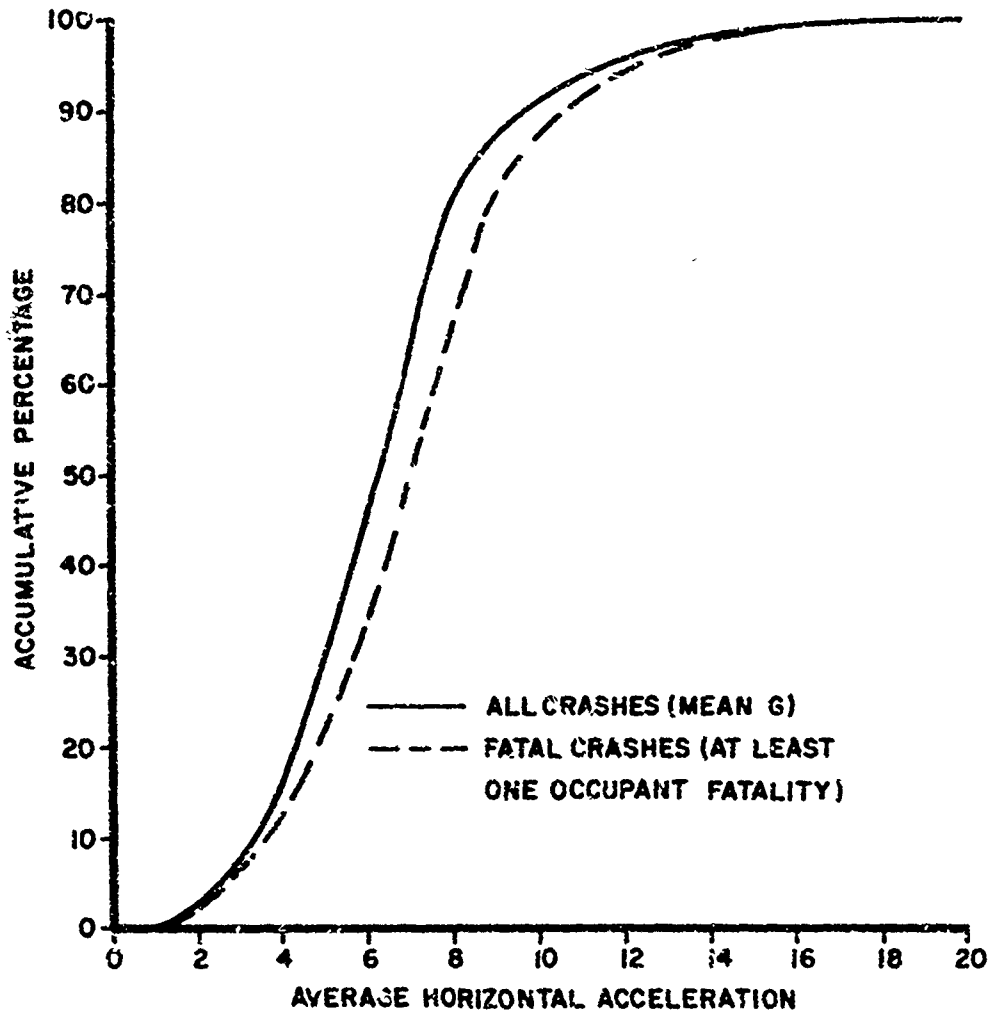


Figure 5. Horizontal Acceleration Distribution of Fatal Crashes

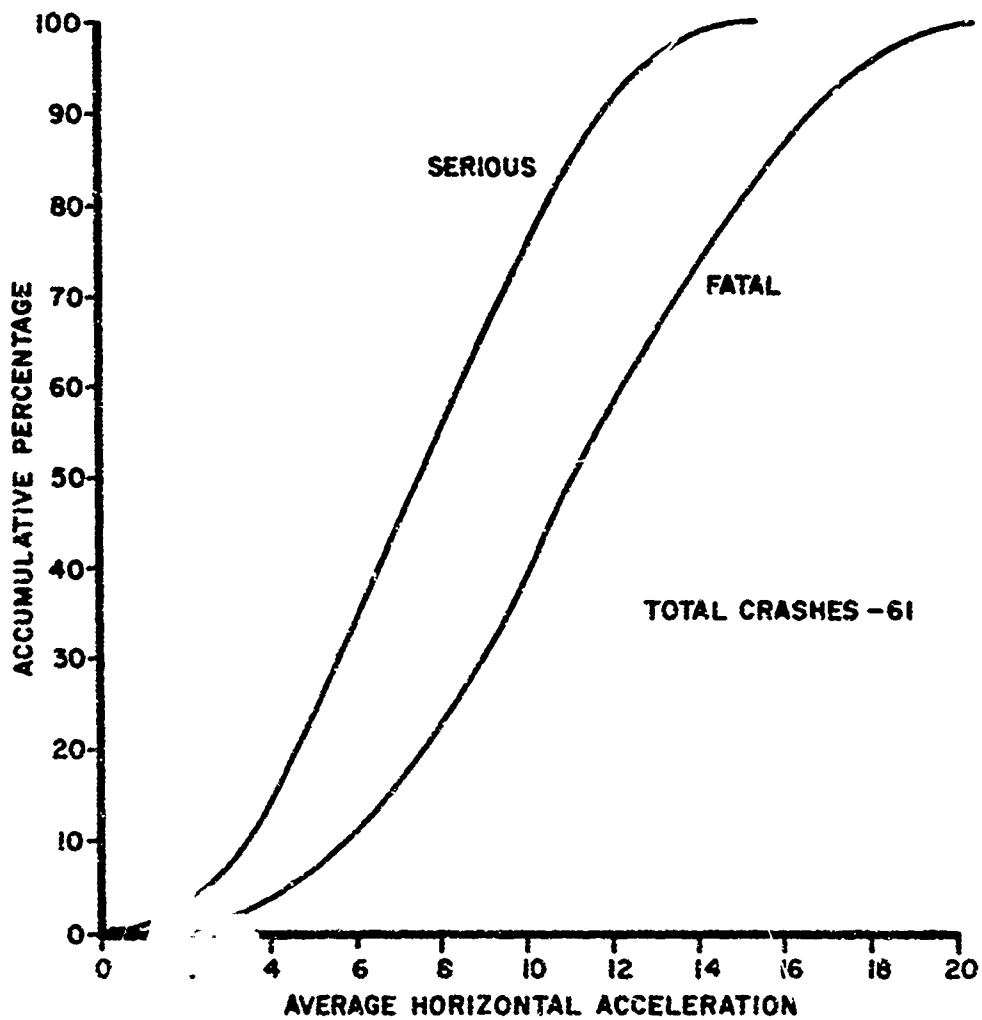


Figure 6. Accumulative Percentage of Crew Injuries in the Survivable Range

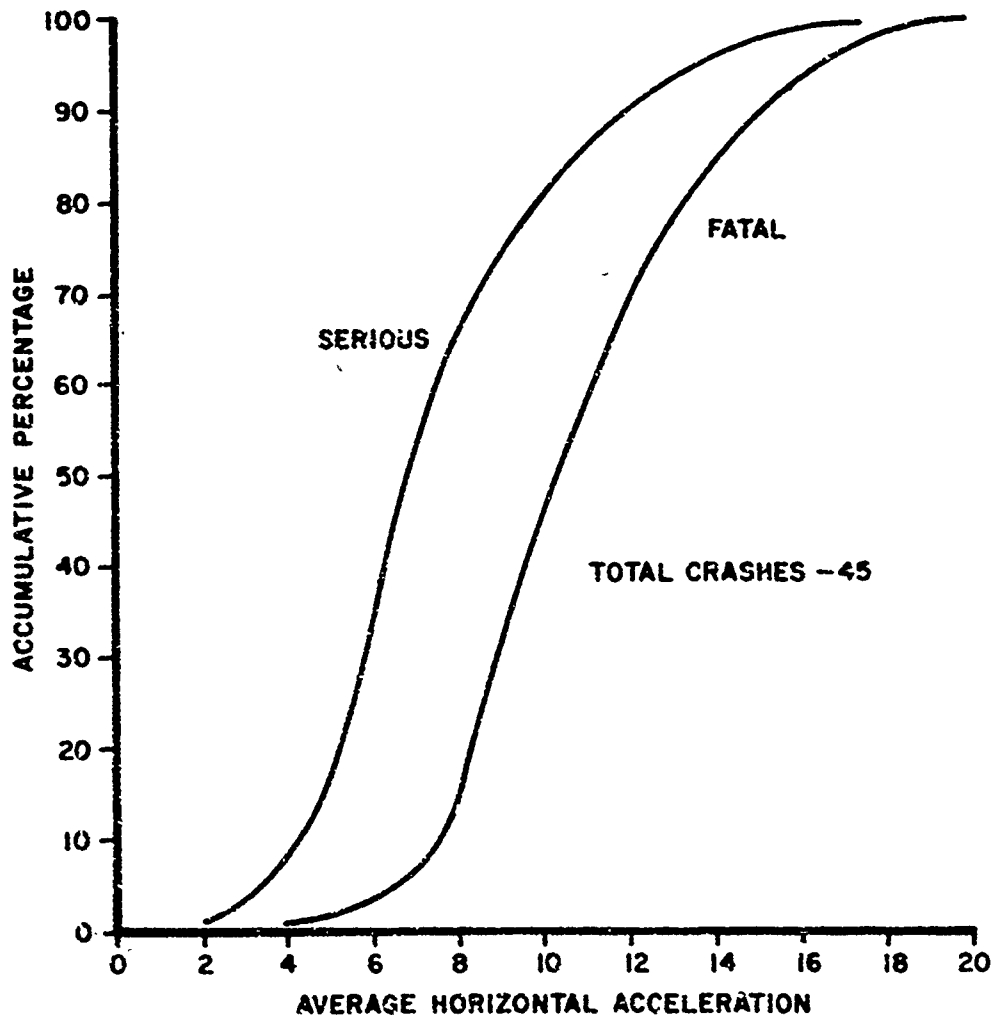


Figure 7. Accumulative Percentage of Passenger Injuries in the Survivable Range

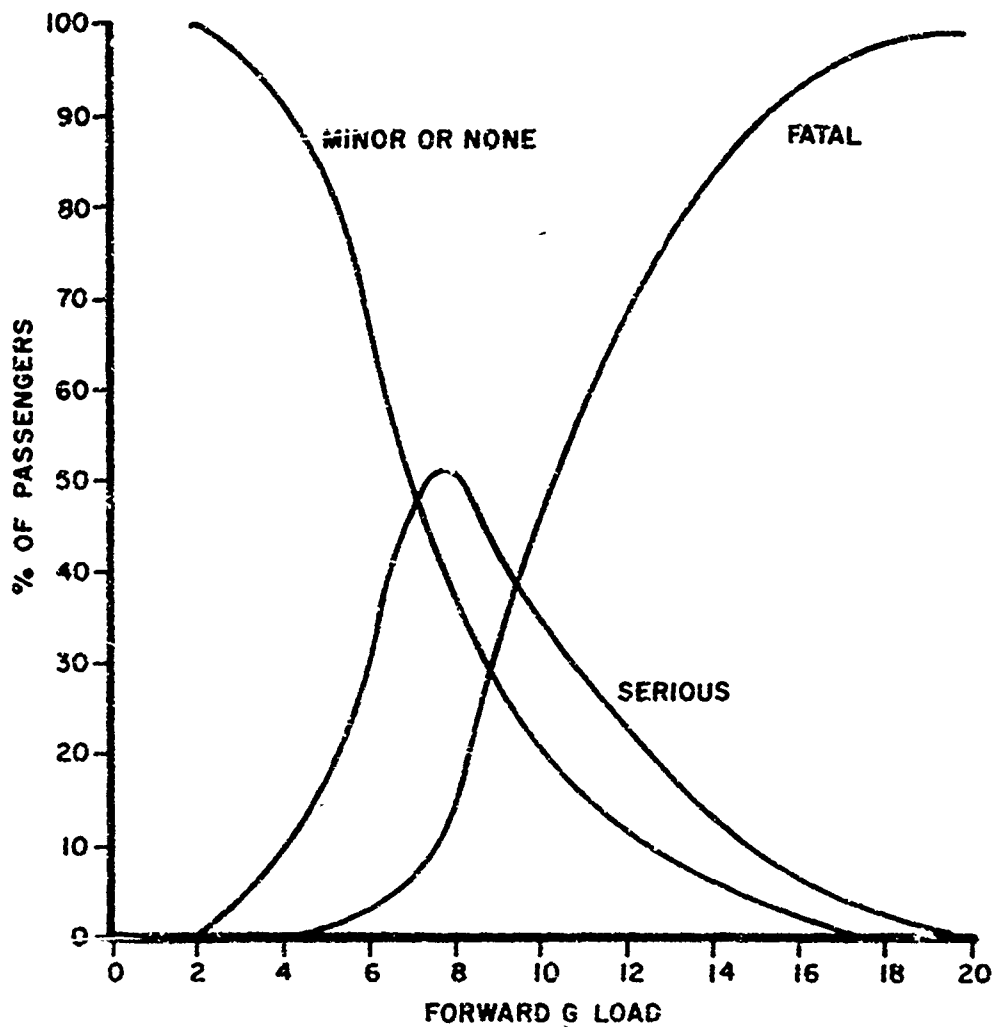


Figure 8. Passenger Injury Trends

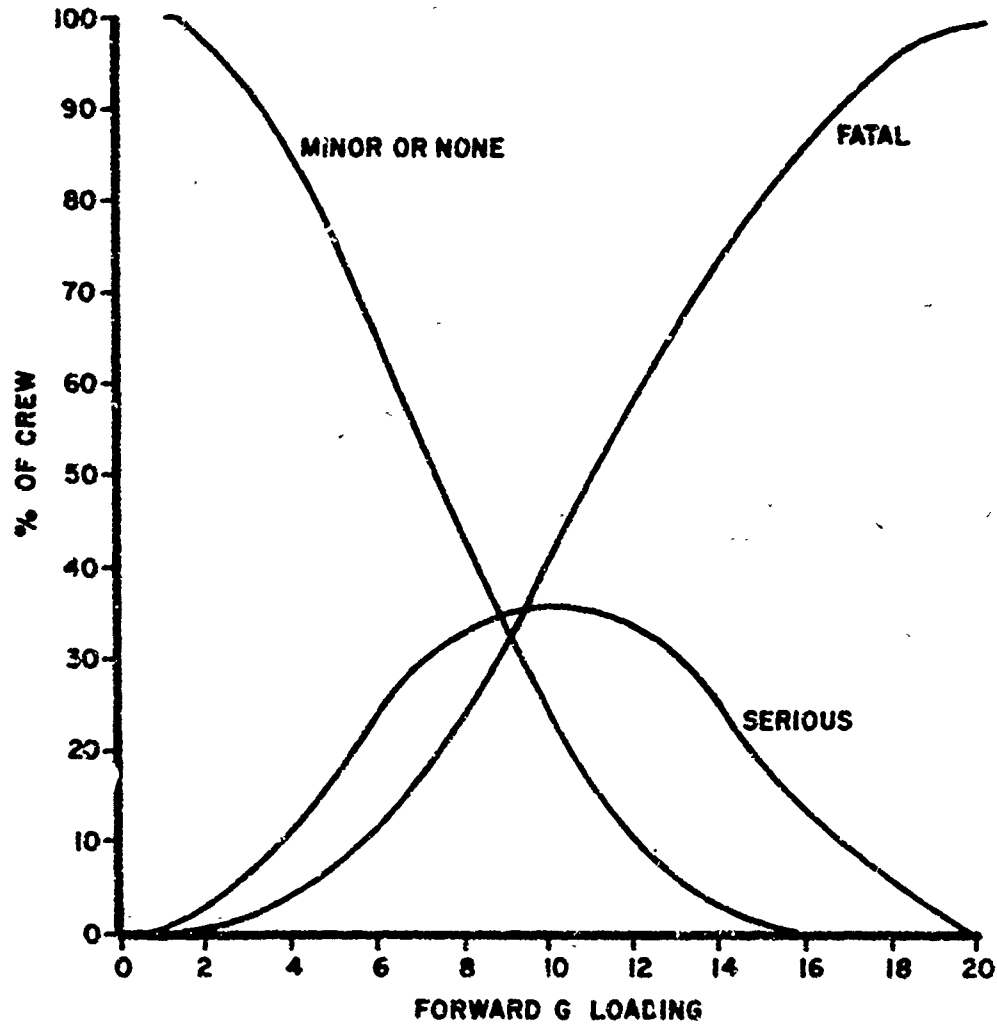


Figure 9. Crew Injury Trends

TABLE I
LOAD FACTOR (G) REQUIREMENTS RELATED TO AIR CARGO RESTRAINT

Cargo/Passenger Loading Configuration	Load Direction	Requirements Applicable To	
		Cargo System Airframe Attachments and Carry-Through Structure MIL-A-008355 A (USAF) 31 Mar 71	Equipment to be Air Transported MIL-A-8421(C) USAF 14 Aug 1969 Flight & Taxi Loads ① Emergency Landing Loads
I Cargo Poses Hazard to Crew & Passengers	Forward	Equal to Seat Installation Load Factor Minimum 9 G	② 3
II Cargo Poses No Hazard To Aircrew or Passengers	Forward	3	
	Aft	1.5	3 9 or 2③
Both Configurations I & II	Lateral	1.5	1.5
	Vertical Up	2	3
	Vertical Down	4.5	3 4.5

NOTES: 1 Equipment must operate after subjection to these loads.
 2 In most cases 9 G ultimate will apply since it is not known in advance which cargo/personnel configuration will be involved.
 3 When the loaded position in the aircraft is fixed or specified for an item of equipment the 2 G applies.

TABLE II
LOAD FACTOR (G) REQUIREMENTS APPLICABLE TO AIR CARGO RESTRAINT
ON EXISTING AIRCRAFT

Load Direction	Aircraft				
	C-7	C-123	C-130	C-141	C-5
Forward	8	8	8/4*	9/4*	3**
Aft	1.5	2	1.5	1.5	1.5
Lateral	1.5	1.5	1.5	1.5	1.5
Vertical Up	2	2	2	2	2.5
Vertical Down	5	4.5	5	5	5

* When passengers are not forward of cargo, the load factor is 4 G's.

** Passengers are assumed to be seated on upper deck away from cargo.

TABLE III
USAF CARGO AIRCRAFT OPERATIONAL AND ACCIDENT DATA

	Year											1st Half
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Flying Hours	2782448	2704753	2560735	2547584	2679931	2746575	2941817	3020742	3470459	3138024	2752801	N/A
Landings	1229322	1232249	1219465	1312710	1390809	1392426	1625028	N/A	N/A	N/A	N/A	N/A
Major Accidents	41	40	47	38	46	47	60	55	49	36	27	11
Accident Rate Per 100,000 Hrs.	1.47	1.48	1.84	1.49	1.72	1.71	2.04	1.82	1.37	1.14	0.98	N/A

N/A = Data not available.

TABLE IV
1962 - July 1971 ACCIDENTS BY PHASE/TYPE PAGE 1 of 3

PHASE OF OPERATION*		TYPE OF ACCIDENT BY CODE**					TOTAL/NONSURVIVABLE		
CODE	PHASE	01	02	03	04	05	06	07	
10	ENGINES RUNNING NOT TAXIING								
21	TAXIING - TO TAKEOFF					3			
22	FROM LANDING					1			
23	OTHER AREAS								
31	TAKEOFF - ROLL	7				2			
32	INITIAL CLIMB			2	1				
33	DISCONTINUED								
41	IN-FLIGHT - NORMAL			3					
42	ACROBATICS								
43	CLIMB PROLONGED								
44	REFUELING								
47	LOW-LEVEL FLIGHT								
48	DESCENT								
51	LANDING - APPROACH			8	1		19/2	1	
52	FLAREOUT		1/1	1	7		22	7	
53	ROLL								
61	GO-AROUND - PREMEDITATED	8				9			
62	UNPREMEDITATED	1					1	1	
71	NONFLIGHT - PARKED								
72	TOWED								
73	TAXIING					5			
74	STOLEN					3			
TOTAL		16	2/1	14	9	25	42/2	9	

* and ** See legend which follows this table.

CODE	08	09	10	11	12	13	14	15	16	17
10										
21	1			1		2				
22	3			2		4				
23				3						
31	1	1		1		1				
32		1/1	31/12	5	4/3		3/1		1	
33		1/1		1	1/1		2			
41		4/2	36/29	3/2	1/1		5/1	9/7	2	
42							1	1		
43		5/4	2/2		1			5/1	1	
44		1			1/1					
47			8/2	1						
48			3/3		1/1					
51			17/7	1	3/2		3	1/1		
52			3	1	1				1	
53	1	1	3/3	10						
61			6		2/1					
62										
71	9			1/1		15				1
72	1		1	7						
73				1						
74			1/1*	1		2				
TOTAL	16	14/7	110/59	39/3	13/8	24	14/2	16/9	5	1

* Suicide Flight

CODE	YY	98	TOTAL NONSURVIVABLE	NO INJURIES AND NO FATAL	NONCRASH	TOTAL ACCIDENTS
10		1		7	7	7
21		1		8	8	8
22		1		7	7	7
23		3		2	2	2
31	2	1	17	14	2	21
32	1	2		14	2	46
33	1	3/1	43	3		5
41				19	2	66
42				1	1	1
43			3	3	2	8
44			4	3	3	7
47			3	3	3	11
48			4	1	1	4
51		1	11	15		53
52		1	1	29		40
53		8		30		46
61	1	1	3	1		6
62	1	17	2	2		12
71				54	54	54
72				5	5	5
73				4	4	4
74			1	1	2	2
TOTAL	6	39/1	92	226	100	415

LEGEND FOR TABLE IV, EXPLANATION OF
"PHASE OF OPERATION" COLUMN

Codes 10 through 60 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 - Any time 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).

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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 IV, EXPLANATION OF
"TYPE OF ACCIDENT" COLUMN

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 - Other Collisions - 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 - Spin or Stall - 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 - Fire and/or Explosion on Ground - Mishaps resulting from and caused by, fire and/or explosion on the ground.

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

15 - Airframe Failure - 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).

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16 - Abandoned Aircraft - Aircraft abandoned in flight by all personnel capable of piloting aircraft.

17 - Propeller or Jet Mishap on Ground - 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.

98 - Type of accident - Not determined.

YY - Not Applicable - Enter this code in any of the three spaces where no other type of Accident is used.

TABLE V
 POTENTIAL COST SAVINGS
 FOR CONTAINER UTILIZATION 1965-68

<u>ITEM</u>	<u>AMOUNT (\$ MILLION)</u>
Cost Avoidance	
Pipeline Reduction 1968 level	147.2
Port Facilities	181.0
Ship Delay Billings	89.7
Covered Storage	86.9
Refrigerated Storage	23.0
TOTAL COST AVOIDANCE	527.8
Recurring Saving (1965 to 1968)	
Shipments (Incl. Port Handling)	344.6
Depot Cargo Handling	8.9
TOTAL RECURRING SAVINGS	353.5
GRAND TOTAL	881.3

APPENDIX I

C-130 AIRCRAFT MAJOR ACCIDENT
DATA ANALYSIS

The IGDS major cargo aircraft accident data for 1962 to July 1971 contained ninety C-130 accidents. Table VI is a summary of these accidents by years, showing personnel injury data; a breakout of the accidents not considered crashes (i.e., ground refueling accidents, major damage during towing operations, etc); and, for the crashes an estimate of the crash force levels was made.

The percentage relationship of crash force level of total crashes (62 cases) is:

<u>0 to 3 G</u>	<u>3 G to N/S</u>	<u>N/S</u>
48.4%	25.8%	25.8%

The following are example C-130 cases identified by the crash force level into which they were placed.

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on 7 July 1966. A loud noise was heard on landing, a go-around was performed, and it was found that the right main landing gear was hanging down. After the cargo was jettisoned a crash landing was made on a foamed runway.

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TABLE VI
C-130 ACCIDENT DATA SUMMARY

Year	Number of Accidents	Number of Personnel Involved	Personnel Injury Data				Non-Crash Cases	Estimated Crash Force Level		
			None	Minor	Major	Fatal		Missing	0-3 G	3-N/S
1962	6	42	9			33				3
63	4	29	28	1				1		
64	4	28	27		1			3	1	
65	12	70	38	1	6	25		3	2	3
66	23	135	108	1	3	23		8	4	2
67	14	269	178	4	9*	78*		4	6	2
68	13	151	128	5	10	8*		7	3	0
69	9	35	23	1*		10**		4	0	3
1970	4	65	4	1		49				
71	1	5	5							
Totals	90	829	548	13	29	227	12	30	16	16

* Includes 1 bystander on ground.
 ** Includes 3 bystanders on ground.
 ***N/S means nonsurvivable.

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