Number: EN-SB-10-002-Appendix A

Subject: Evolution of Air Force Crash Load and Cargo Restraint Requirements

Introduction:

During the development of the Senior Leader In Transit Command Capsule (SLICC), a type of passenger transport module, ASC/EN and the Program Offices held discussions pertaining to current United States Air Force (USAF) crash load criteria in order to identify the applicable crash load criteria. These discussions lead to the compilation of historical crash load criteria, cargo restraint criteria and lessons learned. The purpose of Appendix A to EN-SB-10-002 is to document the historical development and progression of crash load and cargo restraint criteria.

Background:

When a crash occurs, the primary requirement is to assure the occupants (crew & passengers) are able to survive and egress. This is accomplished by making sure that cargo and equipment does not break off and become a projectile during crash deceleration (thus causing injury) and by assuring egress requirements are met.

Originally called "Emergency Landing Loads," crash loads are a consideration in airframe design. Application of crash load criteria will result in an airframe that provides a balance between passenger safety, weight of the structure, and the cost of the system. The primary parameters which affect occupant survival in a crash environment and are considered in the design of a crashworthy airframe are terrain, aircraft descent angle, aircraft impact attitude, and aircraft velocity. A crashworthy airframe acts to retard the total destruction and complete rupture of occupied areas and reduce the accelerations experienced by the occupants.

Historical Perspective on Crash Load Criteria

The origins of crash-load restraint criteria are hard to trace back to their beginnings. The consequences of crash landings first became a concern during the early days of flying in Dayton, Ohio. Just ten years after the Wright Brothers delivered the first American military aircraft, World War I aircraft experiences with fire after an emergency landing became a problem. Early aircraft were made mostly of hardwood (braced with steel wires) and covered with a linen fabric that was doped to provide the stiffness required to form a wing surface. Most aircraft were structurally fragile by today's standards and were susceptible to fire.

Early testing was focused primarily on fire safety, not load factors. In an effort to prevent aircraft fires during emergency landings, the Wright Field Engineering

Division conducted 83 crash tests between 1924 and 1926 to determine the exact cause of fire upon impact with the ground using a DH-4. This effort was the first known attempt to investigate the effects of crash landings and develop design criteria used to protect the airman from loss of life. Testing resulted in an Army Air Corps information circular called “Aircraft Fire Prevention” that was published in 1927. The data was to enhance fire safety aspects of an aircraft after a crash (no crash loads were measured), but the investigation most likely set the stage as the first of many studies and tests to learn how to better protect occupants from a crash.

Another series of tests conducted in the 1950’s and documented in NACA TR-1133 “Mechanism of Start and Development of Aircraft Crash Fires” (Reference 8) investigated fuel spills and the resulting fires incurred upon takeoff. This was accomplished by NACA Lewis in Cleveland, Ohio and took the fire safety aspect of crashes to the next level. Again, no crash force data was measured mostly because human survival was thought likely after a crash and studying the fires that often follow such accidents was the focus of research.

The best indicator of how restraint criteria were developed is to look at historical specifications and how they have changed over time. Literature shows that the restraint levels have increased during peacetime and decreased during wartime based on the risk that could be tolerated. One example of this is Army Air Corps specification number C-1803A which was dated 15 Nov 1938 (several years prior to WW II). The emergency load factor in the forward direction was 8g’s. This document was amended to change the forward restraint value to 6g’s (dated 5 Dec 1941) just prior to U.S. involvement in WW II.

An important report first published in 1943 by the Committee of Medical Research and the Committee on Aviation Medicine of the National Research Council titled “The Relationship of Injuries to Structures in Survivable Aircraft Accidents” (Reference 9) appears to be the first major study of its kind. The study, updated on 9 July 1945, covered 427 accidents involving aircraft produced prior to WW II. The report indicates that a large number of seat belt failures occurred with the seat harness designed for 6g’s. Based on these findings, the report recommended an increase to 10 or 12g’s for both the belt and seat. The result helped engineers realize that there was a need to develop better forward restraint criteria but they did not act to define it at that point in time.

On April 7th 1950, when the military still didn’t have firm criteria for crash restraint, the Civil Air Regulation (CAR) Part 4a on Airplane Airworthiness (Reference 10), required safety belts to be installed to withstand 6g’s forward (2g’s up and 1.5 lateral). This was the first civil criteria to address crash loads. In 1953 the civil regulations were enhanced to provide coverage for transport category aircraft. CAR 4b (Reference 11), which was the result of this enhancement, provided a more robust crash load criteria for seats, safety belts, and all items of mass which would injure passengers or crew if they became loose. An interesting item to note is the forward criteria was increased from 6g's to 9g's. Table 1 contains the crash load criteria from CAR 4b. It is not clear what new testing or data precipitated the update of the forward restraint criteria. Current civil standards (FAR Part-25) have kept the same 9g forward restraint criteria, while the criteria in other directions have been increased.

Table 1 – CAR-4b (1953) Crash Load Factors

Longitudinal (g's)		Vertical (g's)		Lateral (g's)	
Fwd	Aft	Up	Down	Left	Right
9	Not specified	2	4.5	1.5	1.5

Notes
1. These load factors applied to seats, belts, berths, and all items of mass which would injure passengers or crew if they became loose.
2. The criteria for the attachment points of the seat and safety belt had a factor of 1.33 applied to the loads in this table.
3. Provisions were required to protect passengers from cargo coming loose during a crash taking into account the loads listed in this table.

In December of 1954 a new USAF Military specification was released. MIL-S-5705 "Structural Criteria, Piloted Airplanes, Fuselage, Booms, Engine Mounts, and Nacelles" (Reference 12) superseded specification number R-1803-5B. MIL-S-5705 had a complete set of criteria for a variety of circumstances as shown in Table 2.

Table 2 – MIL-S-5705 Crash load Factors (circa ~ December 1954)

<table>
<tr><td colspan="2" rowspan="3">Class of Airplane or
Item being restrained</td><td colspan="6">MIL-S-5705 Structural Criteria Values
The values listed are considered to be acting individually.</td></tr>
<tr><td colspan="2">Longitudinal</td><td colspan="2">Vertical</td><td colspan="2">Lateral</td></tr>
<tr><td>Fwd</td><td>Aft</td><td>Up</td><td>Down</td><td>Left</td><td>Right</td></tr>
<tr><td colspan="2">Class of aircraft</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Liaison Aircraft</td><td>8</td><td>Not specified</td><td>4</td><td>8</td><td>4</td><td>4</td></tr>
<tr><td colspan="2">Cargo, transport, amphibian, reconnaissance, search & rescue, multi-engine, & multi-place trainers, and low speed bombers</td><td>16</td><td>Not specified</td><td>4</td><td>8</td><td>4</td><td>4</td></tr>
<tr><td colspan="2">Fighters, single engine trainers, high speed jet</td><td>32</td><td>Not specified</td><td>4</td><td>8</td><td>4</td><td>4</td></tr>
<tr><td colspan="2">Equipment & mass items</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Class II Cargo-Tie-Down
(no passengers)
Para 4.7.5.2</td><td>3</td><td>Not specified</td><td>2.0</td><td>4.5</td><td>1.5</td><td>1.5</td></tr>
<tr><td colspan="2">Class I Cargo-Tie-Down (with passengers)
Para 4.7.5.1</td><td>8</td><td>Not specified</td><td>2.0</td><td>4.5</td><td>1.5</td><td>1.5</td></tr>
<tr><td colspan="2">Litter installation
Para 4.7.4</td><td>8</td><td>Not specified</td><td>2.0</td><td>4.5</td><td>1.5</td><td>1.5</td></tr>
<tr><td rowspan="3">Fixed equipment in passenger compartment</td><td>Liaison</td><td>8</td><td rowspan="3">Not specified</td><td rowspan="3">4</td><td rowspan="3">8</td><td rowspan="3">4</td><td rowspan="3">4</td></tr>
<tr><td>Cargo, Transport, Amphibian, Recon, S & R, Multi-engine/place Trainers, Low Speed Bombers</td><td>16</td></tr>
<tr><td>Fighters, Single-engine Trainers, High Speed/ Turboprop Bombers and Recon</td><td>32</td></tr>
</table>

In May 1960 MIL-A-8865 (Reference 13) was issued as a common specification for both USAF and USN aircraft design. This new specification replaced both the USAF MIL-S-5705 and the USN MIL-A-8629. The crash load factors for the Navy, documented in MIL-A-8629 “Airplane Strength and Rigidity” (Reference 14), were 40g’s forward (20g’s for VR & VU aircraft parallel and 20 degrees to either side of the airplane longitudinal axis) and 20g’s downward (10g’s for VR & VU aircraft). These were specifically for seats and their installations and any other structures where if failure would occur, the occupants could be injured. No other directions (left / right / up / aft) were specified. In comparison to USAF, Navy requirements would certainly be different than the USAF due to the challenge of shipboard landings (3.5 degree decent glide-slope versus a standard decent glide-slope of 3 degrees USAF and civil runways). Table 3 shows the crash load criteria from MIL-A-8865 for seats only. The rest of the criteria are not listed for the sake of brevity.

Table 3 – MIL-A-8865 USAF & USN Crash load Factors (May 1960)

Aircraft Type	MIL-A-8865 Crash Load Factors for Seat Installations	
	Longitudinal	
	Fwd	Aft
All carrier based aircraft. All land-based aircraft except VR, VP,VW, VS, VU, bomber, transport or cargo	40	40
Land-based VR,VP, VW, VS, VU	20	20
Land-based Bomber, transport, cargo	20	10

Notes:

* The longitudinal load factor shall be directed in all forward azimuths within 20 degrees from the longitudinal axis.

* The vertical load factor shall be directed downward, normal to the longitudinal axis, and equal to the one-half of the longitudinal values.

* The specified load factors shall act separately.

Where:
VA - Attack airplane
VC - Cargo airplane
VE - Electronic airplane
VF - Fighter airplane
VO - Observation airplane
VP - Patrol airplane
VR - Reconnaissance airplane
VS - Antisubmarine airplane
VT - Trainer airplane
VU - Utility airplane
VW - Weather airplane

In 1971, the Air Force and Navy cut their ties to a common design specification and the Air Force released MIL-A-008865A which changed the crash criteria again. MIL-A-008865A was amended three times before being rendered obsolete by MIL-A-87221 in February of 1985. The first amendment to the MIL-A-008865A was released in April of 1973 in response to the findings of the Aeronautical Systems Division's study AFFDL-TR-71-139, titled "Air Cargo Restraint Criteria" (Reference 15) and the follow-on report ASD-TR-73-17 titled

“Final Report – Air Cargo Restraint Criteria” (Reference 16). A second amendment was introduced on November 7, 1973 that provided a small correction to the verbiage of the first amendment. The correction changed the way crash loads were calculated for fuel tanks. The results of the report ASD-TR-76-30 titled “Cargo Aircraft and Spacecraft Forward Restraint Criteria” (Reference 17) prompted the third and final amendment to the MIL-A-008865A on February 17, 1977. The results and conclusions of ASD-TR-73-17 and ASD-TR-76-30 are in the Historical Perspective on Cargo Restraint Criteria section of this report. Tables 4 and 5 give the crash load criteria from MIL-A-008865A, Amendment 3. This version of MIL-A-008865A was the most widely used.

Table 4 – MIL-A-008865A Amendment 3 USAF Seat Crash load Factors (February 1977)

Aircraft	Seat Type	MIL-A-008865A Amendment 3 Seat Crash Load Factors					
		Longitudinal		Vertical		Lateral	
		Fwd	Aft	Up	Down	Left	Right
All aircraft types except cargo	Capsules	40	12	10	25	14	14
	Ejection Seat	40	7	10	25	14	14
Cargo aircraft	Pilot & Aircrew	16	6	7.5	16	5.5	5.5
	Passenger	16	3	4	16	5.5	5.5
	Installation (side facing)	3	3	5	10	3	3
	Personnel Restraint	10	5	5	10	3	3

Table Notes:

1) The longitudinal, vertical, and lateral directions of load factors refer to the major axes of the airplane and the loads shall be applied to the seat in planes parallel to these major axes, except in all forward azimuths within 20 degrees from the longitudinal axis. These loads shall be applied as above regardless of the seat orientation and are applied separately for each of the aircraft axes. Directions noted apply to inertia loads.

Crash loads are applicable to: 1. The design and construction of installations and backup structures which are required to hold occupants (pilots, crew, troops, and passengers, including litter passengers) in their places and 2. The design and construction of fixed and movable mass-item installations and backup structures.

Table 5 – USAF Crash Load Factors for fuel tanks, cargo, bunks, litters, auxiliary in-flight seats and miscellaneous installations (MIL-A-008865A Amendment 3 February 1977)

MIL-A-008865A Amendment 3 Crash Load Factors for fuel tanks, cargo, bunks, litters, auxiliary in-flight seats and miscellaneous installations
Aircraft Bunks: On aircraft equipped with bunks for crew rest, the following apply. a) The crash load factors of Table 4 (above), as specified in the applicable seat specification or determined through trade studies shall be used for bunks occupied as seats during takeoff and landing. b) The criteria for fixed and removable equipment, depending on the bunk location in the aircraft, or determined through trade studies for bunks which are occupied during the flight regime only and not during takeoff and landing. Auxiliary in-flight seats: For auxiliary seats which are not occupied during takeoffs, landings, and emergency conditions, the ultimate loads shall be determined through trade studies or the following shall apply: a) 2,000 pounds evenly distributed over the seat bottom. b) 2,000 pounds applied to the lap belt while at an angle of 45 degrees upward and 20 degrees to the left or right of forward. c) 300 pounds download applied to the armrests; 100 pound side load applied to the armrest. d) 500 pound backload evenly distributed over the seat back. Fuel Tanks – Fuel tanks shall be designed and fabricated to provide a high degree of fuel containment during a crash; all internal fuel tanks, including all critical amounts of fuel up to two-thirds of the individual tank capacities, shall be designed and installed to the ultimate load factor requirements as determined by the analysis and trade studies or of the fixed and removable equipment criteria. Fixed and removable equipment - provisions for miscellaneous installations shall be as follows: a) All fixed and removable miscellaneous and auxiliary equipment and their subcomponent installations, including, but not limited to, armament, avionics, equipment, consoles, static lines, parachute airdrop shackle, emergency and survival equipment, escape capsule/fuselage attachment devices, retention system components for tools, ground handling implements and other portable items, and mechanisms for operating and holding open canopies, doors, and other exits for egress, which in the event of a crash could result in injury to personnel or prevent egress from a crashed airplane, shall be designed to the airplane design load factors, the results of the analysis and trade studies, or the following load factors, as applicable: Longitudinal 9.0g's forward, & 1.5g's aft Lateral 1.5g's right and left Vertical 4.5g's down and 2.0g's up b) Where fixed and removable equipment is located in a manner wherein failure could not result in injury to personnel or prevent egress, their respective airframe

attachments and carry-through structures shall be designed to the airplane design load factors, the results of the trade studies, or the following ultimate load factors, as applicable:

Longitudinal	3.0g's forward, & 1.5g's aft
Lateral	1.5g's right and left
Vertical	4.5g's down and 2.0g's up

Litters – The litter installation ultimate load factors will be established on the basis of a 250 pound occupant utilizing the subject trade studies, airplane design load factors or the following load factors, as applicable:

Longitudinal	9.0g's forward, & 1.5g's aft
Lateral	1.5g's right and left
Vertical	4.5g's down and 2.0g's up

Cargo – Where cargo and passengers can be collocated, and passengers are seated forward of the cargo (exclusive of cargo intended for aerial delivery), analysis and trade studies (mission operations analysis and intended aircraft usage) shall be performed to access the need for supplemental cargo restraint to the requirements listed below:

Longitudinal	3.0g's forward, & 1.5g's aft
Lateral	1.5g's right and left
Vertical	4.5g's down and 2.0g's up

Air Force Guide Specification 87221A (AFGS-87221A) superseded MIL-A-87221 on June 8, 1990 due to the cancellation of MIL-A-87221. Currently, the USAF crash load criteria are documented in the Joint Service Specification Guide: Aircraft Structures, JSSG-2006. JSSG-2006 was released on October 30, 1998 and superseded AFGS-87721A, which was eventually cancelled on June 1, 1999. The crash load criteria for MIL-A-87221, AFGS-87221A, and JSSG-2006 are identical; however, they differ from MIL-A-008865A Amendment 3. The differences lie in the seat criteria, which were increased when MIL-A-87221 replaced MIL-A-008865A. The data or rationale used to make this change is unknown.

Historical Perspective on Cargo Restraint Criteria

The criteria for cargo restraint evolved independently from the rest of the crash criteria, and, in general, the evolution was toward a lower crash requirement. MIL-S-5705 was the first document to contain a comprehensive set of crash criteria for cargo. This document separated cargo into two classes: Class I was cargo which could cause injury to passengers and Class II was cargo which could not cause injury. See Table 2 to find the crash load requirements from MIL-S-5705. When MIL-A-8865 superseded MIL-S-5705, cargo was no longer differentiated in the same manner. MIL-A-8865 required all cargo to meet the criteria shown in Table 6, which is similar to the criteria for Class I from MIL-S-5705. If the cargo was intended for aerial delivery, the forward criterion was reduced to 4g's as noted in the table. In 1971, MIL-A-008865A replaced MIL-A-8865, and the cargo criteria were changed again. This specification categorized cargo in a similar manner as MIL-S-5705. If the cargo was collocated with passengers or crew, it had to be restrained using the criteria given in Table 6. If the cargo was located in a position where it could not cause harm to passengers or crew, the forward restraint criterion was lowered to 3g's. In addition to the MIL specs for the aircraft design, MIL-A-8421 (Reference 18) provided the requirements for equipment designated as "air transportable.'' This specification required the cargo to be designed to remain serviceable after a 3g forward load and intact after a 9g forward load.

Table 6 - Cargo Crash Loads

Cargo Crash Load Requirements (g's)					
Spec	Forward	Aft	Lateral	Up	Down
MIL-A-8865	8*	1.5	1.5	2	4.5
MIL-A-008865A (with passengers & cargo collocated)	9**	1.5	1.5	2	4.5
* = load factor was reduced to 4g's for aerial delivery cargo ** = load factor was reduced to 3g's if cargo and passengers were separate					

Cargo criteria are another example of how criteria can change during wartime. During Vietnam, the 8-9g forward restraint criterion was reduced to 4g's because it was causing problems during combat operations and was increasing turnaround time (decreasing sortie rate). This 4g requirement was the same as the aerial delivery requirement. The rationale was that the cargo could be jettisoned in the case of an emergency.

About the time when MIL-A-008865A was released, advancements were being made in cargo handling equipment, which created the need for realistic crash load requirements. In many cases, it was impossible to restrain the cargo to meet the 9g forward requirement because the cargo and tie downs were not designed to take that load or it would require an impractical amount of chains. Furthermore, all equipment for the Army, Navy, Marine Corp, and Air Force designated "air transportable" needed to be designed to stay intact under a 9g load, which adds weight and cost to the equipment. In response to this, several studies were undertaken to determine the correct crash load requirements.

There were two studies performed in the 1970's that had a large influence on cargo crash load requirements. The first study was AFFDL-TR-71-139 "Cargo Restraint Criteria" which had a summary report titled ASD-TR-73-17 "Final Report – Air Cargo Restraint Criteria" released shortly afterward. The second study was ASD-TR-76-30 "Cargo Aircraft and Spacecraft Forward Restraint Criteria" which expanded upon the results of the AFFDL-TR-71-139 study. Results from these studies have been implemented into the military specifications in the form of amendments to MIL-A-008865A and revisions to MIL-A-8421.

The AFFDL-TR-71-139 investigation utilized USAF cargo aircraft accident data from January 1960 to July 1971 to determine the probabilities of encountering various forward crash load factors and to improve cargo restraint procedures for enhanced operational capability. Examining more than 31 million flight hours, the technical report compared safety and cost factors to current air transportability requirements in an effort to realize cost and weight savings through the reduction of cargo restraint levels. Another purpose of the investigation was to validate the magnitude of load factors that occurred during crashes. A major result of the study was the probability of a crash based on the flight hours examined. The results are given in Table 7, and they show a low probability of crash with passengers and cargo collocated.

Table 7 - Probability of Crash from AFFDL-TR-71-139

Condition	Probability of Crash (in 2 hr flights)
3G – Non-Survivable	1:500,000
3G – Non-Survivable (people & cargo)	1:1,500,000
3G – 9G	1:1,500,000
3G – 9G (people & cargo)	1:4,500,000

The report concluded that a reduction in the restraint level from 4g's to 3g's did not significantly lower the forward restraint protection level, and neither level of restraint provided ample protection for all survivable crash load levels. The report also suggested removing the 9g forward restraint requirement when cargo and passengers are collocated. As a substitute, the report suggested adding an auxiliary forward restraint system of 9g minimum capability for protection when passengers are located in front of cargo and on the same level. For future aircraft, AFFDL-TR-71-139 suggested designing the cargo area so passengers are behind the cargo.

ASD-TR-73-17 presents the impact of the conclusions and recommendations of AFFDL-TR-71-139 on USAF air cargo restraint criteria and the cost and weight savings potential. The investigation imposed major modifications to the military specifications. MIL-A-008865A was amended to remove the 9g forward criteria for cargo and add the requirement for an auxiliary 9g restraint system. MIL-A-

8421 was revised to remove the requirement to remain intact after a 9g forward load.

In an attempt to trace the origins of the cargo restraint criteria changed as a result of the 1971 AFFDL-TR-71-139 investigation, further research was conducted and documented in ASD-TR-76-30. The reanalysis of the AFFDL-TR-71-139 data built upon the ASD-TR-73-17 effort and extended the original data base from 1971 through July 1976. It was decided to revise the data analysis approach for this study. The accident selection rationale was modified to include minor accidents, which included incidents that resulted in an unexpected forward g force but did not cause any major aircraft damage or result in crew fatality.

The results of this study showed the probabilities of a crash presented in AFFDL-TR-71-139 were conservative. The study included nearly 35 million flight hours and found only 8 crashes where cargo and passengers were collocated. While the load factor for these crashes were not provided, the study also stated only 8% of all crashes occurred in the 3g to 9g range. Given this information, the study could not produce a statistically relevant probability for a crash in the 3g to 9g range with cargo and passengers collocated. In addition, the study shows the accident rate for cargo aircraft had steadily declined during the timeframe of the study, and this trend has continued. These two pieces of data were the main substantiations for the following recommendations. The report recommended leaving the 3g restraint requirement unchanged. It also recommended eliminating the need for auxiliary restraint systems above the 3g cargo handling systems. This was implemented into Amendment 3 of MIL-A-008865A. The amendment states that when passengers and cargo are collocated, trade studies should be performed to determine if additional restraint is required.

All this history leads to the current criteria for cargo restraint, which is to restrain the cargo to the 3g forward criteria. However, the increased frequency of flights with passengers and cargo collocated has forced USAF to revise these restraint requirements. Previously, if passengers and cargo were transported on the same flight, the first option was to separate the passengers from the cargo by placing them on separate decks of the aircraft. This is still the preferred approach. If the passengers and cargo must be located in the same bay, every effort should be taken to place the passengers aft of the cargo or employ the use of a 9g cargo net system. The last option is to place passengers in front of cargo with no additional restraint, which was previously acceptable per the specifications. Now all cargo collocated with passengers must be restrained to the 9g forward criteria, unless the airplane cargo bay floor and back-up structure cannot react the 9g ultimate forward tie down load. Then the rational for why this cannot be accommodated must be provided so that the procuring activity can disposition the discrepancy appropriately.

Current USAF Requirements

Design parameters for USAF crash loads are contained in the Joint Service Specification Guide 2006 (JSSG-2006) for Aircraft Structures. The JSSG-2006 defines crash requirements in terms of longitudinal (Nx), vertical (Nz), and lateral (Ny) crash load factors for fixed wing aircraft. These crash load factors are the ultimate load factors required for strength of airframe installations and back-up structures (the structure in the load path responsible for reacting the applied load into the air frame) to protect personnel during crash landings and are treated as static values. The crash load factor recommendations of JSSG-2006 paragraph A.3.4.2.11 and associated Table XIV is based on empirical data in addition to service experience and serve as an integrated requirement for development of a crashworthy structure within the limits of the primary crash parameters (terrain, aircraft descent angle, aircraft impact attitude, and aircraft velocity). Items covered include seat installations, fuel tanks (and their installation), fixed and removable equipment, cargo, litters, and bunks.

The intent of the JSSG-2006 is for the contractor to use the minimum (deterministic) crash load factors recommended in the Appendix. Alternatively, the contractor can conduct analyses (utilizing a probabilistic approach) to investigate egress time from an intact airframe (based upon trade studies which take into consideration-crash attitudes and associated weight penalties) in order to establish crash load factors compatible with system safety requirements.

The minimum deterministic crash load factors for seats installations, fuel tanks (and their installation), fixed and removable equipment, cargo, litters, and bunks are covered in Table 8 and Table 9 below. JSSG-2006 requires that seat deformations not injure or incapacitate personnel during a crash. In addition, restraint of seated-personnel motion shall be provided to minimize contact with surrounding structure. The crash load factors for items of mass (including fuel tanks and their installations along with the normal fixed and removable equipment items) are to be supported in such a manner as to prevent contact with aircraft occupants.

Table 8 - JSSG-2006 Seat Crash Load Factors

Aircraft Type	JSSG-2006 Crash Load Factors for Seats						Applicable Items
	Longitudinal		Vertical		Lateral		
	Fwd	Aft	Up	Down	Left	Right	
All aircraft except cargo	40	20	10	20	14	14	All Items
Cargo	20	10	10	20	10	10	All items except stow-able troop seats
Cargo	10	5	5	10	10	10	Stow-able troop seats only

Table 9 - JSSG-2006 Equipment Crash Load Factors

Aircraft Component	Crash Load Factors for Equipment						Applicability
	Longitudinal		Vertical		Lateral		
	Fwd	Aft	Up	Down	Left	Right	
All fixed and removable equipment	9	1.5	2	4.5	1.5	1.5	where failure will result in injury or prevent egress
All fixed and removable equipment	3	1.5	2	4.5	1.5	1.5	where failure will not result in injury or prevent egress
Cargo, Litters and bunks	3	1.5	2	4.5	1.5	1.5	all

Other Design Considerations:

Designing for crash requires a systems design approach, as it influences more than just the structure of the aircraft. JSSG-2009 Appendix G is the source for fire prevention requirements. It contains a list of requirements for fuel tanks and related systems that must be taken into consideration during design. JSSG-2009 Appendix A covers the system requirements for the landing gear subsystem and its related components. The crash requirement contained within JSSG-2009 Appendix A states: “Extended landing gear shall provide some amount of energy absorption to reduce the vertical velocity of the fuselage under crash conditions.”

Number: EN-SB-10-002-Appendix B

Subject: Air Force Crash Load Requirements Comparison

Introduction: The purpose of Appendix B to EN-SB-10-002 is to provide a comparison of specifications containing crash load criteria.

Discussion:

Specification Comparison

Table 1 shows how crash load factors compare for cargo aircraft, and Table 2 shows how they compare for non-cargo aircraft. The program engineer must be cognizant of all the applicable requirements to fully assess modifications that involve crash load factors. The specifications included in these tables represent the most commonly used sources for crash load criteria. MIL-A-008865 Amendment 3 is the best reference for determining the design specifications for legacy aircraft, while JSSG-2006 contains the current requirements for new designs. FAR Part 25 (Reference 19) and FAR Part 23 (Reference 20) are the source for commercial derivative aircraft. MIL-STD-810G (Reference 21) is a compilation of component test method standards that outline laboratory tests and environmental engineering considerations. It contains the requirements that are most commonly used for qualifying avionics/LRU equipment. In many cases, components that are qualified to MIL-STD-810G have met more stringent ultimate load criteria than those contained in JSSG-2006. However, this is not always the case as seen in Tables 1 and 2 below.

Table 1 – Crash Load Factors for Cargo Aircraft

Cargo/Transport Aircraft CRASH Load Factors							
COMPONENT	**DETAIL**	**SPECIFICATION**	**Long**		**Lateral**	**Vertical**	
			Fwd	**Aft**	**Right/Left**	**Down**	**Up**
Seats[1]	**Pilots & flight deck**	MIL-A-8865A Amend 3	16	6	5.5	16	7.5
		JSSG-2006	20	10	10	20	10
		MIL-STD-810G	16	6	5.5	16	7.5
		FAR Part – 25 (static)	9	1.5	4	6	3
		FAR Part – 25 (dynamic)	16	-	-	14	-
	Passengers	MIL-A-8865A Amend 3	16	3	5.5	16	4
		JSSG-2006	20	10	10	20	10
		MIL-STD-810G	16	3	5.5	16	4
		FAR Part – 25 (static)	9	1.5	4	6	3
		FAR Part – 25 (dynamic)	16	-	-	14	-
	Side facing troops	MIL-A-8865A Amend 3	3	3	3	10	5
		JSSG-2006	-	-	-	-	-
		MIL-STD-810G	3	3	3	16	5
		FAR Part – 25	-	-	-	-	-
	Stowable troop seats	MIL-A-8865A Amend 3	10	5	10	10	5
		JSSG-2006	10	5	10	10	5
		MIL-STD-810G	10	5	10	10	5
		FAR Part – 25	-	-	-	-	-
Litter installation	**All**	MIL-A-8865A Amend 3	9	1.5	1.5	4.5	2
		JSSG-2006	Determine via trade studies				
		MIL-STD-810G	20	10	10	20	10
		FAR Part – 25	9	1.5	3	6	3
Cargo	**Collocated with passengers**	MIL-A-8865A Amend 3	Determine via trade studies				
		JSSG-2006	Determine via trade studies				
		MIL-STD-810G	20	10	10	20	10
		FAR Part – 25	9	1.5	3	6	3
	Located such as would not cause injury or impede egress	MIL-A-8865A Amend 3	3	1.5	1.5	4.5	2
		JSSG-2006	3	1.5	1.5	4.5	2
		MIL-STD-810G	-	-	-	-	-
		FAR Part – 25					
Fixed & removable miscellaneous equipment	**Located where they could cause injury or impede egress**	MIL-A-8865A Amend 3	9	1.5	1.5	4.5	2
		JSSG-2006	9	1.5	1.5	4.5	2
		MIL-STD-810G	20	10	10	20	10
		FAR Part – 25	9	1.5	3	6	3
	Located where they could not cause injury or impede egress	MIL-A-8865A Amend 3	3	1.5	1.5	4.5	2
		JSSG-2006	3	1.5	1.5	4.5	2
		MIL-STD-810G	-	-	-	-	-
		FAR Part – 25	-	-	-	-	-
Fuel tanks[2]	**Internal tanks at two-thirds fuel capacity**[3]	MIL-A-8865A Amend 3	9	1.5	1.5	4.5	2
		JSSG-2006	9	1.5	1.5	4.5	2
		MIL-STD-810G	-	-	-	-	-
		FAR Part – 25	9	1.5	3	6	3

Notes:

1) The seat crash load factors are oriented with respect to the aircraft coordinates.

2) JSSG-2006 separates fuel tanks in to two classifications: integral fuel tanks and installations and fixed and removable miscellaneous equipment (all tanks other than integral tanks). The fuel tanks and installation

category includes typical integrated fuel tanks such as those in the wings and below the flight deck. Fuel tanks that are categorized as fixed and removable miscellaneous equipment are removable additions to the aircraft. These types of tanks include wing tip tanks, the C-130 “Benson” fuel tank, and the F-16 conformal fuel tanks among others.

3) FAR Part 25 criteria for internal fuel tanks consider the fuel tanks to be at capacity.

Table 2– Crash Load Factors for Non-Cargo Aircraft

Non-Cargo/Transport Aircraft CRASH Load Factors							
COMPONENT	**DETAIL**	**SPECIFICATION**	**Long**		**Lateral**	**Vertical**	
			Fwd	**Aft**	**Right/Left**	**Down**	**Up**
Seats[1]	**Pilot Seat (ejection seats)**	MIL-A-8865A Amend 3	40	7	14	25	10
		JSSG-2006	40	20	14	20	10
		MIL-STD-810G	40	7	14	25	10
		FAR Part – 23 (Static)	9	-	1.5	6	3 / 4.5[2]
		FAR Part – 23 (Dynamic)	26/21[3]	-	-	19/15[4]	-
	Personnel capsule	MIL-A-8865A Amend 3	40	12	14	25	10
		JSSG-2006	9	1.5	1.5	4.5	2
		MIL-STD-810G	40	12	14	25	10
		FAR Part – 23	-	-	-	-	-
Fixed & removable miscellaneous equipment	**Located where they could cause injury or impede egress**	MIL-A-8865A Amend 3	9	1.5	1.5	4.5	2
		JSSG-2006	9	1.5	1.5	4.5	2
		MIL-STD-810G	40	20	14	20	10
		FAR Part – 23	18	-	4.5	-	3
	Located where they could not cause injury or impede egress	MIL-A-8865A Amend 3	3	1.5	1.5	4.5	2
		JSSG-2006	3	1.5	1.5	4.5	2
		MIL-STD-810G	-	-	-	-	-
		FAR Part – 23	-	-	-	-	-
Fuel tanks[5]	**Internal tanks at two-thirds fuel capacity**[6]	MIL-A-8865A Amend 3	9	1.5	1.5	4.5	2
		JSSG-2006	9	1.5	1.5	4.5	2
		MIL-STD-810G	-	-	-	-	-
		FAR Part – 23	9	-	1.5	6	3 / 4.5[2]

Notes:

1) The seat crash load factors are oriented with respect to the aircraft coordinates.

2) 3g’s is for normal, utility, and commuter category aircraft. 4.5g’s is for acrobatic aircraft.

3) 26g’s is for the first row seats. 21g’s is for all other seats. The test is completed with seats oriented at a 10º yaw angle.

4) 19g’s is for the first row seats. 15g’s is for all other seats. The test is completed with seats oriented at a 60º pitch angle.

5) JSSG-2006 separates fuel tanks in to two classifications: integral fuel tanks and installations and fixed and removable miscellaneous equipment (all tanks other than integral tanks). The fuel tanks and installation category includes typical integrated fuel tanks such as those in the wings and below the flight

deck. Fuel tanks that are categorized as fixed and removable miscellaneous equipment are removable additions to the aircraft. These types of tanks include wing tip tanks, the C-130 “Benson” fuel tank, and the F-16 conformal fuel tanks among others.

6) FAR Part 23 criteria for internal fuel tanks consider the fuel tanks to be at capacity.

JSSG-2006 is the current design guidance for USAF and USN structures and should be used as the primary source for all requirements when developing or modifying fixed wing aircraft components, including seat installations, fuel tanks (and their installation), fixed and removable equipment, cargo, litters, and bunks. The USAF has a large percentage of aircraft that were designed to legacy specifications. To understand what the design guidance was on those legacy aircraft one must research the design criteria for the specific aircraft. For modifications to the airframe that impact crash loads one must determine if the original design criteria or JSSG-2006 should apply. For example the early C-130 aircraft referenced crash loads factors that were based on MIL-S-5705 but the current C-130J model values coincide with MIL-A-008865A. If a modification was made to one of these aircraft, the engineer would need to determine whether the requirement should be from JSSG-2006 or the legacy specification. The challenge is to know which criteria to apply when dealing with aircraft modifications. Each case is different and must be analyzed on its individual merits.

Airframe specifications are not the only sources for design criteria. Avionics boxes and other such related equipment that are installed on the airframe are designed to the higher (usually conservative) values of MIL-STD-810G crash loads in an effort to make them resistant to becoming projectiles in addition to being compliant with multiple aircraft platforms.

There are two MIL-STD-810G test procedures that cover crash loads. One is Method 513 (Procedure III: Crash Hazard Safety Test) and the other is Method 516 (Procedure V: Crash Hazard Shock Test). Test Procedure 513 relates directly to aircraft loads engineers as it deals with statically applied acceleration loads similar to the USAF crash load requirements. The shock tests in Method 516 involve rapidly applied load for the purpose of exciting dynamic (resonant) response but causes small overall deflections (stresses). Since the loads prescribed in both tests are in terms of g’s, the mistaken assumption can be made that the acceleration requirements can be satisfied by the shock tests and vice-versa. Shock and acceleration tests can never be substituted for each other because the purpose of each test is different. The tests in MIL-STD-810G are intended for small items, such as avionics boxes and LRU’s, where testing is more economical than analysis due to the complexity of the small integrated parts. MIL-STD-810G crash acceleration and shock requirements are not intended for verification of crash loads in primary aircraft structure. JSSG-2006 is the sole source for crash load requirements for military aircraft and they are always given in terms of static (g’s) and not dynamic (shock).

The military's rationale for using static load factors can be attributed to the airframe response to crash conditions. When experiencing a crash, the airframe has been observed to exhibit a collapse and crushing (or crumpling) of the local structure from the nose of the aircraft (at the impact point) all along the fuselage to the tail section. Incorporating "crumple" zones into the airframe structure produces a quasi-controlled collapse that draws out the acceleration in time and decreases the peak deceleration values. Lengthening the deceleration time makes the event more similar to an "acceleration" as opposed to a "shock", which explains why the military uses static crash load requirements.

The FAA regulations, FAR Part 23 and 25, provide both static and dynamic crash load requirements for pilot and flight deck seats, while USAF specifications have only static requirements. The static crash load criteria for these items in the FAR Part 23 and 25 are significantly less stringent than the USAF static seat crash load criteria. To account for the reduced static load requirement, the FAA employs dynamic crash load criteria to ensure similar crashworthiness as USAF cargo/transport aircraft pilot and flight deck seats. This requires a more complex analysis because of the dynamic nature of qualification testing. USAF accounts for dynamic effects by using statically equivalent loads for structural design criteria, thus simplifying the qualification effort.

Number: EN-SB-10-002-Appendix C

Subject: Air Transportability

Introduction: The purpose of Appendix C to EN-SB-10-002 is to outline the process of attaining an Air Transportability Test Loading Activity (ATTLA) certificate for an uncertified cargo item.

Discussion:

Cargo handling on all USAF aircraft is currently governed by three items: the aircraft operations Air Force Instruction (i.e. AFI11-2C-17 volume 3), the– 9 Technical Order (i.e. TO 1C-17A-9), and the loadmaster. All cargo aircraft have at least one loadmaster to oversee the loading, restraint, and unloading of the cargo. The loadmaster's responsibilities are outlined in the aircraft operations AFI written for the particular aircraft, and the cargo capability and limitations of the aircraft in the -9 TO. The loadmaster uses the AFI and the TO to safely load and restrain the cargo for the planned mission. These documents give the loadmaster enough information to perform their responsibilities. Whenever the physical characteristics of cargo meet the criteria listed in DODI 4540.07 defining an air transportability problem item, the system needs to be evaluated and certified for air transport before it can be loaded into the aircraft. This evaluation and certification is performed by the ATTLA office located within ASC/ENFC at Wright-Patterson AFB.

ATTLA's evaluation ensures that the item can be loaded and transported without exceeding the respective cargo aircraft dimensional and structural limits, and that the item can withstand the air transport environment. As part of the air transport environment verification, ATTLA validates that the item's structure can withstand the accelerations that could be experienced during air transport and that the item can be restrained to the cargo aircraft to withstand the same accelerations. Working directly with contractors and system program offices, ATTLA provides engineering and design assistance to ensure that new pieces of hardware are designed from the outset to be air transportable. ATTLA is the document custodian of MIL-HDBK-1791, "Designing for Internal Aerial Delivery in Fixed Wing Aircraft", as a design guide for air transportable systems. This MIL Handbook is the replacement for MIL-A-8421, which was referenced earlier. The ATTLA office uses the criteria listed in MIL-HDBK-1791 and the aircraft technical orders to make their evaluations. They also evaluate items that are currently in the inventory with respect to air transportability and issue Air Transportability Certification memos for both new and current items that meet the requirements. The ATTLA office should be the first contacted when questions regarding cargo air transportability arise.