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LAND SEA AIR SPACE

AEROSPACE RECOMMENDED PRACTICE

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IMPACT PROTECTIVE DESIGN OF OCCUPANT ENVIRONMENT TRANSPORT AIRCRAFT

1. PURPOSE

This ARP provides design guidelines based on currently available information for the impact safety design of the cabin occupant environment.

2. INTRODUCTION

2.1 Injuries are sometimes sustained by occupants of transport aircraft during survivable crashes, turbulence, or unexpected flight conditions. In some instances, these injuries are caused, or made more severe, by equipment within the aircraft. Equipment design factors influencing injury, not generally familiar to the designer, include:

A. Relative velocity of the impacting equipment and the occupant.

B. Impact site on the occupant.

C. Area of impact on the occupant.

D. Mass of impacted or impacting equipment.

ø E. Geometry of the impactor (sharp edges, etc.)

F. Surface hardness or compliance of the equipment (ability to conform to the corresponding surface of the occupant's body).

G. Equipment surface roughness.

H. Energy absorption characteristics of the equipment.

I. Direction of impact (on the occupant).

J. Duration or time history of the impact.

These factors act concurrently and are interdependent in their effect. One other factor, not within the control of the designer, is the tolerance level of the occupant, which varies over a large range due to age, general health, physical size, and skeletal development.

2.2 Although the field of knowledge regarding impact injury protection is not yet fully defined, certain fundamental rules have become apparent:

A. Distribution of load over a large body area will tend to decrease injury.

ø B. Elimination or reduction of the flailing distance available for arms, legs, upper torso, or head generally decreases injury by reducing the relative velocity between the body and the impactor and allowing the body to "ride down" the impact with the aircraft. This is particularly true if the contact surface is sufficiently compliant to distribute the impact load over the body.

2.2 (Continued)

C. Distribution of impact loads over the body by use of lightweight structure or padding which plastically deforms, with minimum elastic rebound, will generally decrease injury. The use of systems that are largely elastic in their response to impact may increase injury since they store the energy of the impact for rebound into the body.

D. Deformation of material under impact loads should not expose structure which could cause injury.

2.3 Items within the passenger cabin which become loose; i.e., fittings, shields, ceiling panels, storage compartments, etc., can cause injury if they contact the occupants during the event. These should be
ø located so as to reduce the likelihood of contact whenever possible, even if their retention system should fail. Deflections of the cabin and the interior contents during an impact should be considered when designing the retention system.

3. DEFINITIONS

3.1 Occupant Environment: The structural area and components which comprise a transport aircraft cabin and which the passengers and cabin crew may impact during turbulent flight and emergency conditions, such as survivable crashes.

3.2 Structural Area: The space adjacent to the occupants which any part of the occupants' bodies may impact during the conditions cited in paragraph 3.1.

ø 4. TYPICAL DESIGN CONSIDERATIONS (PHYSIOLOGICAL)

4.1 Head and Neck: The strength of facial bone under localized impact is relatively low because of the thinness of the facial bones. If the impact load can be distributed over the facial area, the face acts as a unit and its strength approaches that of the cranial vault. Areas to be contacted by the head should be designed for load distribution as well as energy absorption. The load distribution pad should allow the face to penetrate (at least 1.00 to 1.25 in. (2.5 to 3.2 cm)), insure full facial contact, and result in a total resisting load at the time of about 1,100 lb (4890 N). The understructure should plastically deform at between 1,100 and 1,200 lb (4890 - 5335 N) to absorb the energy of the impact. The effect of the cover material over the padding should be considered in the design, since some cover materials increase the resistance to load as much as 100 percent. The understructure should provide even support for the load
ø distribution padding and should not present "hard spots" during deformation.

Angular acceleration of the head can cause loss of consciousness as well as injury. Although firm criteria are not available, localized contact with the head which could produce angularization of the head with respect to the torso should be avoided. Acceleration of the body, without head support, can produce equivalent results. This is of particular concern where "whiplash" reaction could occur due to hyperextension of the head over a backrest as a direct result of the accident or as a result of elastic rebound of the body after the accident. Voluntary head ranges of motion for healthy young subjects appear to be about 35° laterally right or left, 50° forward (flexion), 55° rearward (extension), and 68° right or left rotation. Elderly subjects can show a decrease of over 40% of voluntary range of motion relative to young subjects. The voluntary range of motion can be exceeded during impacts, with injury appearing at about 60° lateral head motion and 80° hyperextension. Localized impact to the neck can produce fracture of the laryngeal cartilage at loads between 90 and 100 lb (400 - 445 N).

4.2 Torso: Chest impact tolerance varies widely with the impact conditions and the biological characteristics of the person involved. Elderly subjects generally have a lower injury threshold than do young subjects and, for the distributed loads, injury appears to be more closely associated with chest deflection than
ø with the magnitude of the load. Chest deflections of less than 2 in. (5.1 cm) have been found to produce only minor injuries. Nevertheless, for design purposes, an impact load distributed over the sternum and producing a force of 400 lb (1780 N) can be considered to produce only moderate injury.

4.2 (Continued)

Fracture of ribs and sternum occur at higher loads, up to 1,000 to 1,500 lb (4450 - 6670 N). Internal injuries to the heart, great vessels, or lungs, are most serious and can occur at relatively low loads.

In an aircraft, the abdomen is usually fairly well protected since the occupant wears a seatbelt. However, if the seatbelt is improperly worn (above the pelvis), is worn adjusted loosely, or is improperly latched in place, abdominal injuries can occur. No data are available to establish load limits for such injuries, but the general guideline of distributing the load over a maximum body surface and avoiding localized loading is most important. For lateral impacts in the abdominal area, serious but reversible injury has been found to occur at 700 lb (3110 N) force.

4.3 Legs: Fracture of the legs, although of relatively minor consequence in itself, can prove fatal if evacuation from a burning aircraft is required. Females and the elderly have lower tolerances to leg fracture than do adult males. Studies measuring the energy required to fracture lower leg bones, at an impact speed of almost 14 feet per second, would vary from 25 to 85 ft-lb (5th to 95th percentile of the population), when the bone was treated as a simply supported beam impacted at the center. Females and males over age 65 required about 80% of the energy required by males under 65. Impacts to the knee can cause damage to the knee-thigh-hip complex as the load is transferred to the body. If the area contacted by the knee is well padded, with about 1.50 in. (3.8 cm) of energy-absorbing low-rebound material, loads of 1,400 lb (6225 N) are estimated to be conservative values for injury threshold.

5. TYPICAL DESIGN CONSIDERATIONS (EQUIPMENT)

5.1 Rigid structural members which can effect injury should be located or provided with energy-absorbing materials as to preclude the possibility of injurious body strikes during normal or abnormal accelerations.

5.2 Components which are normally or potentially in direct contact with the body should be designed with large radii, contain ample surface area, be free of rigid or brittle structures, and be energy absorbing.

5.3 Ash trays, lighting fixtures, switches, recline handles, vents, and other such equipment should be recessed, of smooth contour, and nonshatterable.

5.4 Structures within striking range of the body should present large, low-mass, energy-absorbing surfaces to the body or head. Attachment hardware should be installed so as to preclude contact with the body or head. Safety objectives may be achieved through progressive collapse of structure. Structural collapse should not result in the presentation of "spear" points.

5.5 Materials and structures utilized for impact energy absorption should be capable of providing uniform pressure distribution on the human body as it contacts and progressively "enters" and/or displaces the energy-absorbing material.

5.6 Cabin side walls, partitions, bulkheads, window frames, and other large surface structures should have energy-absorbing characteristics. Breaks in the surface continuity, such as edges and corners, should have generous radii and be of a nonrigid, nonshattering material.

5.7 Cabin components, such as magazine racks, oxygen outlets, lighting fixtures, air duct orifices, handles, and switches should be located out of occupant impact range or should be recessed to avoid contact injury.

5.8 Overhead racks, galleys, coat compartments, and storage units should be designed to preclude their loosening, opening, or falling on the occupants, dumping of contents, or interfering with emergency evacuation.

6. DESIGN AND TEST METHODS

Design of interiors to provide impact protection to occupants requires consideration of dynamics and energy absorption which is beyond the usual result of static analysis. Although empirical approaches have provided useful impact protection in several situations, they cannot be formulated to assure adequate protectio. in the general case.

The designer does have several techniques at his disposal which can be of assistance in his design. One of the first questions which must be resolved is the impact velocity of the occupant with the cabin interior. This varies with the occupant size, the restraint properties and configuration, the seat properties, and the impact. Estimates of the occupant velocity relative to the interior may be obtained by using computer models. In these models, the displacements, velocities, and accelerations of the arms, legs, torso, and head of an aircraft occupant are determined relative to the aircraft interior during dynamic motion. These results can be used to estimate the location and amount of energy-absorbing material required, or can be used to develop test parameters to evaluate the performance of a specific design approach.

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Since the design of equipment and interiors to provide impact protection requires a combination of materials, knowledge, and analytical efforts considering plastic deformation, and since these factors are often indeterminant or interreacting, much design is accomplished empirically. To validate the performance of these designs, test procedures have been developed which enable simple, low-cost evaluations. Of particular interest for interior designers would be Society of Automotive Engineers (SAE) Recommended Practice J921b, Motor Vehicle Instrument Panel Laboratory Impact Test Procedure - Head Area; SAE Recommended Practice J346, Motor Vehicle Seatback Assembly Laboratory Impact Test Procedure - Head Area; SAE Recommended Practice J52, Steering Wheel Rim Faceform Impact Test Procedure; and SAE Recommended Practice J338, Motor Vehicle Instrument Panel Laboratory Test Procedure - Knee-Leg Area. Although these procedures were initially intended for use on motor vehicle systems, their application to structures in the aircraft cabin having similar injury potential should be direct.

ø 7. REFERENCES

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