AAIR Passenger Airbag System for Transport Aircraft

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ABSTRACT

Dynamic performance requirements for aircraft seats were introduced in 1988, greatly expanding the process of certifying a transport aircraft interior. Compliance to many aspects of Federal Aviation Regulation (FAR) and the Joint Airworthiness Requirement (JAR) 25.562 has become a mature process. Compliance to the head injury requirement, however, persists as a difficult and expensive venture. The most practical means to comply with the HIC requirement, although satisfying the regulation, often do not satisfy the original objective of the rule.

AmSafe Aviation developed airbag technology to address both commercial and safety concerns surrounding the head injury issue. This paper first provides a basis to understand the issue by addressing the purpose of 25.562 followed by an explanation of Head Impact Criteria (HIC). The paper then illustrates concerns with the compliance to 25.562, and how the Amsafe Aviation Inflatable Restraint (AAIR) addresses them.

OPPORTUNITY FOR SURVIVAL

The intent of FAR/JAR 25.562 is the de-leathalization of the aircraft interior for a survivable crash event. The objective is simple and makes perfect sense. Events of low enough impact severity to keep the cabin intact should provide occupants the opportunity to survive. In other words the seats should stay attached to the floor, and furnishings should be designed to retain passenger consciousness for evacuation. Seat and floor track structure is validated by dynamic tests. Passenger health for evacuation is the purpose of including various occupant injury criteria. Included are criteria for spinal compression, femur loading and head impacts. Head impact protection, measured via the Head Injury Criteria (HIC), proved to be the most challenging.

This simple in intent turned out to be complex in practice. The AAIR was developed to address the problems surrounding this challenge. The problems are that the compliance comes at a high cost and worse yet, often does not compare well with the intent. Understanding the means of compliance related to the rule first requires an understanding of HIC. HIC is so often cited, and so rarely understood, that a brief look to it’s origin is valuable.

WHAT IS A HIC=1000?

HIC is an injury index. It is based on association of real injury to an indirect measure of head acceleration sustained for a period of time. The value of 1000 is widely regarded as the threshold of severe injury. “Severe Injury” is quite vague and people often search for a more meaningful representation that is more closely associated with actual biological results.

Understanding the practical meaning and limits of HIC has less to do with the mathematical expression than the background in which it was developed. Establishing an index by which to assess head injury in a laboratory test requires first a measure and a comparison to the real world. Both direct measures (pressure, force, or stress) and indirect measures (acceleration) are potential options. Mr. Gadd of General Motors Corp. concluded in 1967 (reference 4), that the difficultly of measuring direct biological tolerance justified indirect methods. He proposed a method based on acceleration of the head relative to time for judging head impact severity. This time weighted impulse criteria is the HIC so widely used today.

The HIC, defined by the equation used in 25.562, represents a linear fit to the Wayne State University human tolerance curve, as shown in Figure 1. The tolerance curve was developed from various injury studies to plot the threshold of serious head injury as a function of acceleration and time. Gadd's index criteria made it dimensionless and more generally applicable. The time durations valid for the curve fit are between approximately 3 and 50 milliseconds. The threshold value of 1000 correlated well to several studies, including 1) human cadaver tests, 2) animal impact data representing dangerous concussion, 3) field accident data from the FAA for a conservative estimate of 50% survivability rate.

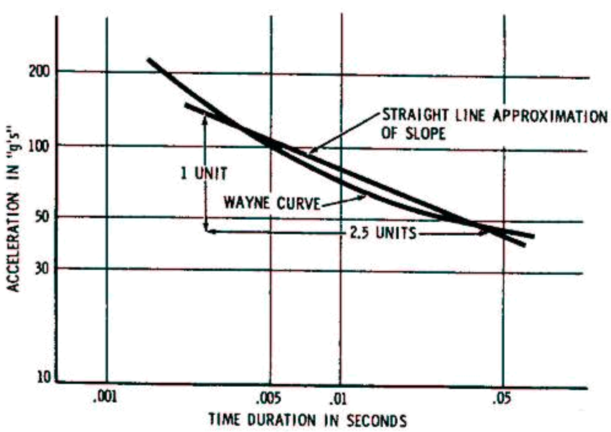

Figure 1: HIC Based on Injury Tolerance Curve

The common question of what happens to an occupant with a HIC of 1000 does not have a clear answer. The measurement is an indirect representation of internal head injury. The answer thus depends on which study or correlation you choose to apply. The onset of severe injury is the most definitive conclusion possible. Interestingly, the correlation to some direct measurement data is quite good. Using a reasonably large surface area in the face, a HIC of 1000 also roughly represents the threshold of skull fracture. Smaller surface area focuses the impact sectional density, which of course drops the threshold rapidly, as shown in Figure 2.

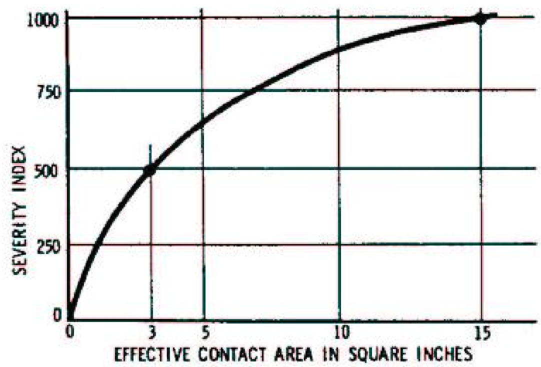

Figure 2: Approximate Severe Injury Threshold as a Function of Impact Area Using HIC

Various forums, led by the automotive industry continue to refine the assessment of human injury tolerance. The injury criteria used in aircraft has remained unchanged.

HIC COMPLIANCE APPROACH

Two approaches can certify an aircraft interior configuration.

a) Dynamic test can measure HIC against the established limit of 1000, or

b) A "no impact" case can be established by headpath analysis.

The first approach is used primarily for row to row seat applications, and is often done in conjunction with the seat/floor interface (structural) tests. The second approach is used primarily for seats at exit rows or situated behind interior furnishings. These include class partitions, galleys, lavatories, premium seat pods, or life raft pods. The seats are positioned far enough away from the strike hazard to show a clear headpath. No measurement of HIC is required for this case. FAR/JAR 25.562 states:

"Where contact with seats or other structure can occur, protection must be provided so that head impact does not exceed a HIC of 1000 units." The guidance material (reference 3) clarifies the definition of other structure to exclude body parts or the aircraft floor.

HIC COMPLIANCE PROBLEMS

The industry has had more than a decade to comply with the 25.562 rule. The problem areas are now clear. It became quickly known that the energy and resulting head velocity of a lap restrained occupant during the 16g event is more difficult to attenuate than expected. Simple padding does not help much, and for row to row applications, energy absorbing seatbacks are developed by iteration. Tests with modifications to material shape and stiffness are conducted until the HIC value passes, rarely lower than 800 or 900. The case of a large setback behind interior furnishings proves to be impossible without either configuring the cabin for headpath clearance or by some advanced restraint. Shoulder harnesses, aft facing seats, and articulating seats were popular concepts until the secondary effects to seat weight and floor structure were fully realized. Complying with 25.562 has been a burden for the industry to be sure, but has a logical end. That is, to offer sufficient survivability for evacuation at crash severities at or below the survivable impact threshold.

A PRACTICAL VIEW

When the option to pursue development of an advanced airbag restraint was presented, AmSafe Aviation took a practical look at the 25.562 compliance methods that had become standard practice. There were related commercial and safety concerns that could be addressed by airbag technology. The two basic HIC scenarios are summarized below, followed by considerations of impact scenarios and occupant safety.

SEAT ROW INTERACTION

Row to Row applications suffer from trial and error engineering that at best complicate the development and certification program affecting timing and cost. The safety concerns are worse. Iterating to a HIC of 900 may not satisfy the ultimate objective of successful aircraft evacuation. Airbag technology offers the potential of confident results with previously unheard of HIC values. The AAIR has been able to deliver. Tests demonstrate HIC values in the range of 200 to 300, even for the notoriously difficult case shown in Figure 3. This test has a row of seats aligned with the arm rests of the row in front. The use of seatback break-over as an effective energy absorber is extremely difficult for configurations like this.

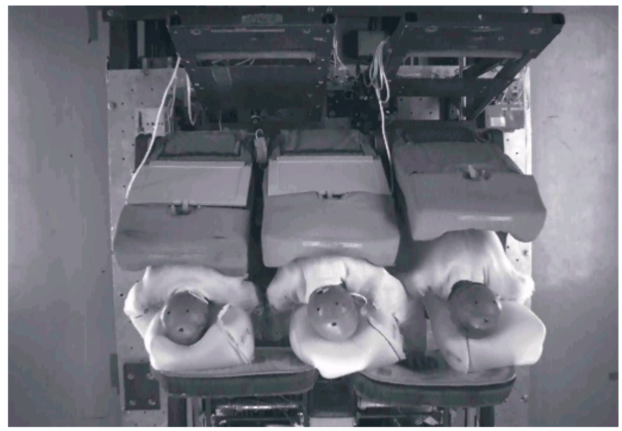

Figure 3: Row to Row 16G Test with AAIR

FRONT ROWS ARE PUSHED BACK

Front Row or Exit Row applications where the occupants are seated within strike zone just didn't work for HIC's below 1000. Thus waivers for seats located in these positions were granted for many years until a solution was found. Extended layouts showing "non impact" became the default solution. HIC for this case is not measured, as we saw earlier by definition of the rule. The operator has to tolerate, at best, a restrictive layout resulting in lost seat pitch, lost seats and ultimately, lost revenue. What happens to the practical view in terms of ultimate safety? Unfortunately when HIC for these cases is measured, violent head strike with the lower legs or floor results in HIC values well beyond acceptable limits. HIC values of 2000 or more are not uncommon. Figure 4 was taken at the point of head contact to the legs for a 3 year old size ATD restrained in a 25.562 compliant system.

The AAIR has experienced the broadest acceptance in front row applications. Aircraft layouts making full use of cabin space are now possible. A typical economy class seat requires about 42 inches from seat reference point (SRP) to the strike hazard for no impact clearance. When unrestricted, large transport aircraft typically use 35 inches. Small commuter aircraft may opt for as low as 29 inches. The AAIR makes these layouts possible without sacrifice to occupant protection.

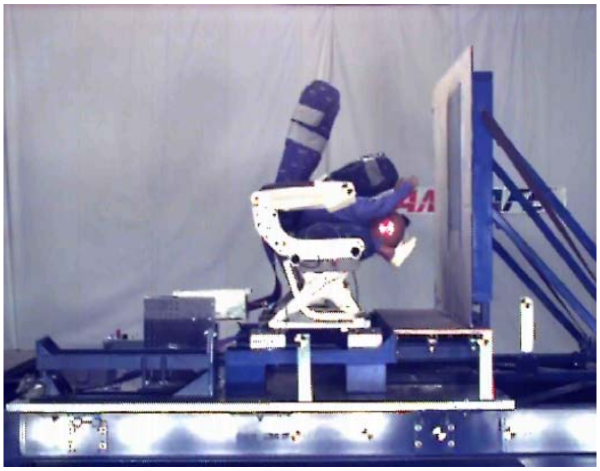

Figure 4: Three Year Old ATD in 16G Event

OTHER IMPACTS CONSIDERED

Consideration of various impact scenarios is also important. The 16G pulse was derived as the maximum severity pulse. Most survivable impacts occur at some lower level. Does airbag technology still offer significant advantages for these events? The use of a calibrated crash sensor makes it possible to pre-determine the activation threshold. This means that it can screen out non-injurious minor events. AmSafe studied the progression of impact severity and determined that the onset of severe head injury is not gradual and proportional to the impact energy as you might expect. The primary function is the point when the occupant begins articulation of the upper torso. The potential for head injury progresses very quickly upon crossing this balance point.

Fortunately the occupant balance point and corresponding sensor threshold occurs at impact severities well above the critical threshold of flight transients or ground maneuvers. This makes the airbag technically feasible, because it can be designed to ensure no inadvertent deployment. It was also found that a wide range of impacts below the 16g maximum can result in severe injury. AmSafe set the threshold for a triangular pulse of similar shape to the 16G pulse at about 8G peak. The airbag demonstrates proper deployment and position for this intermediate level, which makes the airbag affective for any crash pulse severity up to the maximum 16G pulse..

The question of multiple pulses can also be raised. Preliminary impact(s) below the threshold are not an issue (as the airbag would not deploy and be ready for the next impact). For example, the bag does not deploy for the 14G down structural test. The longitudinal component is too low. But what happens if the first impact is severe enough for deployment (bag would be needed), but followed by another, possibly even more severe impact? For this case the occupant would have articulated forward, and no longer be in a position to generate significant head velocity.

An even more extreme case has been suggested. What if multiple severe impacts are separated by sufficient time to allow occupants to move themselves back into position? Every product has it's limits. If aircraft design reaches the point that the structure and all implicated components are able to reasonably address this scenario, we will have come a long way. Questions to that level illustrate the step change in safety airbag technology brings.

OCCUPANTS ARE CONSIDERED

Occupants that are out of the standard position or size were also considered. Creating an airbag system that offers protection for all occupants and does not introduce harm is critical for use in aircraft. People of a wide range of age and size use the seat, and during a known emergency, safety instructions place occupants in the brace position. Wide acceptance in the market is not possible without addressing these topics.

This is accomplished by specific design attributes of the AAIR. Simply stated, the bag is placed on the belt using special design features that make it safe. The design: 1) causes the bag to deploy away from the occupant, 2) allows the deploying bag to find a free/non-injurious path when blocked, 3) positions the bag in the critical zone for deceleration of the torso/head despite occupant size variations, and 4) allows use of the standard centered buckle. No special operating instructions are necessary for the passenger, and the interface is exactly the same as a standard two-point restraint. Further design detail is given in the following sections. Figure 5 shows the bag deployment with a three year old size ATD. The bag does not interact with the occupant during deployment.

Figure 5: Static Deployment with Three Year Old ATD

Figure 6 illustrates deployment for a case that the bag is blocked during deployment by a passenger in the brace position. Because the airbag is not constrained by neighboring structure (as it would be if mounted on the bulkhead for example), deployment follows the least restrictive path. This allows the bag to unfold without exerting significant force to the occupant or moving the occupant out of the brace position.

Figure 6: Static Deployment with 50% ATD In Brace Position

AMSAFE PURSUES AIRBAGS

Airbag technology, when viewed in direct comparison to a simple lap belt, is certainly more complex and expensive. However, the benefits to safety and commercial aspects of cabin certification greatly outweigh the incremental costs. The technology closes the loop on passenger survival and ultimately reduces the cost and time to aircraft delivery. The infamous process from ITCM to cabin closure is simplified by the AAIR. These considerations prompted AmSafe to begin developing a belt mounted airbag restraint in 1997.

AIRBAG ON THE LAP BELT

Amsafe Aviation introduced airbag technology into transport aircraft with the first revenue flight in March of 2001. Now, in spring of 2002 a new generation of the system with improved simplicity, modularity and weight is being introduced. This corresponds to an expanding number of aircraft platforms requiring compliance to head injury requirements.

Locating airbags on restraint webbing has been studied for well over a decade for many ground and air based applications. The AAIR was the first to enter service on commercial aircraft, and the first to place the bag on top of the restraint webbing. The bag in this position deploys away from the occupant, essentially throwing an energy absorber out between the occupant and the strike hazard. Design features create a safe environment for the full range of occupant sizes and positions, eliminating the need for most operational restrictions. The system is deactivated when used with a child restraint.

Placement, fold, shape, and construction of the bag contribute to an effective energy absorber that interacts with the torso and head against femurs and aircraft interior. The occupant is decelerated without impact to the lower legs, floor, or structure.

The system was designed to be self contained and modular, important for retrofit to existing seats and simplify interface tasks. Figure 7 illustrates a typical installation.

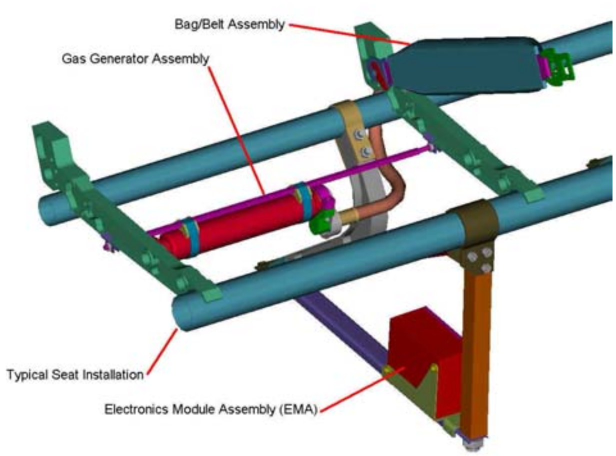

Figure 7: Typical AAIR Component Installation Shown on Seat Structure

The belt attaches to the existing seat belt anchors. The airbag is housed on the fixed portion of the lap belt, and is covered with a durable textile show cover. The buckle is a standard lift flap, center positioned buckle, with the addition of a solid state switch and a key feature. The switch disables the system when not buckled, and the key feature prevents upside-down connection. A special fabric tube connects the bag to a compressed gas inflator, which is deployed via an electronic squib. Each passenger has a bag and inflator. Up to three seat positions are served by one electronics module assembly (EMA). The EMA contains the crash sensor, battery, and related circuitry to monitor the acceleration time profile of the aircraft, and signal deployment during a crash.

Current automotive technology and testing methodology contributed to the design and manufacture of the sensor, inflator and bag. This evolutionary history was critical for AmSafe to achieve design targets for reliability and cost.

CONCLUSIONS

Transport aircraft certified to FAR/JAR 25.562 offer the occupant significantly improved chance for survival in non-catastrophic crashes. The compliance process has matured over the years of it's existence. Standard methods to meet the requirements are taking shape just the applicable aircraft interior programs multiply. Issues remain that burden industry with costs or restrictions while at the same time do not fully meet the objectives of the rule. AmSafe has developed airbag technology that can address some of these issues. The AAIR has the potential to improve the overall cabin interior certification process while providing passenger protection that takes full advantage of the .562 certified cabin.

REFERENCES

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4. Gadd, Charles W.; "Use of a Weighted-Impulse Criterion for Estimating Injury Hazard", SAE Paper No. 660793.