EVALUATING AND CERTIFYING CABIN SAFETY ENHANCEMENTS

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ABSTRACT

This paper presents a model of the Safety Improvement Process as it appears to function in the transport aircraft environment. The process includes identifying injury mechanisms, developing the technology to quantify the injury mechanism, conceiving an injury mitigation technology, objectively evaluating the mitigation technology, deciding to regulate, writing certification criteria, and evaluating the operational results. The follow-up Improvement Cycle can then proceed by one of two paths: iterating to improve the implemented technology, or identifying the next most significant mechanism and beginning the cycle anew. This paper suggests that the industry has been focusing on iteratively improving existing technologies, rather than seeking the next most significant mechanism. The paper further suggests that resources may be better utilized for developing new technologies rather than performing exhaustive certification testing of existing technologies.

INTRODUCTION

The Gore Commission has challenged the air transport industry to reduce fatal accidents by 80 percent within 10 years. Safety is quintessentially an aircraft system characteristic. Much of the effort toward achieving this goal will go into preventing accidents; however, a few accidents may still occur. The other major aspect of achieving the goal is enhanced survivability; cabin safety in particular. The objective of survivability is to design the aircraft system, and especially the cabin area, to enable the occupants to survive a crash and then to safely egress the aircraft to avoid post-crash hazards such as toxic smoke and fire.

Existing aircraft cabin safety systems can be improved. For example, the Federal Aviation Administration's (FAA) regulations on seating systems (Reference 1) have recently been revised to require that seats remain attached to the aircraft floor through a 16-G peak dynamic pulse rather than a 9-G static load. New FAA requirements regarding head injury have also been imposed on the seat/restraint system. This change reinforces the systems nature of safety, because with the implementation of the head injury requirements, bulkheads, galleys, and seat-back-mounted equipment, such as telephones, become a consideration to the seat-restraint designer. These requirements are currently being applied to newly certificated aircraft. However, the FAA is considering applying similar regulations to older aircraft, to be implemented when the aircraft undergo major overhauls. The technology to achieve these improvements already exists, and can be readily implemented. This seating regulation upgrade is one response to the Gore challenge which can be addressed within the timetable proposed.

Achieving additional fatality reductions in the crash survival area will require finding a means to prevent the injuries that still occur despite the safety technology already in place. To accomplish this objective, full use must be made of a comprehensive "Safety Improvement Process." The foundation of the Safety Improvement Process described in this paper is identifying the causative mechanisms of those injuries which continue to occur, and then creating and implementing safety enhancements to mitigate those injury mechanisms.

While there is a formal process for certifying transport aircraft equipment, the larger-scale process of safety improvement is not formalized. This paper will review that large-scale process.

THE SAFETY IMPROVEMENT PROCESS

The process has several key steps:

- Identify a significant injury (its severity and its frequency) and the causative mechanism
- Create mitigation technology to prevent the injury
- Evaluate the mitigation technology
- Implement the mitigation technology with regulation
- Monitor operational performance to verify that the technology is working
- Based on field experience, improve the technology, and/or address the next most significant injury

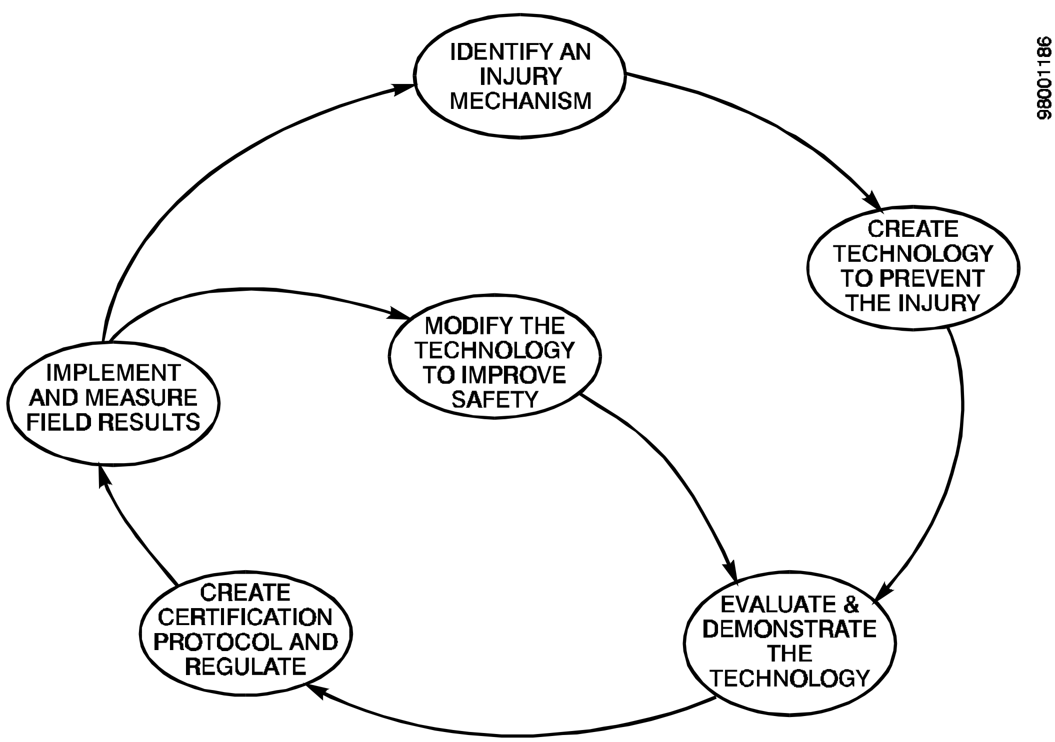

Figure 1.
The Safety Improvement Process.

PROCESS EXAMPLE: ENERGY ABSORBING SEATS

An energy-absorbing seat is a widely used standard form of occupant protection for rotorcraft aircrew. Energy absorbers in today's military rotorcraft seating systems increase occupant protection by reducing the compressive spinal loads experienced by the occupant during a crash. The first energy-absorbing seats were specifically designed to protect the occupant's lumbar spine from compressive injury due to primarily vertical impacts. Early work began with an identification of the spinal injury mechanisms found in aircraft accidents which otherwise appeared to be survivable . These injuries were targeted for prevention.

Research work began in the mid-1960's to characterize the injury mechanisms, the human tolerance to these mechanisms, and the appropriate test devices and injury criteria required to evaluate the system's performance (Reference 2). This early work fell into two categories: evaluation of accidents for data on injury mechanisms, and dynamic testing. The results of these investigations became the basis for a major portion of the U. S. Army's Aircraft Crash Survival Design Guide, a document that has been expanded and updated several times (References 3 and 4). The early version of the Design Guide identified the expected crash conditions for Army aircraft and outlined potential hazards to occupants. Spinal compressive injury was dealt with as a mechanism of injury that had both high frequency and often severe or fatal consequences. The Design Guide recommended that measures be taken to reduce spinal compressive loading.

The first dynamic testing of a seat with provision for reducing spinal loading was conducted by Dynamic Science (The AvSER Facility), a division of Marshall Industries, under contract with the U..S. Navy. Nine tests were conducted, and seat pan accelerations were measured as an assessment of injury potential. The next step in the process was determining a measure of human tolerance to be compared with the results of the dynamic testing. It was concluded at the time that the best available data had been assembled by Martin Eiband for the U.S. Space Program (Reference 5). The Eiband data, a measure of whole-body acceleration tolerance, was based on the seat acceleration as measured on the pan of a rigid seat, with a trapezoidal input pulse. In order to provide a consistent standard for the development of military seats, MIL-S-58095 (Reference 6) was developed by the U. S. Army, which based the spinal injury criterion upon the seat pan acceleration as defined in the Eiband data (Reference 5). Although the Eiband data was extremely comprehensive, it was not gathered under appropriately simulated crash conditions, nor did it quantify the risk of injury.

The first energy-absorbing seats developed for U.S. military rotorcraft utilized the criterion contained in MIL-S-58095. Based on the best information available at the time, the military specification defined the spinal injury criterion in the form of seat pan acceleration measured against Eiband's whole-body acceleration data. In the seat qualification programs, it became apparent that the seat pan acceleration criterion was potentially flawed as a reliable predictor of compressive spinal injury risk. Three large-scale research and development programs were performed to gather data for refining the standard:

1. Dynamic testing using manikins: 60 tests (approximately) with a wide range of parameters (Reference 7)

2. Dynamic testing with cadavers: 12-15 tests in which autopsies were conducted to determine the injuries sustained (Reference 8)
3. Modeling of manikins and energy-absorbing seats to identify potential new injury criteria (Reference 9).

The test programs showed that Eiband's data were fairly accurate for a rigid seat structure with vertical energy absorption (e.g., the Simula, Inc., AH-64A Apache seat), but seat pan acceleration proved to be a poor predictor of injury for other types of seats with less rigid seat pans (e.g., the Simula, Inc., SH-60B Seahawk seat). The seat pan acceleration did not correlate well with the pelvic and chest accelerations measured on the human surrogate. The poor coupling was attributed to seat pan compliance and the elasticity of the seat cushion and the flesh of the occupant's buttocks.

An experimental method of directly measuring spinal loads and moments was shown to be a more reliable predictor of injury (Reference 10). Specifically, the compressive loading in the T12 to L4 section of the spine was of interest, and a lumbar spine load cell installation was developed for this spinal area on a Hybrid II manikin. Using dynamic testing with cadavers and with the new load cell, compressive loading criteria were determined and correlated to injury risk (Reference 8). Military seating specifications continue to use the measurement of seat pan acceleration instead of the lumbar spine loading criteria (Reference 12), although it is generally accepted that the tolerable lumbar loads for military aircraft applications are in the range of 1,800 to 2,200 lb. The Civil Aeromedical Institute (CAMI) continued to refine the load cell installation and determined a lumbar spine loading criterion of 1,500 lb for rotary- and fixed-wing civil aircraft (Reference 13). A lower criterion was determined for the general civilian population, based on anthropometric differences in the military and civilian populations, and the levels of acceptable risk for each population. These lumbar load criteria are now incorporated into FAR Parts 23, 25, and 27.

The stroking seats implemented in military aircraft have been very successful in preventing fatalities and injuries (Reference 14). The seats have been specifically identified as the reason for a reduction in the rate of spinal injuries, compared to helicopters in similar crashes without the benefit of these seats.

The purpose in presenting this rather detailed history is to show how extensive the underlying research can be in order to fully develop and implement a specific safety enhancement. All of the key steps of the process appear in this history: establishing a human injury mechanism and tolerance, developing a human surrogate with sufficient biofidelity and a sensor to quantify the relevant parameters, and finally writing a test or certification protocol. These research steps enabled the development of successful seating systems which reduced the frequency of spinal injury.

THE PROCESS IN TRANSPORT AIRCRAFT

The transport aircraft industry is currently involved in the Implementation Phase of the Safety Improvement Process as it works to improve aircraft seat/restraint technology. However, the entire industry, including the customers, the airplane builders, and the airlines, has come to focus on the certification process. Each group has high expectations for the new solutions, and as a result, the testing protocols are being very strictly implemented. This approach is positive in that it will ensure that the greatest possible injury reduction will be extracted from current regulations. But to a certain extent, we have lost sight of the fact the certification testing is the end of the development cycle, and not the beginning. As such, a certification test is only meant to demonstrate that this particular configuration of the safety enhancement works as effectively as the base enhancement technology which has already been evaluated and demonstrated through extensive dynamic testing.

This strict approach has impacted the industry by increasing costs and causing delays in fielding the seats. The certification process for seats has become such a problem that the industry has become preoccupied with fixing the certification process at this time, rather than looking ahead to the next step in the Safety Improvement Process.

The result of this is that the industry has lost sight of the alternative use of the Implementing and Measuring Field Results Step of the Process (see Figure 1). Rather than spending money and time wringing the last few percentage points of injury reduction out of the current regulations, the industry as a whole should be looking at the remaining injury mechanisms and the potential ways to prevent these injuries. Seats are only one element in the entire aircraft cabin system that can lead to a dramatic reduction in fatal injuries.

SAFETY IMPROVEMENT PROCESS IN DETAIL

Figure 2 depicts the Safety Improvement Process in greater detail. This detailed graphic indicates just how extensive the necessary research may be, depending on the injury identified. The steps in the process are described in the following paragraphs. In focusing on these steps for one particular enhancement, we must keep in mind that aircraft cabin safety is a systems endeavor and each enhancement must function within the entire aircraft cabin system. The following subsections will describe the tasks involved in the process. They will also suggest what organizations are suited to conducting the work and the estimated timing in responding to the Gore Commission challenge.

Identify the Next Significant Injury

For the first major task, identifying the next significant injury, a study would be conducted of survivable crashes. Survivable crashes might be defined as those crashes where a survivable volume was maintained in some portion of the fuselage and in which there was at least one survivor. Adding the condition of having at least one fatality will filter out the very minor accidents. The medical records from these events will be analyzed for trends in fatality and severe injury causes (the injury mechanisms). From these trends, recommendations regarding the direction of future research will be made. One or more injury mechanisms may be frequent enough and severe enough to warrant further research. The study would also extract statistics to be used as a basis for a cost-benefit analysis.

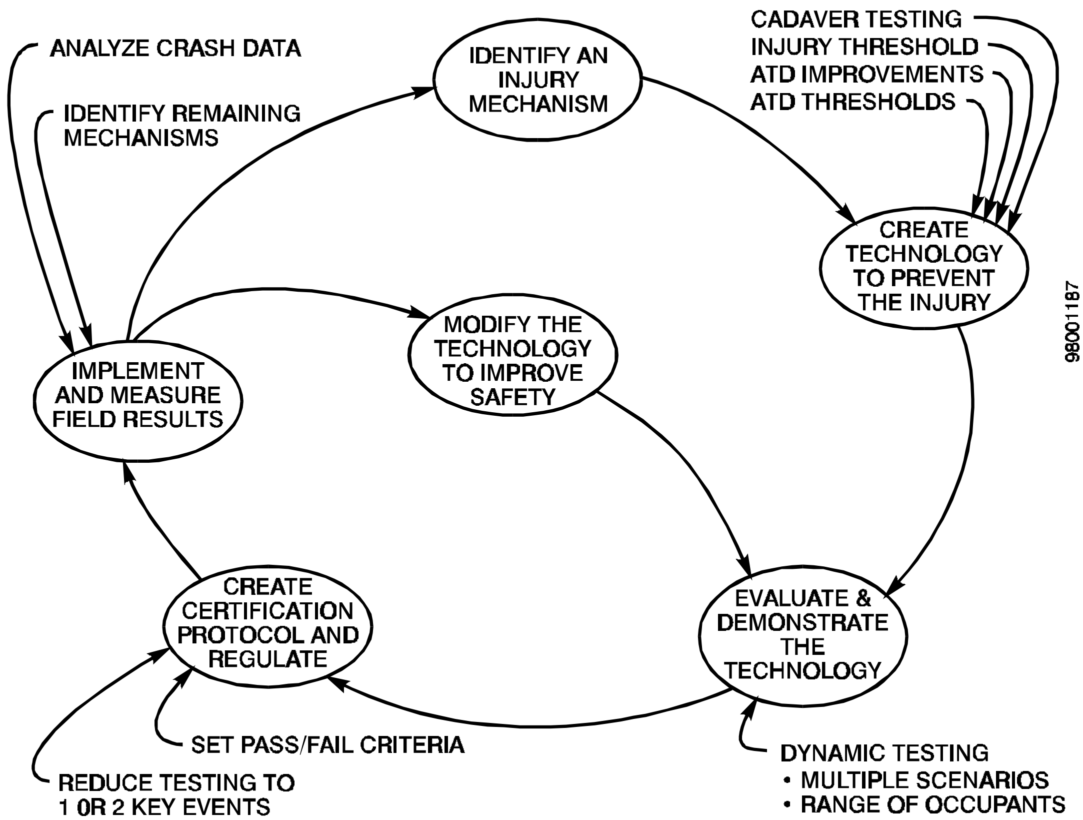

Figure 2.
The Detailed Safety Improvement Process.

The National Aeronautics and Space Administrations' (NASA) Aviation Safety Program (AvSP) has funded a study of crash data to identify the next most significant injury mechanism(s). The study will select several survivable crashes and analyze not only the crash kinematics, but also the medical records of the victims. This program is scheduled to be completed for transport aircraft in the 3rd quarter of 1999. If the research is successful for transport category aircraft, similar research into civil rotorcraft and general aviation fixed-wing aircraft may also be funded.

Conceive New Safety Enhancements
The second major task would be to conceive new safety enhancements to mitigate the injury mechanisms identified in the accident data study. Those safety enhancements that are most likely to be funded are the one(s) identified by the study as the next most significant. At this stage, the technology for quantifying the injury mechanism(s) would also be evaluated. Are the necessary human tolerances, human surrogates, and sensors available and adequate to effectively measure the selected injury mechanisms.

The Advanced Aviation Center of Excellence (AACE) is a consortium of universities and industry sponsored by the FAA to advance aviation safety. These university and industry participants have tremendous potential for conceiving new safety enhancements. This conceptualization and selection stage should be achievable in one year following the identification of fatal injury mechanisms. This same group is also well suited to reviewing the suitability of the supporting technologies.

Evaluate Technology

This stage, evaluating technology, may involve an extensive research and development effort. The underlying technologies must be in place to enable a meaningful evaluation of the new injury mitigation systems. Basic research into human injury tolerance may be necessary to establish a thorough understanding of the injury mechanism and to establish injury thresholds for a range of humans covering at least a substantial majority of the flying public. There would, of course, be a substantial development effort dedicated to the hardware of the enhancement itself. Finally, the suitability of the anthropomorphic test dummies (ATD's) used for quantifying the injury mechanism would be evaluated. The cabin safety industry has been fortunate to be able to make extensive use of the ATD's developed for the automotive industry in its dynamic testing. Although it is hoped that the ATD's already available for automotive testing may be used, new hardware may need to be developed and validated for aviation-specific injuries.

Once again, the AACE and AvSP are ideally suited to the evaluation stage of the process. If the AACE and AvSP are successful in developing the underlying information on injury mechanism, human tolerance criteria, and validation, then the program can focus on developing and evaluating new protective concepts in aircraft cabin systems. The first phase of the evaluation would verify that the hardware does, in fact, mitigate injuries. Verification of the injury mitigation would involve conducting baseline tests without the safety enhancement, and then conducting identical tests with the safety enhancement installed. In this phase of the research, a wide range of impact scenarios and occupants would be evaluated in order to ensure that the proposed enhancement will be beneficial in the majority of circumstances, or at least not detrimental. Results from this phase will also be very valuable in establishing the specific test parameters to be used in certification tests. The time required to complete this stage depends heavily on the availability of the underlying technology, so this period could range from one to seven years, depending on the injury mechanism being addressed.

The second and more subjective phase of the evaluation stage of the process would be a cost-benefit analysis to justify the use of the new enhancement in transport category aircraft. In this phase, the results from the development testing will be used to estimate the number of injuries and fatalities that the enhancement can be expected to prevent. The number of survivable accidents where the enhancement would be beneficial must also be estimated. The value of preventing the estimated number of injuries and fatalities must then be weighed against the total cost of purchasing, installing, maintaining, and carrying the weight of the safety enhancement. This phase would require approximately six to twelve months following the availability of data.

Write Regulations

The final step of the process is to write regulations implementing the new enhancement. These regulations must include a certification testing protocol. Ideally, the testing should include only enough actual tests to demonstrate that the specific configuration being certified will perform as intended. After all, the development and evaluation testing has already proven the overall efficacy of the enhancement.

The regulations include issues like the timing and extent of the implementation. These issues must reasonably consider the complexity and extent of the modifications necessary to implement the enhancement. The question of implementation on new aircraft only, or implementation to older aircraft as well, must also be answered.

To be successful, this task likely will solicit input from the various stake holders in the air transport industry, the passengers, the airlines, the airline employees, the airplane manufactures, the cabin equipment manufactures and the regulating agencies. Consequently, predicting the timing for this task is highly dependent upon the nature of the mitigation technology.

Iterate Design

Once implementation begins, the first cycle of the process is nearly complete. What remains is to monitor aircraft operations for the performance of the enhancement. Information on maintainability and customer interface with the device can begin immediately. If a crash occurs involving an aircraft equipped with the device, then data needs to be accumulated about the actual performance of the device in its intended environment. Ideally, this task would become a standard part of the NTSB investigation and would be an ongoing task and the design iteration could be triggered by an NTSB recommendation.

ONGOING VIGILANCE

As long as survivable accidents occur, the process of analyzing injuries should continue. As long as enough fatalities and injuries occur to justify a given regulatory action, we should be in a position to identify these opportunities and respond to them.

CONCLUSIONS

- The air transport industry has been challenged to reduce fatalities.
- Many successful safety technologies already exist and have been implemented.
- The next large reduction in injuries may require an entirely new stage of safety enhancement.
- The amount of research required to reach implementation may be substantial.
- A good process exists for creating and implementing safety enhancements.

RECOMMENDATIONS

- Use the proven Safety Enhancement Process.
- In particular, exploit the process for injury mechanism information.
- Review the certification process, and modify it to encourage innovation.
- Dynamic testing is essential, but it is expensive, so it should be used more effectively.
- Reduce the testing of well-understood technologies.
- Increase the testing to gather new information and to prove new technologies.

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