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General Aviation Aircraft Rear-seated Occupant Crash Protection: Should Shoulder Restraints be Required in Rear Seats?

R.G. Snyder
University of Michigan
Ann Arbor, MI

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GENERAL AVIATION AIRCRAFT REAR-SEATED OCCUPANT PROTECTION: SHOULDER RESTRAINTS IN REAR SEATS

R. G. Snyder*
The University of Michigan
Ann Arbor, Michigan

Abstract

The NTSB has recommended since 1964 that shoulder harnesses be required for each occupant of general aviation aircraft. The FAA presently requires a shoulder harness for each front seat in certain newly manufactured small airplanes, but not for other seat positions. This paper brings together technical background and current experience to evaluate whether shoulder harnesses should be required in rear seats. It is concluded that installation and use of shoulder harnesses in rear seats of general aviation aircraft would significantly increase occupant protection and decrease the incidence of fatal or disabling (paraplegic) spinal injuries in survivable crashes.

Introduction

Shoulder harnesses have long been recognized as providing important occupant protection in crash impact. However, recognition of the potential safety benefits for rear seat occupants has not been as clearly established.

The technical question of whether shoulder harnesses should be installed in rear as well as front seats of general aviation aircraft has generally been presented from only one viewpoint at a time, without a balanced consideration of all of the environmental factors. For 17 years the National Transportation Safety Board (NTSB) has recommended that shoulder harnesses be required for each occupant of all general aviation aircraft. In 1977 the Federal Aviation Administration (FAA) required a shoulder harness for each front seat in certain (but not all) small airplanes manufactured under Part 23 since 18 July 1978.[1] Shoulder harnesses are not presently required for other seat positions, nor for any seat position for normal category aircraft manufactured prior to that date. The purpose of this paper is to bring together current experience to evaluate whether shoulder harnesses should be required in rear seats of general aviation aircraft.

Development and Operational Experience

The need for occupant shoulder restraint protection in rear seats is not a recent concept. A comprehensive review and evaluation of aerospace, aircraft, and automotive restraint systems has been previously published,[2] as well as a survey of automotive restraint development, use and problems,[3] analysis of civil aircraft restraint systems,[4] and a comprehensive analysis of FAA Safety standards relative to general aviation (FAR CFR23) restraint systems.[5] Morgan has reviewed various types of restraint systems for general aviation aircraft.[6]

*Research Scientist, Head, Biomedical Department, Professor of Anthropology
Member AIAA

Automotive Experience

An integrated full-body restraint system incorporating adjustable cross-chest straps and lap belt, as well as a high-backed seat for each vehicle occupant, was devised by Leveau in France by 1903.[7] The double shoulder harness for both rear and front seated passengers was anchored high into the seat backs themselves (Fig. 1). Off and on through the years other automotive vehicles have featured shoulder harnesses for rear passengers, but these have generally been confined to concept or experimental vehicles, such as the New York Safety Sedan, built by Republic Aviation Division of Fairchild-Hiller Corporation.[8] An aircraft-style upper torso webbing harness consisting of an "X" configuration was attached to two aircraft 2 G inertia reels attached to the head support, and either one or both shoulder belts could be used in conjunction with the lap belt. Seats incorporating shoulder harnesses included the Cox seat from England, featuring full double-shoulder retractable harness in one version and a single diagonal shoulder and lap belt combination in another,[9] the Liberty Mutual seat,[10] and various prototype vehicles of the automotive manufacturers.

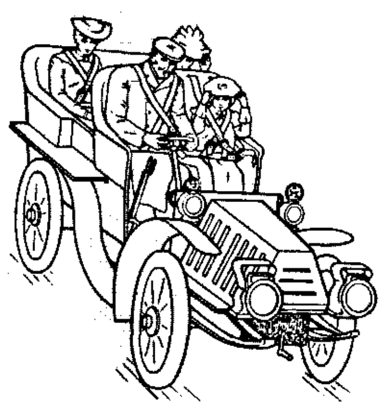

Fig. 1 - Early integrated shoulder restraint system conceived and patented by Leveau of France in 1903 for both front and rear seat occupants.

The shoulder harness has been installed as standard equipment since at least 1959 in automobiles, when Volvo introduced its 3-point safety belt (lap belt and upper torso diagonal belt) in Scandinavia. The 3-point system has been available for the rear seats of Volvos since 1964, and was made standard equipment in all Volvos since 1967.[11] Daimler-Benz (Mercedes) has offered 3-point lap-shoulder restraints for the rear seats of its automobiles since 1967, making 3-point belts in the rear seats standard equipment in the U.S. and Canada in 1972.[12]

Federal Motor vehicle requirements in Sweden, Germany, France, and Switzerland presently require manufacturers to install seat belts in the rear seats.[11-13] In Germany, France, and Switzerland either lap belts or 3-point shoulder harnesses are required, and are used on a voluntary basis in Australia. In Sweden the 3-point shoulder harness is required for outboard seating positions with retractors, and lap belt for the central seating position with or without retractors. In addition to Volvo, Daimler-Benz, Mercedes, and BMW vehicles, Renault and Toyota have shoulder harnesses installed for rear occupants on some models in certain markets, as well as those countries where seat belts are legally required. Anchorages for rear-seat shoulder harnesses have been provided in all cars manufactured for sale in the U.S. since January 1, 1972, as required be Federal Motor Vehicle Safety Standard 210. [16]

Johannessen and Pilarski have recently reviewed rear seat occupant protection in motor vehicles. They cite various surveys and studies which have found that there is a rear-seat occupancy of 10.3 to 11.7%, and that rear-seat occupants comprised nearly one-third (29.5%) of the vehicle passengers, [14] with a trend for increasing numbers of rear-seat passengers. In automobiles rear-seat occupants appear to be injured less frequently than front-seat occupants (32.4% vs 19.6% escaping injury in the crashes studied), and when injury occurs are less severely injured in the rear than *front seats.* [15] *Similarly, a higher percentage of* fatalities for front-seated occupants was found (2.2% vs 5.5%). These authors attributed the difference in apparent safety between front and rear automotive passengers to the fact that nearly 45% of the rear passengers were children, who are less prone to injury at all levels than are adults. Infant and child protection has been increasingly recognized, with many states and countries now having child restraint laws. When used in the rear seat most such devices provide some form of upper-torso restraint.

In the past, rear-occupant shoulder restraints have mainly been available in the U.S. in foreign vehicles such as the Volvo, Mercedes, or BMW imports. However, in 1980 General Motors made rear-seat upper-torso restraint an option for 1981 models, and rear-seat lap/shoulder belts are standard *in the 1981 Renault 18i, 1981 Toyota Cressida and* Mercedes (Fig. 2).

Fig. 2 - Rear-seat shoulder restraints have been available for the automotive customer since 1964. The anthropomorphic model above is illustrating the fit in the rear seat of a Mercedes sedan. (Photo courtesy Mercedes-Benz of North America, Inc.)

General Aviation Aircraft Experience

Beech Aircraft Corporation pioneered the shoulder harness for light aircraft in 1948, conducting tests to 20.4 G in a series of 35 experimental dynamic tests in 1951, utilizing a 97.9 Kg (216 lb) CAA dummy "Elmer". [17-19] The Beech double shoulder harness was patented in November 1951, following application in September 1950. [20] The life-saving protection in the first crash with occupants utilizing this harness was described in a subsequent Beech publication. [21] By 1950 several light aircraft offered shoulder harnesses. The Griswold-Air Associates shoulder harness was installed between 1951-1952 in a number of individual aircraft, including a Cessna 140, 170, and 190, Globe Swift, Navion, Beech Twin-Bonanza, Beech Model 18, Cropduster, Helioplane, Airphibian, and Aerocar. [22] By 1953 the two-place Meyers 145 provided a 4275 lb combination three-point "must be worn" type restraint as standard equipment. In 1953 the Helioplane Courier provided a double upper-shoulder harness for rear seat passengers, attached to the top of the seat back. This installation is shown for the first production model (serial #001) in Fig. 3, and is still in use. Fig. 4 shows a modified version, including higher seat back, in a current production model of the Helio Courier. Rear shoulder harnesses have been standard equipment in this general aviation aircraft for 27 years.

Upper torso restraints have been installed in light aircraft used for flight training by the Department of Aviation, Ohio State University, continuously since 1948, when double shoulder harnesses were installed in 13 Cessna 140's. In-

Fig. 3 - *Original rear-seat shoulder harnesses in-* stalled in 1954 Helioplane Courier aircraft, serial no.001, still flying after 27 years operation. (Photo courtesy P. Duffy, Wycliffe Jungle Aviation and Radio Service)

Fig. 4 - Rear-seat shoulder harness installation in current model of Helio Courier aircraft, featuring upper belt attachment to side structure rather than the seat, and with high backed seats. The left rear seat back is flexed forward to show the upper attachment point.

stallations were with FAA field approval, although, except for harnesses used in Beech aircraft in 1969, no manufacturer was able to provide upper-torso restraint satisfactory to the operators. Many of the training aircraft used during this period had front seats only. However, since 1974, when 15 Piper PA-28 Cherokees were obtained, all four seats have had shoulder harnesses installed (dealer installed, FAA field approval). [23]

Accurate information on the date of origin, type, development, and availability of restraint systems in general aviation aircraft has always been confusing (even to the manufacturer) and difficult to assess, because of conflicts in information relied upon by manufacturers, suppliers, and customers. An attempt to provide a general listing was published in 1977, [3] and more recently this list was reprinted as Appendix D by the NTSB. [24] Yet exceptions are continually noted, particularly where shoulder harness installation kits have been available from the manufacturer but this fact has not been known by many dealers or customers.

According to a recent Aviation Consumer survey, rear seat shoulder harnesses have been standard in all seats (except rear-facing) of Beech aircraft since 1976, have been available as an option in Cessna aircraft since 1977, and as of July 1980, were reportedly not available in aircraft manufactured by Piper Aircraft Co. [25] However, in contrast to the dates cited above for availability of rear-seat shoulder harnesses in Cessna aircraft, a December 1970 optional factory installation in a 1971 model 177 Cardinal was available. It is illustrated in Fig. 5. The front seat shoulder harnesses were standard in this model. The optional rear-seat shoulder harnesses are attached adjacent to the lower corners of the rear window. Each rear-seat harness is stowed behind a retaining clip located at the bottom edge of the aft side window. Similarly, while rear-seat shoulder harnesses were reportedly not available for Piper aircraft, [25] an installation kit was designed by Piper engineers

Fig. 5 - This right rear seat occupant is wearing a Cessna 177B Cardinal shoulder harness factory installed as optional equipment in December 1970.

in 1965 and was available as an option in 1967 for the front seat of the PA-28-140, PA-28-150-160-180 Cherokee Six. [26] A 1971 FAA report notes that Cessna has had nut plates for "easy attachment" of shoulder harness (in the front seats) in most of their general aviation aircraft since 1950. [27,28] Among other current general aviation aircraft that may have shoulder restraint for rear seat occupants is the Grumman American AA5A "Cheetah," since at least 1976 (Fig. 6).

Fig. 6 - Right rear passenger shoulder harness in 1976 Grumman American AA5A.

Often where rear shoulder restraint has been provided, it may be standard in one model but optional in another. For example, the purchaser of a 1971 North American Rockwell Aero Commander 112 or 111 model would have had a choice of three interior options. The "Super Sport interior" included a shoulder strap with inertia reel and lock standard on all four seats. The "sport interior," on the other hand, was equipped with a shoulder harness with inertia reel and lock as standard at crew stations (front seats), and optional manual on the two rear seats. Inertia reel and lock was an option on this latter interior. The rear-seat shoulder strap was integral to the seat itself in this case. [29]

Shoulder restraint protection to rear-seated passengers has to date usually been available only through a special installation by the operator. Fig. 7 and Fig. 8 show such an installation in a rear passenger seat of a corporate aircraft.

Fig. 7 - Rear passenger putting on shoulder harness installed in corporate aircraft. Outboard shoulder strap retracts into seat back with inertia reel. (Photo courtesy G. Lefler, Air Transportation Department, Chrysler Corporation)

Fig. 8 - Shoulder restraint is attached to the lap belt in this system near the buckle at midline. (Photo courtesy G. Lefler, Air Transportation Department, Chrysler Corporation)

Regulatory Background

In June 1961 a Beech Bonanza crash occurred in which the lap-belted pilot received fatal head injuries and crushing injuries of the chest from hitting the control yoke, and the right front passenger received critical injuries from jackknifing into the instrument panel. [30] These injuries were attributed by the CAB to lack of shoulder harness installation.* In November 1964, the CAB recommended to the FAA that a shoulder harness be required for each occupant on all newly certified general aviation aircraft, unless it can be demonstrated that while wearing only a seat belt no injurious objects are within striking radius of the head. [31] The FAA responded, in March 1965, that there was not sufficient justification. [32]

Subsequent fatal crashes in 1962 and 1963 had led to the CAB's recommending to FAA that shoulder harnesses (and crash helmet) also be required for each occupant engaged in hazardous flight, and also that FAA issue a series of advisory bulletins to all pilots, stressing the desirability of using shoulder harnesses as standard practice. [33] The first crash involved a Piper PA-18 (tandem seating) aircraft during a State Fish and Game Elk count mission. Both the lap belts and cabin itself remained intact, but both the front seat pilot and rear seat passenger received fatal head injuries. No shoulder harnesses were installed. In another Piper PA-18 crash, the pilot received fatal head injuries, while again the cabin area was nearly intact. In this case the shoulder harness was not being used.

In August 1970 the NTSB again recommended that the FAA reevaluate its position and require shoulder harnesses on all general aviation aircraft at the earliest practical date. [34] Cited were the reports "Crash Safety in General Aviation Aircraft" [35] provided to the FAA in a petition by Ralph Nader, and an FAA draft research report ("General Aviation Structures Directly Responsible for Trauma in Crash Decelerations") [28] by John Swearingen, Chief of FAA's Protection and Survival Laboratories. Other studies in support of the NTSB position included 1969 FAA dynamic crash tests of shoulder harnesses at the National Aviation Facilities Experimental Center (NAFEC), [36] and data from the U.S. Army "Crash Survival Design Guide," [37] first published in 1967. The FAA's response in September 1970 indicated that additional rules proposals and a notice of proposed rule making (NPRM) was in progress. [38] (The FAA conducted further dynamic shoulder harness crash tests in 1971.) [39] In October 1972 the NTSB requested a progress report on the FAA's efforts. [40] In November 1972, the FAA responded that it expected to issue a NPRM that would require the installation of shoulder harnesses "on airplanes in service that have structural attachment provisions for harnesses, and, after a certain date, on newly manufactured airplanes." [41]

The FAA published a NPRM "Crashworthiness for Small Airplanes" in the Federal Register 31 January 1973 [42]. It proposed amending Part 23 of the Federal Aviation Regulations (FAR's) to require each occupant be protected from head injury by the installation of a combination safety belt and shoulder harness, and that cabin interiors be designed to protect occupants from injury. Part 91 would be

*Ironically, Beech had been a leader in installing 25 g shoulder harnesses in the Bonanza after conducting a series of dynamic tests in 1951; [3-7] but removed them as standard equipment, becoming optional in 1958, and discontinued from 1959 to 1972.

amended to require the installation of shoulder harnesses on all small civil airplanes manufactured prior to that date if they have structural provisions for the attachment of shoulder harnesses, and to require all occupants of seats equipped with shoulder harnesses to use the shoulder harnesses during takeoff and landing. This NPRM (73-1) took into consideration the earlier Nader petition for rulemaking to improve the crashworthiness of small aircraft, as well as the recommendations made by NTSB for shoulder harnesses and cabin interior design. It was proposed that Part 23.785 ("Seats, berths, safety belts, and harnesses") be amended to require that "each occupant" must be protected from head injury (g) by (1) "a safety belt and shoulder harness" in forward-facing seats (2) by a safety belt and an energy absorbing rest" in a rearward facing seat, and (3) by "a safety and shoulder harness" in a sideward facing seat.

It was proposed that Part 91.7 and 91.14 be changed to require each occupant to fasten his shoulder harness during takeoff and landing, while crewmembers would be required to wear the shoulder harness at all times while at their stations. Parts 91.33 and 91.39 would require shoulder harnesses be installed where structurally possible on general aviation aircraft manufactured prior to the acceptance of the proposed amendment.

The NTSB responded on March 1973, supporting the proposed FAA NPRM, but urging that it go further to require shoulder harnesses in rear-facing seats, and that the requirement for shoulder harnesses be made retroactive to all small civil airplanes, since a large number would be exempted as proposed. [43-45]

In 1974 the FAA issued NPRM 74-5, inviting proposals for amending the Federal Aviation Regulations under the airworthiness Review Program. [46] A final rule was published 16 June 1977 (FR 30601) with an operating rule compliance date of 18 July 1978. [1] This amends FAR Part 23 and Part 91, adding requirements for shoulder harnesses and compartment interior design for the type certification of small airplanes, and adds an operating rule requiring a shoulder harness for each front seat only in certain newly manufactured small airplanes.

However, portions of NPRM 73-1 that were deleted by the FAA during the rulemaking process would require shoulder harnesses at all seating positions and be retroactive to older aircraft. This rule will not apply to many current production aircraft and even many manufactured after that date, since the date of manufacture is the date the inspection acceptance records reflect that the airplane is complete and meets the FAA approved Type Design Data - FAR 9.133(i).

The FAA argument against retrofitting existing general aviation aircraft with shoulder harnesses was the contention that a "substantial financial burden would be placed upon consumers over a short (1 year) period of time. The installation of shoulder harnesses on other than front seats was rejected on the contention that cabin interiors can be effectively designed ("delethalized") to protect occupants. [47]

The NTSB has disagreed with the FAA arguments, pointing out that there is "clear justification" that shoulder harnesses should be installed in older aircraft and that they should be installed at all seat locations. On 8 December 1977 the NTSB issued Safety Recommendations A-77-70 and 71 to the FAA:

> Amend 14CFR 23.785 to require installation of approved shoulder harnesses at all seat locations as outlined in NPRM 73-1. (Class II - Priority Action)(A-77-70)
>
> Amend 14CFR 91.33 and .39 to require installation of approved shoulder harnesses on all general aviation aircraft manufactured before July 18, 1978, after a reasonable lead time, and at all seat locations as outlined in NPRM 73-1 (Class II - Priority Action)(A-77-71). [48]

On February 8, 1978, the FAA stated that it was unable to justify the NTSB recommendations. The NTSB submitted a letter to the FAA in October 25, 1978, expressing concern about the level of protection provided occupants in general aviation crashes, and providing information on a pilot ejection attributed to restraint fitting failure. Subsequent correspondence and discussion between the FAA and NTSB on this issue is reviewed in detail in the NTSB Safety Report issued in December 1980. [49-50]

Crash Injury Experience

Early studies of crash injury relationships during the 1940's by DeHaven clearly established the protective role of the shoulder harness, [52-58] although at that time the focus of attention was on front seat occupants who frequently jackknifed into the instrument panel, control yoke, or sharp structures. In a study of the patterns of injury of 800 survivors of light aircraft accidents, DeHaven found that 704 suffered head injury. There were also 548 injuries to the upper torso, similar to fatal patterns, due to lack of support of the upper torso. [55] Marrow subsequently showed that head and chest injuries were responsible for 337 of 342 injuries in light plane accidents. [59]

Pearson found similar results in 248 front-seated occupants of accidents studied between 1942-1952. [60] During World War II several military studies (see pp. 154-161, ref. 5) revealed the need for a shoulder harness. One study by Lovelace showed that 80% of those using a shoulder harness in crash landings were unhurt, while 94% of those not using a shoulder harness were injured. A study of 1,536 accidents during three months of 1943 in the training command showed that the head was involved in 87.5% of the nonfatal injuries. This led to a requirement for shoulder harnesses in 1943 and standardization of the B-15 shoulder harness by the Army Air Forces in 1945.

A 1959 study by Hasbrook of 1596 occupants of 913 light plane accidents recommended occupant restraint "to prevent the Human torso and head from impacting interior structural components." [61] Of 385 deaths in these accidents it was found that 37.1% occurred in structural environments that sustained relatively little damage. Fifteen years later, in a 1964 FAA analysis of a general aviation crash, in which a fatality occurred to a lap-belted rear seat occupant, Hasbrook concluded that a "comfortable shoulder harness should be provided for <u>rear seat occupants</u> of small aircraft." [62]

More recently, in a 1966 FAA study [63] Cierebiej and Stedman found 661 head and neck injuries in 564 fatal general aviation accidents resulting in death to 522 pilots.

Since all crashes involve at least the pilot, attention has remained focused on the need for front-seat shoulder restraint, and few accident injury studies have analyzed the data in a way that provides a significant body of impact injury information on rear-seat passengers. To date the FAA accident reports do not provide sufficient medical information to utilize a statistical analysis of rear-seat injuries. Two sources of detailed but largely unpublished data exist. The University of Michigan has been investigating selected general aviation accidents since 1969 for injury mechanisms, during which time some 1500 accidents have occurred. However, support has not been available to analyze these data to date.[64-66] A second resource is within the FAA itself, relative to the medical and toxicological studies conducted of selected general aviation accidents over the past 15 years. However, little analysis has been published of these data; 27 cases were detailed in 1971,[28] and 78 cases tabulated in the appendix ("A Summary of Selected General Aviation Accidents") of a 1973 report.[67] In the latter case 19 of the 78 accidents involved rear-seated passengers, but insufficient information concerning their injuries has been provided in the published tables to draw conclusions. In four cases injury to rear passengers was reported as resulting from their striking the rear of the front seat, but injury and fatality causation is not detailed for others.

Whether an individual is seated in a front or rear seat, his kinematic motion in response to a crash impact will be the same, given the same conditions of restraint. In a 1962 study of motion of the general aviation aircraft occupant during a crash, it was found that with only lap-belt restraint he can contact structures within "the upper two-thirds of a sphere ten feet in diameter"[68] as the body flails or flexes forward. This showed that the rear-seat passenger as well as the front-seat occupant needs upper-torso restraint.

While the instrument panel area has long been shown to be a lethal area of head impact for the front-seat occupant restrained only by a lap belt, the rear-seat environment also produces lethal contact between the occupant and structures. The medical data to evaluate the rear-seat impact environment is presently too fragmented for precise analyses of the nature, frequency, and seriousness of injury to the rear passenger. Crash test data do provide clear documentation of the increased protection offered the rear-seat passenger by shoulder restraint systems.

Crash Test Experience

Many dynamic crash tests have permitted comparisons between kinematics of front-and rear-seated occupants and between lap-belt and lap-and-shoulded belt restraint. During the early 1950's the National Advisory Committee for Aeronautics (NACA) conducted several dynamic crash tests at the Lewis Flight Propulsion Laboratory. This resulted in many crashworthiness recommendations related to the occupant protection afforded by upper-torso restraints. Restrained anthropomorphic dummies occupied three light aircraft (J-3 Piper Cubs) which were crashed into a barrier at 42, 47, and 60 mph velocities. The tests demonstrated conclusively the need for upper-torso restraint improved anchorages, improved seating, and an improved dummy.[69-71] One conclusion was that "the rear-seat occupants restrained by seat belt and shoulder harness are within the decelerations shown by aeromedical research to be tolerable" up to crash impacts of 60 mph (p. 22, 69).

On 17 April 1956, the NACA held a major conference on airplane crash-impact loads, crash injuries, and principles of seat design for crashworthiness. The accompanying attendance list indicated that manufacturers, suppliers, government agencies, airlines, and other aviation organizations were well represented.[72]

Major findings reported by the NACA were that a shoulder harness in both seats would protect the occupants of a typical two-place Piper training aircraft in stall-spin impact speeds up to the 60 mph tested. It was concluded that without a shoulder harness, severe to fatal injury is likely (due to head and body striking structure) unless an additional space of 31-45 inches was clear of any solid or unyielding protuberances.

These conclusions of nearly 30 years ago have been substantiated in the many crash tests conducted subsequently, including tests at the FAA NAFEC Atlantic City facilities, current sled studies of the FAA at the Civil Aeromedical Institute (CAMI), and the FAA-NASA crash tests at Langley.[73] Of particular importance are 1975 dynamic tests conducted at CAMI by Chandler. In one series a shoulder-harness-restrained rear-seat dummy (5th percentile female) experienced a 36 peak G impact (28 average G) without failure. The effectiveness of shoulder harness restraint in the rear seat of general aviation aircraft could not be more clearly documented than by these FAA tests, which were featured earlier this year in a aviation medicine exhibit at the Smithsonian Institution Air and Space Museum in Washington, D.C. An excellent analysis of the effectiveness of aircraft restraints in aircraft occupants in comparison to automotive crash environments has been done by Chandler.[74] An FAA analysis of benefits of the aircraft shoulder harness was also published in 1972 by Sirkis.[75]

Biomechanical Considerations

Data resulting from crashworthiness investigations of survivable general aviation aircraft accidents have clearly documented that serious and fatal trauma occur most frequently from the occupants jackknifing over his lap belt and the unprotected upper torso and head flailing in contact with the aircraft instrument panel, controls, or other sharp nonyielding structure. This has resulted in the FAA's new requirement for shoulder harnesses applying to front seats only.[1] However, as previously pointed out, most of these studies have concentrated on the front-seat occupants, and less information has been identified relative to the rear-seat passengers.

The rear-seated occupant, while located within the same general cabin environment, is subjected to differing factors which may influence injury. Instead of impacting on instrument panel and controls, the rear-seated lap-belted occupant may contact the seat back (or occupant) ahead, side structure, or the occupant to his side. Since there is a greater distance between the nose of the aircraft and the front and rear occupant seated positions, as the aircraft decelerates and structures collapse, absorbing energy, there usually is less decelerative loading on the rear seat in the longitudinal plane (although vertical loading may vary for either seat). While front-seated occupants may experience a higher peak loading, a more hazardous impact environment, and less longitudinal crush distance, the rear-seated occupant often may be subjected to other factors requiring upper-torso protection. In many aircraft (for example the Piper PA-32 Aztec, all Cessna Twins C-337, 310, and 400 series, and Beech Twins) the front-seat restraints are anchored to the floor structure but the rear-seat belts are anchored to the seats themselves. This usually provides less protection to the occupant, since when a seat fails there is nothing to prevent the seated occupant from becoming a missile. Lap belt restraint anchorages should be anchored to the floor structure unless the seat tie-down has been reinforced beyond minimum FAR requirements.

Vertical Protection

Several advantages of shoulder restraints in the rear seats have consistently been overlooked. A major benefit of a shoulder harness is that during a crash it distributes the loading on the body significantly more than with a lap belt only, and secondarily, it keeps the body in a better upright seated posture, enabling the occupant to tolerate higher impact loading on the spine.

Most restraint tests have shown that when a shoulder restraint is used in conjunction with a lap belt, the loads are distributed between 40 and 60 percent (depending upon whether a single or double belt is used, and other factors). This is, if a lap belt is loaded to 1000 lbs. in a crash, it would only be loaded to between 400 and 600 lbs. if the occupant is wearing a shoulder harness. This provides increased protection by reducing the loading on anchorages, and reduces the chance of exceeding the restraint system design limits. Put another way, shoulder restraint can double the load capability of the total system (as well as reducing the chance of injury due to the belt itself).

In distributing the load over the body to a greater extent, the concentrated loads of body contact with structure are avoided or may be considerably reduced. As indicated in the discussion of body kinematics, without upper-body restraint a ten-foot arc for flail has been projected, which is outside the spatial limits of general aviation aircraft cabin structures.

A further hazard for rear-seat occupants, evident in a number of crashes, is disabling spinal fractures resulting primarily from vertical impact loading. Many rear seats do not have the same level of energy-absorbing or crashworthiness capabilities as front seats. That may partly explain the incidence of such injuries to rear seat passengers. (A detailed discussion of cases of paraplegia attributed to rear-seat failures is in preparation). Even in cases where the direction of impact loading is primarily vertical, the shoulder harness may make a significant difference due to restraining the occupant in a position in which the vertical load is better tolerated. In this regard, the more flexed the vertebral column is, the less load is required to exceed fracture tolerances. Most fractures severe enough to intrude into or sever the spinal cord are primarily due to compression loading (rather than flexion over the lap belt, as is generally thought). In such cases the shoulder harness can be a significant factor in protecting the occupant from paraplegia or other disabling vertebral trauma by keeping the spine more upright during vertical loading. Spinal injuries have been discussed by Pesman and Eiband (1956), and Swearingen has reported that "use of the upper torso restraint can increase human spinal tolerance to fracture by a factor of five by holding the spine in an upright position." [76]

One further biomechanical consideration should be examined further. In 1967 dynamic tests conducted at General Motors Corporation, and in independent tests at Ford Motor Company, the crash dynamics of a front-seat dummy wearing a shoulder harness and a rear-seat dummy wearing only a lap belt showed a time-sequence difference in motion which allowed the front seat (shoulder belted) occupant's head to start back as the rear-seated (lap belted) dummy was still flexing forward. This allowed the rear dummy's head to collide with the front-seated dummy's head. At that time these kinematics were thought to be serious enough to delay the Federal Motor Vehicle Safety Standard requiring a shoulder harness in the front-seat outboard positions only. This was subsequently considered to be a fluke, and later tests with high-backed seats and headrests reduced the chance of reoccurrence. The different cabin dimensions and variable crash kinematics in aircraft between front and rear occupants as influenced by restraint should be further examined, and could be another factor influencing installation and use of rear shoulder harnesses, especially in aircraft with relatively low seat back heights.

Installation Problems

Resistance to retrofit of shoulder harnesses in older aircraft is due to concern for adequate structure to attach to (which also can adversely affect belt angle on the body, proper fit, comfort, and convenience factors). Resistance also stems from problems the aircraft owner is subjected to in certification requirements. These are legitimate concerns. Another problem is that the FAA currently has not published dynamic test criteria for either shoulder harnesses or inertia reels.

Current FAA regulations concerning acceptable methods, techniques, and practices of shoulder harness installations, effective restraint angles, and attachment methods were published in 1967 (AC 43.13-2). [77] Following dynamic tests, additional recommendations for installation of upper-torso restraint, relating to specific location on structures without major airframe modification, were published in an FAA report by Young in 1966. [78] The importance of upper-torso restraint in aircraft accidents (70-80% of fatalities due to head injury; 50% might have been prevented) is shown in "Restraint for Survival," an FAA documentary film of the 1964-65 aircraft cabin dynamic tests conducted at CAMI by Young, upon which the recommendations were based. [79] A functional comparison of basic restraint systems was also made by Young. [80] He pointed out the protective advantages of a double shoulder harness system over a single diagonal upper-torso belt; the importance of the seat belt anchorage (tie-down) which establishes the seat belt angle ("a greater forward location of a tie-down decreases the restraint function of a seat belt and can seriously compromise the entire restraint system"); and the significant difference in occupant kinematics at impact when the occupant is restrained by shoulder harness and seat (lap) belt as compared to a lap belt only.

Most of the retrofit problems can be resolved, since "there is a place on nearly every airplane where you can safely and legally attach a shoulder harness." So "theoretically it's fairly easy to retrofit shoulder harnesses in most airplanes." [25] Nevertheless, major factors in occupant usage depend upon the proper fit, comfort, and convenience of the system, and in some aircraft retrofit may present difficulties. Other problems are discussed by Sircus. [75]

CONCLUSIONS

This paper has reviewed current data relevant to the question of need for shoulder harness protection of rear-seated occupants in general aviation aircraft. Some conclusions are:

1. It required 14 years, from the original 1964 NTSB recommendation to 1978, for the FAA to require shoulder harnesses in the front seat positions of newly certified general aviation aircraft. With approximately 232,000 aircraft in the civil fleet, and an estimated lifetime of 20 years for an aircraft, without some retroactive effort to install shoulder harnesses on operational aircraft, it will be many years before the full effectiveness of such protection may be available under the current FAA shoulder harness requirements.

2. There is a pool of both automotive and aircraft experience to draw upon. Shoulder harnesses have been available for rear-seat passengers in Volvos since 1964 and Daimler-Benz since 1967, and their use is required in some countries. A growing number of general aviation aircraft have rear-seat shoulder harnesses, and the Helio Courier has had them for 27 years (10 years before automobiles).

3. Crash injury experience documented since the 1940's shows overwhelming life-saving benefits of the shoulder harness. Most studies have dealt primarily with the front-seat occupants. Current data comparing front- and rear-occupant crash environments, the nature, incidence, and severity of injury, and lap belt vs. shoulder-lap restraint systems are available from several sources but are fragmented and have not been analyzed.

4. Crash test experience has been extensive, with data showing significant protective benefits of the shoulder harness for the rear-seated occupant. Head-to-head impact between a front-seat occupant restrained by shoulder harness with a lap-belted rear-seat occupant is possible.

5. Among biomechanical considerations advantageous to occupants' use of the shoulder harness are 40-60% decreased loading on anchorages due to the distribution of load between lap belt and shoulder harness, therefore providing significantly increased impact protection.

6. An advantage of the shoulder harness, particularly for the rear-seat passenger (since the seat environment often lacks the energy absorption and strength capabilities of the front seat), is that even in a vertical impact the spine is held in a position providing greater vertebral impact tolerance than when the spine is allowed to flex forward. Use of a shoulder harness restraint could significantly decrease the incidence of disabling (and paraplegic) spinal injuries.

7. Various installation problems, particularly in retrofit in older aircraft, must be overcome. These include certification difficulties with the FAA, adequate attachment structure, proper fit, comfort, and convenience (which might adversely influence wear). However, on balance the increased protection provided the rear-seat passenger makes shoulder harnesses a goal that should be vigorously pursued by the FAA, aircraft manufacturers, and pilots.

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