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<p>16. Abstract</p> <p>The installation and use of shoulder harnesses is a practical and relatively inexpensive solution to the problem of maintaining separation between man and machine during an aircraft crash sequence. The addition of shoulder harness to the tie-down chain of the general aviation aircraft occupant will increase the probability of the user surviving a severe crash and minimize injuries resulting from light-to-moderate crashes.</p> <p>It is concluded that if shoulder harnesses were installed in all general aviation aircraft, considerable benefit to the users of these harnesses would accrue. The user-occupant of older general aviation aircraft would realize a level of safety approaching that enjoyed by the user-occupant of normal, utility, or acrobatic category airplanes manufactured under Approved Type Certificates applied for after September 14, 1969.</p>			
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THE BENEFITS OF THE USE OF SHOULDER HARNESS IN GENERAL AVIATION AIRCRAFT

I. Introduction.

It is fully within the state of the art for a general aviation aircraft manufacturer to produce and market an aircraft that will protect its occupants from death or serious injury in the event of a moderate to severe crash landing if known bioengineering data are incorporated in the design of the aircraft. Data compiled from investigations of survivable general aviation aircraft accidents^{1 2 3 4 5} clearly indicate that serious and fatal injuries occur most frequently to the occupants as a result of the unprotected head and neck or chest flailing in contact with the aircraft controls, instrument panel, or exposed, un-padded structure.

The most casual observer will notice, upon examination of a typical light aircraft interior, the rigid instrument panel studded with heavy instruments, protruding knobs with sharp edges, toggle switches with sharp points, exposed, un-padded structure, and a seat belt assembly that can only be described as meeting some minimum requirements. Sitting on the ground or in normal flight on a turbulence-free day, these items are harmless. During the dynamic crash environment, however, these objects become vicious. They stab, tear, rip, and break the tissues, protoplasm, and bones of the unfortunate human bodies that are forced in contact with them during the milliseconds of sheer terror that occur when the forward motion of the aircraft is abruptly retarded and deflected by impact with ground objects during an emergency landing attempt.

Several approaches are possible to prevent the interaction of human protoplasm and potentially dangerous aircraft hardware and accessories. One way of reaching this objective is by the

elimination of all rigid structures within the passenger cabin that can produce puncture wounds. This approach requires definition of the flailing envelopes of the cabin occupants and the removal or modification of all sharp, elongated, brittle, pointed or otherwise dangerous objects within these envelopes. Implementation of this method is probably restricted to new aircraft designs since the cost of incorporating this in present designs would be substantial.

Another way to reduce injuries would be the installation of energy absorbing structure or slow return padding behind surfaces likely to be struck by the head or chest during impact so that deceleration distance is provided by the rearrangement of the structure or deflection of the padding, rather than the painful rearrangement of human tissue. This concept of energy absorption, which also includes automatically inflating air bag restraint systems, seems again to be more appropriate for incorporation in new designs rather than in existing aircraft.

The installation and use of shoulder harnesses is a practical and relatively inexpensive solution to the problem of maintaining separation between man and machine during a crash sequence. This solution is applicable to existing aircraft as well as new designs. The addition of shoulder harness to the tie down chain of the general aviation aircraft occupant will increase the probability of his surviving a severe crash and minimize injuries resulting from light to moderate crashes.

II. Research Findings.

Swearingen, et al⁶ present a detailed description of the space which may be traversed by the human head, trunk, and appendages during flailing motions when exposed to crash impact forces with lap belt restraint only being used. These researchers reported that the flailing envelope for a single individual restrained by a

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tight lap belt can be roughly defined as a sphere nearly ten feet in diameter. Young,⁷ realizing that this much clear space could not be made available to each passenger, made functional comparisons of basic restraint systems and was able to demonstrate dramatically the lessening of the space traversed by the head when various types of shoulder harness were worn as compared to use of the lap belt only. He found that the maximum forward head travel was reduced to approximately 20 inches from the seat reference point when using a complete double parallel shoulder restraint system with the upper attachment fixed at the midline and the lower attachment continuous as a seat belt. This is compared with a 48 inch head travel when using a lap belt only positioned forward of the seat back plane. The efficiency of other upper torso restraint systems is almost as remarkable. A system with a single diagonal belt with both the upper and lower attachments fixed at the sides effectively limited head travel to less than 28 inches.

Stapp⁸ reported that a properly restrained adult male is capable of tolerating 30 to 40 G without sustaining serious injury in forward-facing decelerations and at least 20 G in lateral decelerations. Turnbow, et al⁹ recommend that restraint systems be designed to maintain their integrity up to the force level where the occupant may be injured, but is not incapacitated and is able to extricate himself from the wreckage in time to avoid such post crash hazards as fire and drowning.

Compression fractures of spinal vertebrae have been reported as a result of eyeballs-down ($+G_z$) accelerations of approximately 25 G sustained for approximately 100 milliseconds. However, these fractures are not necessarily of the nature to incapacitate the occupant and prevent him from extricating himself from wreckage. Tolerance to vertical impact loads is greatly reduced when the spinal column is in a flexed position or is misaligned laterally. Since it is possible for vertical impact loadings in light plane crashes to exceed the longitudinal stresses,¹⁰ an important factor in tolerance to headwards acceleration is the use of a tight shoulder harness to hold the occupant's shoulders tightly against the seat back.

The human tolerance limit for eyeballs-up ($-G_z$) acceleration is approximately 15 G for a duration of 100 milliseconds.¹¹ In the limited amount of research done on footward accelerations, all restraint has been with both shoulder harness and seat belts. Most experiments also included a seat belt tiedown strap and the stated tolerance is based on this configuration.

For forward-facing, eyeballs-out ($-G_x$) accelerations, the human tolerance limit is approximately 45 G for a duration of 100 milliseconds or 25 G for 200 milliseconds.¹² Restraint used to determine these limits was by means of a double thickness, 3-inch wide shoulder harness, a seat belt with thigh straps, and a chest belt. Some debilitation and injuries can be expected at this G level if less than this optimum restraint system is used.

The human tolerance limit for rear-facing, eyeballs-in ($+G_x$) acceleration has not been accurately established. Obviously it is higher than that for the forward-facing limit. The restraint provided by a full-length seat back in this configuration supports this assumption. Beeding and Mosely¹³ reported a subject experiencing a maximum of 83 G with a duration of 40 milliseconds in a backward-facing seat. However, the subject was extremely debilitated, went into shock, and required on-the-scene medical treatment following the test run.

III. Accident Investigation Findings.

De Haven² reported in a study of the patterns of injury of 800 survivors of light aircraft accidents, that 704 of the survivors suffered head injury, 548 injury to the upper trunk, with 307 the next lower number, having injury to the lower third of the legs. A number of fatalities occurred in this group of accidents, but data was not presented in this study because of lack of reliable autopsy data. It is probable that due to the large number of head and chest injuries among the survivors, death was most likely as associated with injuries to those body areas. This assumption is supported by data compiled by Marrow³ which shows head and chest injuries responsible for 337 of 342 fatalities in light plane accidents. A recent tabulation by Cierebiej and Stedman¹ indicates that multiple injuries were responsible for the death of 52 pilots involved in 564 fatal general aviation ac-

cidents during 1966. A summary breakdown of the data follows:

Frequency of Injury in 564 Fatal General Aviation Aircraft Accidents Resulting in Death to 522 Pilots During 1966

Body Region

Head and Neck -----	661
Skull -----	283
Face -----	254
Neck -----	124
Upper Extremities -----	420
Chest -----	313
Abdomen -----	168
Pelvis -----	123
Lower Extremities -----	519
Massive Injuries -----	60
Burns -----	104

Again, note the preponderance of injuries to the head and neck, the extremities, and the chest.

Head, neck, chest, and abdominal injury are most often critical to life. Gregg and Pearson¹⁴ have shown that 76 percent of the variation in injury severity can be attributed to the severity of head injury. Where immediate evacuation is necessary, such as to avoid drowning or a post-crash fire, an injury to the extremities can be critical. In many instances multiple injury is sustained, although not shown in these data. A ten-year study by Hasbrook¹⁵ reported that roughly one-third of the 389 people killed in 913 general-aviation aircraft accidents died unnecessarily since the cabin structure was damaged only slightly. Contact of the occupant with objects or structures within the cabin caused these fatal injuries. The conclusion was reached that in most cases the use of a shoulder harness probably could have saved the occupant's life.

The Bureau of Safety of the CAB, now part of the National Transportation Safety Board, in a letter to the FAA dated November 3, 1964, stated that in many instances lives have been needlessly lost in general-aviation aircraft accidents due to the non-utilization of shoulder harnesses. Through October 20 of calendar year 1964, 826 fatalities were recorded. Of these 826 fatalities, the Board indicated that approximately 200 lives could have been saved.

IV. Regulations Governing the Installation of Shoulder Harnesses in Existing Aircraft.

Shoulder harnesses or equivalent means of protection from head injury are required by the Federal Aviation Regulations to be installed in normal, utility, and acrobatic category airplanes manufactured under Approved Type Certificates applied for after September 14, 1969. Amendment 23-7 to Part 23, Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes (effective: September 14, 1969) specifies:

23.785 Seats and berths

(g) Each occupant must be protected from head injury by—

(1) A safety belt and shoulder harness that will prevent the head from contacting any injurious object:

(2) A safety belt plus the elimination of any injurious object within striking radius of the head; or

(3) A safety belt plus an energy absorbing rest that will support the arms, shoulder, head and spine.

For those aircraft owners who would like to install shoulder harnesses in their own aircraft, FAA Advisory Circular No. 43, 13-2, Chapter 9, Shoulder Harness Installations, contains the information necessary for an acceptable method of installation. The following general conditions must be met to provide a satisfactory restraint:

1. Utilize the original seat-belt attachments and either the original or a new belt provided with shoulder-restraint fittings.
2. Use webbing approved per TSO-C22e for standard seat belts.
3. Use hardware approved per TSO-C22e for use on seat belts.
4. Secure the lower end of the shoulder restraint to one side of the original seat belt or belt anchorage.
5. Secure the upper end of the shoulder restraint to an aft or ceiling mount attached to primary structure independent of the seat.
6. Test the added mount by applying a load of 500 pounds forward at the shoulder point.
7. Have the completed and tested installation approved by a General Aviation Maintenance Inspector or an Airplane and Powerplant Mechanic holding an Inspection Authorization.

8. Have the approval recorded in the aircraft log book.

V. Certain Problems with Shoulder Harnesses

One of the most serious problems with shoulder-harness and other restraint systems is the difficulty in properly fitting all members of the flying population. Injuries as a consequence of wearing lap belts¹⁶ can be attributed either to improper wearing of the lap belt by the occupant or to improper fit (lap-belt angle is not between 45°-55° from the horizontal and firmly positioned over the pelvis). When the single upper-torso belt rides along the side of the neck, pressure or chafing can cause distinct discomfort during normal flight operations and can create pressure upon the nerves and blood vessels of the neck which can be quite annoying to the user. A belt resting against the neck can be directly responsible for injury in a crash as demonstrated experimentally by Snyder, et al.¹⁷ If the upper-torso belt is positioned off the shoulder because the upper belt attachment is too low or too far forward relative to the seated occupant, the occupant may flex over it during a crash sequence and slip out of it completely. He can also be subjected to a simultaneous rotational torquing motion which may be particularly injurious. The optimum angle for the upper-torso belt relative to the shoulder is -5° to +30° from the horizontal.

Even when wearing a harness that is properly fitted, the user may have difficulty reaching certain cockpit controls unless the restraint system incorporates an inertia reel or it is worn loosely while in cruising flight.

The above-mentioned problems can be solved if attention is given in the design of the re-

straint system to incorporate the maximum in features for comfort, neatness of appearance, ease for storage, and ease of donning and escape. People will use shoulder harnesses if these criteria are met. Swearingen demonstrated this in a study¹⁸ where over 90% of the test subjects were motivated to utilize shoulder harnesses in automobiles throughout a 2-year test period. This rate contrasts with an estimated 3-5% utilization of factory-installed shoulder harnesses in over 10 million automobiles manufactured since January 1, 1968.

VI. Summary of Benefits.

Research and accident investigation findings clearly indicate that if occupants of general aviation aircraft would wear properly-designed and installed shoulder harnesses, especially during the take-off and landing phases of flight, the number of fatalities and major injuries from accidents would be substantially reduced. It could be expected that more occupants would emerge from accidents without injury, or, if injuries were sustained, they would be less serious. The survival of more people from currently "non survivable" type accidents can be expected.

VII. Conclusion.

It is concluded that if shoulder harnesses were installed in general aviation aircraft, considerable benefit to the users of these harnesses would accrue. The user-occupant of older general aviation aircraft would then realize a level of safety approaching that enjoyed by the user-occupant of normal, utility, or acrobatic category airplanes manufactured under Approved Type Certificates applied for after September 14, 1969.

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