



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

February 16, 2023

Specialist Restraint Study

SURVIVAL FACTORS

CEN21FA345

A. ACCIDENT

Location: Hartford, WI
Date: July 31, 2021
Time: 1130 central daylight time (CDT)
1630 coordinated universal time (UTC)
Airplane: Piper J3C-65, N42522

B. SURVIVAL FACTORS SPECIALIST

Specialist Amanda Taylor
National Transportation Safety Board
Washington, DC

C. DETAILS OF THE INVESTIGATION

A survival factors investigator was assigned to this case on June 10, 2022, to conduct an analysis of the protection effectiveness of the lap belts worn by the occupants. In this accident the front seat pilot was a female flight instructor who sustained fatal injuries; and the aft passenger was a male pilot receiving instruction who sustained serious injuries.

The specialist reviewed photos and measurements taken at the scene of the postcrash condition of the airplane by representatives from the NTSB, and Federal Aviation Administration.

1.0 Airplane Configuration

The airplane was a Piper Cub J3C-65, non-pressurized single engine airplane. Configured with two seats in line, one in front and one in back, the aft seat could be used for passengers or for instruction. The airplane had a door and window combination for entry, where the window rotated upward and the door downward. In the accident airplane the window had been rotated upward and latched in that position for flight and the door was up in the closed and locked position. Both seats were equipped with a two-point lap belt with a lift latch buckle, which was secured to airplane structure, near the legs of the seat frame. The airplane also included a control stick in front of both the front and the aft seat.



Figure 1. Pre-accident photo of N42522 found on airpigz.com¹. In this photo the door is in a lowered and locked position, however that was not the configuration in the accident aircraft. Note that in the photo the side of the airplane is open, and the lower door can be seen in the down and secured position for flight.

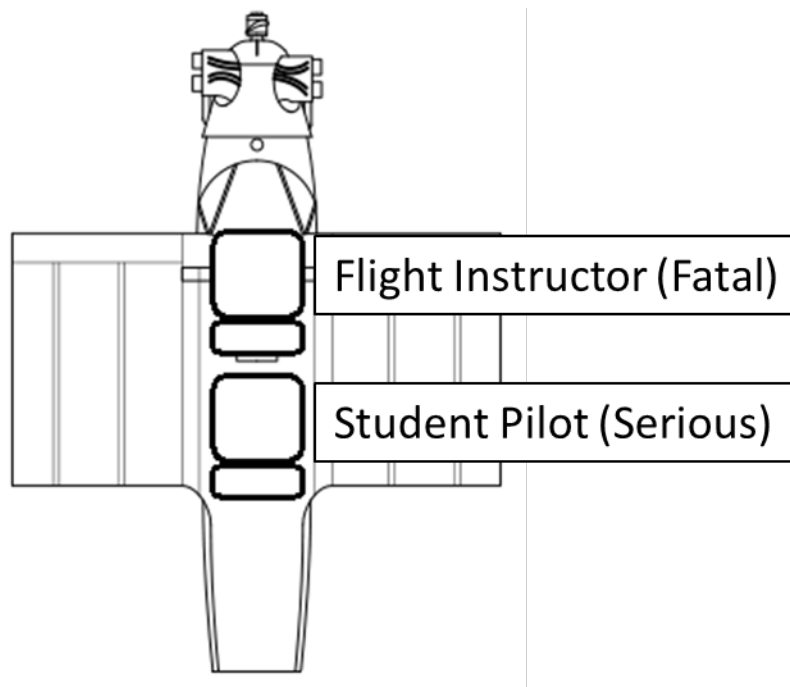


Figure 2. Line drawing of the Piper Cub seating.

2.0 Airplane Exterior

Based on impact signatures and witness statements, the airplane impacted in a left-wing low, nose low attitude, with the airplane coming to rest about 35 ft west of the initial impact point. The left wing was broken, and the landing gear was damaged (see figure 3). According to first responders the damage to the right side of the airplane cabin occurred when extricating the occupants.

¹ Photo downloaded from airpigz.com blog post titled "I'm current for the first time in 18 years!" on November 1, 2022.



Figure 3. Postaccident photograph of N42522.

3.0 Airplane Interior

The cabin area was mostly intact with the damage to the right-side structure and seats occurring when the occupants were extricated according to first responders (see figure 4).



Figure 4. Photograph of N42522 at salvage facility during documentation.

4.0 Seats and Restraints²

The seats were constructed of metallic tube frames with fabric seatpans and backs. Leather covered cushions were attached to the seat pan with hook and loop strips, and leather covered cushions secured over the seatback frames. Both seats were equipped with two-point lap belts with lift latch buckles. The lap belts were secured toward the bottom of the seat frame (see figure 5).

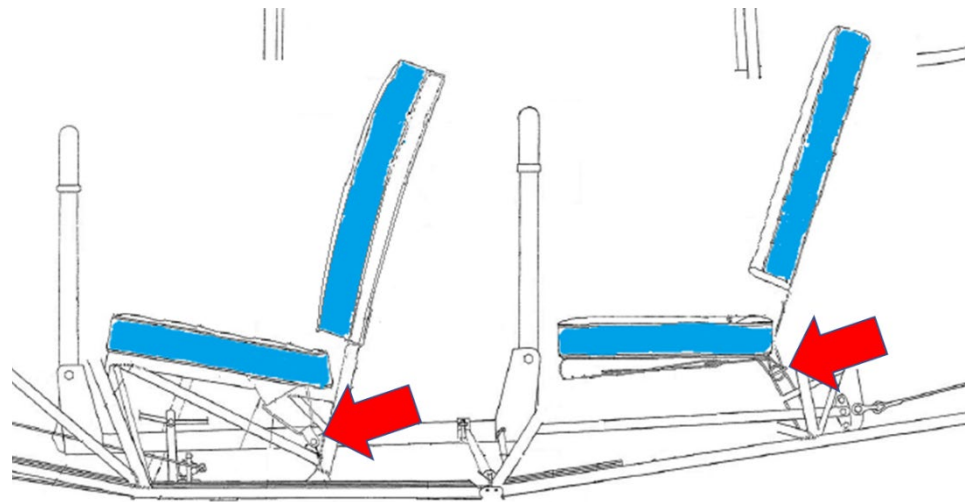


Figure 5. Line drawing showing seats, belt anchor locations, and control sticks.

The flight instructor was in the forward seat (see figure 6). According to the first responders the occupant's legs were trapped under the instrument panel, and much of the seat back and bottom were damaged during the extrication. The student was in the aft seat. The rear seat occupant was removed first and to aid in the removal of the occupant, the seat back and control stick were bent.

² Damage to the airplane seats and structure from emergency responders was based upon a statement in attachment 1 from a responding firefighter.



Figure 6. Seat after the airplane was recovered to the salvage facility.

5.0 Injury Information

The flight instructor in the front seat suffered fatal injuries attributed to blunt force trauma to the head by the medical examiner. The student pilot in the rear seat sustained serious head and torso injuries, including loss of consciousness, lumbar and rib fractures, and broken ulna and radius. For detailed injuries see attachment 2 of this report.

D. DETAILS OF THE STUDY

5.1 Anthropomorphic Measurements

During her last medical the front seat pilot (female) reported being 65 inches tall and weighing 124 pounds, and the rear seat pilot (male) reported being 67 inches tall and weighing 140 pounds. Using this height and the data from The United States Air Force Research Laboratory's CAESAR³, it was estimated that the front she pilot was about a 61st percentile female, and the rear seat pilot was about a 19th percentile

³ United States Air Force Research Laboratory CAESAR: Summary Statistics for the Adult Population (Ages 18-65) of the United States of America. C. Harrison and K. Robinette.

male. Using these percentiles, estimates for body segment lengths were made, see table 1. For a graphical representation of the segment lengths see figure 7 which has drawings from the CAESAR and labels to identify them in table 1.

Table 1. Body Segment Lengths Referenced in Figure 9 Below.

Identifier	Body Segment	Front Seat Female (in.)	Rear Seat Male (in.)
A	Sitting height	34.4	34.9
B	Head height	7.8	9.3
C	Neck height	4.0	3.1
D	Acromial height	22.6	22.5
E	Height of thigh	7.6	6.9
F	Head length	7.4	7.6
G	Knee length	23.4	23.1
H	Hip breadth	16.4	13.7
I	Torso length	14.5	16.7

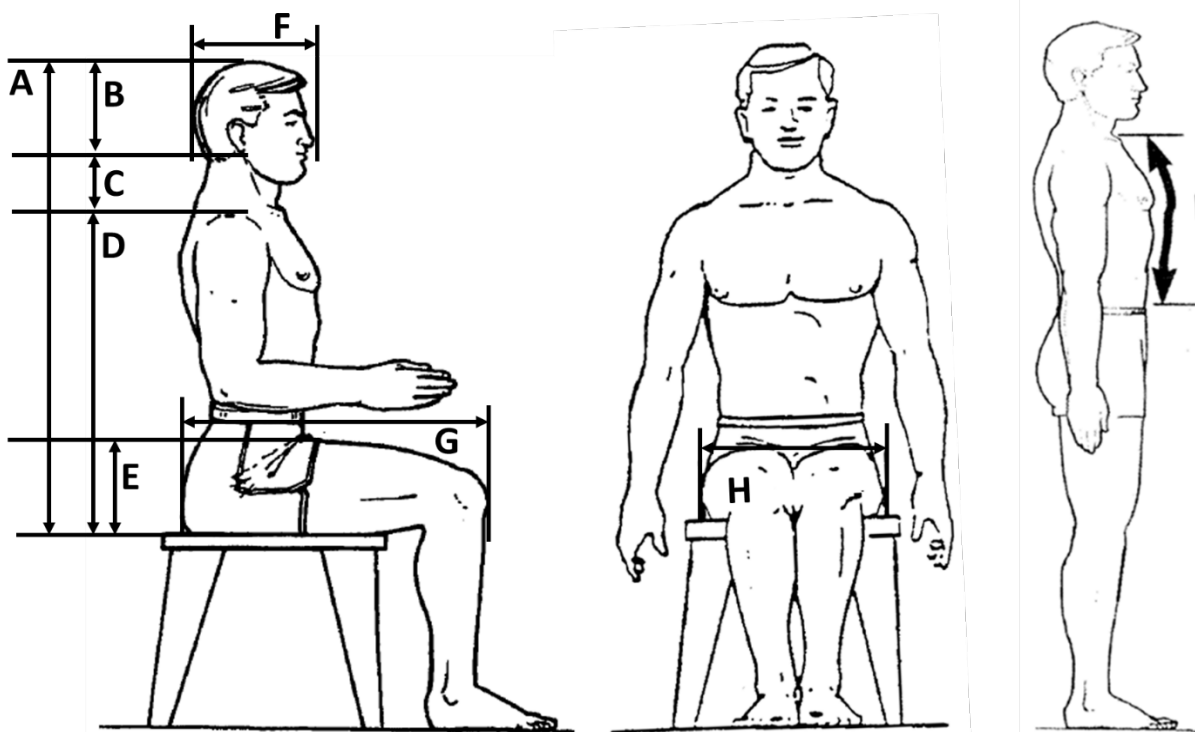


Figure 7. Body segment length measurement locations for table 1.

5.2 Occupiable Space Available

Post-accident damage done while extracting the occupants did not allow for accurate seat belt measurements. Instead, measurements were performed on an

exemplar airplane of the same type and configuration. Drawings provided by Piper were used to estimate the pilots' occupiable volume (see figure 8).

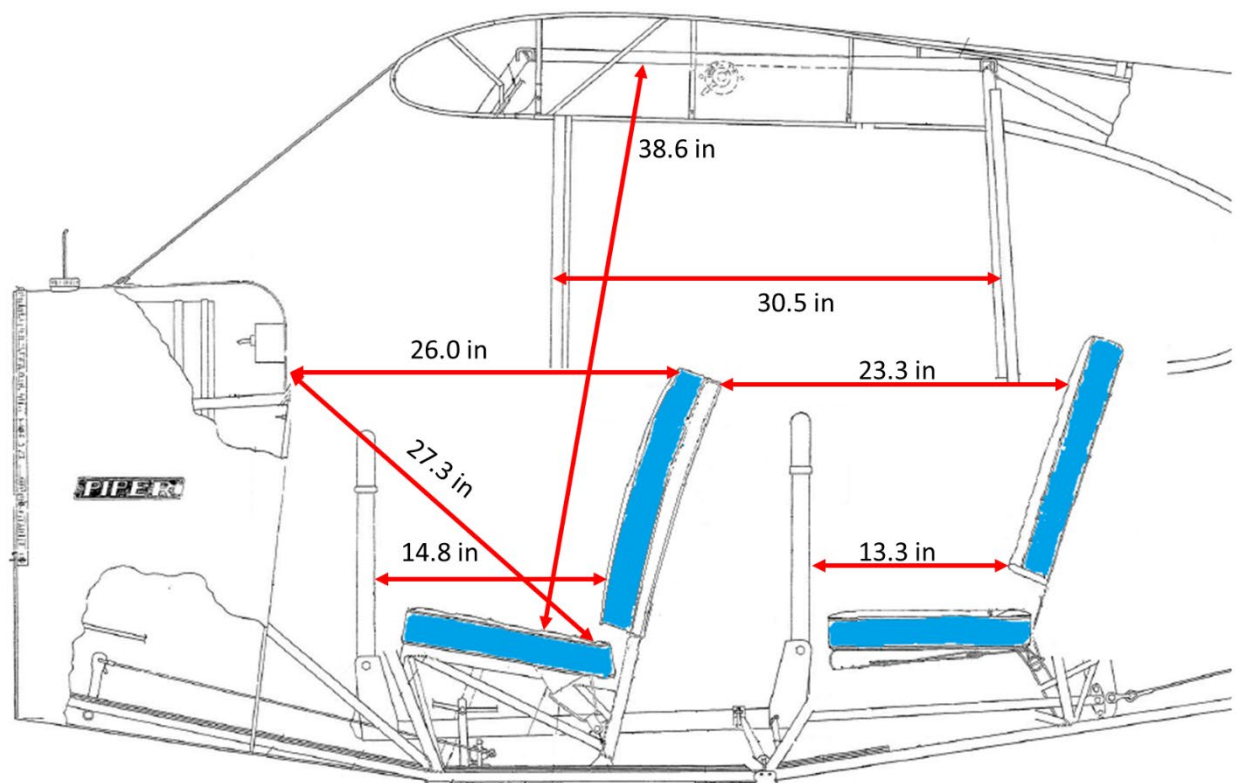


Figure 8. Piper Cub line drawing with distances estimated off other drawings.

5.3 Webbing Elongation

When certifying a restraint assembly, belt manufacturers use SAE Aerospace Standard 8043⁴ which specified in section 4.3 "Elongation" that webbing elongation shall be less than 20% when tested. Additionally in section 6.1.3 "Pelvic Restraint Elongation" specified that the pelvic restraint between anchorages shall not increase more than 12 inches.

5.4 Belt Lengths

5.4.1 Lap Belt

The length of the nominal lap belt was estimated (see table 2) by using the length in the drawings from the anchor point of the belt to the top of the thigh of the occupant (12.8 inches), multiplying it by two and adding the length of the occupant's hip breadth from table 1. The stretched length was calculated with the addition of the 12 inches allowed in 8043B.

⁴ SAE International, Aerospace Standard 8043 revision B, "Restraint Systems for Civil Aircraft."

Table 2. Lap belt length estimates for each seat.

Lengths	Front Seat (in)	Rear Seat (in)
Anchor point to top of thigh	13.6	12.5
Hip breadth	16.4	13.7
Total nominal lap belt length	43.6	38.7
Lap belt length with 12 inches of stretch	55.6	50.7

5.4.2 Upper Torso Belts

To estimate the difference in head path the occupants would have had with upper torso restraints, an approved restraint system⁵ for a Piper cub was used for comparison purposes. This system did not include an inertia reel. The length for a nominal two-strap upper torso belt was estimated (see table 3) by using an anchor point aft of the occupant secured on overhead structure as shown in an exemplar Piper cub (figure 9). The length was from the anchor point to the top of the shoulders, which was then added to the waist front length from the torso length from table 1 which ends at the waist. This is where the webbing would end, and the buckle would start.



Figure 9. Mounting position for a set of upper torso restraints in an exemplar Piper Cub.

⁵ Hooker Harness model 2Y562430-3D, with a rated strength of 1500 pounds.

Table 3. Upper torso belt length estimates for each seat.

Lengths	Front Seat (in)	Rear Seat (in)
Anchor Point to top of the shoulder	26.8	13.8
Torso Length	14.5	16.6
Total Nominal Upper Torso Belt Length	41.3	30.4
Upper Torso Belt Length with 20% stretch	49.6	36.5

6.0 Head Paths

In the following sections head paths are overlaid on the AutoCAD® drawings showing the path the top of the occupants head and shoulder would have taken if allowed to rotate forward. This simplified analysis assumes the body remains rigid and no additional accelerations or friction between the occupants and the supporting structure were considered. Head paths are in red, and shoulder path in green. Line drawings of a Piper Cub interior and occupant, the size of the front seat flight instructor, and rear seat student were made using AutoCAD® 2D software based on the anthropometric measurements derived in section 5.1 of this report. Head and torso paths were then drawn with the arc tool assuming rotation about either the lap belt or upper torso belt.

6.1 Lap Belt Only Head Path

The head paths for the two occupants for the lap belt with no stretch are shown in figure 10. If the lap belt was stretched to the full length allowed per the regulations the occupants would impact in a different manner with more of the torso and head impacting the surfaces in front of them as shown in figure 11, which is consistent with the injuries seen.

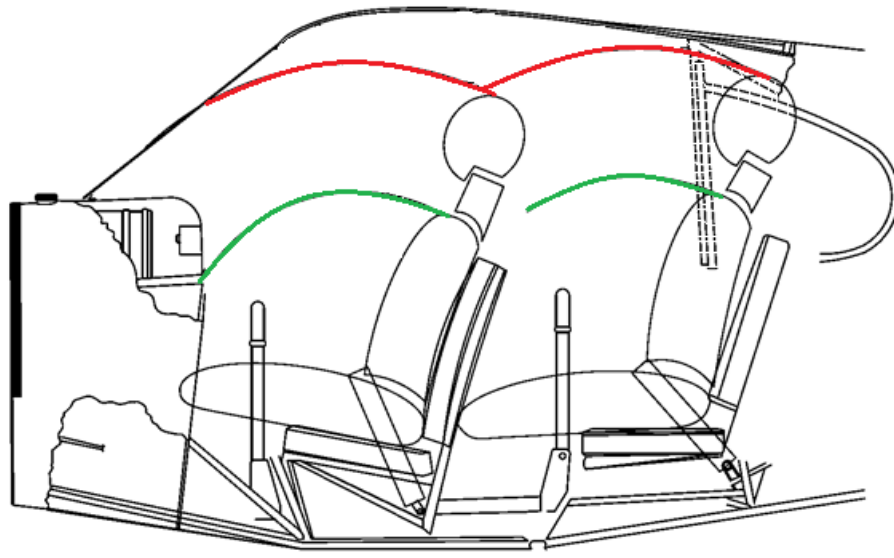


Figure 10. Occupant head and shoulder path arcs with a lap belt only restraint and no stretch, head paths are in red, shoulder paths in green.

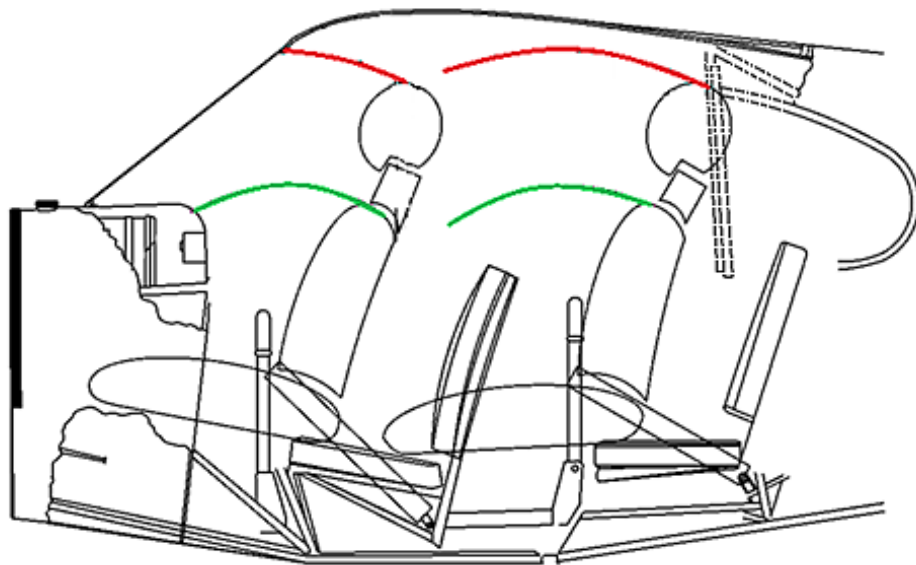


Figure 11. Occupant head and shoulder path arcs with a lap belt only restraint and 12 inches of stretch, head paths are in red, shoulder paths in green.

6.2 Upper Torso Belt Head Path

The upper torso restraint described in 5.4.2 was added to the AutoCAD model to show the head path that would have occurred had the occupants been wearing one. The occupant's upper torso was then rotated forward about the lap belt until the full calculated length, including 20% of stretch, was taken up. The occupant head

path arc was then based upon rotation about the upper torso belt contact of the shoulder and is shown in figure 12.

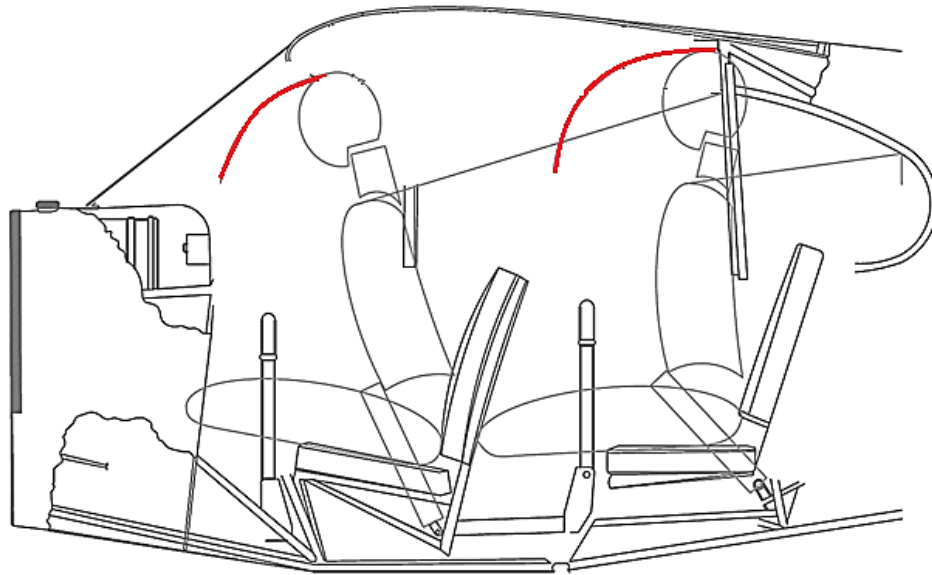


Figure 12. Occupant head path arcs after the forward rotation was stopped by their upper torso restraints, head path in red. Note the shoulder path is not depicted on this figure since the torso has already been rotated forward.

7.0 Upper Torso Belt Requirements

Effective July 18, 1977, Section 23.785 of 14 *CFR* Part 23 required all normal aircraft, for which application for type certificate was made on or after July 18, 1977, to have approved upper torso harnesses for each front seat. Section 14 *CFR* Part 91.205(b)(14) required all small civil airplanes manufactured after December 12, 1986, to have an approved upper torso harness for all seats. However, aircraft that were manufactured prior to that date were not required to have an upper torso restraint installed.

In 1981 the NTSB initiated a multi-part general aviation crashworthiness program. The NTSB examined accidents and their effects on the occupants and airplane structure for the purpose of upgrading occupant protection design standards⁶. In the second report in this program the NTSB found that 20 percent of the fatally injured occupants in those accidents could have survived with upper torso harnesses (assuming the seatbelts were fastened properly) and 88 percent of the serious injuries could have significantly less severe injuries with the use of upper torso harnesses. The NTSB concluded that upper torso harness use was the most effective way of reducing fatalities and serious injuries in general aviation accidents⁷. As a

⁶ NTSB safety report SR8301 "General Aviation Crashworthiness project, Phase one."

⁷ NTSB safety report SR8501 "General Aviation Crashworthiness Project - Phase Two -- Impact Severity

result of the program the NTSB issued safety recommendation A-85-124 recommending the FAA issue an advisory circular to provide information on crash survivability aspects of small aircraft.

In March 1987, Technical Standard Order (TSO) C114, "Torso Restraint Systems," was issued by the FAA. The TSO prescribed the minimum performance standards that upper torso harness restraint systems must meet to be identified with a TSO marking. Then on September 19, 2000, the FAA issued policy statement number ACE-00-23.561-01, "Methods of Approval of Retrofit Shoulder Harness Installation in Small Airplanes." This provided guidance to make it easier to retrofit shoulder harnesses in certificated aircraft by making it a "minor change" if the following criteria were met:

- The aircraft was manufactured before July 19, 1978, for front seats and Dec. 12, 1986 for rear seats.
- TSO-C114 belts were used.
- No drilling or welding had been performed.
- The mechanic doing the install consulted Advisory Circular 43.13-2A, Chapter 9, for information on restraint systems, effective restraint angles, attachment methods, and other details of installation.
- The installing mechanic made an entry in the aircraft's maintenance log.
- If drilling or welding was required, then a supplemental type certificate or field approval was required to make the modification.

E. Summary

The FAA has required shoulder belt installation on newly type certificated small airplanes since 1977. This requirement did not apply to older model airplanes, allowing for those certificated before that date to continue to be manufactured with a lap belt as the only means to restrain an occupant. In the early 1980s the NTSB conducted a large study of general aviation accidents showing 20 percent of fatalities would have benefited from a properly worn shoulder harness, and that it was the most effective way of reducing fatalities and serious injuries in general aviation accidents. In 2000 the FAA issued a policy statement to make it simpler to install shoulder belts on older models of airplanes.

The current study used approximated anthropometric measurements of the two occupants in order to estimate their head paths during the impact and to determine what their bodies might have struck. The study also assumed a worst-case situation where the belts stretched to their full length allowed in the SAE standards. The results showed that the occupants were likely to impact much of their head and

and Potential Injury Prevention in General Aviation Accidents"

upper torso on structures located within the cabin interior when restrained only by a lap belt; and the addition of an upper torso restraint would likely have lessened the severity of the blunt force injuries sustained by either keeping the occupant away from structure in front of them or lessening the force of impact with those objects.

F. Attachments

Attachment 1. Injury chart

Attachment 2. Firefighter narrative

Submitted by:

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