Survival Factors and Biomechanics Factual
In support of the General Aviation Airbag Study

January 22, 2008

Location:	Indianapolis, IN
Aircraft Type:	Cirrus SR 22 N91MB
Accident Date:	August 28, 2006
Accident Time:	10:38 am eastern daylight time
Accident Number:	CHI06FA245
Airbag Equipped:	☒

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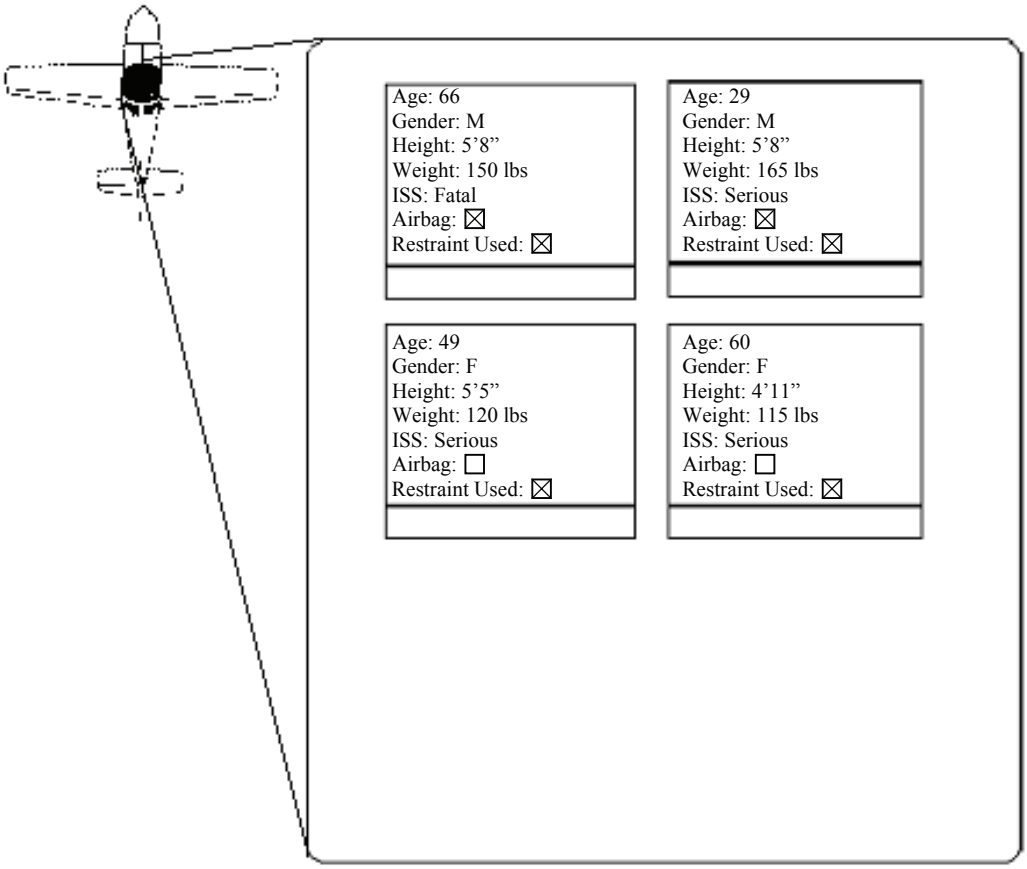
Accident Summary:

On August 28, 2006, at 1038 eastern daylight time, a Cirrus SR-22, N91MB, was destroyed when it impacted a water retention pond located about 2.4 miles from the Eagle Creek Airpark (EYE), Indianapolis, Indiana, after a loss of control during cruise climb. The 14 Code of Regulations Part 91 personal flight departed EYE at 1034 en route to Hilton Head Airport (HXD), Hilton Head Island, South Carolina. The pilot received fatal injuries, and the three passengers received serious injuries. Instrument meteorological conditions prevailed at the time of the accident. The flight was on an instrument flight plan.

Abstract:
The survival factors documentation focused on damage to the aircraft fuselage, damage to the cockpit, condition of the seats, restraints and the airbags that may have affected the passenger's motion or their level of injury. Hospital records and autopsy reports were also reviewed to document the level and extent of occupant injury. Indications of severe vertical loading on the seat pan energy absorbing materials and the non-severe markings of the lap belt webbing indicate a primary impact vector in the vertically downward direction, with significant but minor components in the forward longitudinal and left direction. Injuries to the occupants support this direction of impact force.

Seating Chart:



Documentation:
The aircraft landed in water. At final rest, the nose of the aircraft, forward of the first row of seats, including the instrument panel was rotated downward away from the occupant space. (See Figure 1.) During the accident sequence, the parachute was deployed and both front seat airbags deployed. Damage to the plane was noted on the underside of the nose cone. (See Figure 2.) Damage was also noted on the wings in a 45-degree pattern. The landing gear was not damaged to any measurable amount. The instrument panel was examined for occupant impact marks but due to the water landing, it was difficult to determine impact marks. Both doors of the aircraft were inspected for indications of occupant impact but no marks were found. The aft fuselage occupant space was also inspected for occupant impact, but nothing was found. The foot wells of the pilot and co-pilot seats were intact with minimal loss of occupant space. However, the position of the seats relative to the foot wells and the instrument panel (see Figure 3) at impact is not known. The foot wells of the rear passenger seats were intact. The side walls and roof fractured during the impact and were displaced during the extrication.

Figure 1: A photograph showing the aircraft lifted from the water.

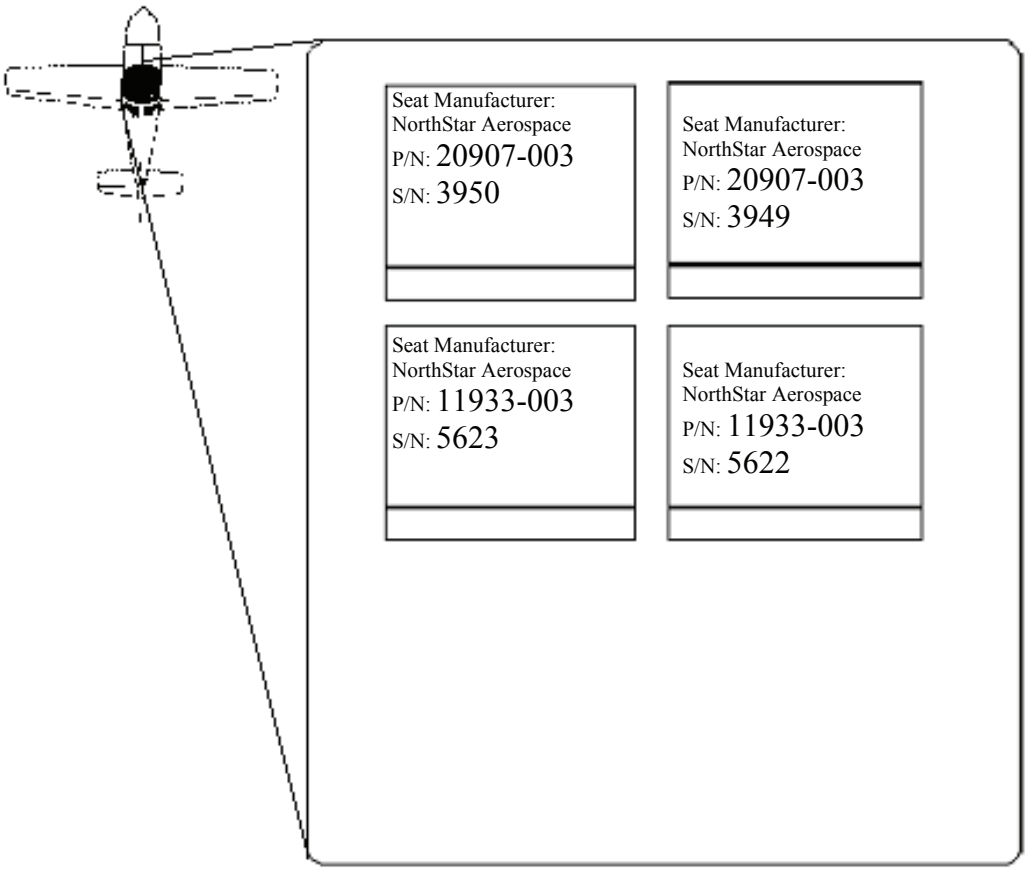
Figure 2: A photograph showing the damage to the underside of the nosecone.

Figure 3: A photograph showing damage to the instrument panel.

Seats

The aircraft was equipped with four seating positions: two in the first row and two in the second row. Four point belts were present for all seating locations. The front passenger seats were also equipped with airbags mounted in the outboard shoulder harnesses. A scrape mark, shown in Figure 4, was noted on the top of the front, left pilot seat. The scrape was into the leather material. A corresponding mark was not found on the roof of the plane in the area of this seat.

Seat Numbers:



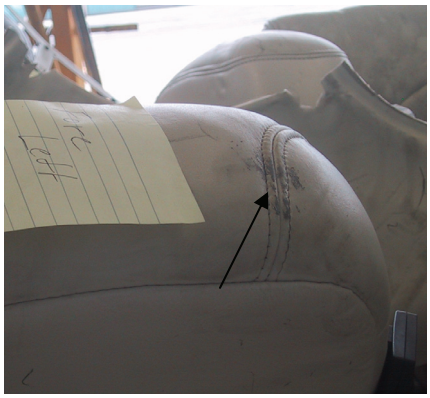


Figure 4: A photograph of the scrape mark on the left front pilot seat. The scrape mark is on the top of the seatback on the inboard side, marked by the black arrow.

The leather upholstery and the underlying foam padding were removed from all four seats to examine the structural components of the seats. The right rear seat back had impact marks 15" from the base of the seat. (The total seat back height was 25".) No other damage was noted to the seat backs. Damage to the seat pans is documented in the following photographs and description.

Rear (Aft) Seats

The rear seats have three layers of energy absorbing foam separated by a thin sheet of aluminum in the seat pan. The forward center region of the seat pan exhibited the most crush, as shown by the pictures and measurements in Figure 5 and Figure 6, below.

Figure 5: A photograph of the left rear energy absorbing seat pan. (Top sheet of aluminum was bent up to view lower layers) Measurements indicate the remaining height of the energy absorbing foam.

Figure 6: A photograph of the right rear energy absorbing seat pan. (Top sheet of the aluminum was bent up to view lower layers) Measurements indicate the remaining height of the energy absorbing foam.

Front Seats

The front seats are mounted on a seating track and each track is then mounted on the wing spar tunnel. The front seats are adjustable fore and aft and have a total of 11 seating positions.

The front seats were constructed with the following layers:

- Leather upholstery
- Rate sensitive compressible open cell foam
- Aluminum seat pan
- Aluminum honeycomb energy absorbing block (about 4 inches thick)
- Carbon fiber seat pan (attached to the aluminum frame structure)

The aluminum seat pan, honeycomb block, and the carbon seat pan are designed to absorb impact energy through permanent deformation and fracture. Vertical loading was noted on the seat layers. The front seat pans measured 17” wide by 17.5” long.

Right Front Seat

The right front seat was found in a position that was one pin position rearward of the full forward position. The air conditioning (AC) unit (or evaporator) was located under the co-pilot seat, just forward of the wing spar.[1]

Prior to removing the metal cover, the deformation to the pan was measured. The seat pan was evenly deformed about the centerline. The maximum crush depth was measured at 2.625". The nominal depth of the seat pan is unknown. The aluminum honeycomb block has a nominal thickness of 3.5". When examining the honeycomb block, for this seat, the inboard front portion was completely crushed (0.0"); the outboard front measured 0.5"; the rear center was heavily crushed with less crushed 'camel humps' on each side, measuring a crush depth of 3.125" for the inboard rear hump and 2.825" for the outboard rear hump. The deformation and fracture patterns of the right, front seat are documented in the following figures.

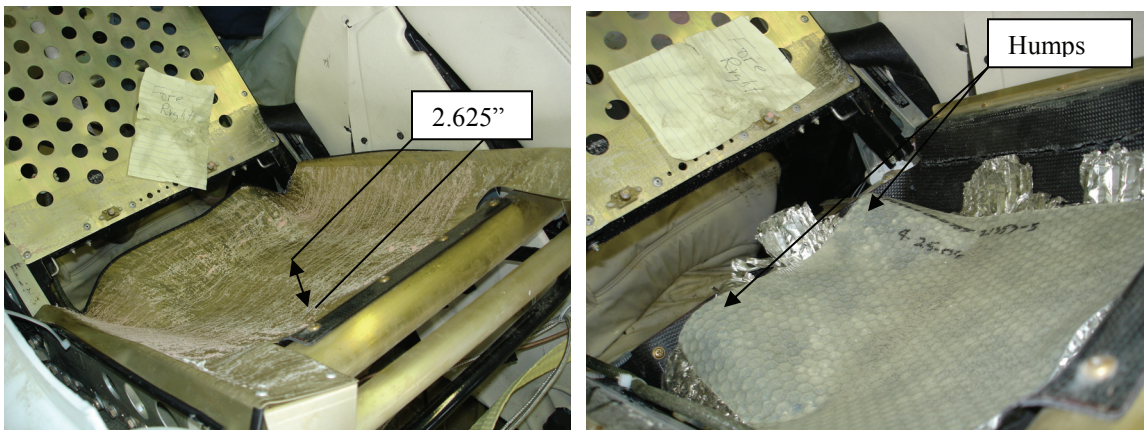


Figure 7: Photographs of the right front seat pan and honeycomb block

Figure 8: Detail of buckled honeycomb on outboard edge of the right, front seat.

[1] In the forward-most seating position, the evaporator unit is directly under the seat.

The aluminum honeycomb material on the left, rear portion of the seat was sheared outward as shown in Figure 7 above, while the right side of the honeycomb was displaced in, as shown in Figure 8. This indicates loading toward the left.

The right front seat carbon pan structure was fractured along the entire inboard (left) edge, and from the top to the seat base in each forward corner. The carbon seat pan and cover of the AC unit exhibited corresponding damage, as shown in Figure 9 and Figure 10.

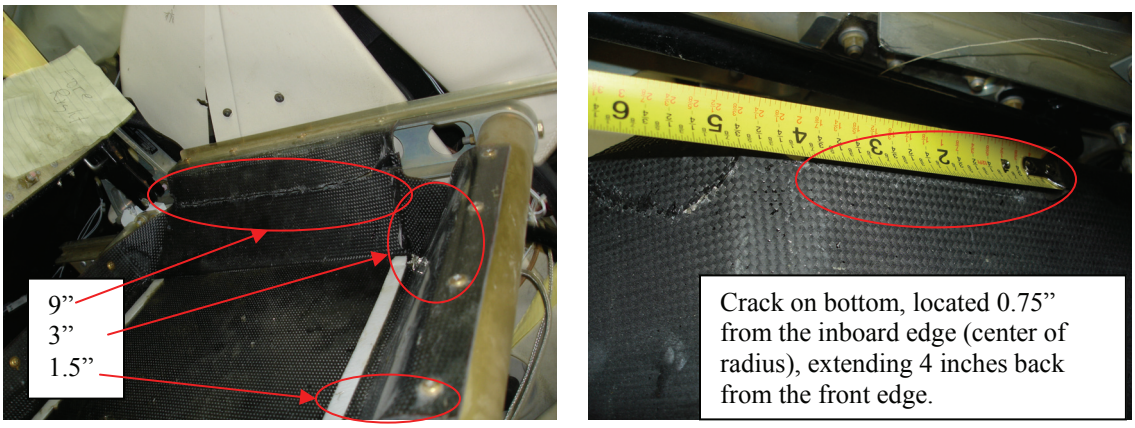


Figure 9: Photos of the right front carbon seat pan (view from above and below seat pan). The view is looking from outboard to inboard with the front of the seat toward the right side of the photo.

The aluminum AC cover was also damaged. The location of the crease started 5” aft of the front edge, and was 3” long. An additional section was punctured for 1” long. The crease/puncture was parallel with the longitudinal axis of the aircraft, located 2.5” from the inboard edge of the AC cover.

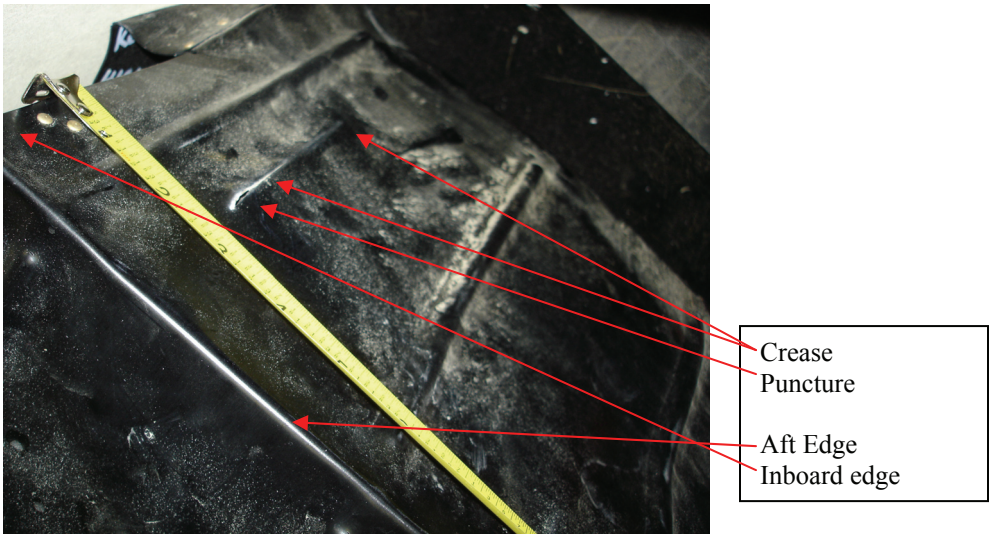


Figure 10: Damage to the AC cover under the right, front seat.

Left Front Seat

The left front seat was found in a position that was one pin position forward of the full rearward position. The skywatch box is installed under this seat.

The maximum vertical deformation of the seat pan examined prior to removing the metal cover was in the outboard, rear quadrant, about 4” in from the rear edge and 5 inches in from the outboard side. Depth at this point was 2.5”. Depth on the inboard rear quadrant was measured at 2”.

The honeycomb block was heavily crushed. The center region had the maximum deformation with a measured thickness of 0.625” at location 4” from aft edge and 3” from outboard edge. (See Figure 11.)

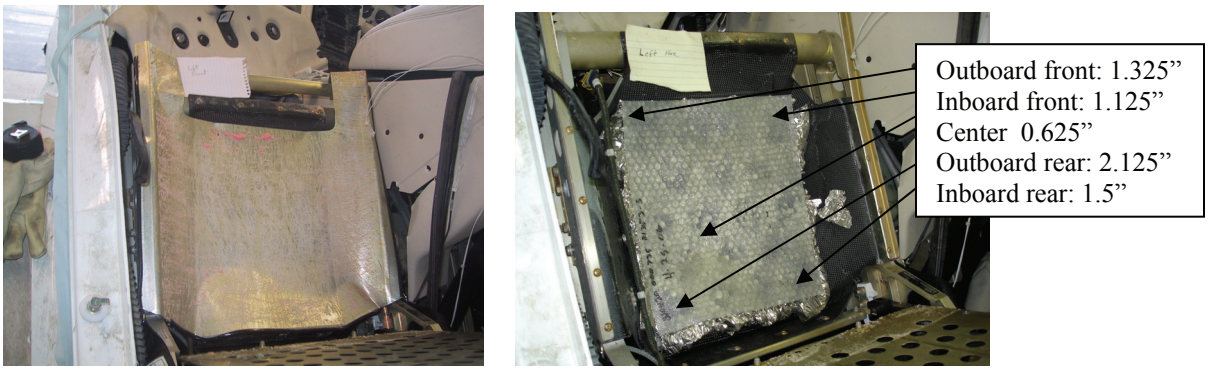


Figure 11: Photos of left front seat pan and honeycomb block. The view is looking down on the seats with the front of the seat pan at the top of the photograph.

The left front seat carbon seat pan was fractured around the perimeter on all four walls. The cracks were closer to the base of the pan than for the right front seat. The cracks are circled in the adjacent photos.

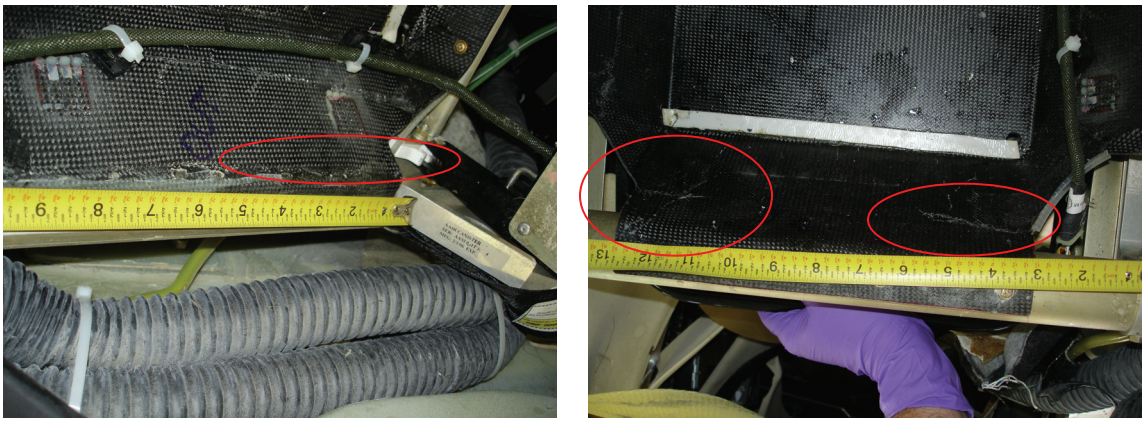


Figure 12: Photos of left front carbon seat pan.

Comparison of Front Seat Deformation

Greater vertical loading of the forward, left quadrant of both seats was noted. The left seat position indicated a more distributed and complete crushing, while the deformation to the right seat position was more localized. The localized loading of the right seat position may have been intensified by the presence of the AC unit below. A comparison of the two front seats is also shown in Figure 13.

Figure 13: Comparison of the seat pan and honeycomb block of the two front seats. For orientation, the left, front seat pan and honeycomb block are on the left side of the photograph. The front of both seat pans is toward the top of the photograph.

Seat Testing

A review of the test results for the SR22 seats indicated that the seats met the Type Certification Basis specified in 14 CFR 25.562. [2,3]

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[2] b) Except for those seat/restraint systems that are required to meet paragraph (d) of this section, each seat/restraint system for crew or passenger occupancy in a normal, utility, or acrobatic category airplane, must successfully complete dynamic tests or be demonstrated by rational analysis supported by dynamic tests, in accordance with each of the following conditions. These tests must be conducted with an occupant simulated by an anthropomorphic test dummy (ATD) defined by 49 CFR Part 572, Subpart B, or an FAA-approved equivalent, with a nominal weight of 170 pounds and seated in the normal upright position.
(1) For the first test, the change in velocity may not be less than 31 feet per second. The seat/restraint system must be oriented in its nominal position with respect to the airplane and with the horizontal plane of the airplane pitched up 60 degrees, with no yaw, relative to the impact vector. For seat/restraint systems to be installed in the first row of the airplane, peak deceleration must occur in not more than 0.05 seconds after impact and must reach a minimum of 19g. For all other seat/restraint systems, peak deceleration must occur in not more than 0.06 seconds after impact and must reach a minimum of 15g.

[3] It does not appear as though the seats were tested with either an evaporator or a skywatch box installed.

SR20 IDI Model Cabin Seat Dynamic test

The SR20 passenger seats and restraint system were tested in accordance with 14 CFR 23.562(a), (b) and (c) and met all requirements in 1998. Longitudinal and down load tests were conducted with the seats attached to the yaw plate and the inclined 60 degree fixture, respectively. All the pulses were acceptable and the injury criteria[4] were satisfied.

Crew Seat Vertical Test

In 2005, Cirrus tested the SR20/22 seat assemblies with a new seat bottom foam to ensure compliance with the requirements in 14 CFR Part 23.562(b)(1). The original seat bottom foam became obsolete and the new foam has a different density and compression stiffness. Testing was only required in the vertical case because the foam is not critical in the longitudinal case. Only the SR22 seat was tested but the SR20 seat was compared for compliance. The SR22 seat has a thicker energy absorbing module and thus compression could not exceed the thickness of the SR20 module. To enable load cell measurements, the seat and a portion of the seat track are the only items from the airframe seat attach used in the testing fixture. The results indicate that the new seat foam met all requirements concerning the accelerations, seat belt loads, and lumbar loads. In addition, the energy absorbing module was crushed 2.0" which is less than the SR20 energy absorbing module thickness. Thus, the seat met requirements for both the SR20 and SR22 seats.

SR22 CAPS Occupant Protection Test

In 2000, Cirrus conducted a test to show compliance with *Parachute Performance* of special condition 23-ACE-88 "… although the airplane structure may be damaged, the airplane impact during touchdown will result in an occupant environment in which serious injury to the occupants is improbable." The SR22 CAPS occupant protection drop test was conducted under FAA approved test plan 13995 Rev C, CAPS System Occupant Protection Test Plan.

The SR22 drop test was conducted with an aircraft gross weight of 3400 lbs. The results of the test showed no damage to the seat or the seat belt attachment points. Maximum compressive lumbar loads for the four anthropomorthic test dummies during the drop test were as follows:

[4] Injury criteria include lumbar load and head injury criteria. Additional criteria included the shoulder harness load, the seat must remain attached to the track, seat deformation must not impede egress, and the lap belt must remain on the pelvis.

Table 1: Measured maximum compressive lumbar loads for the four seating positions.

Seating Position	Maximum Compressive Lumbar Load (lbs)
Pilot	1522
Co-Pilot	1575
Right Rear Passenger	1003*
Left Rear Passenger	1357

* A developmental passenger seat was tested in this position.

The Pass/Fail Criteria established for the test specified a 1500 lbs maximum compressive lumbar load to pass the test. Although the measured loads for three positions were above the limit, the calculations of the drop test height in the test plan were determined to be conservative estimates that included the weight of the rocket, the deployment bags and the CAPS cover which are ejected during deployment. The drop test also included a full fuel load and did not account for the drag effect on the aircraft. Calculations showing the effects of the "conservatisms" on the test result showed that the torso g-loads and peak lumbar loads from the actual filtered test data could be reduced by a factor of 0.923. The resulting lumbar loads were:

Table 2: Adjusted maximum compressive lumbar loads accounting for conservative estimates during the drop test.

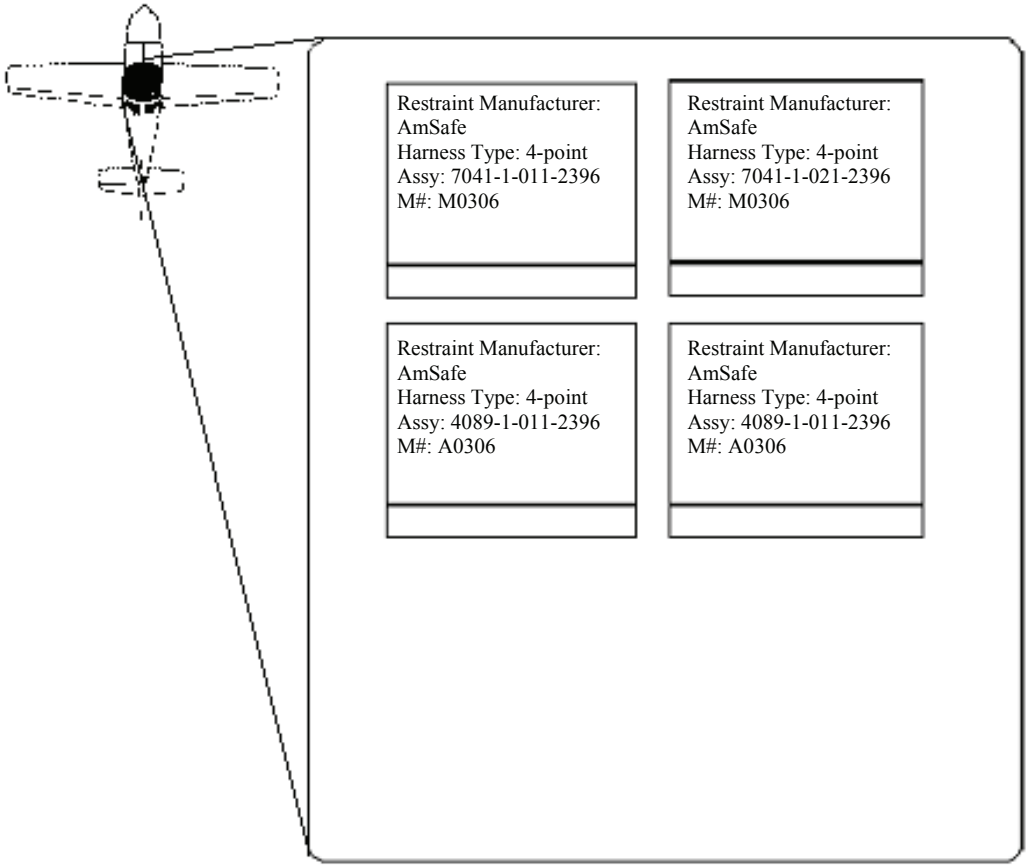
Seating Position	Maximum Lumbar Load (lbs)
Pilot	1405
Co-Pilot	1454
Right Rear Passenger	926*
Left Rear Passenger	1253

* A developmental passenger seat was tested in this position.

The test demonstrated compliance with the requirements of Special Condition 23-ACE-88 for occupant restraint and post-touchdown occupant protection.

Restraints:

Restraint Numbers:



The front left and front right belts were found in the unlatched position. The rear belts were found in an unusual condition where the inboard buckle from the right seat and the inboard connector from the left seat were connected. This configuration does not provide any potential for occupant restraint.

During recovery, the attachment points of the rear seat shoulder harnesses to the two retractors in the rear of the plane were cut to facilitate removal of the plane in two separate pieces. The manner of cutting made it appear as though the rear right retractor was locked but it actually was the result of the belt being cut most of the way through and then slipped back inside the retractor and became stuck. See Figure 14 and Figure 15.

Figure 14: A photograph showing the cuts on the shoulder harness retractors for the rear seats.

Figure 15: A photograph showing the cut most of the way through the right rear webbing that was stuck in the retractor.

Seat belt loading marks were documented on all four restraint systems. For the *front left side seat*, load marks were noted on the outboard (buckle side) lap restraint at 17.5 - 18" from the anchor point. On the inboard (connector side) lap restraint, load marks were also located between 17.5 and 18". The pattern of the load marks showed three or four lines across the webbing, typically at an angle or curve and corresponded to the shape of

the load bar in both the buckle and connector. Load marks were not found on either shoulder restraint.

For the *front right side seat,* load marks were noted on the outboard (connector side) lap restraint at 12 - 13". On the inboard (buckle side) lap restraint, load marks were noted at 17.5 - 18" and also at 12.75". The marks on both portions of these lap restraints were less distinct than on the left side seat and thus were difficult to determine if they resulted from the accident scenario. Load marks were not found on either shoulder restraint.

For the *rear left side seat*, load marks were noted on the outboard (buckle side) lap restraint at 20-21" from the anchor point. On the inboard (connector side) lap restraint, load marks were also located at 19" from the anchor point. These marks were not as distinct as those on the outboard side. Load marks were not found on either shoulder restraint.

For the *rear right side seat*, load marks were not noted on the outboard (connector side) lap restraint. On the inboard (buckle side) lap restraint, load marks were noted at 21" from the anchor point. Load marks were not found on either shoulder restraint.

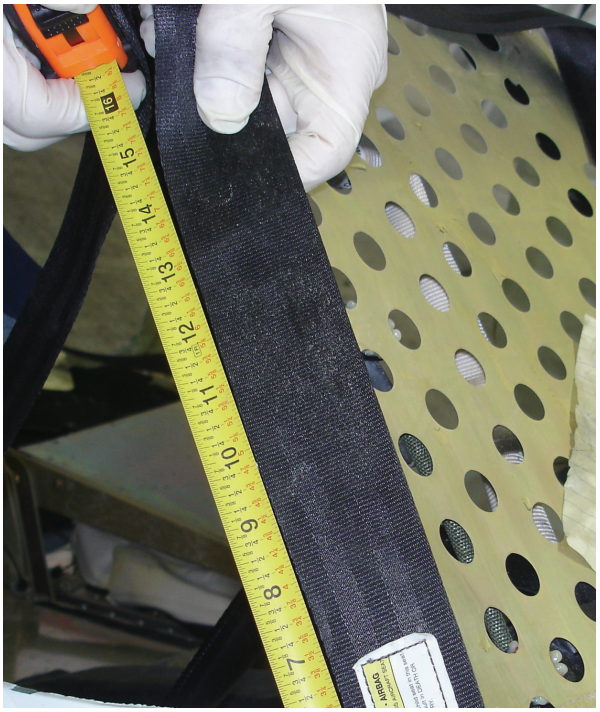
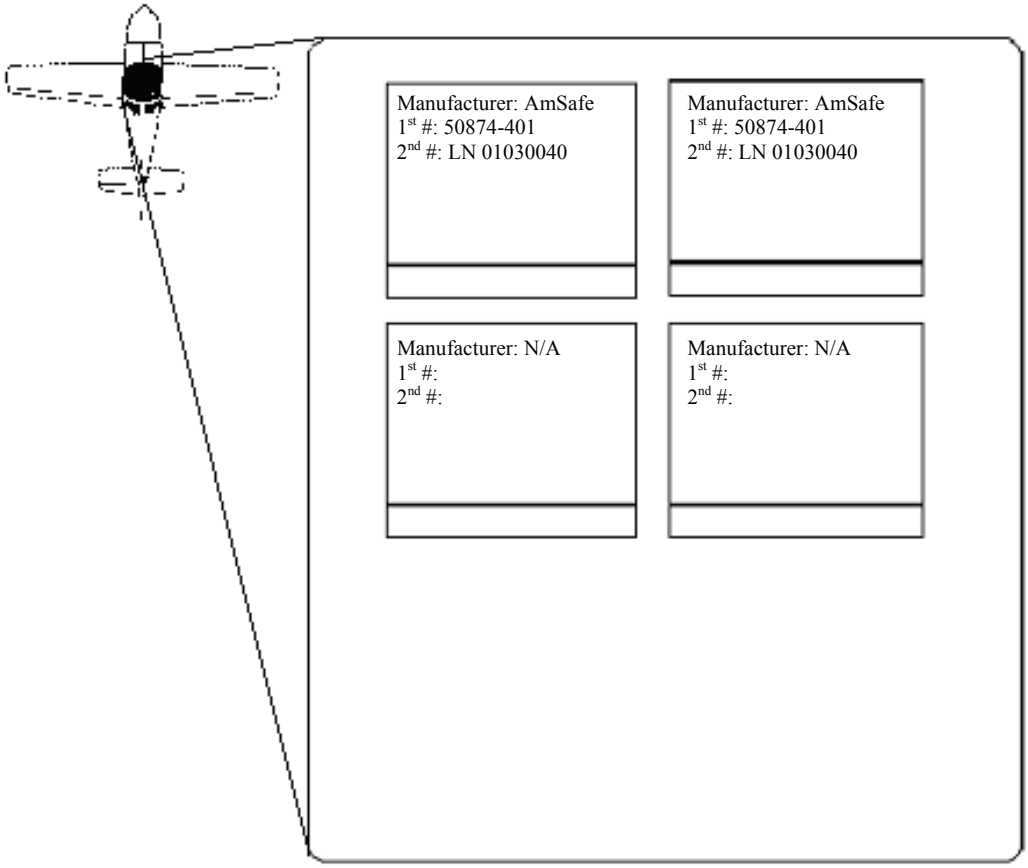


Figure 16: A photograph showing the load marks on the front right side seat.

Airbags:

Airbag Labels:



The airbag inflators were both labeled 50874-401, LN 01030040. The airbags were located on the outboard shoulder harness for each front seat. Witness marks were not noted on the airbags but differences in loading were documented based on the squaring[5] of the vent holes. Two vent holes were present on each airbag facing away from the occupant. (See Figure 17 and Figure 18.) The left airbag showed squaring in both the upper and lower vent holes. The right airbag showed squaring in the lower vent hole and slight fraying in the upper vent holes. The amount of squaring indicated that the left airbag achieved higher pressures than the right airbag.

[5] Squaring of the vent holes occurs from fraying of the threads in line with the weave pattern.

Figure 17: Photographs of the left front and right front airbags.

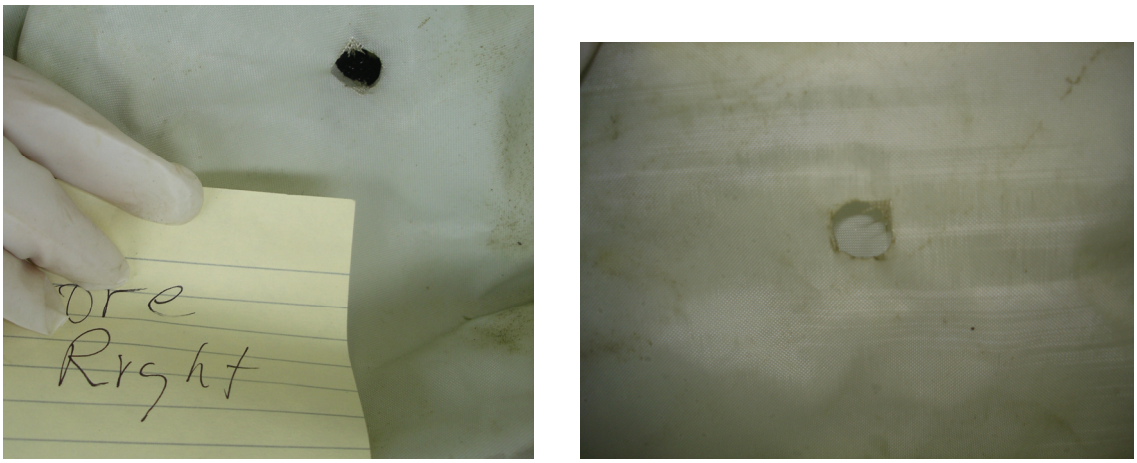


Figure 18: A photograph showing the squaring of two vent holes.

Medical/Autopsy Information:
The male occupant, the pilot, in the 1st row on the left side was initially treated at Methodist Hospital in Indianapolis, IN. (701 N Senate Ave., Indianapolis, IN 46202 (317) 962-2000) An autopsy was performed for the Marion County Coroner by Forensic Pathology Associates of Indiana. The occupant in the 1st row, right side and the occupant in the 2nd row, left side were treated at Methodist Hospital, as well. The occupant in the 2nd row, right side was initially treated at Wishard Hospital in Indianapolis (1001 West 10th St. Indianapolis, IN 46202 (317) 639-6671) and subsequently was treated at Methodist Hospital. The occupant seating location, gender, age, height, weight and injuries are listed in Table 3 below.

Table 3: A table of the occupant injury description and classification.

Occupant Location	Gender	Age	Height	Weight	Description Of Injuries	Injury Classification
1st Row, Left	M	66	5'8"	150 lbs	Subgaleal hemorrhage; left orbital roof fracture, left sided subdural hemorrhage; bilateral subarachnoid hemorrhage (diffuse); bilateral frontal and left temporal contusion; 2 sternal fractures; non-displaced posterior left 1-3rd, 6, 7, 9, 12 rib fractures; lateral left 3rd-8th rib fractures; Aortic lacerations (2cm in length and 1.5cm in length); moderate right homothorax; small left hemothorax; bilateral pulmonary contusions; transverse fracture through body of C2; burst fracture of L1, L4; bilateral L1 and L2 transverse process fractures; left transverse process fracture at L3 and L4; nondisplaced L4 laminar fractures; nondispalced fracture of the coccyx; multiple contusions and	Fatal

					abrasions on extremities; 2-3cm laceration in the left parietal scalp	
1st Row, Right	M	29	5’8”	165 lbs	Right side small subdural hematoma; right subarachnoid hemorrhage; mild right mid lobe pulmonary contusion; sternal fracture; L2 burst fracture; bilateral L1 and L2 transverse process fracture; nondisplaced right side L5 vertebral body fracture; small chin laceration; contusion to the right temporal lobe and right frontal lobe; abrasion to right lateral neck; abrasion to the right forehead and left mandibular region	Serious
2nd Row, Left	F	49	5’5”	120 lbs	Blunt trauma to chest and abdomen; L1 burst fracture; T12 posterior element fractures; nondisplaced sternal fracture; minimally displaced left 2nd, 4th, and 5th rib fractures; mildly displaced right anterior 2nd rib fracture; nondisplaced posterior left 11th rib fracture; nondisplaced right posterior 1st rib fracture; severe left mid-foot sprain; fracture anterior nasal spine of the maxilla; minimally depressed medially angulated incomplete fracture of the right nasal bone;	Serious

					chin lacerations, small right frontal scalp hematoma	
2nd Row, Right	F	60	4’11”	115 lbs	T12 burst fracture; transverse process fracture of right L1, L3 and L5 and left L1, L2, and L3; nondisplaced left 2nd-6th rib fractures; nondisplaced posterior left 9th, 10th, and 11th rib fractures; minimally displaced right 4th rib fracture; nondisplaced right 7th rib fracture; left upper back superficial burn; partial thickness burns to the back and left foot	Serious