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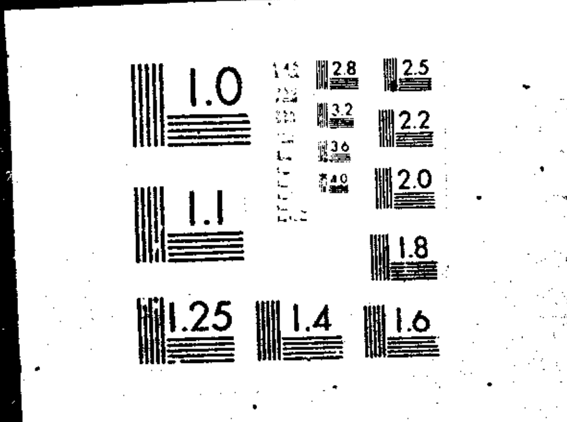

FAA-AM-80-3

LEVEL II

B.S. 10

AIRCRAFT CRASHWORTHINESS STUDIES: FINDINGS IN ACCIDENTS INVOLVING AN AERIAL APPLICATION AIRCRAFT

William R. Kirkham, M.D., Ph.D.
James M. Simpson
Terry F. Wallace
Paula M. Grape
Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, Oklahoma

April 1980

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
Office of Aviation Medicine
Washington, D.C. 20591

NOTICE

Technical Report Documentation Page

1. Report No.: FAA-AM-80-3

2. Government Accession No.: AD-A084 619

3. Recipient's Catalog No.:

4. Title and Subtitle: AIRCRAFT CRASHWORTHINESS STUDIES: FINDINGS IN ACCIDENTS INVOLVING AN AERIAL APPLICATION AIRCRAFT

5. Report Date: APRIL 1980

6. Performing Organization Code:

7. Author(s): William R. Kirkham, James M. Simpson, Terry F. Wallace, ~~and~~ Paula M. Grape

8. Performing Organization Report No.: 44

9. Performing Organization Name and Address:
FAA Civil Aeromedical Institute
P.O. Box 25082
Oklahoma City, Oklahoma 73125

10. Work Unit No. (TRAIS):

11. Contract or Grant No.:

12. Sponsoring Agency Name and Address:
Office of Aviation Medicine
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

13. Type of Report and Period Covered:

14. Sponsoring Agency Code:

15. Supplementary Notes:

This work was performed under Task AM-B-79-TOX-23.

16. Abstract

Aircraft crashworthiness features are presented, as others have done, in terms of packaging principles. Modern aerial application aircraft are recognized as being the most crashworthy in the civil aviation fleet. Eighteen accidents involving an aerial application aircraft are presented in regard to crashworthiness findings, crashworthiness being the protection afforded by the aircraft against injury to the pilots from impact forces.

A summary of findings showed that the cockpit afforded good protection but in many of the accidents pilot restraint systems failed. There were no failures in lap belts or lap belt attachments. The structural attachment of the shoulder harness failed in a rare accident and the manufacturer strengthened the attachment. In three aircraft the inertia reel, to which the shoulder harness was attached, failed, diminishing the effectiveness of the shoulder harness in attenuating impact forces on the pilots. In 14 of the 18 accidents the seat completely or partially separated from the seat track, and in 14 accidents one or more of the cast alloy seat legs or pedestals broke.

These accidents illustrate two areas of concern in terms of improved crashworthiness of these aircraft. One is the strength of the attachment of the shoulder harness, and the other is the apparent ease of detachment of seats from the seat tracks and failure (fracture) of the cast alloy seat parts--legs and pedestals in particular.

17. Key Words:
Crashworthiness
Aerial application aircraft
Crash injury
Restraint systems

18. Distribution Statement:
Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	41	

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AIRCRAFT CRASHWORTHINESS STUDIES: FINDINGS IN ACCIDENTS INVOLVING AN AERIAL APPLICATION AIRCRAFT

I. Introduction.

Crashworthiness as applied to aviation is an expression of the degree or quality of protection from injury the aircraft provides the crew and passengers in or following an impact accident. Crashworthiness in a broad sense may be thought of as including such diverse elements as maintaining structural integrity of the fuselage, attenuating impact forces on the occupants, preventing items of mass from breaking free and becoming injury-producing missiles, providing acceptable escape potential for occupants, and reducing the hazards of fire, water, and other conditions as may be incurred in an accident. One important aspect of crashworthiness is sparing occupants from the full impact forces encountered in the accident. Engineers can more readily provide systems for attenuating impact forces on the occupants than they can provide means for optimum potential for rapid evacuation or for fuel containment to avoid a postcrash fire.

Principles of attenuating impact forces on aircraft occupants have been advocated since the early 1940's and have found wide and successful application in modern agricultural application aircraft following demonstration of these principles in the AG-1, a prototype built in 1950 at Texas A&M University.

DeHaven (1), a pioneer in vehicular crashworthiness, compared the safe transportation of people in any type of vehicle to the application of practical principles used by packaging engineers.

The shipping container (the cockpit or cabin) should not open up or spill its contents (occupants) under reasonable or expected conditions of impact forces. Nor should it collapse on the occupants. Thus, occupants of the crashworthy aircraft should be surrounded by a relatively rigid envelope that will resist impact forces, will possibly deform to some extent to attenuate impact forces, but will not collapse on the occupants.

Articles contained in the package (aircraft occupants) should be held and immobilized inside the container (cockpit/cabin) to prevent movement (and resultant damage) against the inside of the package itself. In an airplane this principle calls for an effective restraint system that will hold the occupant within the crashworthy cockpit/cabin during the deceleration associated with the impact. Ideally, the occupant should be encased in a suspended impact-resistant cocoon-like structure that will prolong deceleration, thereby decreasing maximally the peak impact forces on the occupant. A modern, practical aircraft restraint system consists of a seat that will resist impact forces but will deform without breaking, a lap belt, and a shoulder harness.

A third principle of packaging is that the means of immobilizing the contents (the restraint system) inside the container should transmit forces to the strongest part of the contained article (occupant). In this regard, the seat engages the muscularly padded bony pelvis from below, supporting the body from vertical forces but also functioning to attenuate forward decelerative forces. The lap belt engages the pelvis anteriorly and laterally, and the shoulder harness engages the shoulder or shoulders and the anterior portion of the upper torso.

The inside of the container (the cockpit/cabin) should be designed to cushion and distribute impact forces over maximum surface area of the content and have yield qualities to increase deceleration time in case the content breaks loose from its restraint. To accomplish this, modern aerial application aircraft employ a relatively thin roll of aluminum at the head strike area on the instrument panel so that a prolonged broad impact may result if the pilot's head and upper torso reach the instrument panel in a crash deceleration. In such aircraft protruding knobs, handles, corners, etc., are minimized. A crash helmet worn by the pilot distributes decelerative forces over a broad area of the head to avoid focally intense forces that would fracture the skull.

Studies from the Civil Aeromedical Institute (CAMI) by Swearingen have called attention to injury patterns directly related to specific general aviation aircraft structures (2). A further study (3) analyzed crash survival in a number of agricultural aircraft accidents. The latter study illustrated many crashworthiness features of several designs of modern aerial application aircraft and pointed out that most of the specialized aircraft structures are well engineered to protect the pilots even in severe crashes. Injuries were associated with factors in restraint equipment, seats, rollover structures, and lack of attenuation of head impact at the top of the instrument panel.

As part of the continuing concern for occupant protection, research at CAMI includes continuous field investigations relative to crashworthiness, crash injury, and biomedical findings in aircraft accidents and accident victims. Because aerial application aircraft have been specifically designed to be crashworthy, selected accidents of various designs and models of aerial application aircraft have been investigated to study the dynamics of the crashes and their effects on the occupants. The decision to investigate a given accident has depended on any of a number of factors such as proximity to CAMI, funds available for travel, personnel available to investigate the accident, information relayed from investigators or persons at the scene, current interest in a specific feature that may be found in the aircraft, or request from another person involved in investigating the accident. Relative to the material in this report, no attempt was made to investigate all accidents involving any design or model aircraft over any period of time. A few of the findings in some of the accidents have been included in a previous report (3). Here we review some findings in 18 accidents involving an aerial application aircraft that represent all but one of the accidents we have investigated for one series of agricultural aircraft. In the one excluded accident, the pilot left the aircraft before impact. The accidents are reported sequentially by year of manufacturer of the aircraft, only partly reflecting the sequence in which they were investigated.

II. Review of Accidents.

Case 1. This 1967 model aircraft crashed in a heavily wooded area, breaking tree trunks up to 10 inches in diameter. The major impact forces were forward and to the left. A main impact was from contact made with a tree in the hopper (Figures 1-1 and 1-2). The cockpit sustained minimal deformation.

The pilot was wearing a lap belt and shoulder harness, but not a crash helmet. He received a fracture of the medial malleolus of the tibia and distal fibular shaft of the left leg requiring open reduction and stabilization with an orthopedic screw. There were anterior compression fractures of the 12th thoracic and 1st lumbar vertebrae and a fracture in a finger of the left hand. He received some lacerations on the face and moderate trauma to shoulders and knees.

The shoulder harness and lap belt remained intact. There was some fraying of the shoulder harness webbing at its attachment point behind the pilot, and a slight tearing of the threads securing the shoulder harness to the lap belt. The seat was completely detached from the seat tracks. The hole for engaging the seat locking pin on the left track was elongated and the seat appeared to have come off the forward end of the track (Figure 1-3). Three of the four seat-to-track attachments of the seat legs were broken, primarily by shearing of the attaching rivets (Figures 1-4 and 1-5); only one remained intact. There was a fracture of the seat back adjustment mechanism.

The left ankle and vertebral injuries were consistent with the pilot's having been propelled downward and to the left. Detachment of the seat from the track and breaking of the seat-to-track attachments increased the freedom of the pilot to move forward against the cockpit structures.

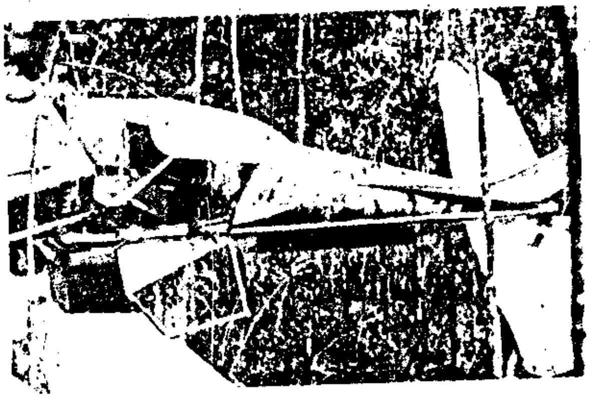

Figure 1-1. 1967 model aircraft partially suspended above ground. Cockpit structure and empennage were relatively undamaged.

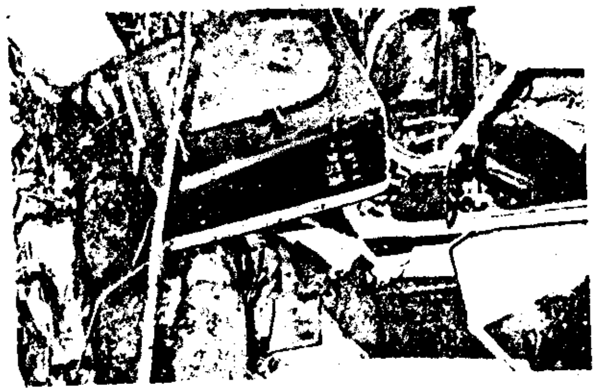

Figure 1-2. Fuselage contact with trees was above engine and into hopper of aircraft. The seat was loose in the cockpit.

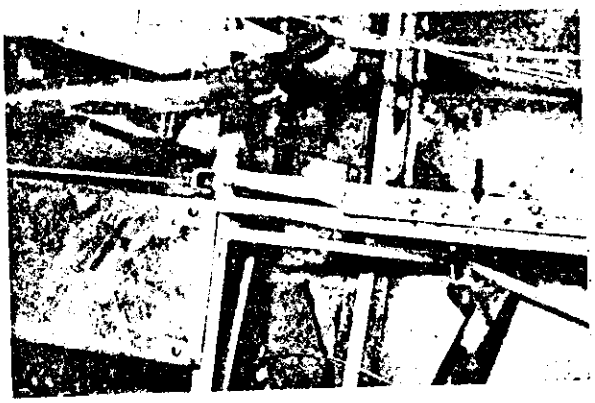

Figure 1-3. This left seat track showed elongation of the hole where the seat locking pin was apparently engaged.

Figure 1-4. Three of the seat-to-track attachments were broken and free from the seat leg by shearing of the attaching rivets or shearing of rivets and fracture of the seat leg.

Figure 1-5. Broken seat-to-track attachments free in the cockpit.

Case 2. This 1968 model aircraft crashed into trees. Both wings and the empennage were torn off (Figure 2-1). The pilot was wearing a helmet, shoulder harness, and lap belt.

The seat remained intact and on the tracks (Figure 2-2). All restraint systems appeared to have functioned properly and the pilot received no injuries in this accident of moderate impact forces.

Case 3. This 1968 model aircraft stalled at 100 to 150 feet and struck with relatively minor forces in a soft wheat field. There was slight damage to the wings and fuselage (Figure 3-1). Both landing gears were torn off. The pilot was wearing a crash helmet, shoulder harness, and lap belt. The shoulder harness, lap belt, and seat showed no evidence of impact damage. The seat remained on the track (Figure 3-2). The pilot hit the right window with his head but received no injuries in this accident.

Case 4. This 1969 model aircraft was spraying a field in level flight. The engine failed at an altitude of 75 feet necessitating a forced landing. The aircraft nosed over, damaging the propeller, overhead canopy, and vertical stabilizer (Figures 4-1 and 4-2). The pilot was wearing a lap belt and shoulder harness. There was no damage to the shoulder harness, lap belt, or seat. The pilot received no injuries.

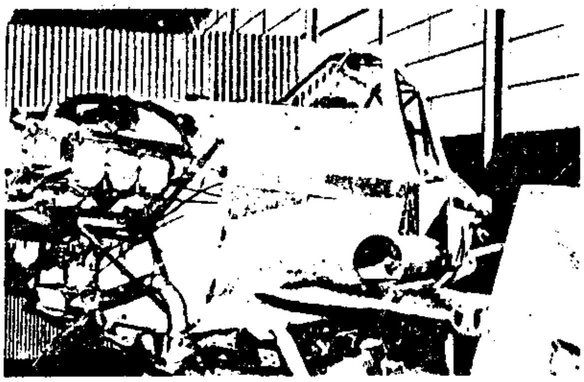

Figure 2-1. Empennage and wings were torn off this 1968 model aircraft in a crash into trees.

Figure 2-2. Seat remained in position on seat tracks and showed no failures of structures.

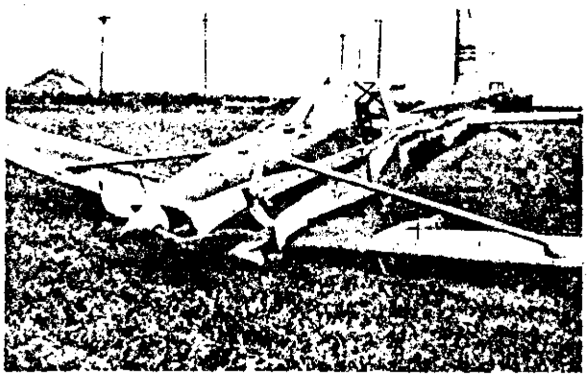

Figure 3-1. 1968 model aircraft with minor damage of wings and fuselage.

Figure 3-2. Seat and restraint systems undamaged.

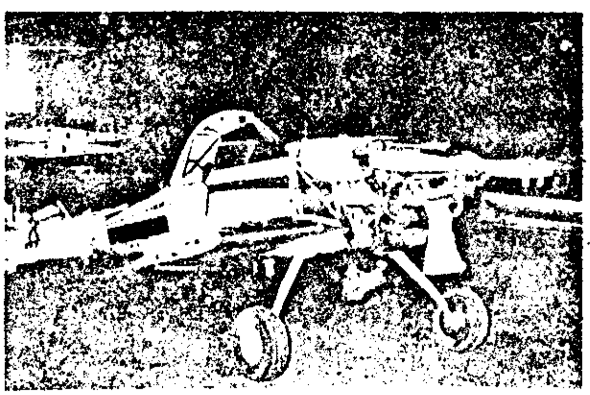

Figure 4-1. 1969 model aircraft in minor impact nosed over damaging propeller, overhead canopy and vertical stabilizer.

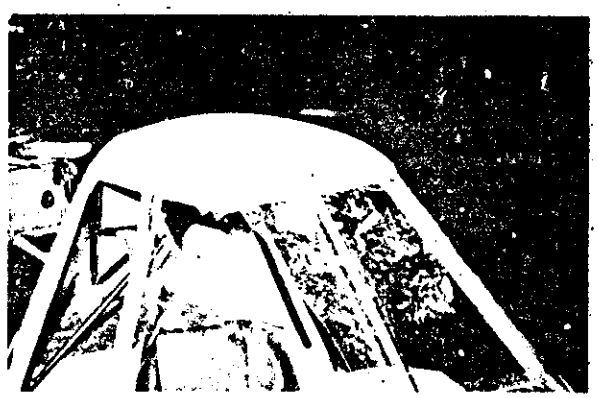

Figure 4-2. Damage to overhead canopy.

Case 5. A 1970 model aircraft lost lift in a left turn shortly after takeoff, striking a large oak tree and then the ground in a right-wing, nosedown attitude. The impact sheared both gears. The engine mounts were broken and the engine was displaced to the left. The right wing spar was fractured and the wing inverted. The cockpit structures were relatively undamaged (Figure 5-1).

The pilot was wearing a lap belt (loosely), shoulder harness, and crash helmet. He was admitted to a hospital with multiple contusions more pronounced across the right scapula and right shoulder, and suspicion of fractures of cervical vertebrae. X-ray examination did not reveal fractures.

The shoulder harness and lap belt remained intact although the shoulder harness attachment bracket was bent slightly forward. The seat was completely separated from the seat track. The right track was displaced to the right. The left track showed elongation of the hole for the locking pin and gouging along the track apparently caused by the locking pin as the seat left the track (Figure 5-2). The right front seat leg fractured at mid-shaft (Figure 5-3). The instrument panel showed an impact area with white paint consistent with a helmeted head impact to the right of center (Figure 5-4). Failure of the right front leg of the seat and detachment of the seat from the track may have let the pilot strike the right side of the aircraft injuring his right shoulder area. The straining of the neck may have been caused by head flailing due to the slack in the lap belt and the seat separation.

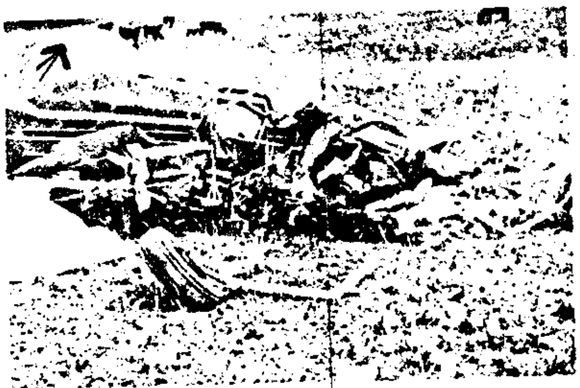

Figure 5-1. 1970 model aircraft after striking ground in right-wing nosedown attitude. Cockpit was relatively undamaged.

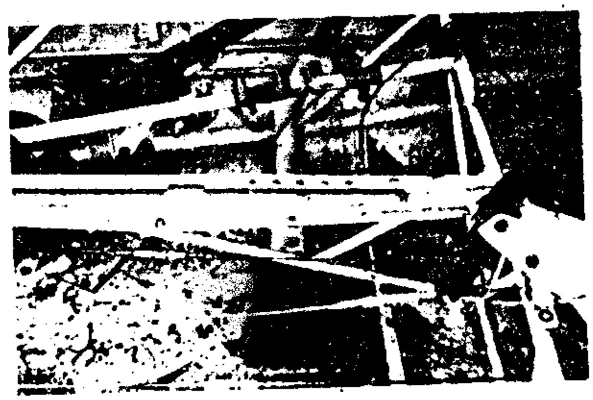

Figure 5-2. Left seat track with elongation of seat pin retaining hole and gouging of the metal forward of this hole.

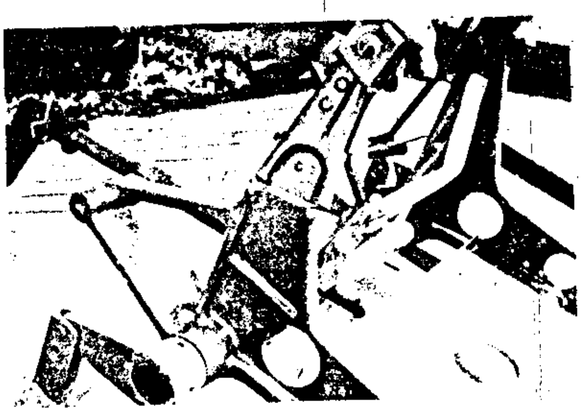

Figure 5-3. Mid-shaft break in right front seat leg. The seat was detached from the seat track.

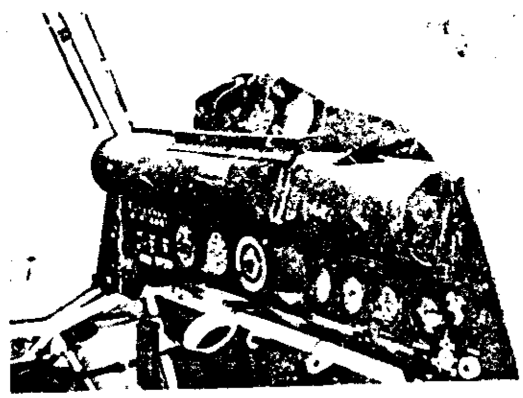

Figure 5-4. Indentation on the panel consistent with a mild head strike.

Case 6. Following the striking of a powerline this 1971 model aircraft made impact with the ground in a slight left-wing-down attitude. The engine broke downward from its mountings (Figure 6-1). The major impact forces were forward, and to the left. The pilot was wearing a lap belt, but neither shoulder harness nor crash helmet. The pilot received multiple injuries to the head including fracture of the right mandible, fracture of the nasal bone, brain concussion, multiple lacerations of the face with avulsion of the right upper eyelid and deep lacerations into the right submaxillary salivary gland. He also had a fracture of the left radius, contusions of the kidneys with hematuria and ligamentous strains in the neck at C_5 and C_6.

The shoulder harness was found hanging undisturbed from its attachment in accordance with the pilot's admission that it was not used. The lap belt and its attachments were intact. To the left of center on the instrument panel there was an indentation consistent with having been struck by the pilot's head (Figure 6-2). The seat was found detached from the seat tracks. The right track appeared normal but the left track was twisted to the left and there was a fracture where the track support was joined to a crossmember (Figure 6-3). Both forward seat legs were fractured (Figure 6-4). These findings suggest that the pilot's unrestrained torso flexed forward and his head struck the instrument panel to the left of center. The vertical and left yawing impact caused twisting of the left seat track to the left and fracture of both forward legs of the seat. Much of the severity of injury possibly could have been prevented had the pilot worn his shoulder harness and crash helmet. Detachment of the seat from the tracks and fracture of the seat legs probably allowed a greater degree of unrestrained movement of the pilot than would have occurred otherwise.

Figure 6-1. 1971 model aircraft with damage to engine and hopper area. Cockpit showed little structural damage.

Figure 6-2. Indentation on the left side of the instrument panel of the type seen with impact from the head.

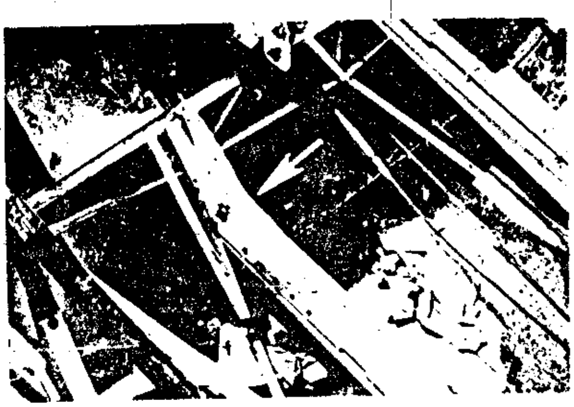

Figure 6-3. The left seat track and its support were twisted to the left.

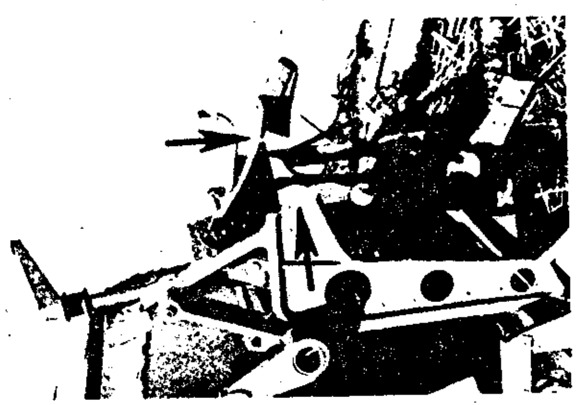

Figure 6-4. Both forward seat legs were fractured. The rivets of the leg-to-seat-track attachment were sheared.

Case 7. This 1971 model aircraft pulled up into a stall at approximately 600 feet, then made three complete spins before crashing into a cornfield at a nosedown attitude of approximately 65°, causing an impact crater 18 inches deep and 5½ feet across. The aircraft sustained extensive damage. The cockpit retained its structural outline but had various degrees of structural deformation (Figure 7-1). The pilot, wearing lap belt, shoulder harness, and helmet, was fatally injured. At autopsy the major findings were multiple lacerations and abrasions of the frontal region of the head, more extensive on the left side. There were puncture wounds of the left upper lip and chin. A 3- by 6-cm puncture wound extended through the left upper anterior chest wall with exposure of the underlying lung. The left clavicle had multiple comminuted fractures. There were fractures of the right ulna, 4th and 5th metacarpals on the left and 3rd and 4th metacarpals on the right. Both right and left femurs were multiply fractured.

The interior of the cockpit revealed that the D-ring attachment for the shoulder harness had failed (Figure 7-2). There was a large area of impact with forward deformation of the instrument panel (Figure 7-3). The lap belt was intact. The seat was detached from the track. The two forward seat-to-track attachments had failed (Figure 7-4).

This accident resulted in severe impact forces primarily directed forward. Failure of the D-ring of the shoulder harness allowed the upper torso to travel forward against the instrument panel. The field investigator believed the parking lever penetrated the left side of the chest. The forward movement of the pilot at impact was probably enhanced by fracture of the forward seat-to-track attachments and the movement of the seat off the track.

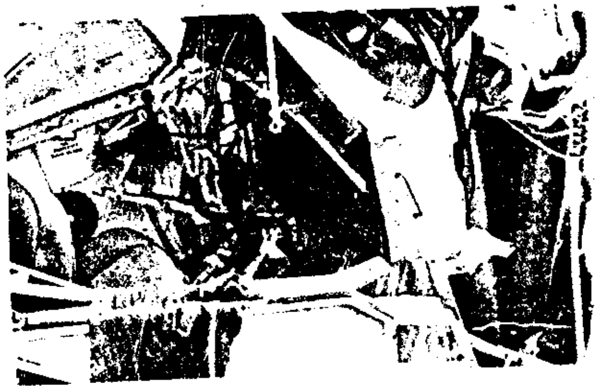

Figure 7-1. The structural outline of the cockpit of this 1971 model was relatively intact.

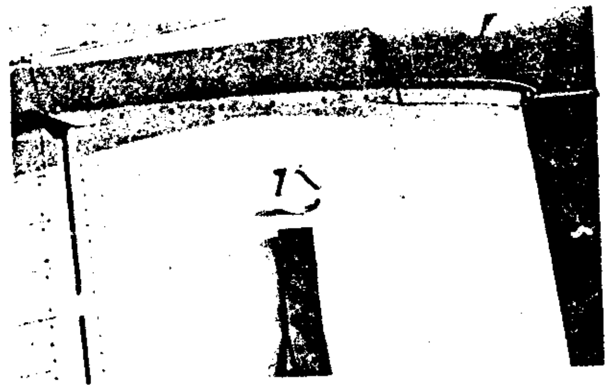

Figure 7-2. The D-ring attaching the shoulder harness was broken.

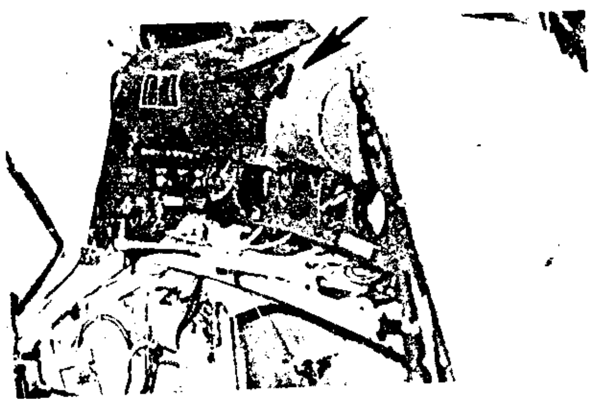

Figure 7-3. Large area of impact deformation in the instrument panel.

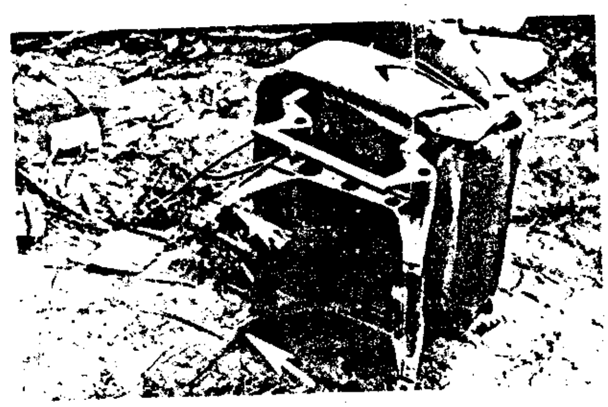

Figure 7-4. In the area of fixation of the seat track attachment to the forward seat leg the rivets were sheared and the seat legs broken.

Case 8. This 1972 model aircraft contacted three powerlines 35 feet above ground, then traveled forward 170 feet before striking the ground. The plane tumbled end-over-end another 63 feet and stopped upright. The aft portion of the fuselage and empennage were torn off. The cockpit structure remained intact (Figure 8-1). The accident was fatal to the pilot and, although no autopsy was performed, the coroner related that death was due to multiple injuries and possibly fractures of the neck.

The pilot was wearing a lap belt, shoulder harness, and crash helmet. The lap belt was found intact. The shoulder harness attachment bracket, where welded to the aft cockpit structural bars, had failed (Figure 8-2), allowing this bracket to separate from the structural members. The seat was off the seat tracks. The seat tracks were twisted slightly to the left. The left front seat leg was broken at the point of contact with the horizontal portion of the seat pedestal and the right seat-to-track attachment was broken (Figures 8-3 and 8-4). There was a broad impact indentation of the instrument panel.

In this accident of moderately severe impact forces, deceleration of the pilot's upper torso probably caused failure and separation of attachment bracket of the shoulder harness, allowing the upper torso to come forward into the instrument panel where fatal injuries were received. Failure of the seat leg on the left and the right seat-to-track attachment probably allowed the seat to detach from the track, enhancing movement of the pilot's body forward during the deceleration.

Figure 8-1. Severe impact of this 1972 model caused extensive damage but cockpit integrity was maintained.

Figure 8-2. The shoulder harness attachment bracket had failed where it was welded to the aft cockpit structural bars.

Figure 8-3. The left front seat leg and the right front seat-to-track attachments were broken.

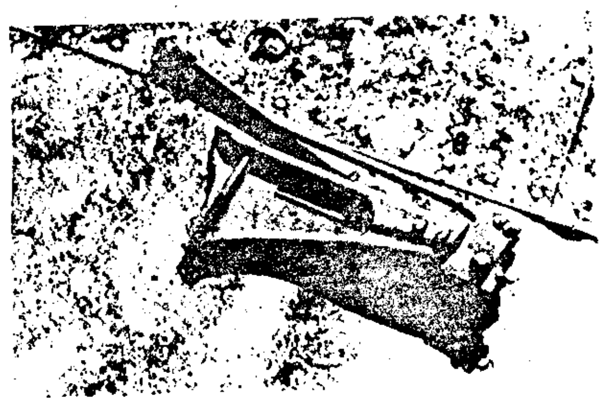

Figure 8-4. Broken left front seat leg.

<u>Case 9</u>. This 1972 model aircraft, on fuel exhaustion, stalled and struck the ground in a 45° nosedown attitude. There was moderately severe damage to the engine and hopper area of the aircraft. The pilot was wearing a lap belt, shoulder harness, and crash helmet. The pilot sustained a contusion and laceration to and above the right eye and fractured left arm and left knee. He had conspicuous shoulder harness and lap belt abrasions and contusions.

The cockpit remained structurally intact (Figure 9-1). The shoulder harness attachment brace was deformed forward (Figure 9-2) but the shoulder harness remained intact. There was a head impact type deformation of the instrument panel (Figure 9-3). The lap belt remained intact. The seat was found detached from the seat tracks and a locking pin hole on the left seat track showed forward elongation probably caused by forcible displacement of the seat retaining pin as the seat came forward during deceleration. The forward portion of each seat pedestal was fractured and the track attachment mechanisms were deformed (Figure 9-4).

During deceleration this pilot exerted considerable force on the shoulder harness causing the attachment bracket to deform forward. The shoulder harness and lap belt held but the seat fractured and came off the seat track. The forward bending of the shoulder harness attachment bracket and the forward displacement of the seat from the seat track probably permitted the pilot to be thrown forward more forcibly increasing the severity of injuries.

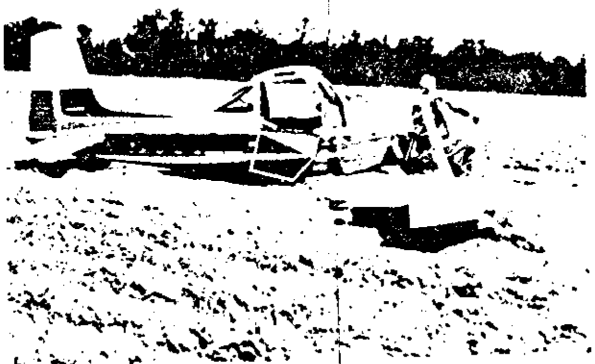

Figure 9-1. 1972 model with substantial engine, hopper and wing damage but intact cockpit.

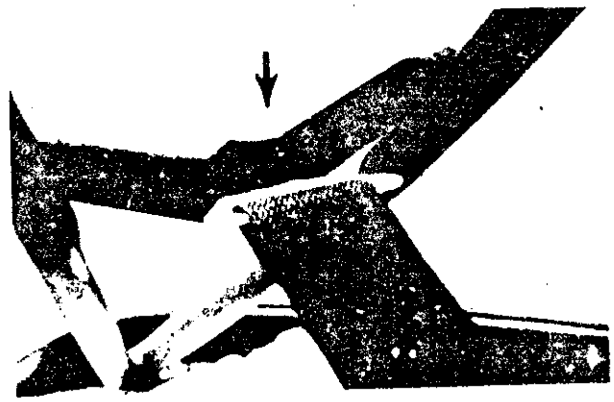

Figure 9-2. Forward bending of shoulder harness attachment bracket indicated considerable force exerted to this structure during deceleration.

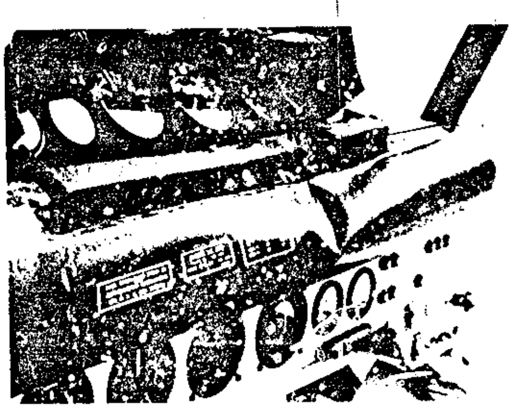

Figure 9-3. Instrument panel deformation of the type caused by head impact.

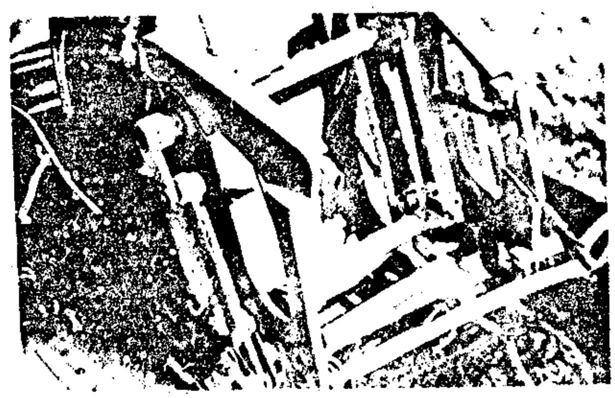

Figure 9-4. Fractured seat pedestals on each side and deformed seat track attachments.

Case 10. Smoke was observed coming from this 1972 model aircraft at about 100 feet of altitude. The aircraft nosed over and struck at a 65° nosedown and right-wing-down attitude.

There was marked damage in the engine and hopper areas; the cockpit canopy was displaced upward (Figure 10-1). The pilot was wearing a lap belt and a shoulder harness but not a crash helmet. The accident was immediately fatal to the pilot. No autopsy was done but it was observed that there were extensive skull fractures with blood and spinal fluid coming from the left ear canal, multiple lacerations of the face, a fracture of the right forearm, and minor burns on each hand. There was an indentation at the extreme right of the instrument panel with tissue debris present, consistent with a head impact (Figure 10-2). The restraint system attachments and webbing remained intact except that the right shoulder strap separated where it was sewn to the lap belt (Figure 10-3). In this area the threads were torn. The seat completely separated from the seat track. The right front seat-to-track attachment was spread and the seat leg completely fractured at mid-shaft (Figure 10-4). The three remaining seat-to-track attachments were spread; the locking pin rod was bent and the locking pin retracted.

In this severe nosedown, right-wing-down impact, the pilot during deceleration was thrown forward and to the right. The failure of the right shoulder strap where attached to the right limb of the lap belt probably permitted the pilot to travel forward and to the right striking his head on the right side of the instrument panel and cockpit frame. Separation of the seat from the track probably added to the freedom of the pilot to travel forward. The slack in the lap belt customarily used by this pilot probably increased the peak loading on the right shoulder strap. Use of a crash helmet undoubtedly would have lessened the extent of head injuries.

Figure 10-1. General cockpit integrity was maintained but the left side of the cockpit and wind screen was broken and displaced upward.

Figure 10-2. The right side of the instrument panel was deformed, consistent with head impact.

Figure 10-3. The right shoulder harness was detached from the right side of the lap belt. The torn threads were evident.

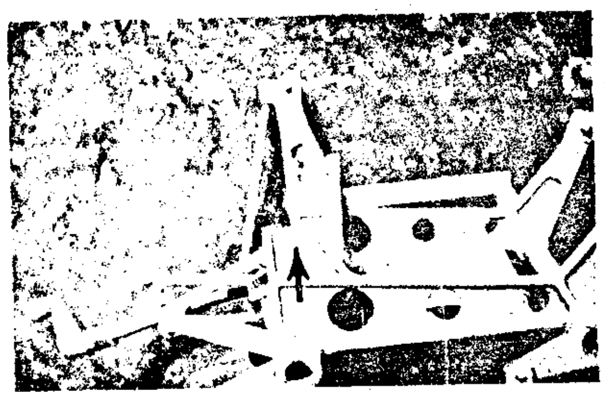

Figure 10-4. The right front seat leg was broken.

Figure 10-5. The left front seat-to-track attachment was spread and the seat track locking pin was retracted.

Case 11. This 1972 model aircraft had engine failure shortly after takeoff. The aircraft descended through trees and struck a slight downslope in a left-wing-low attitude (Figure 11-1). The left wing deformed backward; the left gear was separated. The engine was displaced downward and to the left and the frame was bent in the hopper area. The pilot was wearing a lap belt, shoulder harness, and crash helmet. The pilot had lacerations of the nose and chin (with red plastic material buried in his chin) and fracture of the left wrist. The center of the instrument panel was moderately deformed and there was breakage of a red plastic row counter (Figure 11-2); this damage was consistent with a head impact. The lap belt and shoulder harness were undamaged but the shoulder harness was extended its full length from the inertia reel. The inertia reel housing was intact but the tips of some of the reel ratchet gears showed impact flattening and the engaging pall showed impact abrasive grooving (Figure 11-3). A portion of the plastic inertia-activating mechanism was broken. The seat was detached from the seat track. Both forward seat legs were fractured near the seat-to-track attachments (Figure 11-4). The rear seat-to-track attachments remained essentially undamaged but were detached from the track.

The forces in this accident caused the pilot to travel forward against the shoulder harness. Failure of the inertia reel to completely engage and hold, thereby letting the shoulder harness fully extend, probably accounts for the pilot's head striking the instrument panel. Fracture of the forward legs of the seat and the seat separation probably added to freedom of the pilot to come forward.

Figure 11-1. The cockpit showed no structural damage.

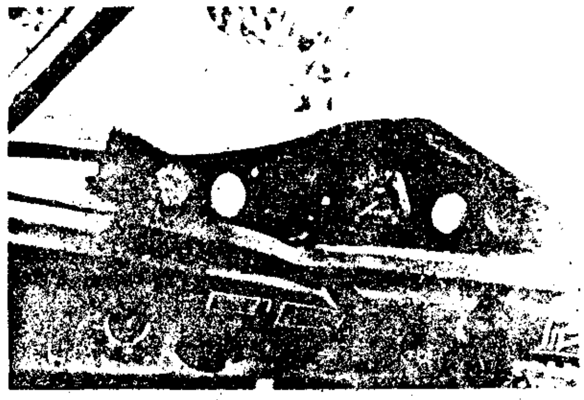

Figure 11-2. There was deformation of the instrument panel and the plastic row counter was broken.

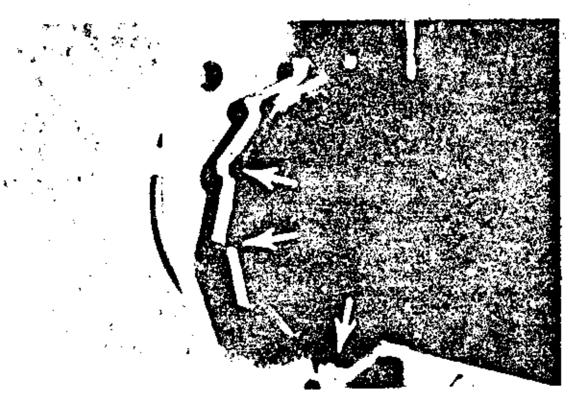

Figure 11-3. The reel ratchet gears were flattened and the engaging pall was grooved.

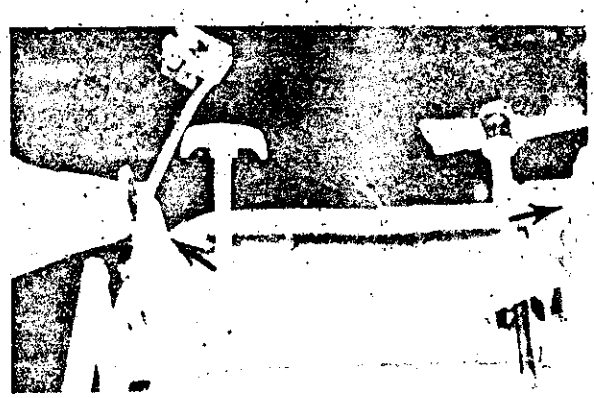

Figure 11-4. The front legs of the seat were broken.

Case 12. During routine operations the engine on this 1973 model aircraft blew the top off a cylinder, filling the cockpit with smoke. The pilot opened the doors to see and hit the ground at a slightly nosedown attitude. The aircraft slid on the level wheat field and struck a drainage terrace causing the gears to collapse. There was some damage to the bottom of the fuselage but very little structural damage (Figure 12-1). The pilot was wearing a lap belt, shoulder harness, and crash helmet. The pilot was able to get out of the aircraft but had pain in the back. X-ray examination showed a compression fracture of the 12th thoracic vertebra. The lap belt, shoulder harness attached to an inertia reel, and seat showed no damage. There was no evidence of the pilot's having struck the instrument panel.

This was a relatively minor impact with peak loading when the aircraft struck the terrace, collapsing the gears and apparently causing significant vertical loading at that time to cause a compression fracture of a vertebra.

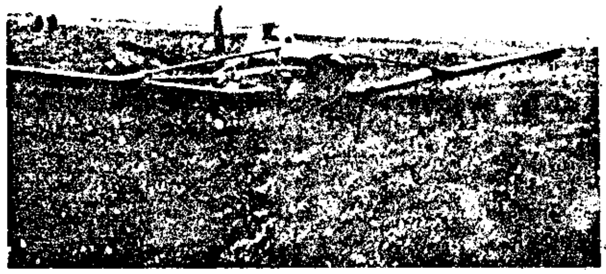

Figure 12-1. 1973 model with smoke from engine obscuring pilot's vision struck the ground in near horizontal attitude. Gears collapsed as aircraft hit a terrace. Restraint systems functioned normally but pilot received a compression fracture of a thoracic vertebra.

Case 13. This 1974 model aircraft struck a dike around an oil drilling rig. The engine, wings, gear, hopper, and empennage broke off as the aircraft rolled to the right. The cockpit came to rest upright. The pilot was wearing lap belt, shoulder harness, and helmet. The pilot received only minor injuries.

Although the aircraft was severely damaged, the structural integrity of the cockpit was maintained (Figure 13-1). There was no damage of the instrument panel. The seat tracks were undamaged. Both right seat and left front seat legs were broken above the seat-to-track attachment. The remaining portion of the right seat legs punctured the floor. The left rear seat track attachment was spread. The lap belt and shoulder harness were intact.

This accident was investigated primarily to examine the shoulder harness attachment bracket in an accident with such severe aircraft damage. The modified attachment (see discussion) apparently held the load well during the deceleration (Figure 13-2). The seat broke but the pilot was restrained and protected sufficiently to avoid serious injury.

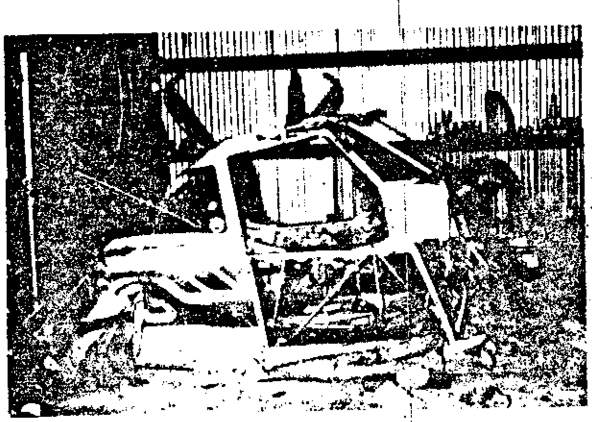

Figure 13-1. Only the structural integrity of the cockpit is maintained in this aircraft.

Figure 13-2. The shoulder harness attachment bracket has been modified and adequately supported the shoulder harness and pilot in the deceleration.

Case 14. This 1974 model aircraft experienced engine malfunction during a swath run. In an attempt to land, the aircraft struck several large trees and the ground in a nose-down and left-wing-down attitude. The engine was broken downward and the hopper area received considerable downward deformation. There was breakage of the cockpit frame to the left of the instrument panel (Figure 14-1). The pilot was wearing a lap belt, shoulder harness, and crash helmet. He died of traumatic injuries which at autopsy were revealed to be multiple fractures of the face involving frontal sinuses and upper jaw, multiple fractures of ribs, fractures of the right distal humerus and right lower leg, transection of the aorta and exsanguination.

There was a broad impact area on the instrument panel (Figure 14-2). The shoulder harness attachment bracket was bent forward and the shoulder harness had failed at its attachment to this bracket (Figure 14-3). There were fractures of all but the right rear seat leg (Figure 14-4).

In this severe accident the forward force of the pilot's body during deceleration probably caused forward deformation of the shoulder harness attachment bracket and overloading to an extent that caused failure of the attachment of the shoulder harness to the attachment bracket. The pilot was thereby allowed to come forward and strike the instrument panel. Breakage of the legs of the seat probably gave additional freedom for the pilot's body to move forward.

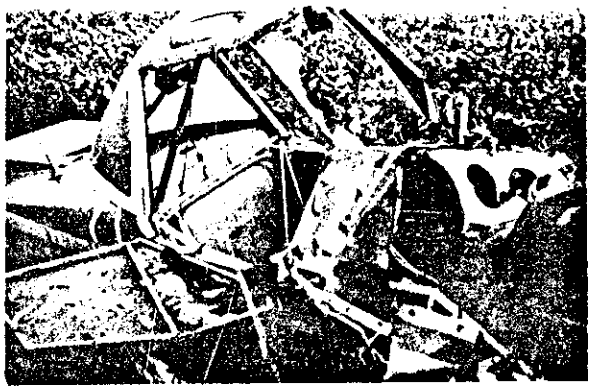

Figure 14-1. Severe impact of this 1974 model caused fracture of left structural member of the cockpit.

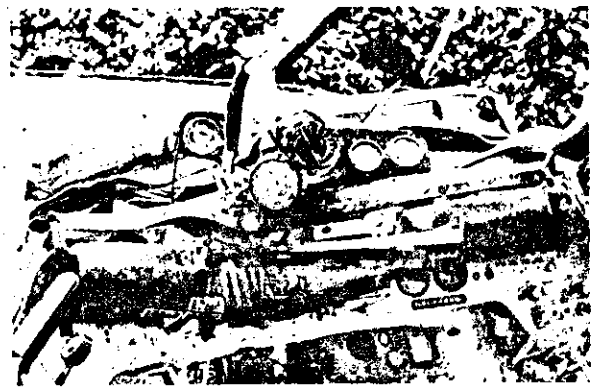

Figure 14-2. A broad torso impact area was present on the panel.

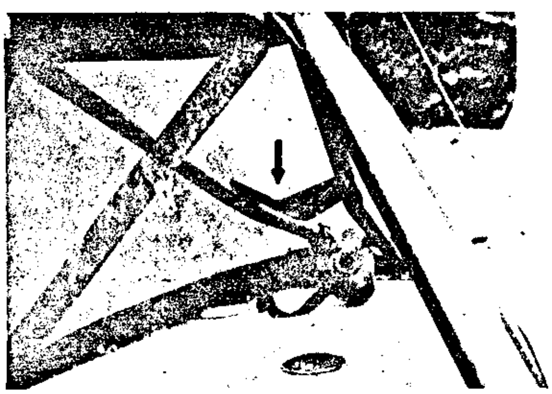

Figure 14-3. The shoulder harness attachment bracket was bent forward and the shoulder harness attachment to the bracket had failed.

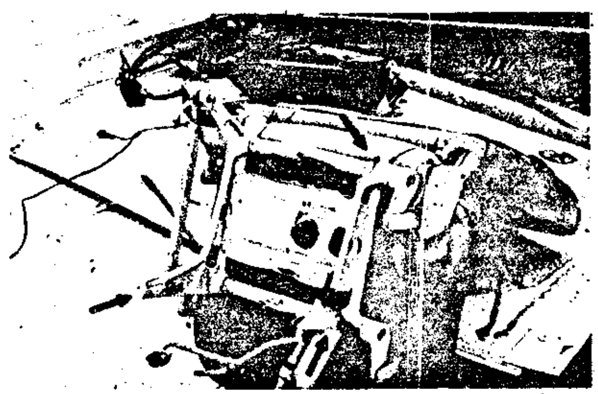

Figure 14-4. Three seat legs and seat pedestal were broken.

Case 15. This 1974 model aircraft lost altitude in a left turn and struck the ground in a nosedown and left-wing-down attitude. It cartwheeled to the left, struck the ground inverted, bounced, and came to rest upright. The engine was torn off, the hopper was crushed, and the frame forward of the cockpit was bent downward and to the left. Overhead structure of the cockpit was deformed downward 10 inches on the right side but the frame remained intact (Figure 15-1). The structural support of the instrument panel was broken permitting forward and aft movement of the panel on the left side.

The pilot was wearing a lap belt, shoulder harness and crash helmet. The pilot received severe trauma to the face with multiple fractures of facial bones and a fracture of the frontal bone of the skull with posterior displacement of the face. There were fractures of the left wrist, left ankle, and a finger of the left hand, and multiple abrasions and lacerations of the chest and shoulders. There were no fractures in the chest. The pilot survived and recovered to return to flying. The lap belt was intact. The shoulder harness was intact as was the inertia reel. There was a moderate forward bending of the rising aft cockpit structural bars where the inertia reel attachment was welded (Figure 15-2). There was a forward indentation of the roll of aluminum on the instrument panel consistent with impact by the lower portion of the pilot's face (Figure 15-3). An underlying transverse instrument panel support was deformed forward consistent with loading by severe head impact forces. The seat was loose in the cockpit. The left seat pedestal had complete fractures of the vertical and horizontal supports (Figure 15-4). The seat locking pin, which was deployed in the fractured area of the seat pedestal, was displaced aft and appeared to have been forcibly disengaged from the track.

The pilot's major injuries probably resulted from head impact with the instrument panel, partly because the pilot wore his lap belt loose and because of fractured instrument panel support structures that allowed the instrument panel to displace aft to the pilot's head during the impact. Fracture of the left seat pedestal and displacement of the seat forward off the seat tracks probably allowed greater freedom for the pilot to move forward during the impact.

Figure 15-1. The engine and hopper were broken downward and to the left. The overhead cockpit structure was deformed downward on the right.

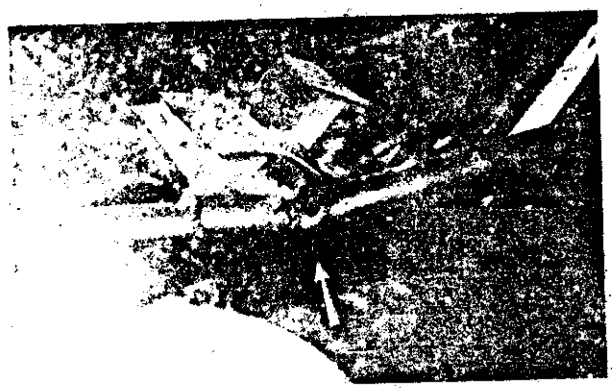

Figure 15-2. The rising aft cockpit structural bars were bent forward at the site of welding of the inertia reel support bracket.

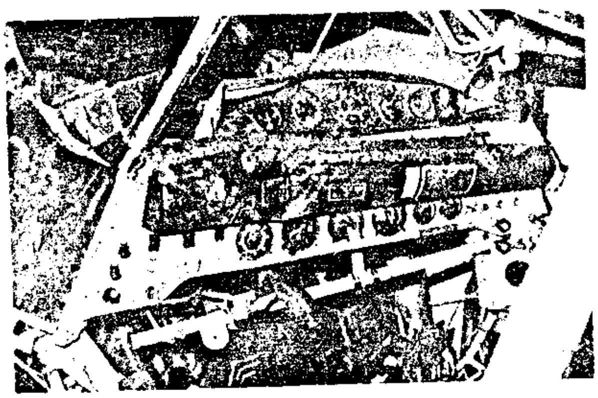

Figure 15-3. The roll of aluminum on the instrument panel was deformed forward.

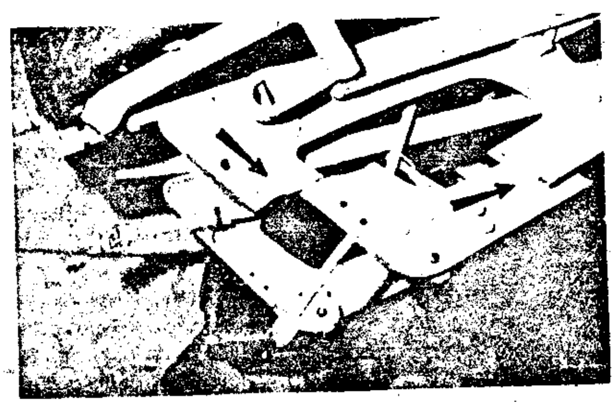

Figure 15-4. The left seat pedestal was fractured in two places and the seat locking pin was displaced aft. The seat was loose in the cockpit.

Case 16. This 1974 model aircraft nosed down in a right turn and struck the ground at a 45° angle. The engine and hopper were broken downward and displaced slightly to the left (Figure 16-1). The pilot was wearing a lap belt, shoulder harness, and crash helmet. Two hours after the crash, the pilot was found sitting lifeless outside the aircraft. An autopsy revealed fractures of the nose, frontal sinuses, mandible, 5th, 6th, and 7th left ribs, right femur and left fibula; a large amount of blood in and behind the abdomen secondary to trauma to the bowel; bilateral contusions of the lungs; and lacerations of the right leg, hip and chin. Death was attributed to shock due to trauma and blood loss.

The lap belt was intact. The shoulder harness was intact and there was a slight bending forward of the shoulder harness attachment bracket. Centrally in the instrument panel was a broad impact area consistent with being struck by the cockpit occupant (Figure 16-2). The seat was loose in the cockpit and the two front legs and left rear leg were broken. There was a fracture in both horizontal seat frames (Figure 16-3).

It appears the pilot, even though severely injured, was able to get out of the aircraft but expired before rescuers arrived. The head injury was probably caused by the pilot's head striking the instrument panel. The shoulder harness showed evidence of loading during the deceleration and the left rib fractures may have been due to a greater left shoulder strap pull on the left side of the chest. The pilot's striking the instrument panel so forcibly while wearing a shoulder harness suggests that the pilot's body may have come through the shoulder harness because the shoulder harness was loosely worn or the shoulder harness slid laterally off the shoulder of the pilot. Some paint on the shoulder harness (Figure 16-4) suggests that there was forcible contact between the shoulder harness strap and the seat back. The seat leaving the track and fracture of the seat legs probably gave greater freedom for the occupant at impact to possibly rotate forward and upward through the shoulder harness. The internal abdominal bleeding is consistent with the lap belt having ridden above the pelvis, compressing the abdominal viscera as the seat broke from under the occupant.

Figure 16-1. Severe impact on this 1974 model broke engine and hopper downward. The structural integrity of cockpit was preserved.

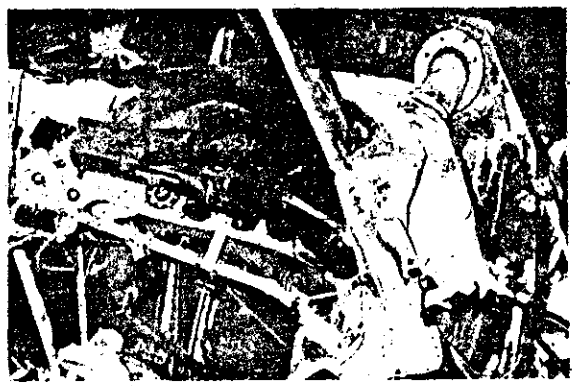

Figure 16-2. A broad forward deformation of the instrument panel was consistent with the pilot's being thrown forward into it during the deceleration.

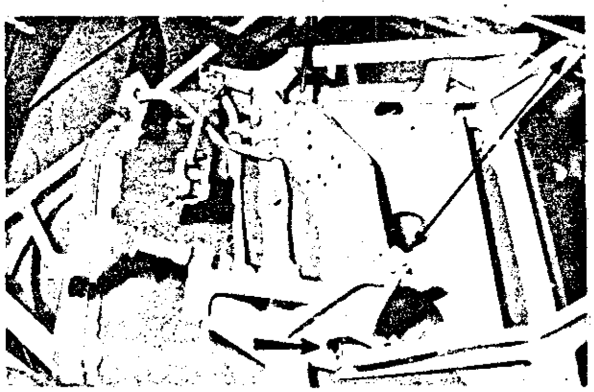

Figure 16-3. The seat-to-track attachments were broken on three of the seat legs and both horizontal portions of the seat frame were broken.

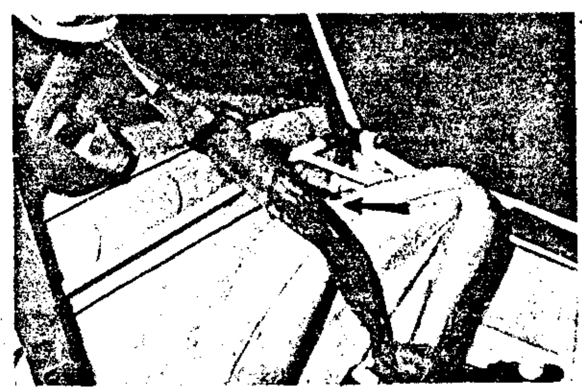

Figure 16-4. Blue color of seat material was apparently transferred to shoulder harness during impact (see text).

Case 17. On flying toward the sun the pilot of this 1976 model aircraft let the aircraft strike the ground breaking loose the right wing and right gear. The engine contacted the ground and the aircraft pivoted to the left and slid backwards into trees. The engine separated from the aircraft and the hopper was bent to the right. The major cockpit structural damage was a break on the right side where the instrument panel attached to the fuselage. There was some compression of the cockpit on the right (Figure 17-1).

The pilot was wearing a lap belt and shoulder harness but not a crash helmet. The pilot had trauma to the face with multiple lacerations and fractures of the nasal bone and right maxilla. There was a compression fracture of the third lumbar vertebra and contusions and abrasions of the right thigh, lower leg, abdominal wall and chest.

The lower right side of the instrument panel was indented and switches in this area were bent to the right (Figure 17-2). There were no other impact areas on the instrument panel. The lap belt was intact. The inertia reel frame was still attached to its mounting bracket, but the reel housing was fractured and the spool was completely detached (Figure 17-3). The shoulder harness webbing was attached to the separated spool but at the point of attachment to the spool the webbing was torn three-fourths through the width of the belt (Figure 17-4). The seat was found attached to the seat tracks by the front attachments only. The aft seat-to-track attachments were spread and detached from the tracks. The right seat locking pin was completely broken at the upper portion of the alignment bracket. There was a crack in the left seat pedestal near the locking pin but this did not compromise the structural integrity of the pedestal. There was considerable damage to the left seat track forward stop.

With impact forces down and to the right, the occupant probably traveled forward against the shoulder harness and the inertia reel stopping mechanism engaged momentarily, but the inertia reel housing failed, allowing the belt to spool out and separate from the reel housing. This let the pilot's head strike the instrument panel where he received the head injuries. During the impact the rear seat legs apparently detached; the locking pin broke allowing the seat to go forward and probably rotate upwardly increasing loading on the shoulder harness. The left-to-right tear in the shoulder harness webbing is consistent with the occupant's being thrown forward and to the right causing greater loading on the left shoulder harness. The compression fracture of the lumbar vertebra was probably incurred at the time of peak loading at initial impact but might have occurred when the aircraft struck trees on its slide backwards.

Figure 17-1. The engine separated from the aircraft and the hopper was bent to the right with breaking of the right instrument panel attachment.

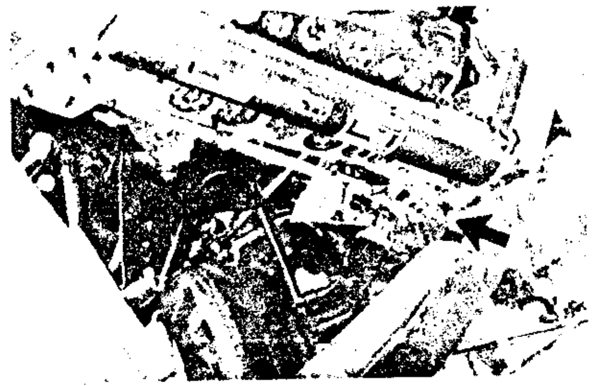

Figure 17-2. Lower right portion of instrument panel showed damage consistent with having been struck by pilot's head.

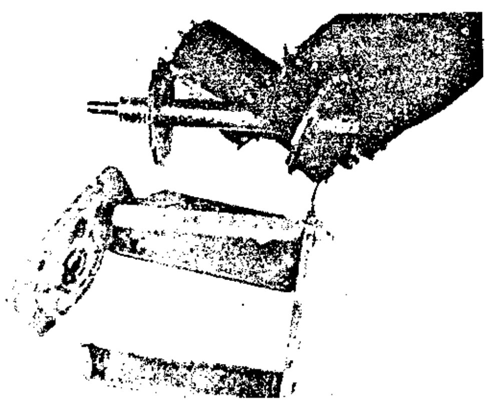

Figure 17-3. Inertia reel housing was broken and spool was completely separated.

Figure 17-4. Shoulder harness retainer was displaced from reel axle and belt was torn.

Case 18. This 1977 model aircraft stalled at 3,000 feet, entered a flat spin striking the ground in a nosedown attitude, and stopped abruptly in a soft plowed field. The engine and hopper were deformed downward and there was damage to the underside of the fuselage and main gear. There was a 3-inch fracture aft of the cockpit (Figure 18-1).

The pilot was wearing a lap belt, shoulder harness, and crash helmet. He had a fracture of the left fibula at the ankle, a compression fracture of the 11th thoracic vertebra, and lacerations on the front and back of his head. The instrument panel was deformed forward slightly to the left of center (Figure 18-2), consistent with having been struck by the pilot's head. There was a deformation of a bulkhead ledge behind the seat consistent with having been struck by the pilot's head on the rebound. The lap belt was intact. Inertia reel parts were found scattered throughout the cockpit area. The inertia reel housing, spool, and belt were still attached to the mounting bracket (Figures 18-3 and 18-4). The belt was fully extended and the webbing was intact. On the right ratchet (toothed wheel) of the inertia reel all teeth were blunted by force except for one, which was broken off. The right end of the engaging pall was broken where it passed through the housing. The ratchet wheel on the left side was jammed between the housing and locking bar (Figure 18-5). The seat was detached from the seat tracks and three legs were fractured just above the seat track attachment (Figure 18-6). The unbroken seat-to-track attachment on the right rear leg was slightly spread.

This was a predominantly vertical loading accident. During deceleration the pilot traveled forward against the shoulder harness. The inertia reel apparently engaged but the force caused failure of the locking mechanisms. This failure probably allowed the shoulder harness to fully extend and the pilot to strike the instrument panel. The breaking of the seat legs allowed more freedom for the pilot to come forward into the instrument panel and rebound. The crash helmet probably prevented serious or even fatal head injuries.

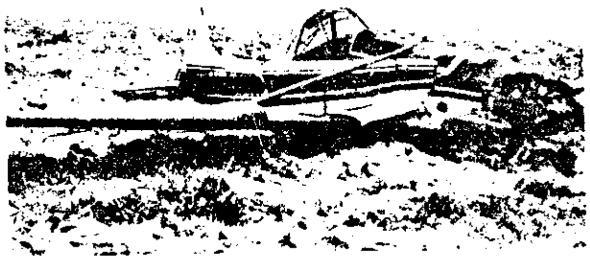

Figure 18-1. This 1977 model aircraft struck the ground in a flat spin. Downward deflection of structures indicated considerable vertical loading.

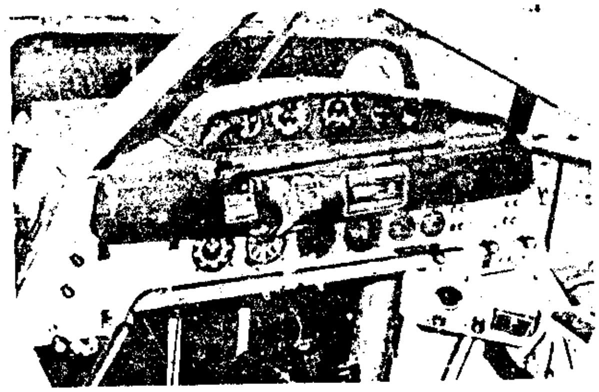

Figure 18-2. Instrument panel showed forward deformation probably caused by pilot's head.

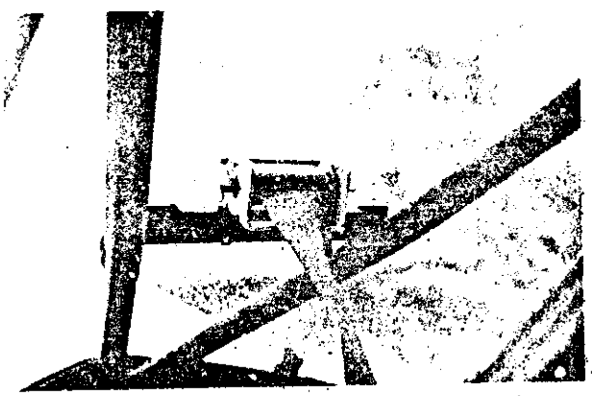

Figure 18-3. Inertia reel housing, reel, and belt remain attached but other parts of reel were scattered throughout the cockpit.

Figure 18-4. Inertia reel parts recovered from cockpit.

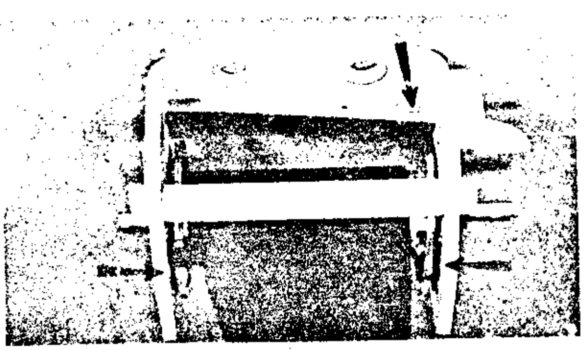

Figure 18-5. Teeth on the ratchet were blunted. On the left, the toothed gear was jammed between the engaging pall and the housing and on the right the locking bar was broken as it passed through the reel housing.

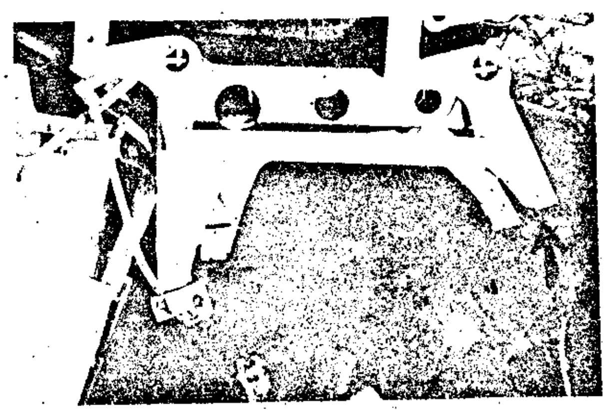

Figure 18-6. Both front legs and the right rear leg were broken near seat track attachment. Seat track engaging mechanism was bent and the pin was deformed rearward.

TABLE 1. Major Crashworthiness Findings in Studied Accidents

Case No.	Cockpit Structural Damage	Lap Belt	Shoulder Harness Attachment	Shoulder Harness Webbing
1	minor	0*	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	minor	0	bent forward	0
6	minor	0	--------not worn----------	
7	moderate	0	D-ring failed	0
8	minor	0	attachment failed	0
9	0	0	bent forward	0
10	moderate to severe	0	attachment to lap belt failed	0
11	0	0	inertia reel failed	0
12	0	0	0	0
13	minor	0	0	0
14	severe	0	brace bent, attachment failed	0
15	moderate to severe	0	0	0
16	minor to moderate	0	0	0
17	moderate	0	inertia reel failed	partly torn
18	minor	0	inertia reel failed	0

*No significant findings

TABLE 1. (Continued)

Seats Attached to Tracks?	Seat Legs	Helmet Worn?	Injury
detached	3 broken	no	serious
attached	0	yes	none
attached	0	yes	none
attached	0	no	none
detached	1 broken	yes	moderately serious
detached	2 broken	no	very serious
detached	2 broken	yes	fatal
detached	2 broken	yes	fatal
detached	pedestals broken	yes	serious
detached	1 broken	no	fatal
detached	2 broken	yes	minor
attached	0	yes	moderately serious
detached	3 broken	yes	minor
detached	3 broken	yes	fatal
detached	pedestal broken	yes	very serious
detached	3 broken	yes	fatal
back legs detached	pedestal cracked	no	serious
detached	3 broken	yes	serious

III. Discussion.

The findings in these 18 accidents are grouped into broad categories and summarized in Table 1. On review of these accidents and this summary, it is obvious that the cockpit structure around the pilot or, in packaging terms, the container in which the aerial application pilot is packaged, is good and can withstand rather severe impacts with little deformation.

How well is the pilot restrained in this crashworthy cockpit? The lap belt attachments or webbing did not fail in any of the accidents reported. In one accident (case 10) the threads attaching a right shoulder harness strap to the lap belt tore, letting the belts separate. Shortly after this accident the manufacturer took steps to replace belts sewn in this manner with belts in which the shoulder harness strap was lengthened and wrapped around the lap belt and then sewn.

The most important way to prevent serious or fatal injuries in pilots is to keep the head and chest from striking the instrument panel and other objects in the cockpit during decelerations. In the accidents cited there are instances where the shoulder harness performed this life-saving function well. In other accidents it did not function as well. In cases 5 and 9 the shoulder harness bracket attached to the aft rising cockpit structural bars was bent forward (but held) by the force of the pilot's body on the shoulder harness during the deceleration. In case 7 the force was enough to cause the D-ring to fail. In case 8 the shoulder harness attachment bracket failed where it was welded to the aft rising cockpit structural bars. This failure was probably a significant factor in the severity of the pilot's injuries. The finding of this failure of a shoulder harness attachment bracket was communicated to the manufacturer and a modification was made using a longer piece of metal and welding it more securely to the cockpit structural bars. That this modification was effective is illustrated by case 13 (see modification in Figure 13-2). This aircraft was badly damaged. The cockpit remained intact. The shoulder harness held and the pilot suffered only bruises and soreness. The modification is also illustrated in case 15.

In three accidents reported here involving models of this aircraft there have been malfunctions in the inertia reels. In one case (case 11) the inertia reel locking mechanism apparently failed to fully engage and hold. The shoulder harness was allowed to play out and the pilot was not afforded the protection of a securely held shoulder harness. In two other accidents (cases 17 and 18) there were failures of metal and mechanisms in the inertia reels that rendered the shoulder harness relatively ineffective. The review of findings in this limited series of accidents suggests that the fabric portions of the lap belts and shoulder harnesses are strong and adequate and that the weakest portion of the restraint system is the attachment for the shoulder harness. The few cases in which the inertia reel failed suggest that if the convenience of an inertia reel is to be provided, a stronger reel with a more reliable engaging mechanism should be installed.

The accidents demonstrate that the most consistent failure in the pilot's r-straint system in this aircraft is the seat. The seat is an integral rt of the restraint system, counteracting vertical and to some extent forward decelerative forces. As these forces are major in almost all aircraft accidents, a crashworthy seat is essential. It should cushion (prolong deceleration) the occupant from impact forces and distribute these forces over as large an area of the occupant as possible. The seat should be firmly attached to the floor on supporting structures or deform progressively. In most of the accidents cited the seats were found to be loose in the cockpit, completely detached from the seat tracks. Several factors appear to be responsible. First and foremost is that the legs or pedestals of the cast alloy seats break, as is evidenced in the majority of the accidents cited. These fractures occur in structural members or as a result of shearing of rivets where the seat track attachment portion is affixed to the cast leg. These findings indicate that this metal alloy fractures when subjected to the forces operative in most accidents. Such fractures attest to sudden structural failures allowing the occupant to move during deceleration with possible peak loading when finally stopped.

Secondly, the seats are secured to the tracks by metal pieces that extend around the upper portion of the track but allow enough room for the seat to be adjusted fore and aft. On impact these clasps appear to spring open allowing the seat to detach from the track.

A third factor operational in the seat's leaving the track is the seat-to-track locking arrangement. Aircraft manufactured prior to 1976 have a mechanism attached to the left front leg of the seat which deploys a pin that engages a hole in the seat track to lock the seat in place. Aircraft manufactured in 1976 and thereafter have a similar mechanism attached to each front leg. In accidents the legs are frequently broken and thus the pin-stop mechanisms are detached and the seat is free to travel forward on the track. In other accidents the pin is found to be bent, retracted, or broken and displaced from the hole in the track by the force of the impact. A more secure locking mechanism would help keep the seat from detaching from or coming [illegible] seat tracks.

The packaging principle of [illegible] as widely as possible over the contained articles was [illegible] pilots in these accidents. The aluminum roll [illegible] functioned in this regard in some cases, but in [illegible] wear a crash helmet so they did not have the bene[illegible] buting impact forces widely over the skull. Other pilots [illegible] wear a shoulder harness or had the custom of wearing the shoulder harness rather loosely. Such factors contributed to the severity of the injuries in some of these accidents.

Aerial application aircraft embody, more than elsewhere in civil aviation, the basic principles of crashworthiness, and many of these accidents illustrate well their crashworthiness. On the other hand, these accidents illustrate two areas of concern in terms of improved crashworthiness of these aircraft. One is the strength of the attachment of the shoulder harness, and the other is the apparent ease of detachment of seats from the seat tracks and failure (fracture) of the cast alloy seat parts--legs and pedestals in particular.

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