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Safety Report - General Aviation
Crashworthiness Project: Phase 3
Acceleration Loads and Velocity Changes of
Survivable General Aviation Accidents

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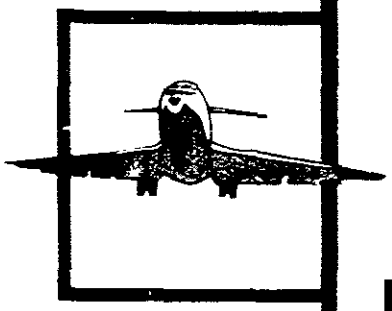

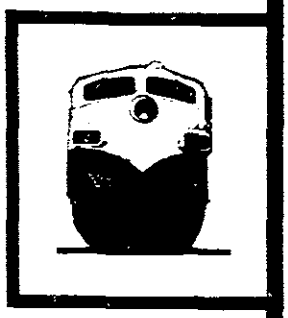

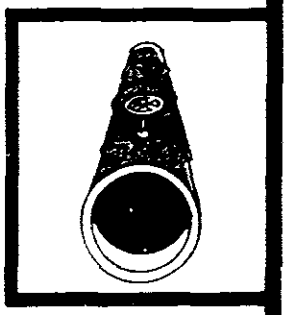

PB85-917016

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SAFETY REPORT

GENERAL AVIATION CRASHWORTHINESS PROJECT: PHASE III -- ACCELERATION LOADS AND VELOCITY CHANGES OF SURVIVABLE GENERAL AVIATION ACCIDENTS

NTSB/SR-85/02

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16. Abstract

This report is the last in a series of three reports issued by the National Transportation Safety Board as a result of its General Aviation Crashworthiness Program. The purpose of this program is to provide information to support changes in crashworthiness design standards for seating and restraint systems in general aviation airplanes. A Phase One report presents a methodology for documenting impact severity. A Phase Two report presents specific data on survivable accidents which demonstrate that if all occupants wear shoulder harnesses, fatalities are expected to be reduced by 20 percent. Eighty-eight percent of the seriously injured persons in survivable crashes are expected to experience significantly fewer life-threatening injuries. The Phase Three report provides analytical results of actual crashes. The values of acceleration loads and velocity changes that occupants can sustain in survivable, modern general aviation airplane accidents are defined. This report also discusses specific crashworthiness problems including seat/restraint systems that failed, shoulder harnesses that were not worn, and inadequate or nonexistent seat stroking ability.

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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

AVIATION SAFETY STUDY

Adopted: September 4, 1985

GENERAL AVIATION CRASHWORTHINESS PROJECT: PHASE THREE—ACCELERATION LOADS AND VELOCITY CHANGES OF SURVIVABLE GENERAL AVIATION ACCIDENTS

INTRODUCTION

In the years 1972 through 1981, 36,500 accidents occurred involving general aviation airplanes. Of the 76,600 occupants of these airplanes, more than 12,500 (16 percent) were killed and more than 6,600 (9 percent) were seriously injured. The National Transportation Safety Board's investigations of these accidents found that many of the fatal and serious injuries could have been prevented if the occupants had been provided with effective occupant protection systems. The Safety Board, in 1980, started its General Aviation Crashworthiness Program to provide data to the general aviation industry and the Federal Aviation Administration (FAA) for the purpose of improving crashworthiness 1/ in general aviation airplanes. The rationale for this program, the program's plan, and the investigative and analytic methodology are described in the Safety Board's report, "General Aviation Crashworthiness Project, Phase One" 2/.

The Safety Board on March 15, 1985, issued its Phase Two report 3/ which presented more detailed kinematic 4/ and injury information on general aviation airplane accidents. The Phase Two data, gathered from more than 500 accidents involving more than 1,200 occupants, were used to define survivable accidents 5/. The report included information on impact severity (impact angles and impact speeds) and provided estimates of the potential benefits from the use of shoulder harnesses and energy absorbing seats. The Safety Board concluded that a potential 20 percent reduction in fatalities could be realized if all occupants were to wear shoulder harnesses; that potentially 88 percent of seriously injured occupants could be expected to incur significantly reduced injuries with the use of shoulder harnesses; and that the availability of energy absorbing seats could have had the potential of reducing significantly the injuries of 34 percent of the seriously injured occupants.

1/ Crashworthiness refers to the capability of a vehicle to protect its occupants during a crash.

2/ "General Aviation Crashworthiness Project, Phase One," National Transportation Safety Board, Washington, D.C. 20594, June 27, 1983 (NTSB/SR-83/01).

3/ "General Aviation Crashworthiness Project: Phase Two—Impact Severity and Potential Injury Prevention in General Aviation Accidents", National Transportation Safety Board, Washington, D.C. 20594, March 15, 1985 (NTSB/SR-85/01).

4/ Kinematics is a branch of dynamics that deals with aspects of motion apart from consideration of mass and force.

5/ A survivable accident is one in which the forces transmitted to the occupant through the seat and restraint system do not exceed the limits of human tolerance to abrupt acceleration and in which the structure in the occupant's immediate environment remains substantially intact to the extent that a livable volume is provided throughout the crash sequence.

For the Phase Three report, detailed onscene investigations of 39 selected survivable accidents were completed, documenting the structural deformation of the airplanes, the impact parameters, and the resultant injuries to the occupants. Peak acceleration loads (G's) and velocity changes were then calculated for these accidents, where possible.

An understanding of the magnitude of acceleration and velocity changes experienced in the more severe, but survivable, crashes is important if adequate seat/restraint system design requirements are to be established. Once these parameters are established for a range of survivable crash scenarios, reasonable design standards can be developed. These will guide the designer in creating and testing a seat/restraint system which will perform properly during a survivable crash without creating excessive penalties in cost and weight because of unnecessarily severe standards.

Several seat/restraint systems currently in use, such as those in which the shoulder harness is attached to the airplane structure, provide occupant protection to acceleration loads considerably in excess of the minimum 9 G requirement prescribed in 14 CFR 23.561 6/. Energy absorbing seat designs have demonstrated their protective capabilities in severe crashes and many of the seat/restraint systems have been tested dynamically. However, the manufacturers developed these systems without a clear understanding of the airplane occupant's tolerance to abrupt acceleration and without a precise definition of the loads generated in a survivable crash, but with the intuitive belief that these systems probably offered significantly more protection than was required.

In February 1983, an industry task force, the General Aviation Safety Panel (GASP), was convened at the invitation of the FAA to explore general aviation safety issues, including crashworthiness. The GASP issued a position paper containing several recommendations dealing with crashworthiness. The GASP forwarded a proposal to the FAA on May 2, 1984 that proposed standards for seats and seat restraints, including requirements for the dynamic testing of seat/restraint systems to 26 G's in the longitudinal direction and provisions for energy management in the vertical direction. (For excerpts from the proposal, see appendix C). The GASP-developed seat testing requirements were stringent enough to ensure that seat and restraint designs would protect most occupants of survivable general aviation airplane crashes. These standards, based on test data and accident data and developed with the expertise of designers and manufacturers, were set to achieve those goals without creating unmanageable design requirements or unnecessarily costly changes. Using crash test data developed by the National Aeronautics and Space Administration (NASA) 7/, seat/restraint test data developed by the Civil Aeromedical Institute (CAMI) 8/, and automobile crash data, the

6/ Title 14 CFR Part 23 is that part of the Federal Aviation Regulations which prescribes airworthiness standards for small airplanes in terms of minimum performance.

7/ In 1982, NASA completed a program of crash testing general aviation airplanes that began in 1973. Crashes of 24 instrumented test airplanes with anthropomorphic dummies provided data on structural and occupant responses in specific crash scenarios. In these crashes, survivability was determined by using accelerometer data obtained from the test articles. Refer to NASA Technical Paper 2083, "Correlation and Assessment of Structural Airplane Crash Data with Flight Parameters at Impact," 1982.

8/ CAMI, at the FAA Aeronautical Center in Oklahoma City, has conducted extensive dynamic tests of seats and restraints for general aviation applications. CAMI, in conjunction with several small airplane manufacturers, conducted tests to study the feasibility of the proposed GASP standards presented in appendix C.

GASP concluded that the recommended test loads and velocity changes accurately represented crash loads and velocity changes experienced by the occupants in survivable transportation accidents.

Data regarding survivable acceleration loads in "real world" crashes confirm the validity of the NASA crash tests and the GASP proposal. The appropriateness of the GASP proposal is discussed later in this report.

During the Safety Board's accident investigations that form the basis for this report, many seat and restraint design problems were documented, some of which are discussed here. Some of the seat/restraint systems which were examined did not afford adequate crash protection because of specific design problems, even though they met the current FAA design standards. It is believed that many of these problems can be eliminated by more stringent test requirements, including multi-axis dynamic testing, and by better design guidelines.

ACCELERATION LOADS AND VELOCITY CHANGES OF SURVIVABLE ACCIDENTS

Over the years, many studies and dynamic tests have been conducted which attempted to define the limits of human tolerance to abrupt acceleration. Many of these studies used automobile crash data, which describe primarily single-axis loading (longitudinal). Automobile crashes also are of relatively low energy compared to airplane crashes. In the dynamic tests, the live occupants were completely restrained, including their limbs, which allowed them to sustain greater acceleration loads than could be tolerated by occupants restrained only by a lapbelt and single-shoulder harness. Also, most of these tests with live occupants used a single-axis load application and were stopped at a point where the loads approached the limits of pain or reversible injury. The conclusions from these studies and tests have helped define the limits of human tolerance to abrupt acceleration, but they do not describe adequately the severe but survivable crash environment of general aviation airplanes.

Unlike many automobile crashes or the tests performed as a part of studies airplane crashes are high-energy crashes which generate acceleration loads that can considerably exceed the limits of pain or reversible injury, and which act along many axes simultaneously. The restraint systems that are and will be used in general aviation in the future cannot approach the capabilities of the totally restrictive restraints that have been used in the dynamic tests with live occupants. Instead, the restraints of choice probably will be the lapbelt and the single, diagonal shoulder harness, comparable to those used in automobiles.

Since existing data defining the limits of human tolerance to abrupt accelerations do not adequately represent the crash environment of small airplanes, the Safety Board examined a number of general aviation airplane crashes in an attempt to define the limits of likely peak acceleration loads and velocity changes of survivable crashes. It is important to note that the occupant tolerance to acceleration, as presented in this study, may apply only to general aviation airplane crashes, with the limiting factors being the crashworthiness of the fuselage structure and the multi-axis loading on the occupants.

Summary of Results

Analysis of the selected 39 general aviation airplane crashes revealed that survival could be expected in crashes in which the longitudinal acceleration loads were in the 30 to

35 G range, with a velocity change of 60 to 70 feet per second. In the vertical direction, the acceleration loads were in the 25 to 30 G range with a velocity change of 50 to 60 feet per second.

There are significant differences in how the longitudinal and vertical loads affect the occupant. An occupant can withstand a 30 to 35 G longitudinal load and sustain only minor injuries, as long as the severity of the secondary impact into the instrument panel or other objects is limited. In the vertical direction, the occupant can survive the 25 to 30 G load, but usually sustains severe injury to the back or neck (paraplegic or quadriplegic injuries). Thus, the vertical loads must be attenuated to a greater degree than the longitudinal loads if the occupant is to escape major crippling injuries.

The impact scenarios described in this study conform to the basic definition of a survivable crash. However, certain design factors limit the ability of current airplane structures to provide crash protection. These include (1) the present shoulder harness systems which cannot preclude occupant contact with the instrument panel in the more severe accidents; and (2) the airplane structure which cannot absorb relatively high crash loads without collapsing, thus limiting the occupiable area that protects the occupant. The next major advance in crashworthiness protection may well come from more effective fuselage design. 9/

Selectivity

Accidents selected for this study were severe, but survivable. One guideline used for the selection of accidents was that the accident had to have a serious or fatal injury and had to have at least one survivor. Accidents involving fire were rejected unless the fire was very minor.

Crashworthiness investigations were conducted on 39 accidents, one of which was determined to be nonsurvivable. Nineteen accidents had at least one fatality and 18 accidents had no fatalities but had one or more seriously injured occupants. In two accidents, the occupants had only minor injuries, but these accidents were included because of the severity of the impact. (Refer to appendix A for the case studies and Appendix B for the tabulation of data from the case studies.)

Methodology

The methodology described in the Phase One report was used to calculate acceleration loads and velocity changes. Data were evaluated that led to conclusions about impact angles, impact speeds, and stopping distances for the airplanes. Acceleration loads and velocity changes were calculated when sufficient data existed.

When a range of values was possible for a parameter, the most conservative values were used. This established minimum acceleration loads for those cases in which more precise acceleration loads could not be calculated. In many of these cases, even the conservative acceleration loads greatly exceeded the current FAA design requirement of 9 G's.

9/ Reference "General Aviation Crashworthiness Project—Phase Two" and NASA Technical Paper 2380, Full Scale Crash-Test Evaluation of Two Limiting Subfloors for General Aviation Airframes, Huey D. Carden.

Validity of Data Base

It was important to establish that the accidents used for this study represented the more severe, survivable general aviation accidents so that the upper bounds of the survivable envelope could be better defined. To test the selection process, the data in this study were compared to the data presented in the Phase Two report. Figure 1 depicts the impact angles and impact speeds of the accidents that were selected for this study. The solid line represents the boundary of the survivable envelope for general aviation airplane crashes developed in the Phase Two report. By plotting the data points from each crash and comparing them to the survivable envelope, it can be seen that the selected accidents are in the severe but survivable range. In addition, the plot is very similar to the impact severity plot of the NASA crash tests. (Reference "General Aviation Crashworthiness Project— Phase Two", Appendix B.)

A second comparison between the Phase Two and Phase Three data was made showing the relative availability and use of shoulder harnesses and energy-absorbing seats and the potential reduction in injuries through their use. As can be seen in Table 1, the two data sets compare favorably. Although qualitative in nature, a third comparison of both the airplane damage and general injury level of the two sets of accidents was made. The amounts and types of damage to each airplane and the severity of injuries to the occupants in the Phase Three data set were found to be consistent with the Phase Two data set.

Evaluation of the Acceleration and Velocity Change

Longitudinal Acceleration and Velocity Changes.--Acceleration loads and velocity changes are expressed in relation to the airplane's axes. Figure 2 depicts the longitudinal acceleration loads and velocity changes that were calculated for 22 of the 39 accidents that are the basis for this report. Acceleration loads or velocity changes could not be calculated for all cases because of missing data, such as impact velocity, stopping distances, and/or long slides after impact. The upper limit of the range of acceleration loads in these survivable accidents is 30 to 35 G's and the upper limit of the range of velocity change is 60 to 70 feet per second.

In two cases the velocity changes were over 80 feet per second, but they were not typical cases. In one case the airplane flew into a grove of trees, came to a stop, and remained suspended in the trees with no injury to the occupant. The second case involved a straight-down impact which was nonsurvivable for the front seat occupants because of the crushing.

Based on the extent of airframe damage and the severity of injuries, velocity changes greater than 60 feet per second were judged to approach the upper limits of survivability (cases 11, 16, 24, 28, and 30). In the most severe of the survivable cases, shoulder harness use did not always prevent the occupants from contacting the instrument panel. Because of inadequate shoulder harness adjustment and material stretch, either the occupants were able to move forward too far, or severe airframe crushing caused the instrument panel to move aft a significant distance, thus compromising the potential of shoulder harness use. Cases 3, 6, 7, 11, 15, 28, and 37 are examples of these situations.

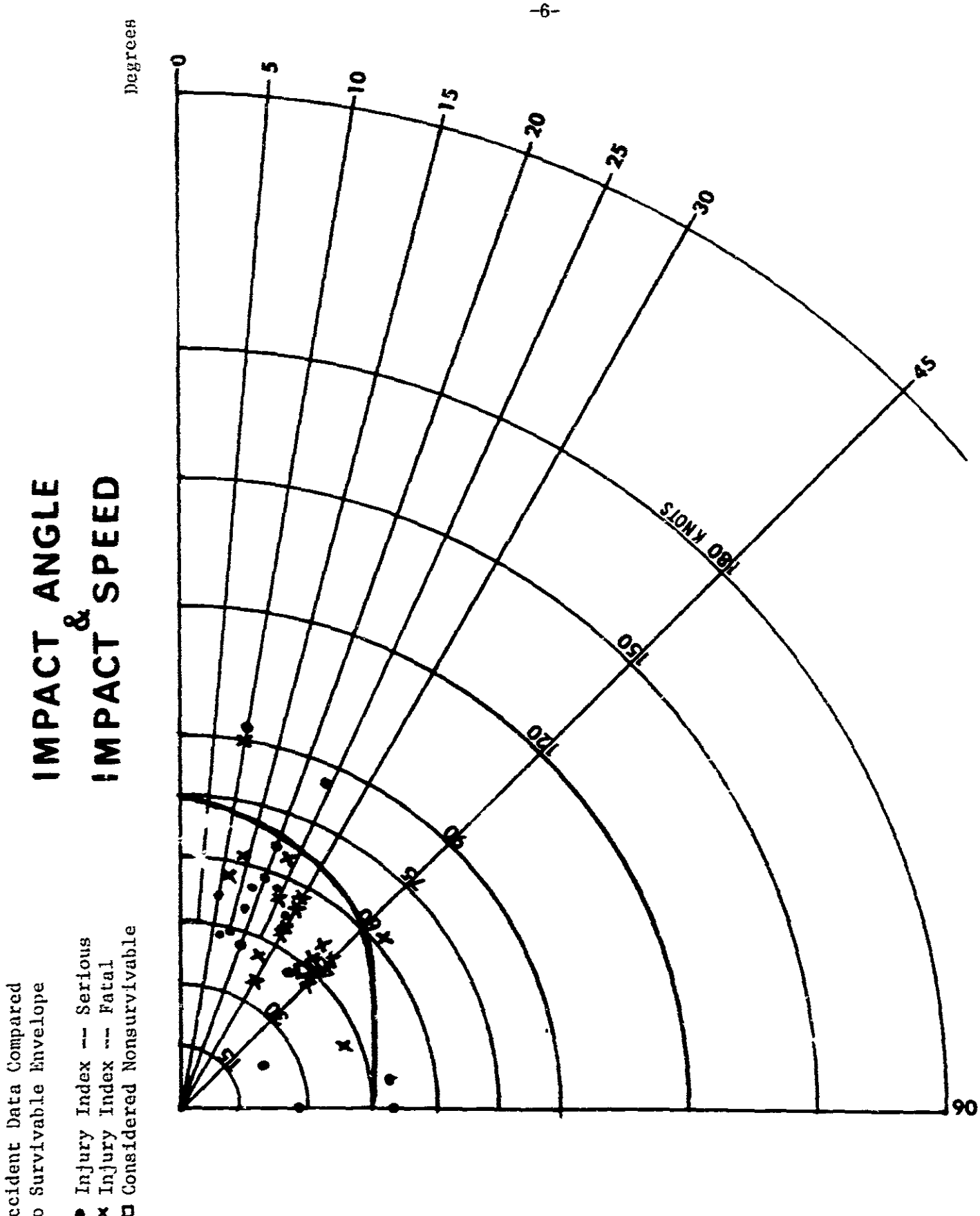


Figure 1.—Impact Angle and Impact Speed of the Accident Cases Compared to the Survivable Envelope.

Table 1.—Comparison of Data from the Phase Two Study and the Phase Three Study

	Phase Two	Phase Three
Accidents	535	39
Occupants	1,268	118
Survivable crashes	59 percent	97 percent
Fatally injured occupants	800 (216 in survivable accident)	27 (23 in survivable accident)
Seriously injured occupants	229	65
Minor/none injured occupants	87	27
Fatally injured who would have survived with shoulder harness use	75%	65%
Seriously injured who would have benefited from shoulder harness use	88%	77%
Seriously injured who would have benefited from energy-absorbing seat use	34%	24%
Shoulder harness available	40%	32%
Shoulder harness use (if available)	40%	45%
Shoulder harness overall use	16%	14%

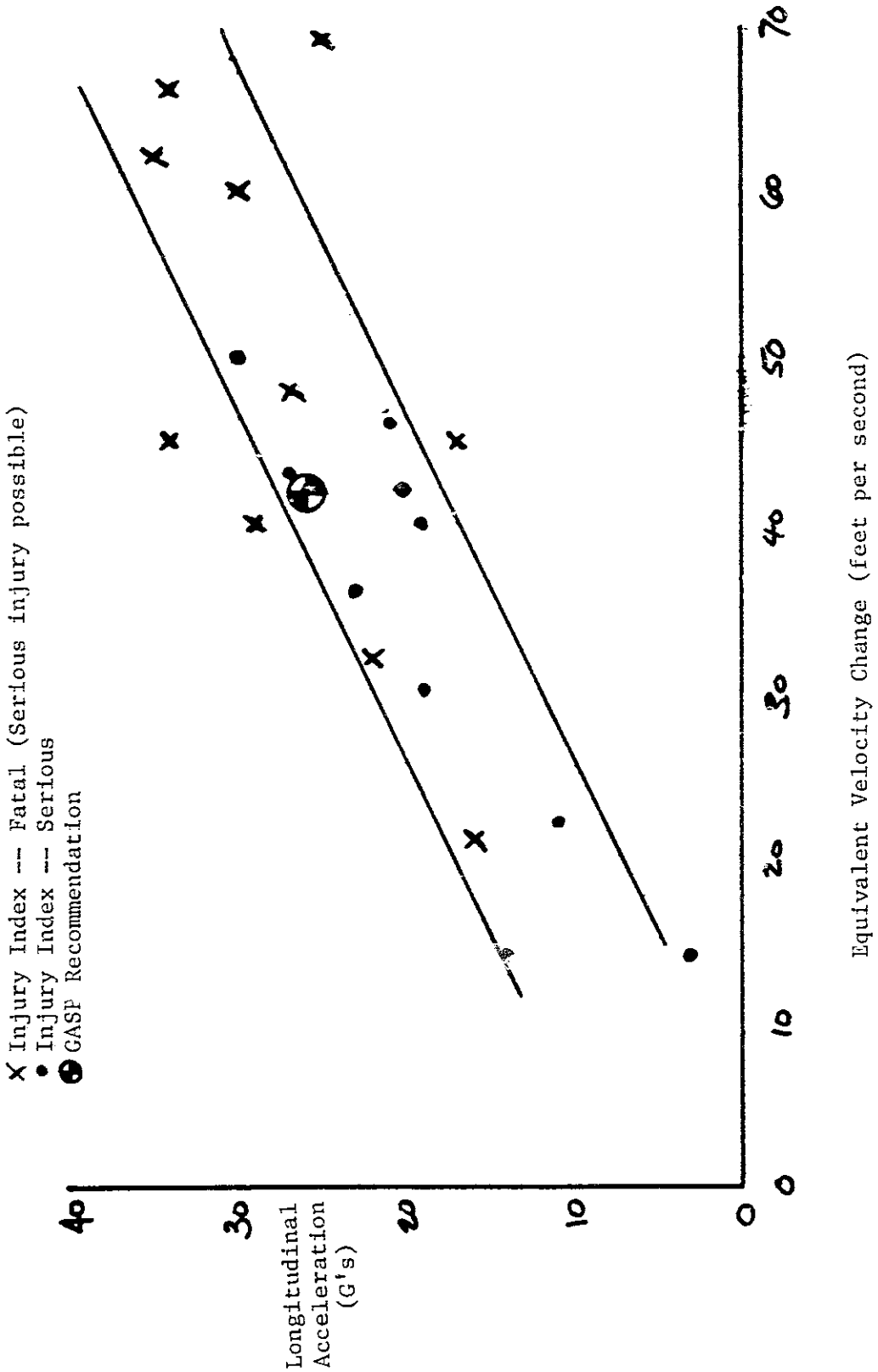


Figure 2.—Longitudinal acceleration and equivalent velocity changes of survivable accidents.

Vertical Acceleration and Velocity Changes

Figure 3 depicts the vertical acceleration loads and velocity changes that were calculated for 12 of the 39 accidents. Acceleration loads or velocity changes could not be calculated for all cases because of missing data, such as impact velocity and/or impact angle. The upper limit of the range of survivable acceleration loads approached 25 to 30 G's and the corresponding velocity changes were in the 50 to 60 feet per second range.

For two of the cases in which energy-absorbing seats were used, acceleration levels were calculated for both the fuselage and the occupants. The corresponding acceleration levels are shown connected by vertical lines in figure 3. The occupant acceleration calculations are identical to the fuselage acceleration calculations except that the stopping distance of the occupant is increased by the stroking distance of the seat; this decreases the acceleration level of the occupants. In case 20, the seat stroked about 6 inches, decreasing the acceleration level of the occupant from 24 G's to 18 G's. In case 27, both seats stroked their full travel of about 1 foot. This decreased the acceleration level of a 180-pound occupant from about 36 G's to 18 G's. The seat did not bottom out and therefore safely dissipated the occupant's energy. However, the other occupant, a 270-pound male, sustained fatal spine/skull injuries when his seat bottomed out against the floor, creating a large, fatal acceleration spike. Thus, the weight of an occupant in an energy-absorbing seat is an important factor in the amount of protection provided by the seat.

This relationship can be described as follows. An energy-absorbing seat should stroke at a constant force exerted by the occupant. A seat that strokes at 2,000 pounds would be a 20 G seat for a 100-pound occupant (2,000/100) and it would be a 10 G seat for a 200-pound occupant. A seat that can stroke 1 foot at 2,000 pounds can slow a 100-pound occupant from 36 feet per second to zero feet per second, but that same seat can slow a 200-pound occupant only from 36 feet per second to 25 feet per second. In case 27, the seat dissipated most of the energy of the lighter occupant, whereas the heavier occupant still was moving at a relatively high velocity when the seat's stroking capability was expended and he contacted the floor.

OCCUPANT INJURY AND SEAT/RESTRAINT SYSTEM DESIGN

With a single exception, all of the crashes discussed in this report were survivable. In some of those cases, the occupants were provided good crash protection by properly designed seats and restraints. Those seat/restraint systems greatly exceeded the current design requirements of the Federal regulations. However, many occupants were needlessly injured because seat/restraint systems either were not able to structurally withstand the crash loads, shoulder harnesses were not available, or they were not used. Most of those injuries could have been prevented if the seat/restraint systems had been built to withstand more realistic dynamic crash loads, or if the occupants had used shoulder harnesses.

During the investigations of these accidents, many seat and restraint problems were documented. These included problems with seat strength, seat feet design, lack of energy absorption capability, inadequately designed seat pans, lack of shoulder harness installation or use, and equipment that was added to seats. Another recurring factor was failure to use the installed shoulder harnesses.

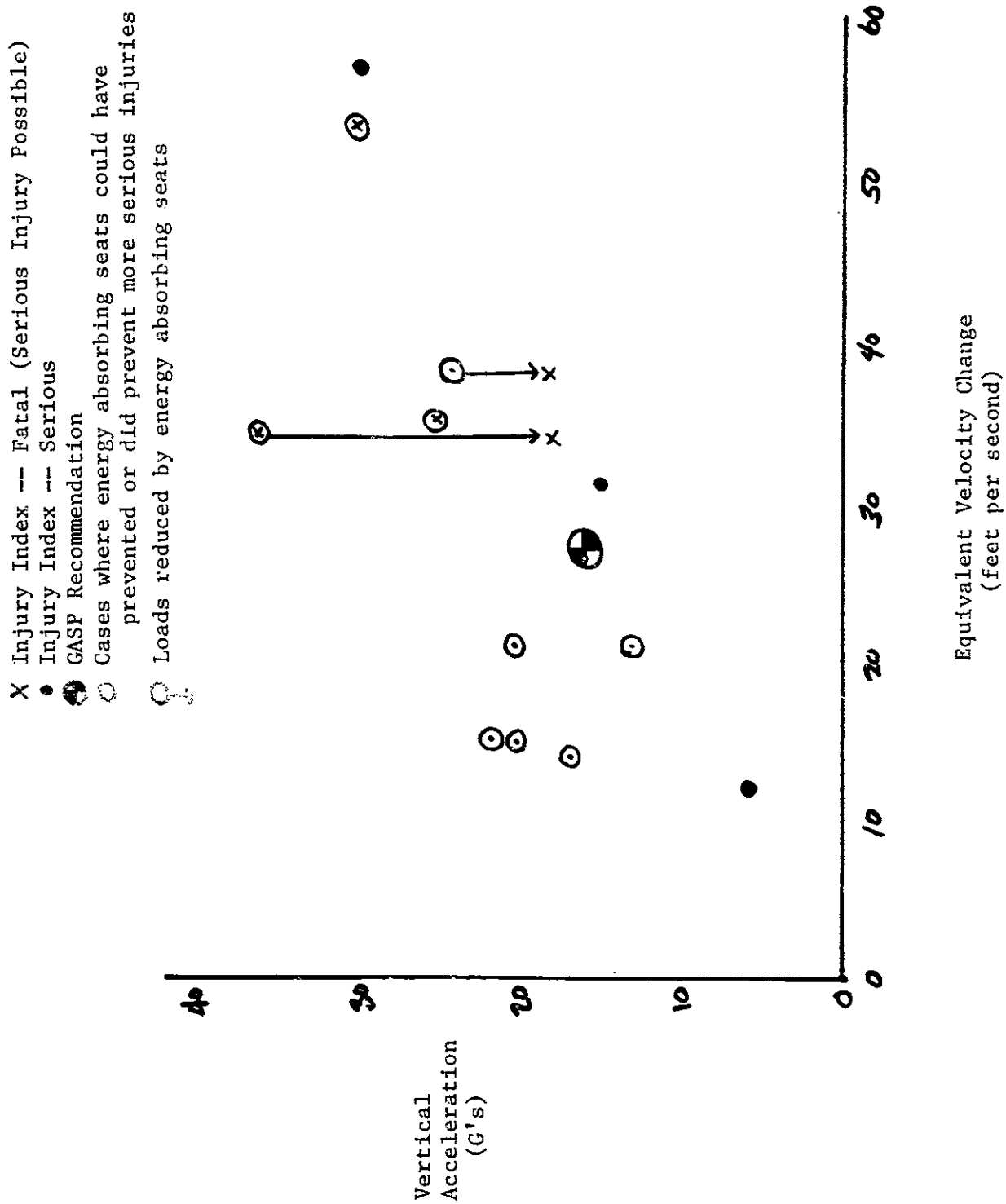


Figure 3.—Vertical Acceleration and Equivalent Velocity Changes of Survivable Accidents.

It is noteworthy that, although the number of airplanes in this study is small but representative, in almost every accident the airplanes had design features that were less than adequately crashworthy. This suggests that these types of problems are widespread in the general aviation fleet.

The Federal regulations that cover the seat/restraint system designs for general aviation airplanes are found in 14 CFR Part 23, and the regulations that define the required use of the restraints are found in 14 CFR Part 91. Title 14 CFR 23.561 specifies that

(a) The airplane, although it may be damaged in emergency landing conditions, must be designed as prescribed in this section to protect each occupant under those conditions.

(b) The structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when-

(1) Proper use is made of belts or harnesses provided for in the design; and

(2) The occupant experiences the ultimate inertia forces shown in the following table for normal and utility category airplanes:

Upward	3.0 G's
Forward	9.0 G's
Sideward	1.5 G's
Downward	3.0 G's

(A greater value of up to about 6 G's downward is frequently used to allow for the flight loads of the airplane.)

Title 14 CFR 23.785 specifies that:

(a) Each seat, and its supporting structure must be designed for occupants weighing at least 170 pounds . . . and for the maximum load factors corresponding to the specified flight and ground load conditions, including the emergency landing conditions prescribed in 14 CFR 23.561.

(b) Each seat, safety belt, and harness must be approved.

* * *

(f) Proof of compliance with the strength and deformation requirements of this section for seats approved as part of the type design and for seat installations may be shown by-

(1) Structural analysis, if the structure conforms to conventional airplane types for which existing methods of analysis are known to be reliable; or

(2) A combination of structural analysis and static load tests to limit loads; or

(3) Static load tests to ultimate loads.

(g) Each occupant must be protected from serious head injury when he experiences the inertia forces prescribed in 14 CFR 23.561(b)(2) by—

(1) A safety belt and shoulder harness that is designed to prevent the head from contacting any injurious object, for each front seat; and

(2) A safety belt, or a safety belt and shoulder harness, for each seat other than a front seat.

* * *

(j) The cabin area surrounding each seat, including the structure, interior walls, instrument panel, control wheel, pedals, and seats, within striking distance of the occupant's head or torso (with the safety belt fastened), must be free of potentially injurious objects, sharp edges, protuberances, and hard surfaces. If energy absorbing designs or devices are used to meet this requirement they must protect the occupant from serious injury when the occupant experiences the ultimate inertia forces prescribed in 14 CFR 23.561(b)(2).

Title 14 CFR 23.1413 specifies:

(a) The rated strength of safety belts and harnesses may not be less than that corresponding with the ultimate load factors specified in 14 CFR 23.561(b)(2), considering the dimensional characteristics of the belt and harness installation for the specific seat arrangement.

In summary, seats must be designed and tested, in most cases, to loads that represent 9 G's forward, 3 G's upward, 1.5 G's sideward, and 3 to 6 G's downward. The restraints must be compatible. Within the flail area of the head, the cockpit and cabin are supposed to be "delethalized," the extent of protection depending upon whether shoulder harnesses are available.

Title 14 CFR 91.7 specifies:

(a) During takeoff and landing, and while en route, each required flight crewmember shall-

* * *

(2) Keep his seat belt fastened while at his station.

(b) After July 18, 1978, each required flight crewmember ... shall, during takeoff and landing, keep the shoulder harness fastened while at his station - if a shoulder harness is available.

Moreover, Title 14 CFR 91.14 states:

(a) Unless otherwise authorized by the Administrator. . .

* * *

(3) During the takeoff and landing ... , each person on board that aircraft must occupy a seat or berth with a safety belt properly secured about him.

The operating rules in 14 CFR Part 91 require that pilots and copilots wear their lap belts most of the time and, if available, the shoulder harnesses for takeoff and landing. Passengers are required to wear their lapelts only for takeoff and landing. Passengers are not required to wear their shoulder harnesses, even if they are seated in the front seats.

RESTRAINTS - SHOULDER HARNESSES AND LAPBELTS

In survivable accidents, the most commonly seen injuries of a severe nature are to the head or upper torso. The Phase Two report established that 20 percent of the fatally injured and 88 percent of the seriously injured occupants had serious but preventable head and upper body injuries and that only 16 percent of the occupants were wearing shoulder harnesses. Almost all case studies in this report show examples of head and upper body injuries that could have been prevented with the use of upper body restraints. Shoulder harness use not only prevents or minimizes head and upper body injury, but the harness can redistribute a large portion of the crash loads to the upper body so that the lapbelt and pelvic loads are less. High lapbelt loads can cause pelvic and internal injuries.

In many cases, shoulder harnesses were not worn by the occupants for one of two reasons, either they were not available or passengers were not required to wear them. The Phase Two report established that shoulder harnesses were available only in 40 percent of the front seats of the general aviation airplanes examined and that they were almost nonexistent in rear seats. Further, only 40 percent of the occupants were wearing their available harnesses when an accident occurred.

As shown in Cases 1, 8, and 26, several pilots who were wearing their restraints for takeoff stated that they removed the shoulder harness portion of the restraint after the takeoff was completed. When an emergency occurred, they did not remember to put the harness back on. In four other accidents, in which shoulder harnesses were not available (cases 3, 5, 34, and 38), rear seat occupants sustained fatal injuries because of head strikes or fractured or dislocated cervical vertebrae which could have been avoided if shoulder harnesses had been available and worn.

Shoulder harnesses provide additional protection during an accident. Without a shoulder harness, the entire occupant load is carried by the lapbelt. That can create excessive belt loads to the pelvic and abdominal regions of the body. In Cases 1, 3, 11, 17, 29, 30, 31, 34, and 35, 13 occupants received injuries consistent with high lapbelt loads. Typical injuries were fractures of the pelvis, tears of internal organs, and tears of the soft tissue in the lower abdominal area.

In survivable crashes, restraint systems sometimes separate because they are required only to meet the static test loads described in 14 CFR Part 23. The more severe, survivable crashes generate forces that easily can exceed these levels by a factor of two or three. In Cases 39 and 3, the restraints separated. Case 39 involved a Piper Model PA32 airplane that used cables to attach the rear lapbelts to the floor. Two of the cables broke, causing the occupants to sustain more serious injuries than expected. In 1973, the Safety Board issued to the FAA Safety Recommendation A-73-59 recommending that it require the owners to replace the existing lapbelt attachment cables with stronger cables. It was believed that the cable was under-designed and that extra stresses were imparted to the cable as it bent around the seat frame. The FAA declined to implement the recommendation, stating that the crash exceeded the design standards applicable to that airplane. Shortly after the incident in Case 39 took place, another crash occurred

involving a Piper airplane 11/ in which the rear lapbelt cable broke. The occupant, who was not restrained because the cable broke, probably sustained more serious injuries than if the lapbelt had held. All of the cables that broke were 1/8 inch in diameter and were in airplanes manufactured before 1973, the year Piper upgraded to a 3/16-inch cable. Each cable exhibited signs of breaking due to static overload and additionaly, a cable in Case 39 was corroded. The corrosion weakened that cable, but it still would have met the current design requirements. Cable breaks and lapbelt separations typically have not been a problem in survivable crashes in which other designs have been used.

In Case 3, the pilot's lapbelt attachment separated, allowing the occupant to hit the panel with his whole body. The bolt that holds the attachment in place was pulled out when the cabin deformed, causing the fitting to twist and shear the attachment bolt.

SEATS AND RESTRAINTS - DYNAMIC TESTING

Design and test requirements for general aviation seats are not adequate because the required static test procedures do not adequately prove the capabilities of the seat/restraint designs. Seats that meet the current requirements may offer little protection in a crash because they are understrength or they may not perform properly in an actual crash environment. It was found that present test load applications are not realistic and that the design load requirements are too low. For example, a seat with the lapbelt attached to the floor may weigh about 20 pounds, thus requiring a static pull test of 180 pounds to the seat (9 G's times 20 pounds). The body block 12/, on the seat and restrained by a belt, would be subjected to a force of 9 times 170 = 1,530 pounds. The test requirements also allow simultaneous forward and upward loads, which prevent the body block from pushing down on the seat in a manner more representative of an actual airplane impact condition. In an actual crash, a seat may come off the tracks or may break at less than 9 G's since the body normally moves down and forward during a crash. When this happens, the seatpan deflects, allowing the pelvis to move below the seatframe which causes the body's weight to load the front of the seat (1,530 pounds at 9 G's). This event can occur even before the lapbelt restraint becomes effective. This scenario causes the seat to be loaded quickly in excess of its 180-pound design limit; the seat therefore is most likely to break or separate from its tracks.

Another problem typically encountered in crashes, and which is not accounted for in current design practices, is overshoot. Overshoot is a phenomenon in which the occupant acceleration is greater than the airplane crash acceleration. Overshoot occurs when the occupant is accelerated and then stopped abruptly by the lapbelt or shoulder harness; it is similar to the high occupant acceleration loads being generated by secondary impacts into the instrument panel. A seat/restraint system can be tested to 9 G's equivalent static load, but in an actual 9 G crash, overshoot may generate loads that are 1.5 to 3 times greater, significantly greater than the static test loads. This problem is more severe for systems that have the restraints attached to the seats. The extra loads created by overshoot may cause the entire seat/restraint/occupant system to become detached from the airplane structure. To be assured that a seat/restraint system meets any prescribed load, the system must be dynamically tested, and the loads applied in proper directions.

11/ NTSB accident number NYC-83-F-A030, at Plymouth, MA, on 11-19-82.
12/ A body block is used to simulate the occupant during a seat test. The test load is applied to the body block, which in turn loads the restraint and seat.

Because shoulder harnesses are optional, seats and lapbelts in combination or of themselves must accommodate the loads prescribed by 14 CFR 23.561. However, since a shoulder harness can transfer large loads directly to the fuselage, it is possible that, in a particular seat/lapbelt/shoulder harness system, the shoulder harness could carry a large portion of the prescribed 9 G load. When the installation and use of shoulder harnesses are made mandatory, designers will be in a position to reduce the strength of the seat/lapbelt combination and meet the standard on the basis that the combined seat/lapbelt/harness system accommodates the prescribed load. For instance, for certification purposes as a 9 G system, a seat could be designed to sustain a 6 G load and the shoulder harness could be designed to sustain the remaining 3 G load. At least one manufacturer designed and tested a seat using multiple loads and later found that a single axis forward pull test would fail the seat. Rather than redesign the seat, the solution was to require the use of a shoulder harness and use the contribution of the shoulder harness to meet the 9 G requirement. When shoulder harness use is not required or when the crew or passengers forget to put the harnesses back on during an emergency, a 6 G seat does not offer the expected protection. The Safety Board believes that the seat/lapbelt combination of itself should continue to be required to handle the prescribed load, as should the entire seat/lapbelt/shoulder harness system.

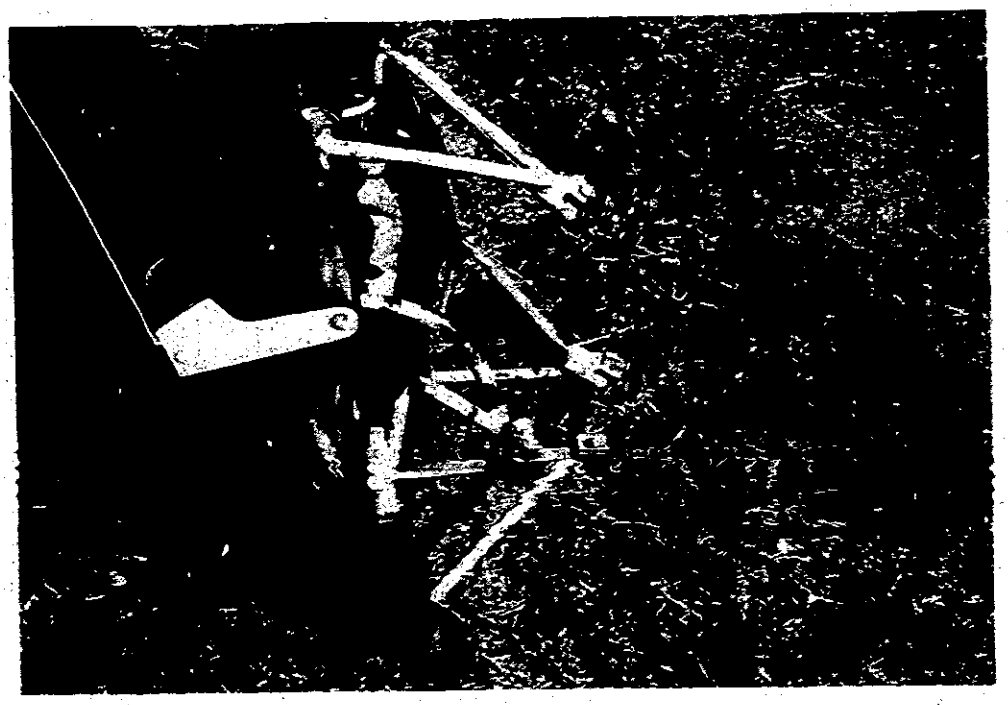
SEAT FEET AND SEAT LEGS

Many of the seats in the general aviation fleet break or come off the tracks during survivable crashes (reference appendix B). The cases in this study showed that 44 percent of the occupied seats became detached from the airplane structure, usually because the seat feet or legs broke or separated. Case 9 is an example of a seat that came loose, which allowed the occupant, who had survivable injuries, to fall out of the airplane and drown in shallow water. Had the seat remained in place, the occupant would have been held in place by the lapbelt.

Case 13 is an example of inadequate seat frame strength. There were no braces between the front and aft legs of the seat and since the front legs had adjustment pins in the tracks, they resisted all of the forward loads exerted on the seat during the crash. As the seat was forced to move forward, the frame bent allowing the rear legs to move closer to the front legs (photograph 1). When the frame broke, the rear legs were free to move forward on the tracks until they contacted the front legs. During this process, the rear of the seat rotated down accelerating the occupant toward the floor.

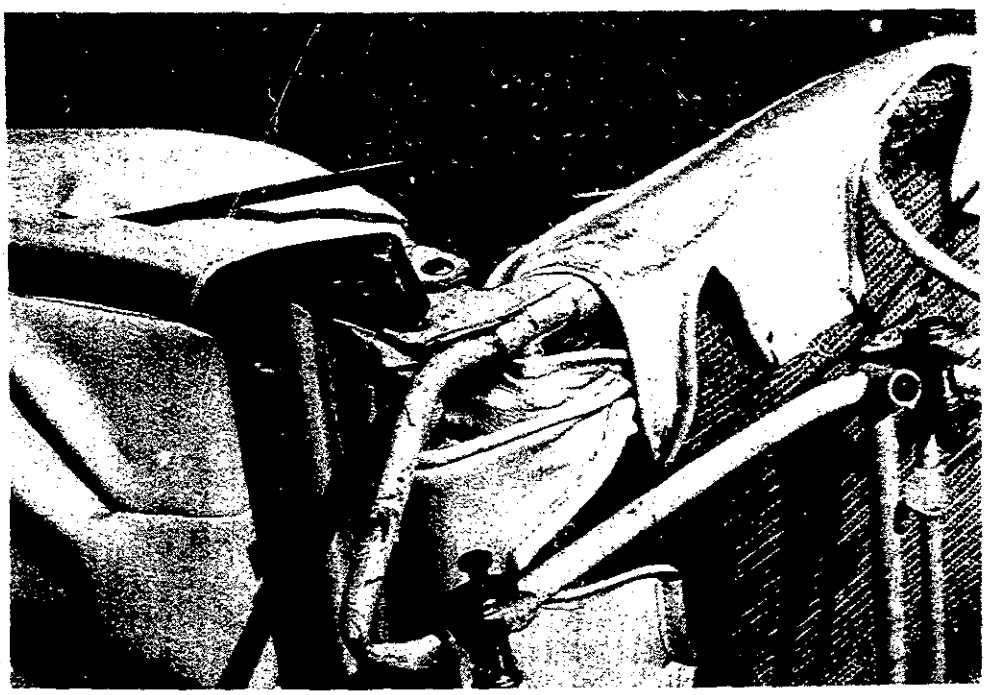
Many of the seats separate because of small side loads to the seat coupled with the warping of the floor and seat tracks. Seat separations because of side loads are directly related to low side load test requirements. The side load requirement of 1.5 G's is totally inadequate. With a misalignment of only 10 degrees, a 9 G forward acceleration can create a side load of 1.5 G to the seat feet. Small side loads can result in seat separation because the seat feet spread (cases 1, 9, 12, 18, 25, and 27). To combat this problem, several manufacturers have added extra structure to the seat foot area (cases 20 and 23). Beech Aircraft has designed an extra bracket (photograph 2) for the seat feet in their Model 23 series of airplanes, and Piper Aircraft has recommended adding two large washers to each seat foot in many of the PA-28 series of its airplanes (photograph 3).

Floor warping can cause seats to fail. Photograph 4 shows warping of the floor area because the bottom of the fuselage contacted the nose gear. As a floor warps, extra stresses can be placed on the seat feet as the seat resists changing its original shape to accommodate the floor warp. Several seats in Case 33 separated because floor warping placed additional stresses on the seat feet (other cases 1, 3, and 12).

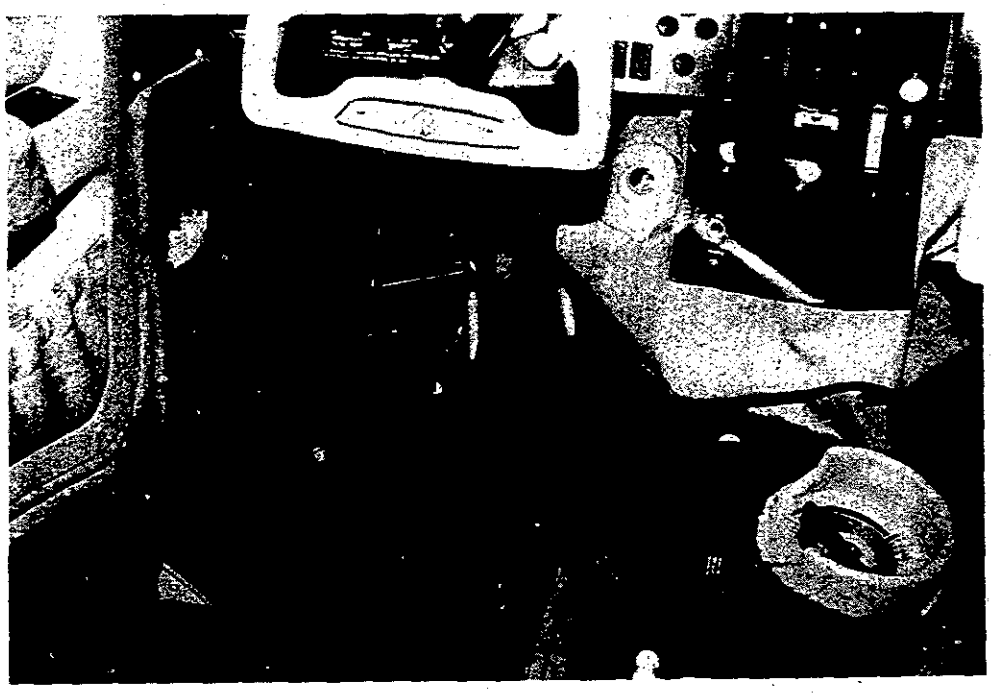


Photograph 1.--Pilot's seat with buckled seat frame due to lack of support bar between the front and rear legs.

Photograph 2.--Extra bracket added to strengthen the seat feet.



Photograph 3.--Washers added to help
the retention of the seat feet. The front foot is still spread.



Photograph 4.--Warped floor in minor accident.

Piper designed an energy-absorbing seat that is flexible in several directions. The seat can stroke vertically, which absorbs energy, but it can distort and twist also without much resistance. With that built-in flexibility the Piper "S" tube seat (photograph 5) can deform to the contour of the floor warp without causing excessive stress on the seat feet.

Cases 11, 33, and 34 involve seats that were struck by the occupants who were seated directly behind them (photograph 6). When a seat is struck from behind, it has to carry the loads of its own occupant and the additional loads of the occupant behind. This type of extra loading is not considered in any current design practice.

Multi-axis dynamic testing of seats can uncover these types of design problems. Higher strength requirements would ensure that the seats would not break when exposed to minor loads.

ENERGY-ABSORBING SEATS

Energy-absorbing seats are needed to dissipate excess energy and prevent lower back and pelvic injuries. The Phase Two report concluded that 34 percent of all seriously injured occupants could be expected to have had significantly less serious injuries if energy-absorbing seats had been installed. Twenty-nine of the occupants in this study (24 percent of the total occupants) did benefit or would have benefited from the use of energy-absorbing seats. Cases 1, 3, 8, 13, 14, 16, 21, 26, 34, 36, and 39 are examples of accidents in which occupant seats collapsed or there was no room for vertical stroking, causing the occupant to contact substructure at a high velocity instead of allowing the seat to dissipate the energy by controlled collapse (vertical stroking).

Photograph 5.--Warped floor with flexible seat.
The left seat conformed to the warped floor and stayed in place.

Photograph 6.--Seat hit from behind by another occupant and it separated.

An allowance for vertical stroking distance is a primary requirement if an energy-absorbing seat is to perform its function. Little or no room is provided for vertical stroking of the back seats in some of the smaller general aviation airplanes. Many of the rear seats are mounted on the floorboards so that the occupant is seated only an inch or two above solid structure. In case 3, a 3/4-inch plywood floor covered several inches of space that was available for stroking. During the high vertical loading experienced in this accident, the occupant bottomed out on the plywood floor and sustained a broken back. In case 14, the second row of seats was placed on structure that houses components of the air conditioning system. There was no room for the seat pan to move down, and the occupant bottomed out on the structure, sustaining a broken back.

Only one seat in general aviation airplanes is designed as an energy-absorbing seat. The Piper "S" tube seat (case 20) offers a significant amount of protection by absorbing energy in a controlled manner as it deforms and deflects toward the floor. This seat was dynamically tested to fine tune its energy absorption characteristics. There are other seats designed in the early 1960's (case 27), that can absorb energy, even though that was not a part of the design criteria. For instance, the front seats in the Beech Sport/Sundowner series airplanes, can absorb significant crash loads. Some of the occupants in cases 1,3, 15, and 23 also had the benefit of energy absorbing seats.

Seatpan Design

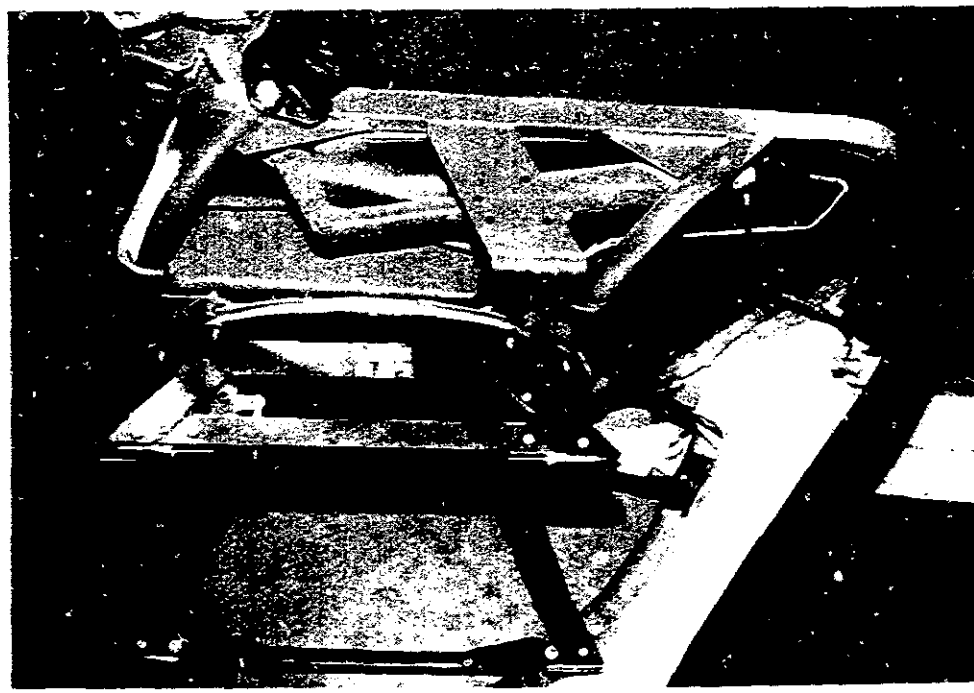
One of the least discussed components in seat/restraint system design is the seatpan. The seatpan can perform the important function of absorbing energy in the vertical direction through deflection or by transmitting the occupant loads to the seat frame. However, design requirements for the seatpan are almost nonexistent.

The front seats in Case 36 are a good example of seatpans that separated incrementally, absorbing energy in the process. (See photograph 7.) The crew seatpans in this airplane consist of formed aluminum sheets that are attached to the steel tube seat frames by rivets. As the pilot and copilot moved downward, the aluminum seatpans began to tear away from the rivets sequentially. Although the seats did not stroke, the tearing seatpans increased the stopping distance of the crewmembers in a relatively controlled manner, which resulted in less severe acceleration loads on their spines. In contrast, the rear seats in this airplane did not have an actual seatpan. Instead, they had a lower surface made of plastic which is not structural. Below that surface is a plastic book compartment and a steel ring mechanism that allows the seat to swivel. (See photograph 8.)

These seats offer little protection from high vertical loads, although a static test of these seats would indicate that they had adequate vertical strength. Only a dynamic test of this seat could show if the occupant would bottom out on the steel ring.

Seatpans can tear in a catastrophic manner. In Cases 4, 8, 13, 14, and 21 seatpans tore, causing the occupants to bottom out on the floor. In Cases 13 and 21, the tie-wires that stabilize the seatpan springs became detached and allowed the springs to spread apart. The occupants moved down through the springs to the floor (see photograph 9). In Case 8, the nylon fabric seatpan tore, allowing the occupant to contact the floor. During the investigation, a small tear was found in the seatpan of the unoccupied right front seat.

Photograph 7.--Incrementally torn seatpan.



Photograph 8.--Steel ring and plastic seatpan.

By pulling at the tear with one finger, the tear was propagated along one side of the seatpan (photograph 10). The material appeared to be strong, but the tear resistance was minimal while the material was under tension, acting as a diaphragm. Once the material was torn enough to ease the tension, it could no longer be torn by hand. It is believed that the loads on the occupied seat were high and that a tear started in the pan and propagated with little resistance.

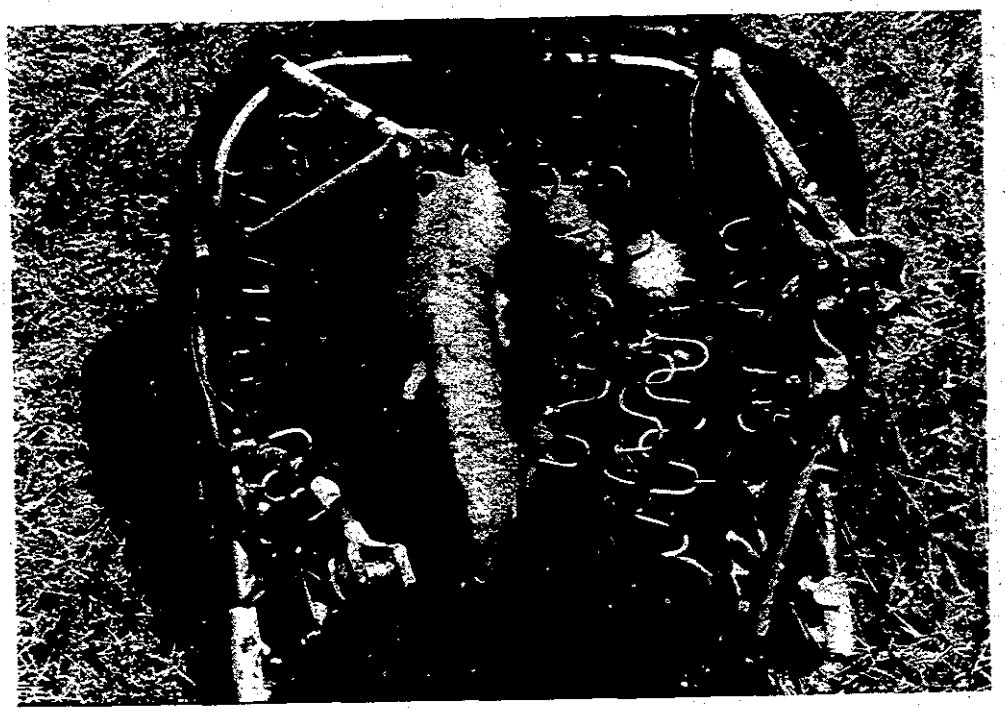
In Case 14, a seatpan exhibited characteristics similar to the ones discussed above. The seat was over air conditioning ducting which limited vertical movement. However, there were two small holes in the nylon mesh seatpan (photograph 11). During the investigation, the seatpan was torn by pulling at the holes with a finger. The pan could be torn in that manner until it no longer was in tension.

The seatpans in Case 4 presented another problem. The pans were made from a neoprene material that had deteriorated with age. (See photograph 12.) Although the crash generated relatively minor loads in the vertical direction, the seatpans had separated at the steel fittings and were held in place only by the foam rubber comfort cushions.

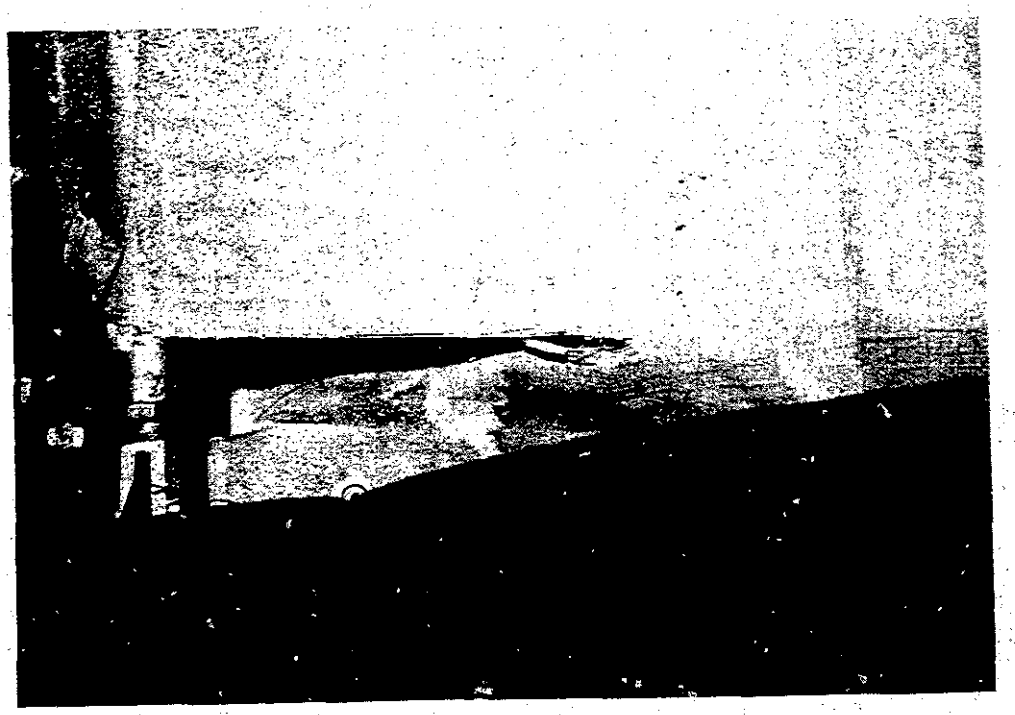
The Safety Board believes that more stringent design requirements, such as dynamic testing, would have precluded the production of these poor seatpan designs. Evaluation of the rip-stop capabilities of seatpan material may be in order, as would be an evaluation of the effects of seatpan deterioration with age.

Seat Add-ons

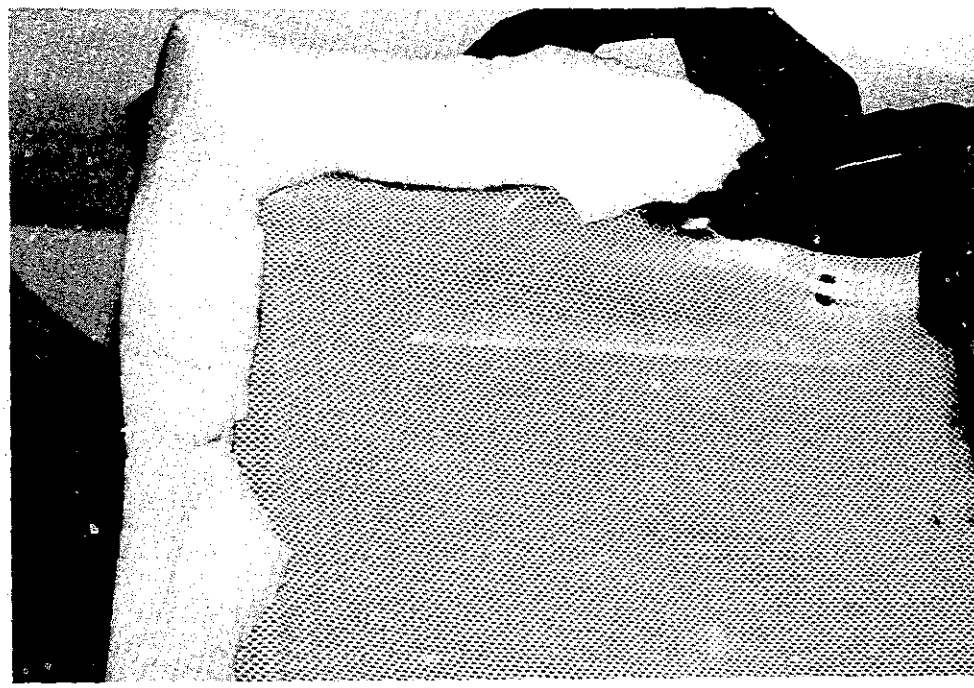
Present general aviation airplane seats generally do not exceed greatly the minimum FAA strength requirements and they do not offer much protection to occupants in more than a minor crash. Attaching additional equipment to the seats adds extra weight and further degrades their protection capabilities. Cases 4, 11, 12, 14, 30, and 34 are examples



Photograph 9.--Split springs.



Photograph 10.--Seatpan torn by pulling.



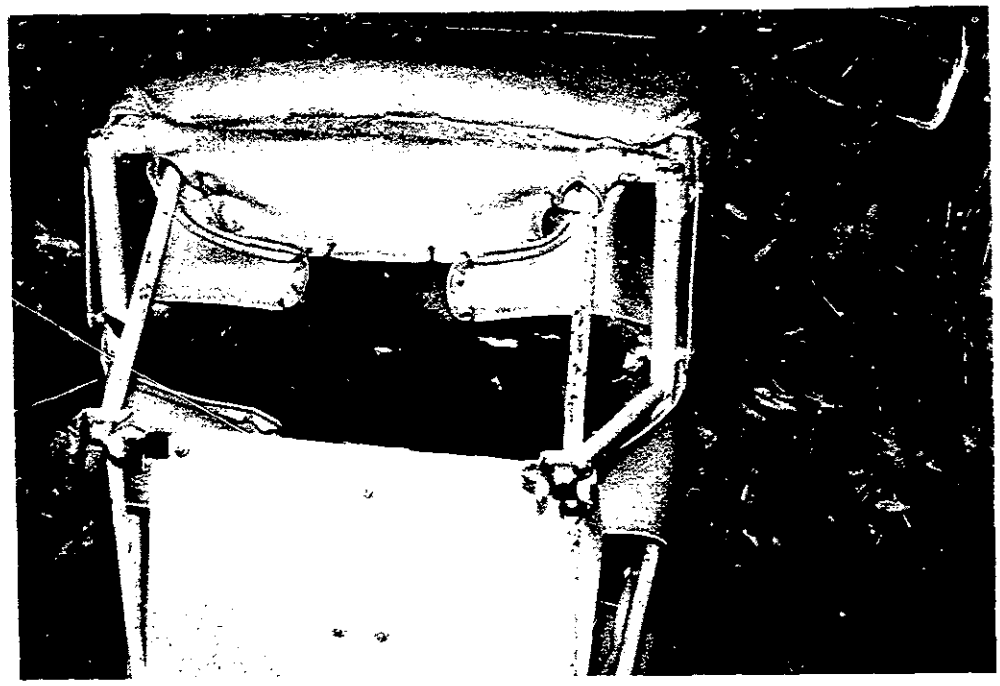
Photograph 11.--Seatpan before being torn by hand.

where equipment had been added to the seats. One oxygen bottle supplier advertises oxygen bottle holders that can hang over the backs of the front seats. These holders have three negative aspects: first, the system can add as much as 20 pounds, which decreases the seat's G-load capabilities by 1 percent. Second, the positioning is dangerous because, in a crash, the bottle could drive into the head or back of the front seat occupant. Third, a rear seat occupant could pitch forward and contact the unpadded bottle.

The drilling or modification of a seat frame is another problem related to adding equipment to seats. Field modification procedures that are acceptable for other airplane structures are not acceptable for seats. This is because the stresses and load paths in seat structures are far more complicated than on other airplane structures on which field modifications are permitted. Any modifications to seat structures should comply with the more rigorous requirements that apply to the primary airplane structure, such as wing spars or engine mounts. The drilling of holes or other modifications of seats have been demonstrated by dynamic testing to have potentially disastrous effects.

Attaching or storing objects under a seat also may prevent a seat from stroking in the vertical direction, thus negating any potential energy-absorbing benefits that the seat might provide. For example, fire extinguishers are often stored under the front seats which results in a reduction of the seat stroking distance by as much as four inches.

Improper seat modifications or seats in poor repair can be overlooked by a mechanic. In Case 39 one of the seatpans had been removed and replaced with lawnchair webbing which was fastened with the kind of staples used for paper. The deteriorated seatpans in Case 4 were not discovered during normal inspections. Analysis of the material indicated that the deteriorated condition of the seatpan material was of long standing.



Photograph 12.--Split seatpan and add-on equipment.

Although in this study there were no injuries that could be attributed to seat add-on equipment, the person in the seat with lawn chair webbing did sustain a serious back injury. These problems do not appear widespread; nevertheless, the Safety Board believes that better education of the aviation community about the critical nature of general aviation airplane seats and the need to improve them is warranted.

VALIDITY OF THE GASP PROPOSAL

Beginning in July 1983, the GASP held a series of meetings to explore general aviation crashworthiness issues. As a result of the meetings, the GASP forwarded a proposal to the FAA on May 2, 1984 that defined standards for seats and restraints. (For excerpts, see appendix C.) The stated goal was to prevent or reduce airplane crash injuries in a reasonable manner.

To ensure that the goal was met, panel members evaluated information presented by experts in such areas as crashworthy seat design, dynamic testing, manufacturing, crashworthiness accident investigation, full scale crash testing, Army helicopter crashworthiness, and human tolerance to vehicle crashes. The main objectives, in order of importance, were to: (1) require dynamic testing that adequately represents an actual crash; (2) increase the strength of the seats and restraints; (3) require energy-absorbing seats to attenuate vertical loads; and (4) establish performance standards by which the tests could be evaluated.

Dynamic testing was proposed to ensure proper performance of crashworthy designs that operate in a dynamic environment. Some of the problem areas that are addressed by dynamic testing are dynamic overshoot, floor warping, and secondary head impacts; such

testing also validates energy-absorbing devices and defines occupant reactions in the restraint system. A dynamic test load of 26 G's longitudinal with a velocity change of 42 feet per second would result in the design of a high strength seat that would provide protection in severe, but survivable crashes. A 19 G vertical test with a 31-feet-per-second velocity change would dictate that at least some energy management be incorporated into the design. The test criteria, or performance standards, would ensure that the equipment would actually perform as required. The GASP proposal would require the measurment of pelvic loads in order to identify stiff seats. The proposal also would require that shoulder harness loads be limited to prevent injuries to the chest, that the restraint system remain in place and function properly, and for each specific design, that the test determine if head contact is possible with the instrument panel. If head contact is predicted, a second test would quantify the severity of the impact so that corrective actions could be taken.

The GASP proposal would require seats to withstand the longitudinal loads generated by a 26 G pulse and a 42 feet-per-second velocity change over a period of 0.1 seconds. Occupants in crashes of less severity than represented by these standards would be well protected. The longitudinal load and velocity change test requirements would be sufficiently rigorous so that the seats and restraints designed to these requirements could protect occupants even in crashes that exceed the velocity change of 42 feet per second, as long as the crash loads were similar to the 26 G test loads.

A test involving sufficient energy (velocity change) is important so that the test dummy will become fully engaged in the restraints. In low energy tests (small velocity change), the pelvis and the upper body will not engage the restraints simultaneously. The restraints therefore are not loaded by all parts of the dummy at the same time and a lesser strength restraint system could pass the low energy test. Thus, the test requirement of 42 feet per second longitudinal velocity change would ensure that all parts of the dummy fully engage the restraints at the same time; this would ensure that the seats were truly 26 G seats.

Another advantage of a high energy test (dummy fully engaged in the restraint system) is that the proven restraint system theoretically has the capability of sustaining greater velocity changes than those demonstrated in the test as long as the G-loads (forces) remain near the design levels. This means that as long as the acceleration loads are near or below the 26 G test requirement, the velocity change could be much greater than the 42 feet per second without causing the restraint system to break. The only difference is that the restraint system would have to withstand the loads for a longer period of time than for the 0.1 second test requirement.

The GASP proposed test loads for the vertical direction purposely were kept lower than optimum because of limiting underseat stroking clearances at certain seat locations. The 19 G load and the 31 feet-per-second velocity change were a compromise to ensure that at least some energy management design had to be incorporated into the seats, without forcing some smaller airplane designs from the market.

The vertical test would create high vertical loads but still would involve some forward loading that would ensure the the stroking mechanism would not bind. To create this combination loading, the test vehicle would be rotated 30 degrees so that the 19 G acceleration load would create resultant vertical load to the seat of 16 G's with a velocity change of 27 feet per second. The longitudinal component would be about 9 G's with a 15 feet-per-second velocity change. Although this test requirement would provide a minimally acceptable level of protection, once energy management (stroking) is introduced into a seat design, the length of the stroke (potential velocity dissipation) will

be limited only by the available stroking distance. If the manufacturers use the available space for stroking distance, most passengers will be better protected from vertical loading injuries. A problem in some of the small, two place, general aviation airplanes is that because of the aerodynamic and structural properties of the airplane, the main wing spar is located under the seats. This limits the available stroking distance for the seats. Similarly, in small four place airplanes, the occupiable space for the rear seat occupants is quite limited. In those airplanes, the stroking space for the aft seats can never approach the stroking distance that can be found in some larger four place models.

It is important to compare the requirements of the GASP proposal with the real world crash data that form the basis of this report to confirm that the proposed GASP requirements are reasonable and provide proper protection, but not at the expense of requiring over-designed hardware. A comparison is made by evaluating how a seat designed to the GASP requirements would have performed in the crashes that were evaluated in this report. The GASP criteria falls in the middle of the longitudinal acceleration loads and velocity changes of the accidents in this report. (See figure 4.) It is believed, however, that most of the occupants would have received substantial benefit from a seat/restraint system that was designed to the GASP proposed standards. The accidents which resulted in the higher velocity changes of 60 to 70 feet per second would have had a pulse duration of about 0.17 seconds, 0.07 seconds longer than the test requirement. Experts in the field of dynamic testing of seats/restraint systems believe that the extra time is not critical to the system's capabilities and integrity. It is believed also that the systems could offer substantial protection in the cases where the acceleration levels do not greatly exceed 26 G's, such as those that remained below the 30 G level.

It is concluded therefore, that seat/restraint systems designed to the GASP design criteria for the longitudinal direction would have had enough strength to protect most of the occupants involved in the accident cases used in this study. In the accident cases in which the loads were greater than the test loads recommended by GASP, the occupants still would have received substantial protection.

Examining figure 5 reveals that seats designed to the GASP proposal for the vertical direction would have protected a large number of occupants who were injured. The two accident cases in which energy-absorbing seats were available demonstrate the significant protection that can be provided by energy-absorbing seats. It is recognized that the GASP proposal does not extend to the higher loads which were present in some of the survivable crashes presented in this study. However, it is believed that, in light of cost and other design considerations, the GASP proposal represents a good compromise which should result in less severe injuries to most of the occupants of the more severe, survivable crashes.

RECOMMENDATION HISTORY

The findings of this study lend further support to a number of previous recommendations issued by the Safety Board related to the crashworthiness of general aviation airplanes. Multi-axis dynamic testing, higher strength seats/restraint systems, and the availability and use of shoulder harnesses for all occupants would lead to a significant reduction of death and injury in general aviation airplane crashes. Some of these recommendations include the following:

CY-70-42 August 28, 1970

Part 1-Require shoulder harness on all general aviation airplanes at the earliest practical date. (Status: Closed—Acceptable Action)

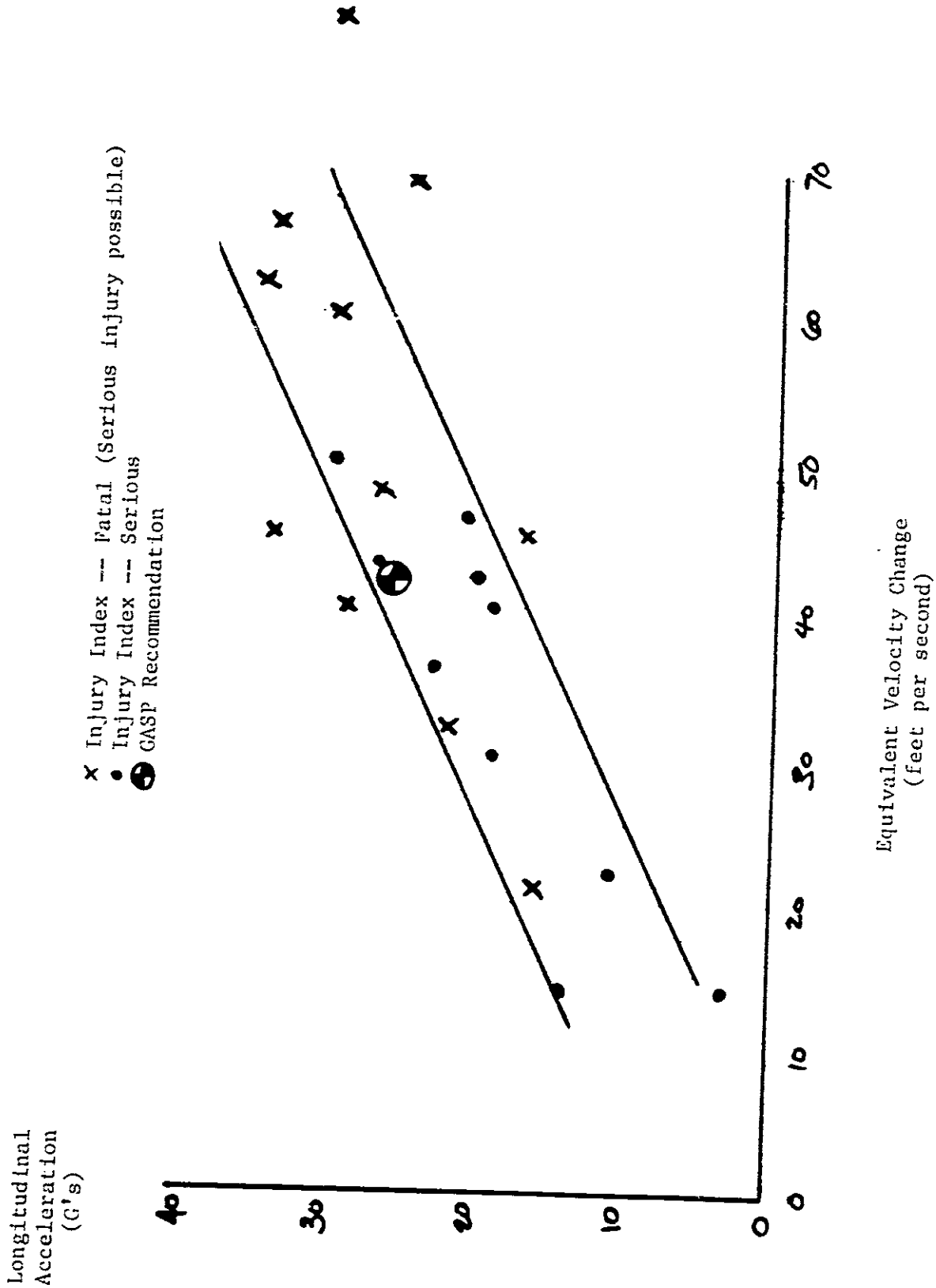


Figure 4.—Longitudinal Acceleration and Equivalent Velocity Changes of Survivable Accidents Compared to the GASP Proposal.

Part 3-Require dynamic testing of aircraft seats. (Status: Closed--Unacceptable Action)

Part 4-Initiate regulatory action to raise the "minor crash landing" inertia forces of FAR 23.561 to a level comparable to those produced by a moderate-to-severe crash landing. (Status: Open--Acceptable Action)

The FAA addressed Part 1 by requiring that shoulder harnesses be installed for the front seats of general aviation airplanes by July 18, 1978. Parts 3 and 4 have been recently addressed by the FAA when it established the "Special Projects Office," which is responsive to crashworthiness issues. It is expected that the current FAA/GASP effort will lead to the fulfillment of these parts.

A-77-70

Amend 14 CFR 23.785 to require installation of approved shoulder harnesses at all seat locations as outlined in NPRM 73-1. (Status: Open, Acceptable Action)

As for Parts 3 and 4 of Recommendation Cy-70-42 above, the FAA established the "Special Projects Office," which is responsive to crashworthiness issues. It is expected that the current FAA/GASP effort will lead to the fulfillment of this recommendation.

A-77-71

Amend 14 CFR 91.33 and .39 to require installation of approved shoulder harnesses on all general aviation aircraft manufactured before July 18, 1978, after a reasonable lead time, and at all seat locations as outlined in NPRM 73-1. (Status: Open, unacceptable action.)

The FAA has not required, nor proposed to require, airplanes manufactured before July 18, 1978 to be equipped with shoulder harnesses. Although many airplane manufacturers have provided shoulder harnesses for all seats since January 1, 1985, the FAA has not required this form of occupant protection for other than front seats.

A-75-71

Amend 14 CFR 23.785(f) to require dynamic testing of seats to insure more realistic protection of occupants from serious injury in a minor crash. (Status: Open, Acceptable Action.)

The FAA responded that it would be unable to amend 14 CFR 23.785 as requested until realistic criteria were established. The FAA has undertaken programs to develop dynamic testing criteria, but formal rulemaking, which would require dynamic testing, has not been accomplished.

The lapbelt cables on certain airplanes in the Piper series have broken, causing increased injury to the occupants. Those cables were the subject of Safety Recommendation A-73-56. At that time, the FAA declined to issue an Airworthiness Directive for PA28 airplanes to increase the size of the cable because the crash was more severe than was provided for in the design standards. As documented in the present study, a PA-32 accident (Case 39) resulted in the cable breaking. A similar result occurred in a PA28-180 accident at Plymouth, Massachusetts on November 19, 1982. In these accidents, five people were injured, with one receiving fatal injuries.

Safety Recommendation A-73-56 (previously closed, unacceptable action,) read as follows:

> Issue an Airworthiness Directive for all Piper PA-28-140/180 airplanes, which have the rear bench seat installation, to require replacement of the present 1/8-inch diameter seatbelt attachment cable with a stronger cable, or, alternatively, to reroute the present 1/8-inch cable to eliminate the stress concentration which may result from the cable contact with the seat frame.

The FAA initially declined to issue an Airworthiness Directive as requested in the recommendation because it concluded that this cable met the strength requirements, but that during the accident, loads in excess of the design requirements were imposed. Although the FAA's response indicated that no further action would be taken, the intent of the recommendation was fulfilled with the issuance of AD 74-09-04, which required rerouting the cable.

The Safety Board now believes that the scope of the AD should be expanded to include all Piper airplanes that use the 1/8-inch cable, whether on benches or individual seats. Restraint separations other than at the attach fittings are typically not found in other general aviation airplanes, and these separations could easily be resolved with an increase in the cable size.

SUMMARY

The Safety Board believes that the GASP proposal provides a method of accomplishing most of the stated Safety Board objectives for newly certificated airplanes. Seats and restraints developed to the GASP proposed standards would offer substantial protection in severe but survivable crashes with the added protection of energy management in the vertical direction. It is recognized that the proposed standards for energy management in the vertical direction are minimal and that even higher standards are desirable where the size of the airplane can accommodate more stroking distance. The mandatory use of shoulder harnesses should be extended to all occupants for takeoffs and landings, and pilots should be discouraged from releasing shoulder harnesses while enroute because they may forget or not have time to put them back on during an emergency.

Many of the current seat/restraint systems provide only the minimal protection required at the time of the airplane's original certification. It is recognized that, historically, the FAA has not required manufacturers to institute improvements in equipment that meets the original certification standards. Seat/restraint design, in the view of the Safety Board, is an area where an exception should be made. Additional action is needed to upgrade general aviation seat/restraint designs, particularly where specific weaknesses are identifiable, even though the seats or restraints meet the minimum standards required for certification.

Throughout the cases in this study, many examples of good seat/restraint designs were found as well as examples of very poor designs. Most of the poor designs easily could have been improved if the designers had had better information on crash dynamics.

The Safety Board believes that the broad knowledge available on general aviation crashworthiness must be shared. The exchange of information which has occurred as a result of the meetings of the GASP has been a noteworthy step in the sharing of this knowledge. Further, this mutual effort permitted the formulation of a proposal which was

acceptable to all, or nearly all, segments of the aviation community. Efforts to educate designers on the finer points of crashworthiness design include the recent issuance of a proposed Advisory Circular on human tolerance to impact and the FAA's request that the Society of Automotive Engineers (SAE) develop standards for shoulder harness design.

CONCLUSIONS

1. The accidents in this study were severe, but survivable, general aviation airplane crashes.

2. Acceleration loads and velocity changes of 30 to 35 G's and 60 to 70 feet per second in the longitudinal direction are generally survivable.

3. Acceleration loads and velocity changes of 25 to 30 G's and 50 to 60 feet per second in the vertical direction are generally survivable but the loads experienced by the occupants must be limited to a lower level to prevent crippling injuries to the back and neck.

4. The impact severities (angles and speeds) of the cases in this study closely match the impact severities of the NASA crash tests.

5. The current seat design requirements of 9 G's forward and 3 to 6 G's downward are inadequate.

6. The practical limits of survivability in general aviation airplane crashes are governed by the type of seat/restraint systems used and the capability of the fuselage structure to withstand acceleration loads.

7. Based on the results of this study, the GASP recommendation for a dynamic seat/restraint system test to 26 G's and 42 feet per second velocity change longitudinally appears to be reasonable and appropriate.

8. The GASP recommendation for a dynamic test seat/restraint to 19 G's and 31 feet per second velocity change vertically represents a minimal level of protection, but many occupants will be protected in seats designed to this standard. If the manufacturers also were to use available stroking distances effectively (and thus exceed the GASP requirement), most occupants will be protected in survivable accidents.

9. Many occupants in airplane accidents would derive substantial benefits from seat/restraint systems designed to GASP standards, even if the impact loads were more severe than the prescribed test loads.

10. Head impacts into the instrument panel cannot be precluded, even with properly designed restraint systems. The GASP requirement for the use of a Head Injury Criteria (HIC) test is important, if head impact to the panel is predicted during dynamic testing.

11. In the accidents analyzed as part of this study over 1/2 of the seats became detached in severe but survivable accidents. Current design requirements call for seat feet to withstand only very low side loads. Floor warpage also causes excessive stresses and separations in the feet of seats that cannot conform to the warpage.

12. Study data indicate that shoulder harnesses are not being used to the fullest extent, even when available. Only crewmembers are required to wear them for takeoff and landing, and many crewmembers fail to do so. In other cases, the occupants released the shoulder harnesses while enroute and forgot to put them back on when an emergency arose.

13. Shoulder harness use can reduce the lapbelt loads, preventing many internal organ and pelvic injuries.

14. Shoulder harnesses should not be used to meet the 9 G longitudinal static load requirement for the entire occupant restraint system. Instead, each seat/lapbelt system should be required to restrain the occupant to 9 G's, i.e., the protection of a shoulder harness should be additive.

15. Energy-absorbing seats are necessary to prevent many of the spinal injuries that occur in survivable accidents.

16. Seatpan design requirements are needed to ensure that occupant loads are carried by proper structure. Seatpans should have rip- stop capabilities and should be designed so that they do not collapse catastrophically.

17. For most seats, add-on equipment should be prohibited because the added weight degrades the protection capability of the seat/restraint system.

18. Energy-absorbing seats, lapbelts, and shoulder harnesses should be designed as an integrated system so that the maximum advantage from each system can be gained.

19. Unique features of some airplane seat/restraint designs can contribute to the failure of the systems at loads that would otherwise be tolerable. For example, seatbelt attachment cables have been shown to be the first element to break in some airplanes. Simple actions to install larger diameter cables would improve the seat strength in these airplanes.

20. Available stroking space must be efficiently utilized and not covered over with flooring and cabinetry materials.

RECOMMENDATIONS

As a result of its special study, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Amend 14 CFR Part 23 to specify performance standards for the seat/restraint systems in small airplanes consistent with the standards proposed by the General Aviation Safety Panel; and require the multi-axis dynamic testing of seat/restraint systems as necessary to demonstrate energy management in the vertical direction and structural adequacy in the longitudinal and lateral directions. (Class II, Priority Action) (A-85-122)

> Amend 14 CFR Part 91 and Part 135 to require that all occupants of small airplanes use shoulder harnesses for takeoff and landing when they are available in the airplane. (Class II, Priority Action) (A-85-123)

Issue an Advisory Circular to provide pilots, passengers, and maintenance personnel with information regarding the crash survivability aspects of small airplanes. The Advisory Circular should contain, as a minimum, discussion of the benefits of using lapbelts and shoulder harnesses during all phases of flight, discussion of the hazards of modifying seats, appendages to seats and stowage of articles in space designed or available for energy management, and discussion of the need for regular inspection and maintenance of seats. (Class II, Priority Action) (A-85-124)

Issue a series of Airworthiness Directives to require modification of seats installed in general aviation airplanes which have identified deficiencies. For example, require the replacement of the 1/8-inch diameter lapbelt attachment cable on applicable airplanes with a cable of a strength more compatible with the seat design, require replacement of plastic-type seatpans on applicable airplanes with a structural seatpan, and require additional stabilizing support on seats using "S"-shaped springs for the seatpans. (Class II, Priority Action) (A-85-125)

As a result of its special study, the National Transportation Safety Board recommends that the General Aviation Manufacturers Association:

Encourage its members to evaluate the design of the seat/restraint systems in those models of airplanes in wide use to identify additional weaknesses which could be easily correctable. Definitive actions should be taken to implement the corrections, including installing the many modifications and retrofit kits that are presently available for the installation of shoulder harnesses and for the strengthening of seat feet. (Class II, Priority Action) (A-85-126)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JIM BURNETT
Chairman

/s/ PATRICIA A. GOLDMAN
Vice Chairman

/s/ G. H. PATRICK BURSLEY
Member

September 4, 1985

APPENDIX A

CASE HISTORIES and PHOTOGRAPHS

INTRODUCTION

The following case studies are presented to highlight the important crashworthiness information that was gathered during on-scene investigations. Information that was used to calculate the impact conditions and acceleration loads is presented in a very brief format. The full accident file would be needed for a comprehensive crashworthiness reconstruction and cannot be presented here. However, these studies illustrate important points about design problems, lack of use of available restraints, equipment added to seats, and general information about crash kinematics. Where possible, the crash loads of the airplane were calculated to demonstrate the relative severity of these accidents.

Defining the mechanisms of injury causation can never be done with complete certainty. For example, a lumbar vertebral fracture can be caused by high vertical loads from a stiff seat, or by the occupant slamming into the floor, or by high longitudinal loads resulting in a wedging fracture as the torso jacknifes around a lapbelt. Such fractures also could result from a combination of loads which misalign the spine, reducing its strength. Throughout these case studies, the stated mechanisms of injury causation are based on the most probable events, taking into account known circumstances about the accident.

Generally, terms and definitions used in the case studies are the same as those presented in the two previous reports in this series.

> Impact velocity refers to the velocity at the principal impact; exit velocity is the airplane's remaining velocity after the major acceleration loads have dissipated. In many cases, the exit velocity is the same as the velocity at the beginning of the final slide to a stop.
>
> Pilot and copilot seats are the left front and right front seats, respectively.
>
> Principal impact is impact in which the majority of the energy is dissipated over the smallest period of time. It is not always the first impact.

Case 1

SYNOPSIS

While on a cross-country flight, the low-wing, single-engine airplane crashed into the side of a mountain just after dark in deteriorating weather conditions. The pilot and a passenger were both seriously injured in the crash; the passenger died several days later. Both occupants had been wearing seat belts. Neither occupant was wearing an available shoulder harness. Although the airplane was destroyed on impact, there was no fire. The bottom of the fuselage, in the area where the passenger was sitting, was crushed upward 14 inches on the right side of the airplane, caused by hitting a large rock at initial ground contact.

SEATS, RESTRAINTS, AND INJURIES

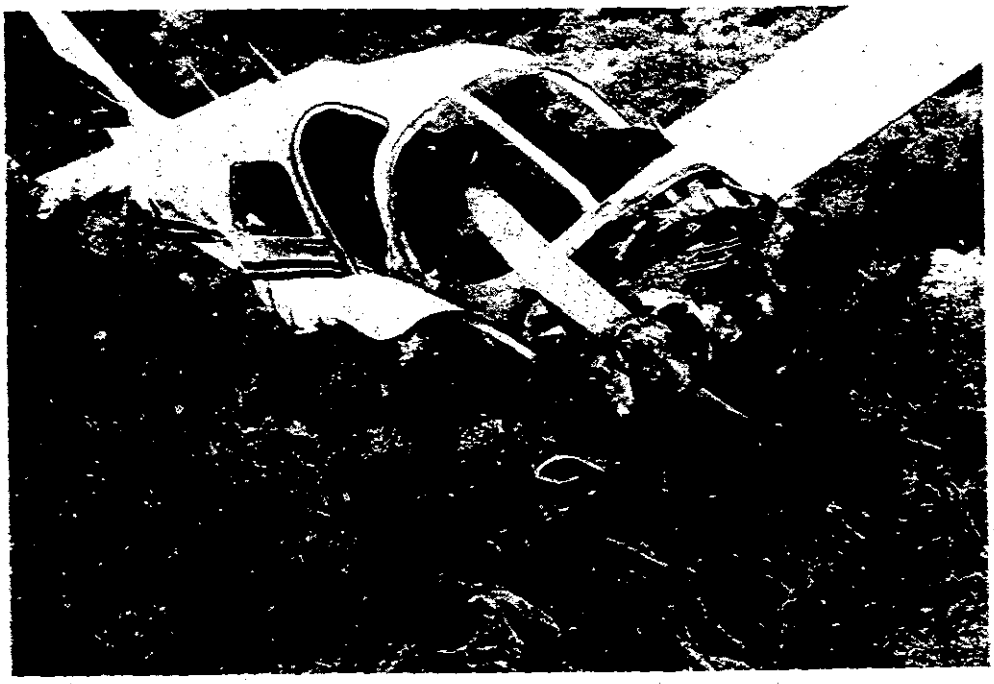
The pilot, who had a concussion and a number of fractures and lacerations, would have had substantively less serious injuries had he been wearing a shoulder harness. In particular, it is likely that the concussion received when his head hit the instrument panel (photograph 1-2) would have been prevented by a shoulder harness. Additionally, his orbital fractures, jaw fracture, and rib fracture would have been prevented. The pilot stated that he had worn his shoulder harness, as required, for takeoff, but had removed it during the flight. During the emergency he forgot to put it back on.

The passenger, whose injuries proved to be fatal, might have survived if he had been using a shoulder harness. On admission to the hospital, he was described as being comotose without detectable blood pressure or pulse. His facial lacerations, chest contusions, and depressed skull fracture could all have been prevented. The crushed foot would not have been preventable. It is possible that a shoulder harness would have lessened the loads on the lapbelt, reducing the pelvic and internal damage. Death was attributed to large blood loss due to internal bleeding, typical of injuries caused by high lapbelt loads.

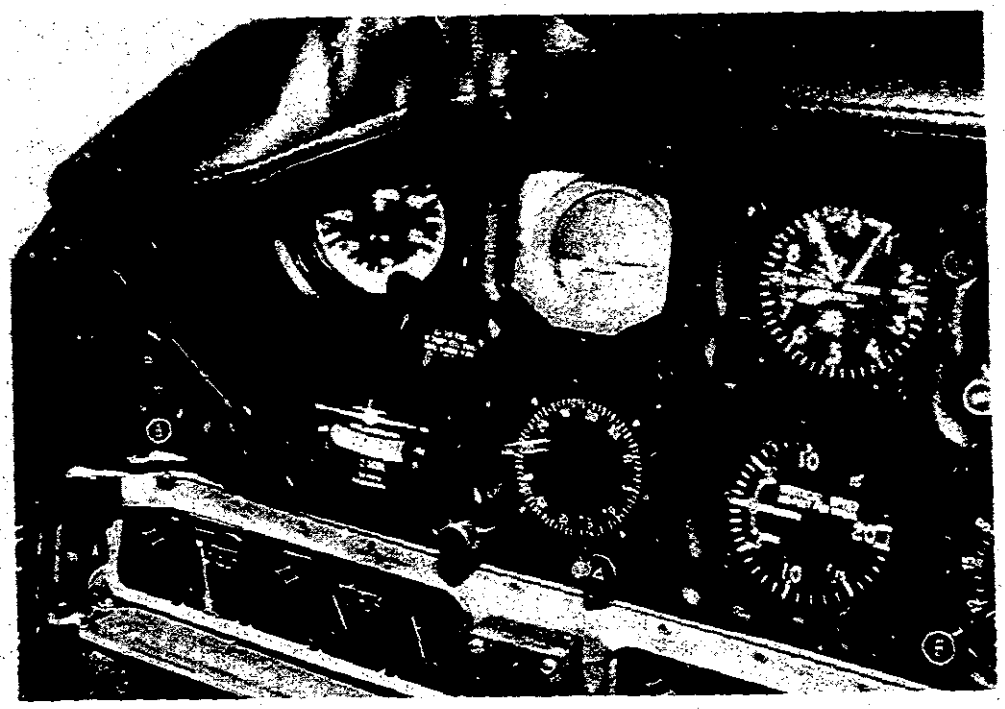
This airplane was equipped with "S" tube energy-absorbing seats. The passenger's seat reacted to the localized crushing as it was designed to do, absorbing some of the energy which would otherwise have been transmitted to the passenger. The passenger's seat did become separated from the airplane during the impact because the seat feet spread apart, allowing the seat to separate from the floor tracks. The pilot's seat, also the "S" tube type, did not stroke in the crash because the loads on it were insufficient to cause deformation of the tubing. However, the tubing deformed response to the warping floor.

G-PULSE

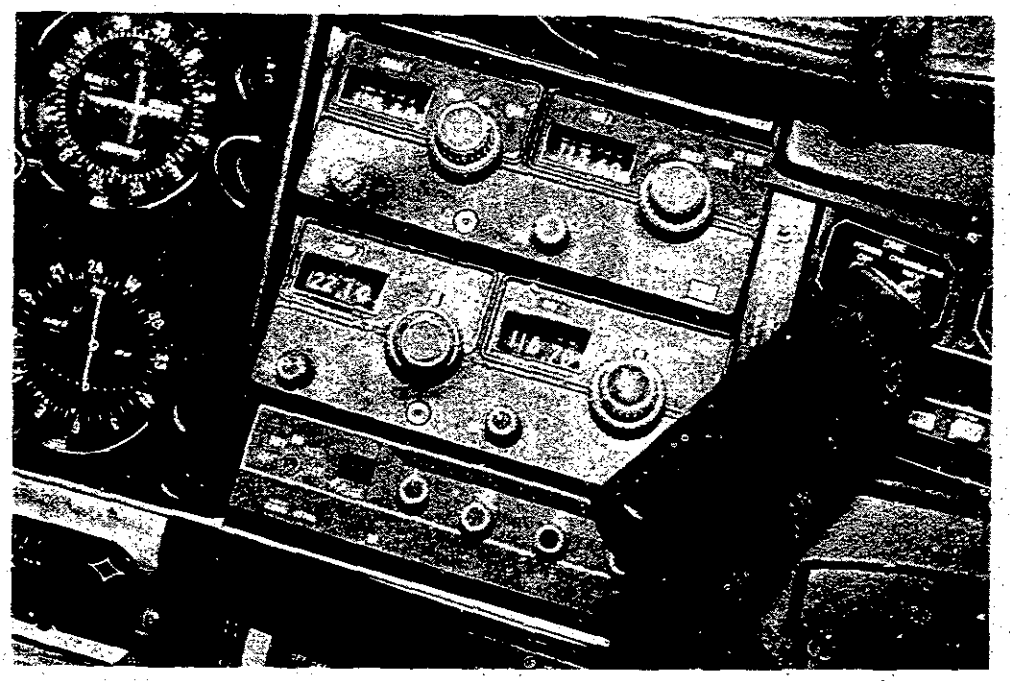
The impact velocity could not be determined. The airplane was at or below cruise speed and starting a turn immediately prior to impact. The right wing sustained several major tree strikes which caused velocity losses that also could not be estimated. The velocity change at the rock impact (principal impact) could not be estimated because the 96 yard slide precluded an accurate estimate of the exit velocity. Small errors in the estimate of the sliding friction coefficient would result in large errors of estimated velocity change. The 1-degree downward flight path was defined by multiple tree strikes. The airplane impacted a rock and a 9-degree slope simultaneously, resulting in a 10-degree impact angle. (See sketch of crash site).



1-1 Wreckage.



1-2 Pilot's head contact area.



1-3 Passenger's head contact area.

1-4 Stroked energy absorbing seat; note that legs separated.

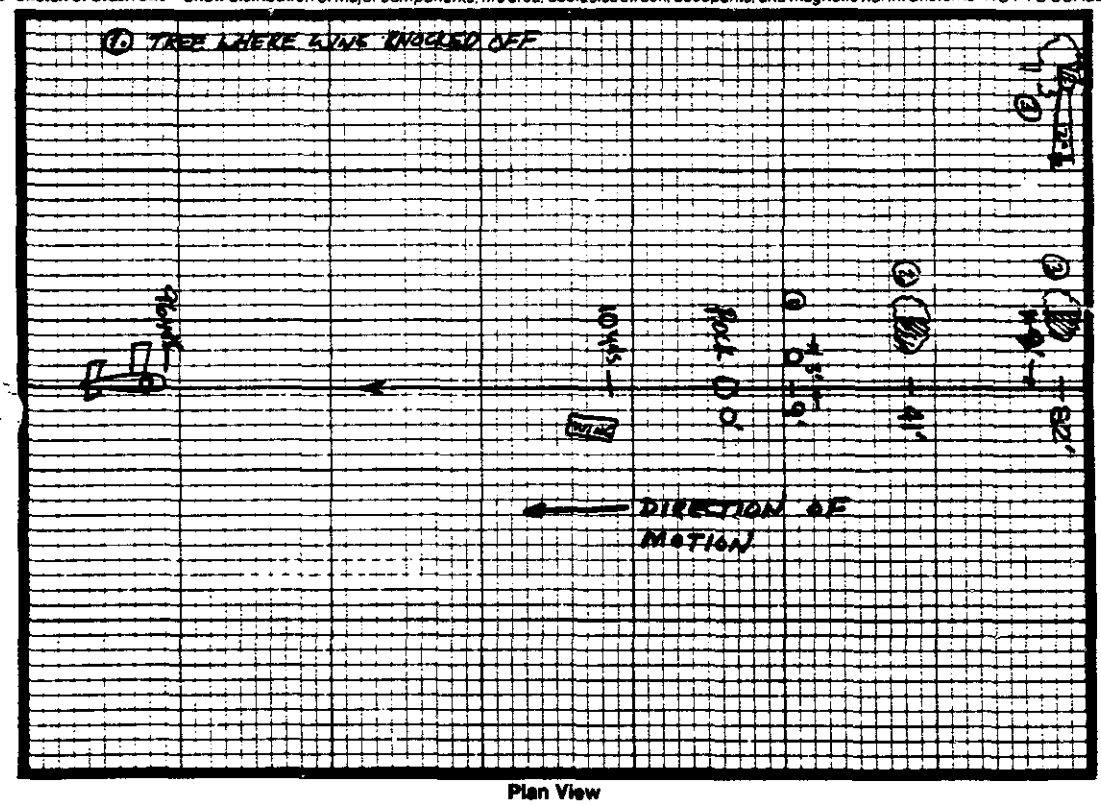
National Transportation Safety Board

FACTUAL REPORT
AVIATION

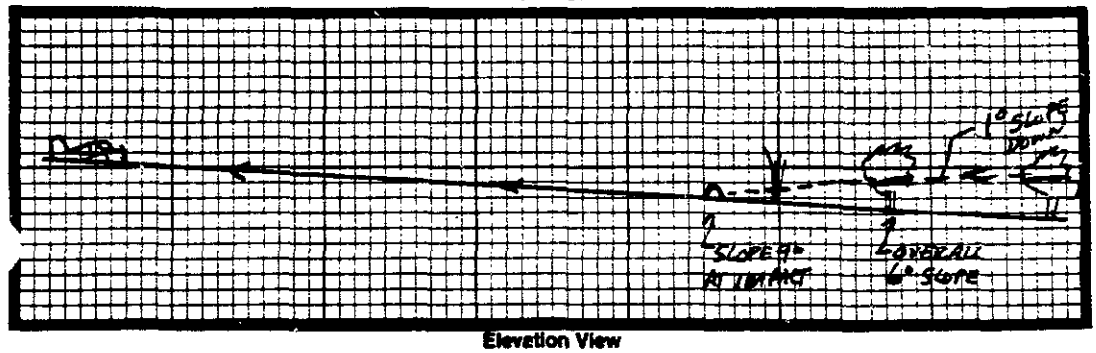
Supplement I - Crash Kinematics (continued)

Crash Site Plan/Elevation

36 **Sketch of Crash Site**—*Show distribution of major components, fire area, obstacles struck, occupants, and magnetic north. Sketch is "NOT TO SCALE".*



Plan View



Elevation View

1-5 Airplane's final approach and ensuing crash sequence.

Case 2

SYNOPSIS

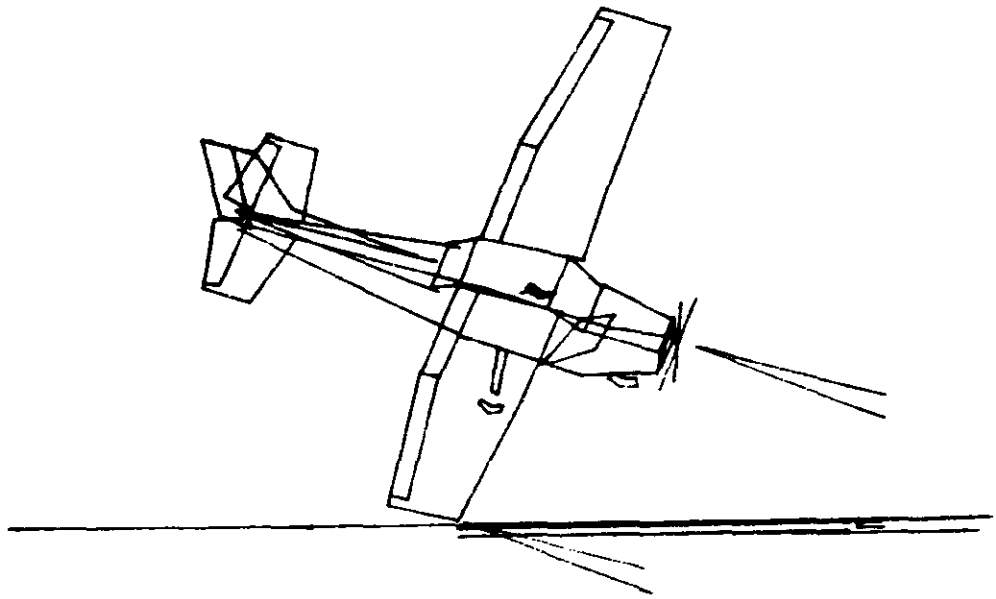
This high-wing, single-engine airplane was taking off from a private dirt strip during daylight, VFR, conditions. Shortly after takeoff, the engine stopped, and while maneuvering at low altitude to avoid obstacles in the path of the intended landing, the pilot stalled the airplane. The airplane crashed at a 24-degree impact angle and a 46-degree left roll attitude. The nose gear subsequently broke off and the airplane stopped in an inverted position. The nose crushed 2.4 feet. The pilot received serious injuries, one of the passengers had minor injuries, and the other passenger had no injuries. Each of the occupants was wearing a seatbelt; neither of the front seat occupants was wearing the available shoulder harness.

SEATS, RESTRAINTS, AND INJURIES

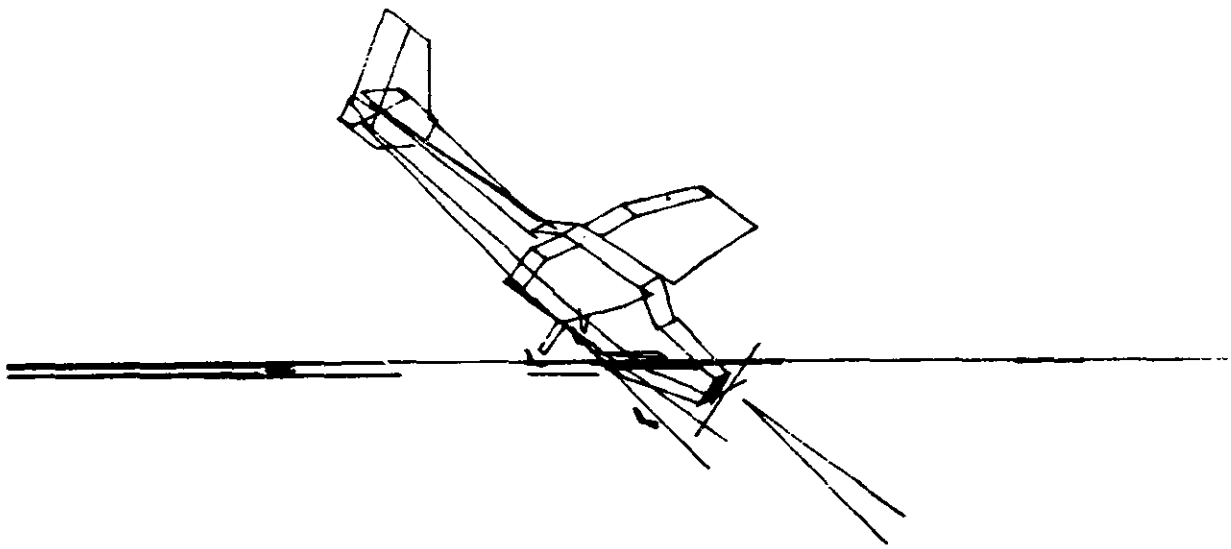
The pilot sustained multiple lacerations which required closure, a fractured pelvis, and a concussion resulting in loss of consciousness. There was substantial disruption of the entire floor structure; the pilot's seat separated from the floor tracks during impact because the seat feet spread. The front seat passenger suffered seatbelt bruises, some facial lacerations, and a sprained ankle. The floor was distorted in the location of this seat, but it remained attached to the floor. The wearing of shoulder harnesses would have prevented most of the injuries to the front seat occupants, or at least injuries would have been less severe. The occupant in the rear seat had only temporary stiffness as a result of the crash. Her seat remained attached to the floor.

G-PULSE

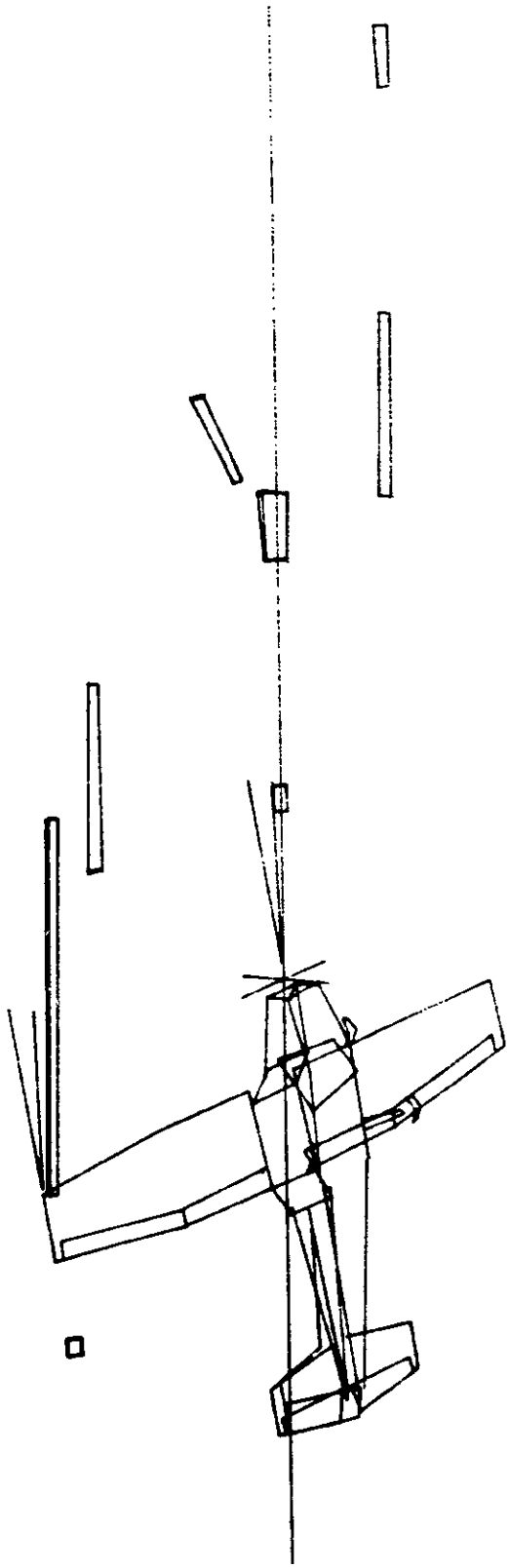
The calculations of the G-loads for this accident assumed 24 degrees as the impact angle and 56 knots as the impact speed. The impact angle was determined by matching the ground scars and airplane components. The impact speed was determined by correcting the published landing configuration stall speed to account for the flaps up condition, a 46-degree bank angle, 360 pounds less than gross weight, and an 8-knot head wind. The vertical velocity was calculated to be 33.5 feet per second, and the horizontal velocity was 75.4 feet per second. A vertical stopping distance of 2.4 feet would yield a peak acceleration load of 14.5 G's over a period of 0.14 seconds. A slide of 40 feet and a sliding friction coefficient of 0.7 would yield an exit velocity of 42 feet per second. The horizontal velocity change would then be 75.4 -2.0 or 33.2 feet per second. That velocity change over a period of 0.14 seconds would yield a peak pulse of 14.8 G's horizontal (earth axis). Correcting to airplane axis (36 degrees nose-down at the fullest crush) would yield a horizontal pulse of about 20 G's and a vertical pulse of about 3 G's. The velocity changes (airplane axis) were calculated to be 46 feet per second horizontal, but were very small in the vertical direction.



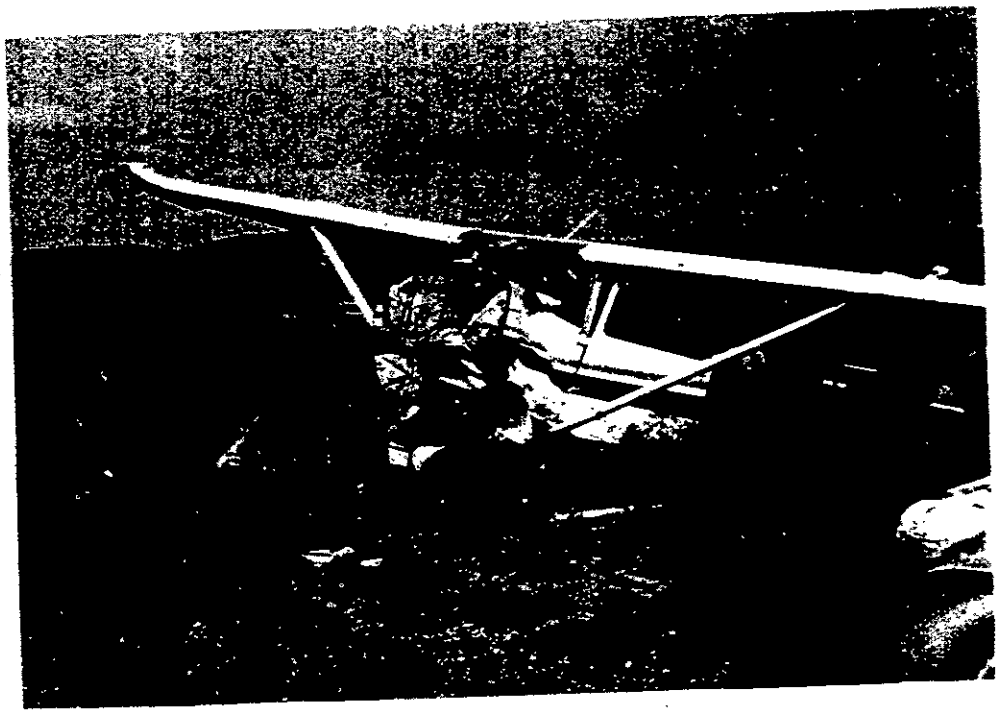
2-1. Side view at initial contact.



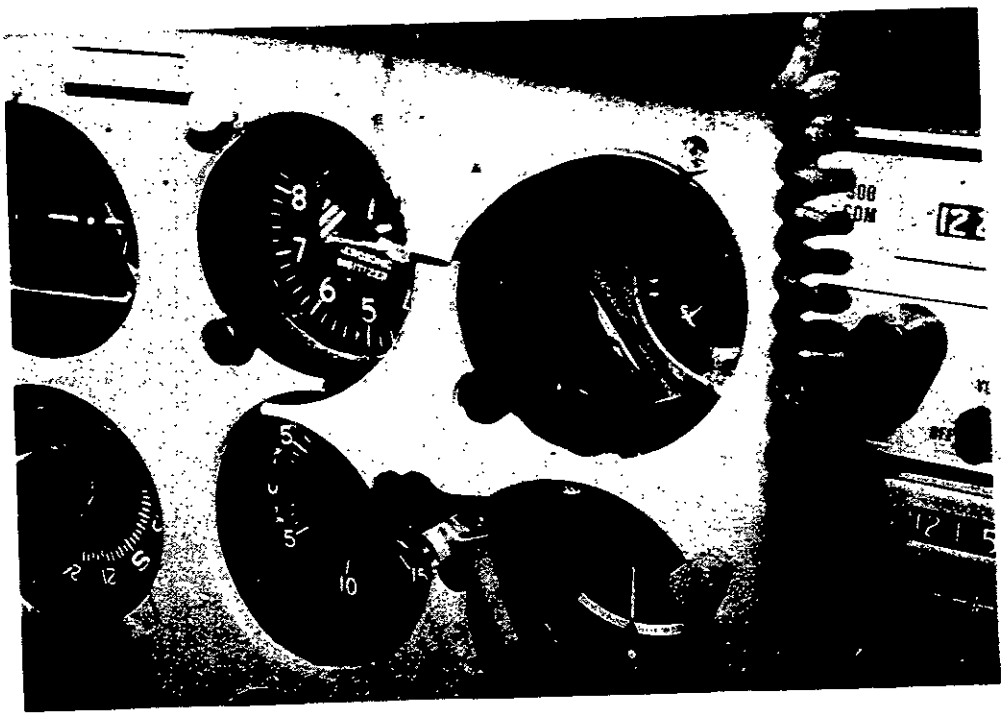
2-2. Side view at full crash.



2-3. Top view.



2-4. Wreckage.



2-5. Pilot's head impact area.

Case 3

SYNOPSIS

This accident involved a twin-engine airplane which made a forced off-airport landing as a result of fuel exhaustion. According to the pilot, neither engine was feathered. A field was selected on which to make the emergency landing. During the final phases of the approach to landing, the pilot saw a power line in the airplane's flight path and he pulled up the nose in an attempt to clear it, resulting in a stall which was not recoverable. The airplane impacted the ground in a 51-degree left roll and a 37-degree pitch down attitude. The impact angle was 48 degrees and the impact speed was 62 knots. The airplane was destroyed on impact.

SEATS, RESTRAINTS AND INJURIES

The pilot received a fracture of the left femur, numerous lacerations and contusions, a broken nose, other mid-facial fractures, and was described on arrival at the hospital as being semi-comatose. He had been wearing only a lapbelt. The lapbelt became separated from the airplane when the attach bolt pulled loose. The other front seat occupant received a depressed skull fracture, a comminuted fracture of the right tibia, a fracture of the left calcaneous, and a compression fracture of the L4 vertebra. This passenger was wearing a lapbelt and a shoulder harness; however, the loop length of the shoulder harness may have been too long to be maximally effective. The floor collapsed throughout the cockpit area. The energy absorbing seats offered some protection to the persons seated in the front seats.

A passenger riding in the left most seat in the aft row had his seatbelt fastened; there was no shoulder harness in this position. His injuries included a dislocated knee, fractures in both ankles, and closed head injuries. He also was described as being comatose. The passenger in the right aft seat was also wearing a lapbelt. His injuries included multiple fractures of each arm, a fractured pelvis, closed head wounds, and numerous lacerations and abrasions. His seat was not equipped with a shoulder harness. A shoulder harness could have prevented nearly all of these injuries to these occupants except possibly those to the arms and legs.

One occupant received fatal injuries which included a fracture-dislocation of the first vertebra, as well as fractures of the left and right femurs and numerous lacerations. The vertebral fracture resulted in complete severing of the spinal cord. This individual was seated in a rear seat and he was wearing a lapbelt. There was no shoulder harness available.

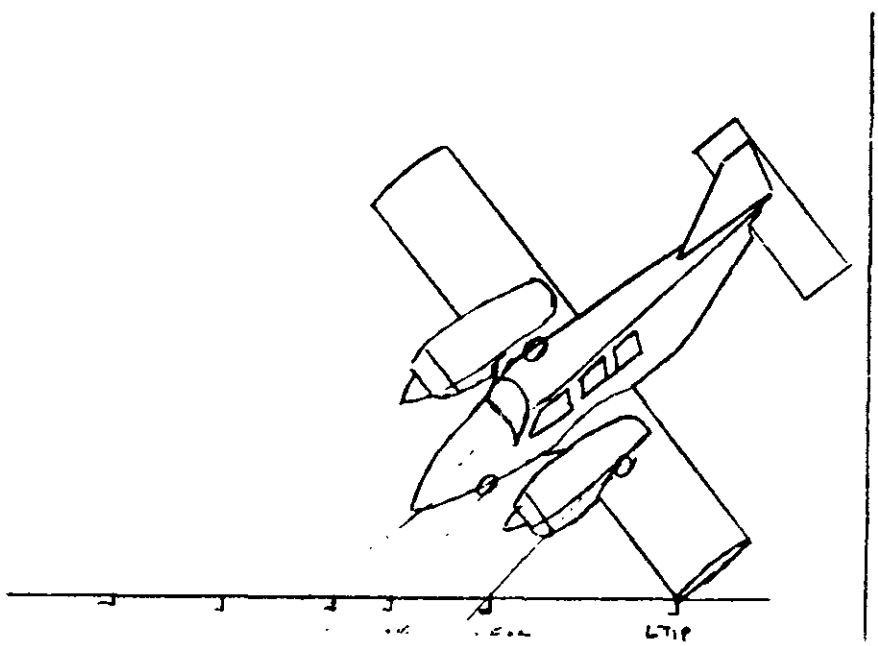
G-PULSE

The airplane was estimated to have impacted the ground at approximately 62 knots, accounting for the airplane's actual weight and flap configuration. By matching ground scars to airplane components, it was concluded that the airplane was in a 51-degree left bank and a 37-degree pitch down attitude. The impact angle was 48 degrees. By the time the fuselage was fully stroked, the crushline indicates that the pitch attitude was reduced to about 13 degrees.

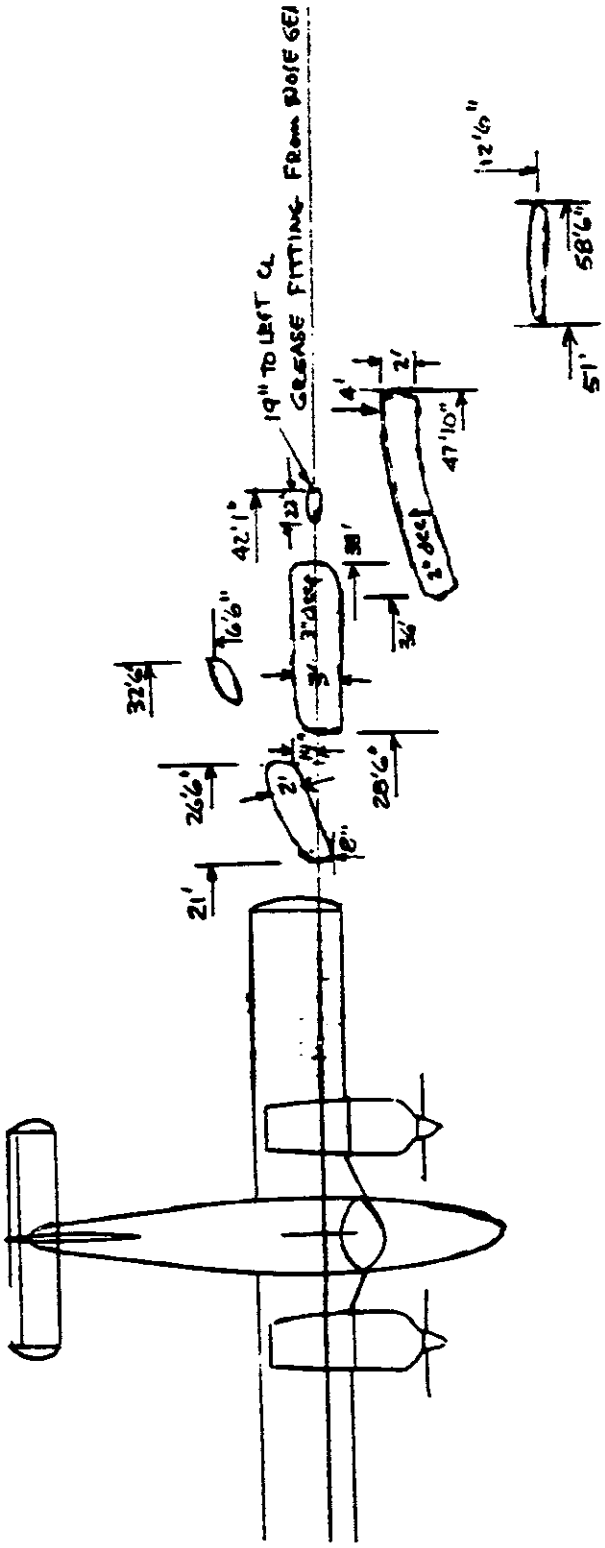
The vertical velocity component was 78 feet per second and the horizontal component was about 70 feet per second. Since the slide over green wheat resulted in very little gouging, a sliding friction coefficient of 0.5 was used. The exit velocity was calculated to be 29 feet per second with a net horizontal velocity change of 41 feet per second (70-29).

The large change in pitch attitude during the crushing sequence of the crash required adding several corrections to the normal acceleration calculations. One correction was to compensate for the fact that rotation creates a "ride down" effect that gives the occupants an additional stopping distance of 1.7 feet. Another correction was needed to compensate for the direction of the acceleration vector, since during rotation the acceleration vector starts out as primarily longitudinal and ends up as primarily vertical.

The net stopping distance in the vertical direction then would be the cumulative effect of the 2 feet of crush to the fuselage, the 1.7 feet due to rotation, and an additional 6 inches of stroke to some individual seats. By stepping the airplane drawing through the crushing and rotation sequence, a half sine wave pulse was judged to be the most representative. The velocity change of 78 feet per second and a stopping distance of 4.3 feet yields a maximum vertical acceleration of 34 G's (earth axis) over a period of 0.11 seconds. Again, using a half sine pulse, the horizontal loads were calculated to be about 14 G's. Converting from earth axis to airplane axis yields a vertical load of 30 G's and a horizontal load of 21 G's. The velocity change (airplane axis) was 48 feet per second horizontal and 53 feet per second vertical.

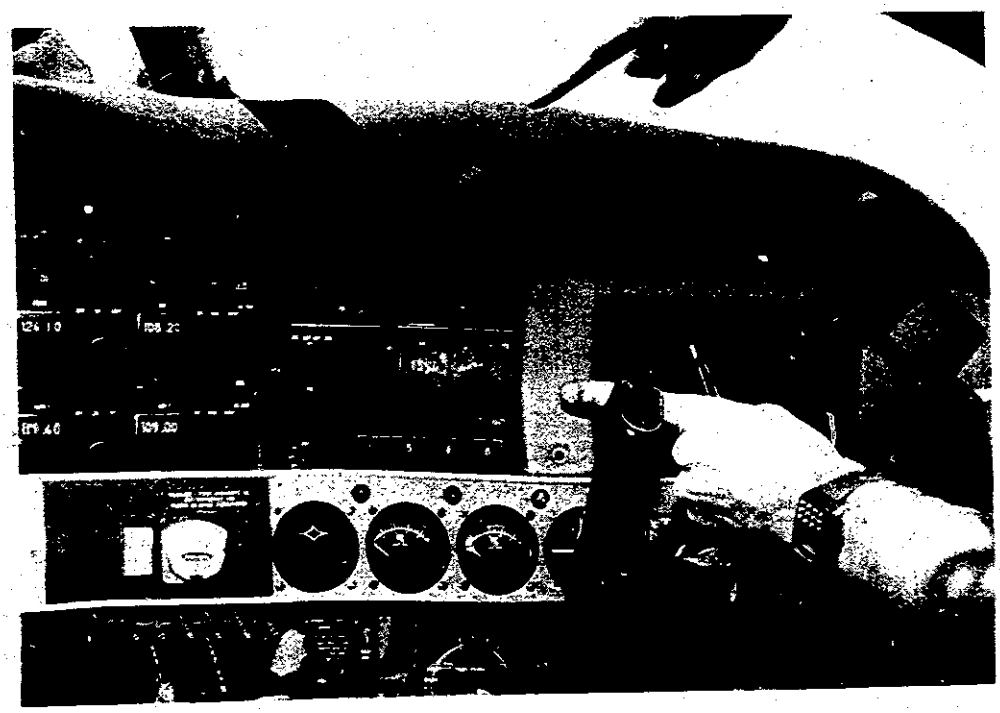


3-1. Impact progression.


19" TO LEFT CL
GREASE FITTING FROM BOTE GEI
42'1"
23
16'6"
32'6"
26'6"
21'
28'6"
36'
47'10"
4'
2'
112'6"
58'6"
51'

3-2 Top view.

3-3. Wreckage and crush line.



3-4. Area where right front occupant contacted panel.

Case 4

SYNOPSIS

The pilot of this low-wing, single-engine airplane attempted to make a forced landing on an airport following a perceived engine malfunction. The airplane impacted at the crest of a ditch approximately 200 yards short of the runway in an area of uneven bushy terrain.

SEATS AND RESTRAINTS

This airplane was not equipped with shoulder harnesses. The pilot was wearing a lapbelt. His head impacted the instrument panel (see photograph 4-2), resulting in deep lacerations to the forehead. Numerous pieces of glass from the instrument panel were embedded in the pilots forehead and around his eyes. He also sustained a fractured rib and nose, and multiple contusions and lacerations. Most, if not all, of these injuries would have been prevented by a shoulder harness.

A passenger seated in the right front seat wore a lapbelt and received minor injuries to the face and neck. These injuries would have been prevented by a shoulder harness.

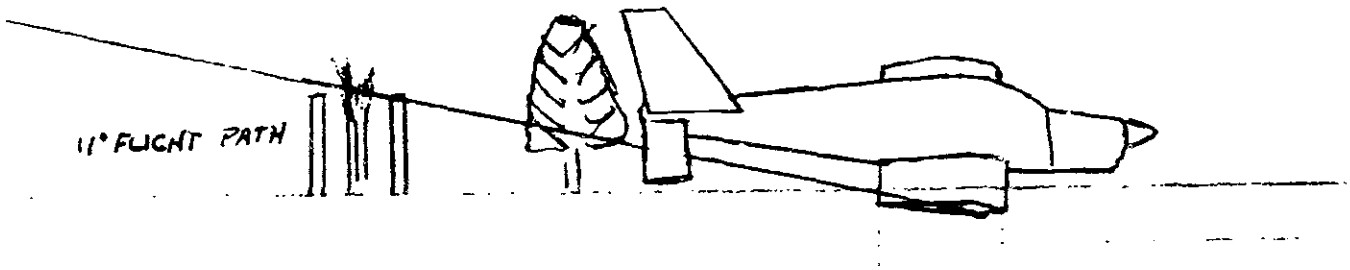
Several problems were discovered with the seats. The seat pans of both seats had rotted and only the foam comfort cushions supported the weight of the occupants. The pan material, neoprene, had been structurally sound when new, but had lost all of its strength with age. In addition, a fire extinguisher had been installed on one of the occupant seats. The seat legs where this extinguisher was mounted had not been designed or tested to bear this additional weight. While neither the aged seat pan nor the fire extinguisher contributed to the occupants' injuries, they could have directly caused other injuries had the impact forces been more severe or more predominately vertical.

G-PULSE

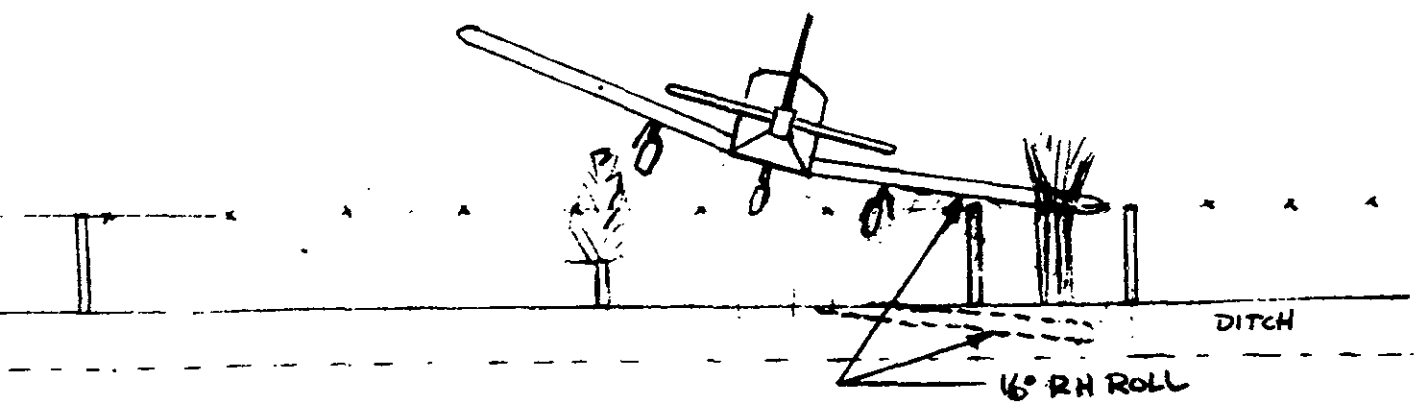
The impact speed was estimated from the airplane's published stall speed with corrections for flap position, weight, and a headwind. The impact speed was estimated at 43 knots at wing contact. Reconstruction using ground scars reveals an impact angle of the fuselage of 11 degrees and a right roll angle of 14 degrees.

The right wing impacted into the side of the ditch, which exerted longitudinal loads on the occupants. The crushing lasted over a distance of 7.8 feet.

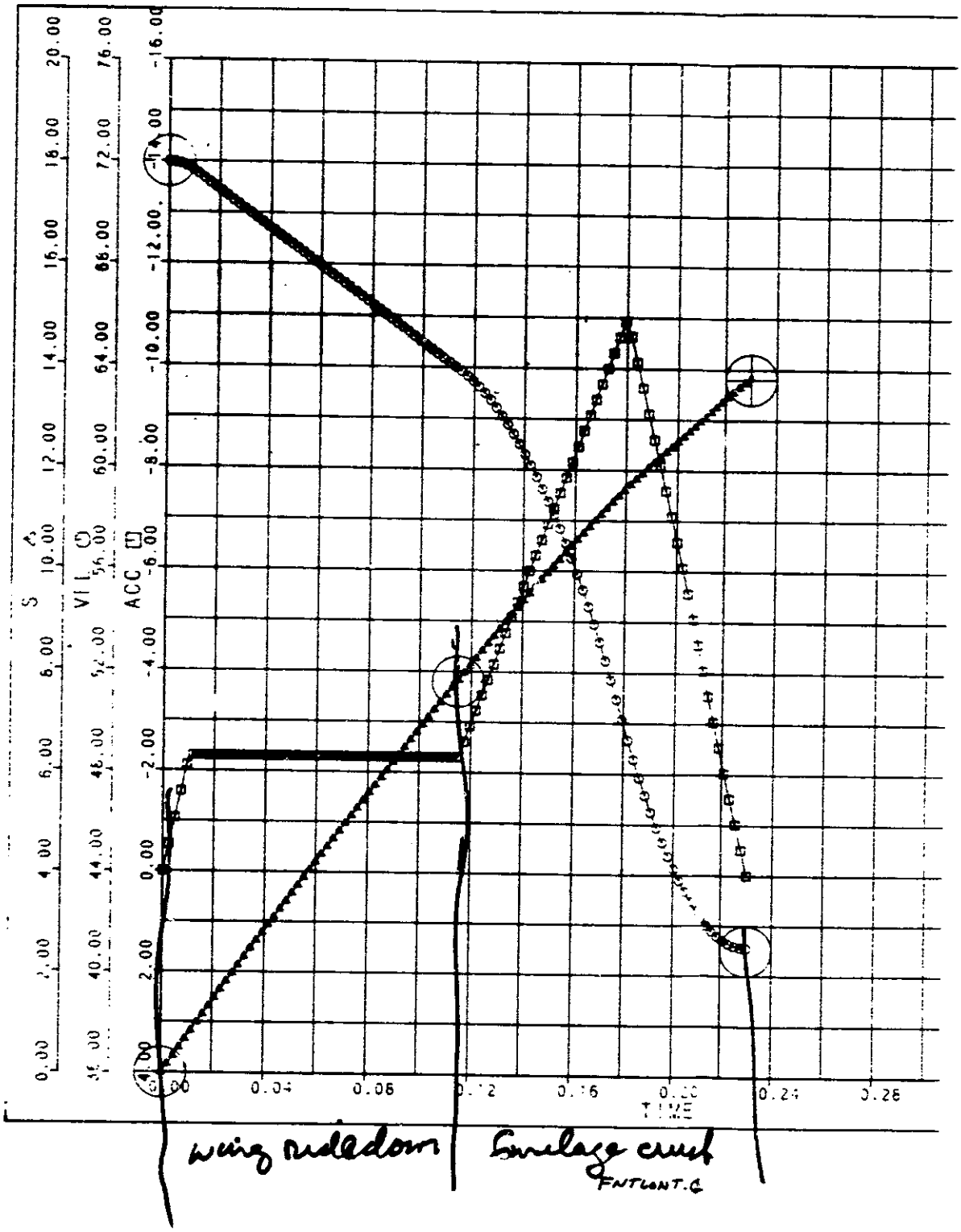
The horizontal velocity was 72 feet per second into the side of the ditch and the exit velocity was calculated at 41 feet per second, using a sliding distance of 32 feet and a 0.8 friction coefficient. A computer program that integrates accelerations to obtain velocity and distance was used to derive an acceleration pulse. The stopping distance was 13.8 feet (7.8 feet for the wing and 6 feet for the fuselage gouge). Estimating a 2 G acceleration due to the wing contact would yield an 11 G pulse to the fuselage (see plot). A vertical impact velocity of 11.6 feet per second was estimated because the wing contact slowed the fuselage down to 61 feet per second at fuselage contact. The vertical component at that point would be 11.6 feet per second. A stopping distance of 4 inches crush and 4 inches gouge would yield a peak vertical load of 6 G's.



4-1. Side view.

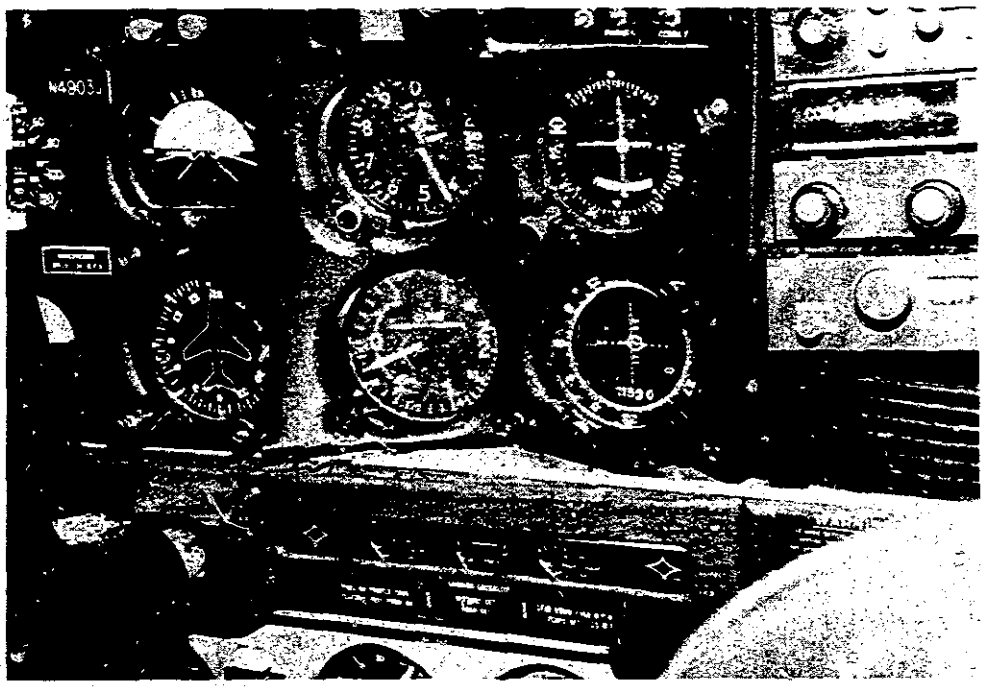


4-2. End view.

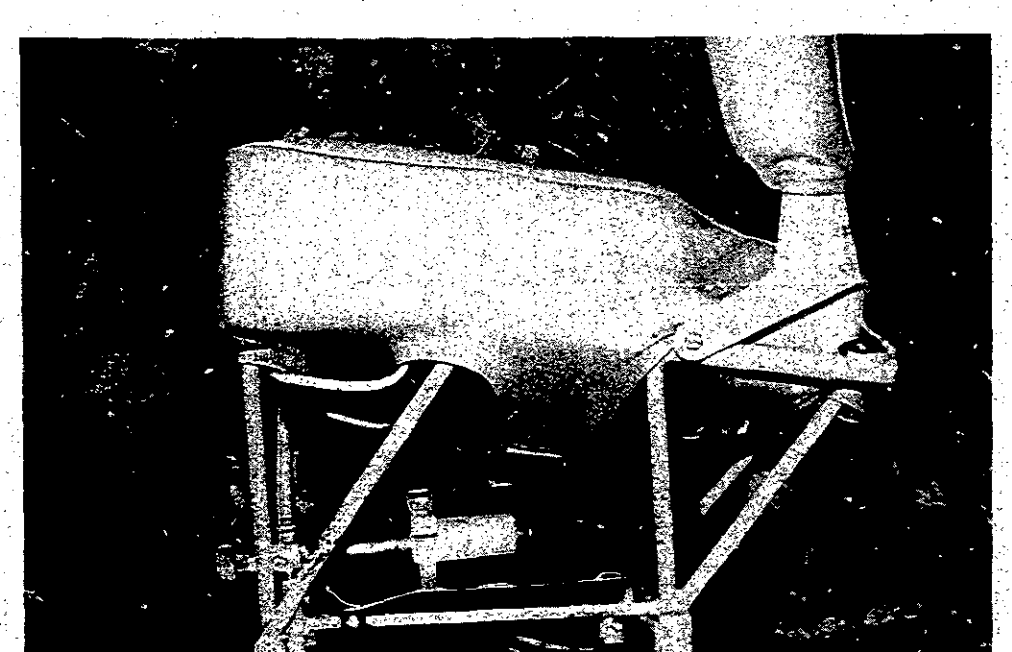


4-3. Crash pulse depiction.

4-4. Wreckage.



4-5. Pilot's head impact area.



4-6. Fire extinguisher was added to seat, but seat was not certificated for extra weight. Stabilizing bar is located between front and rear legs.

4-7. Rotten seat pan and typical seat foot.

Case 5

SYNOPSIS

The pilot and three passengers of this high-wing, single-engine airplane were flying at low altitude, spotting big game animals. As a result of the low altitude and pilot inattention, the airplane impacted steeply sloped terrain.

INJURIES

The pilot, who was wearing a lapbelt but not the available shoulder harness, was seriously injured. His head impacted the instrument panel resulting in the loss of one eye, serious injury to the other, a fractured jaw, assorted facial fractures, a basilar skull fracture, and a fractured ankle and fingers. Most of those injuries would have been less severe had he worn a shoulder harness.

One rear seat passenger who was not wearing a lapbelt was ejected from the airplane and suffered a concussion and a head laceration. Both the passengers on the right side were fatally injured. The right front occupant, who neither was wearing a shoulder harness nor a lapbelt, received crushing injuries to the head and spinal injuries during the impact with the instrument panel in addition to receiving lacerations and puncture wounds from secondary impacts with structures in the airplane. (See photographs 5-4 and 5-5.) The other fatally injured passenger wore the lapbelt and had a bruise on the forehead, a fractured vertebra in the neck and a dislocated shoulder. Both seats became disattached during the impact; the floor in the pilot and copilot area was disrupted and deformed.

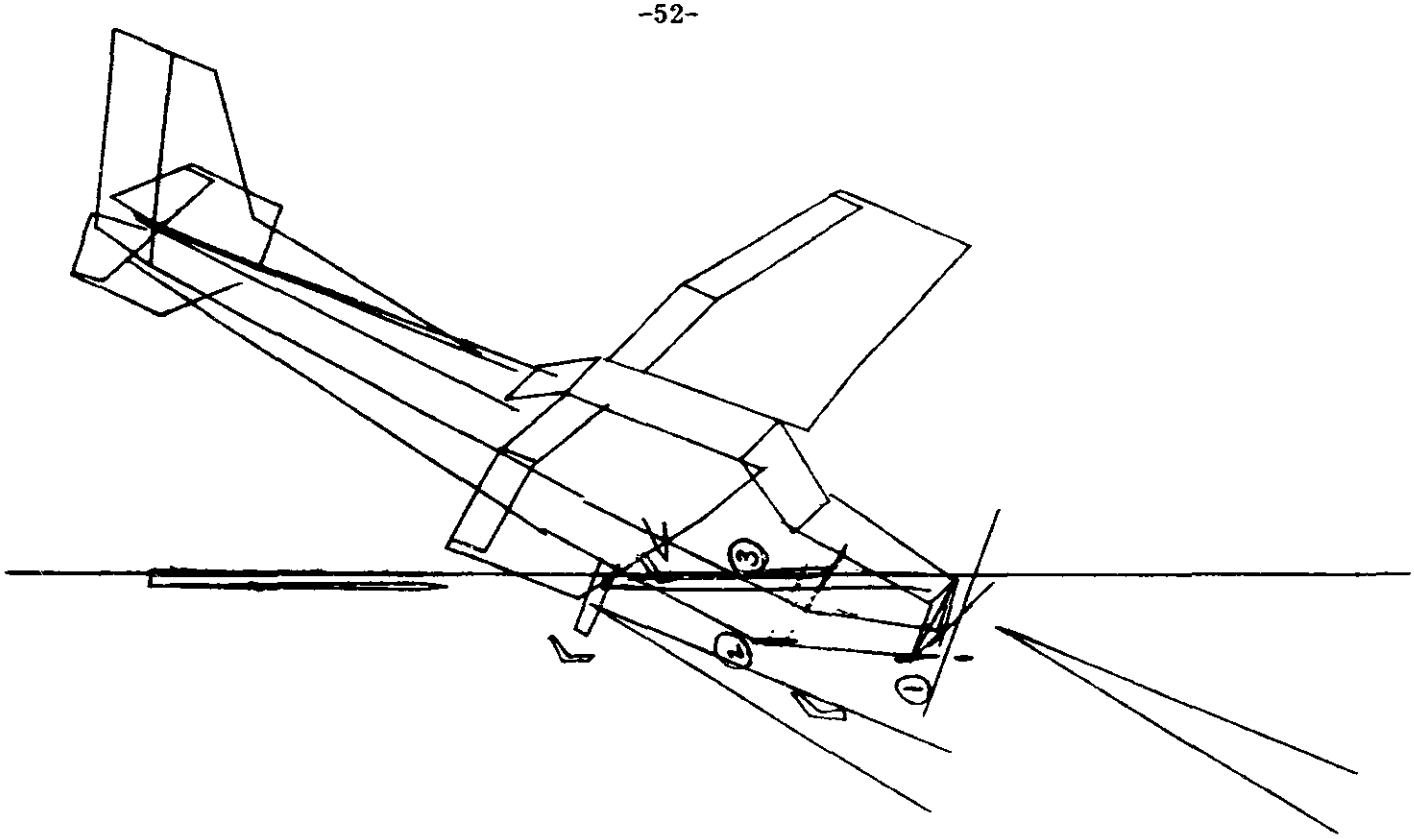
G-PULSE

The impact speed, using the landing configuration stall speed and corrections for the 10-degree flap position, power on condition, altitude, bank angle and gross weight, was estimated to be 53 knots. The pitch attitude could not be reconstructed.

By aligning the ground scars and airplane components, the roll angle was estimated to be from 30 to 45 degrees relative to the ground with a pitch attitude of 22 to 30 degrees. The slope of the mountain was 23 degrees. The resultant bank angle was calculated to be from 53 to 68 degrees.

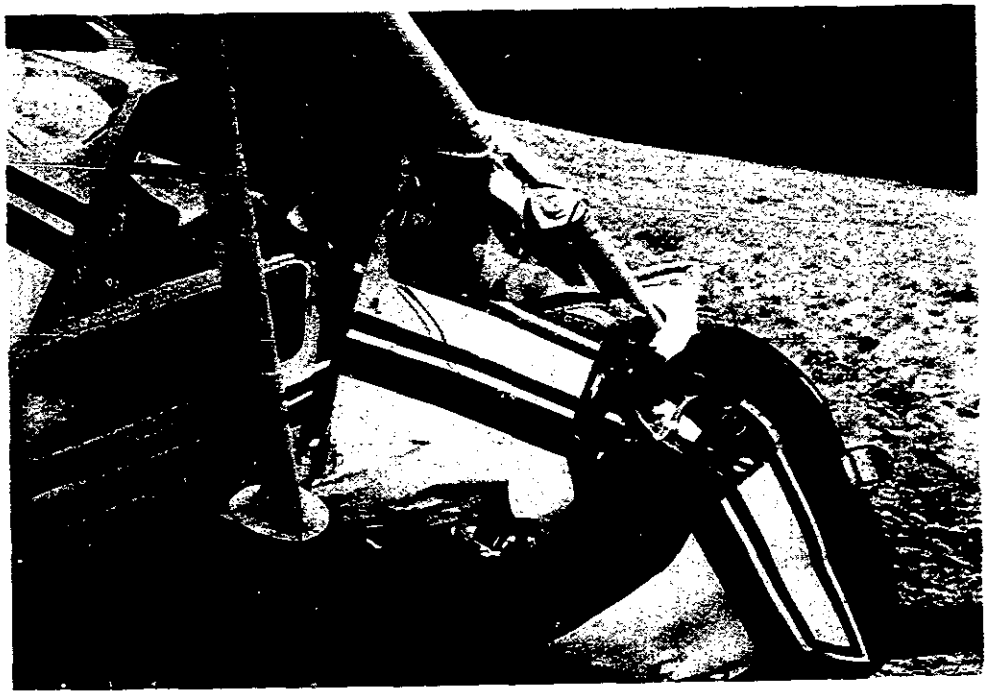
The slide was 36 feet with a 0.7 friction coefficient and the exit velocity was calculated to be 42 feet per second. The length of the ground scar/airplane combination was estimated at 10 feet maximum. Combined with the 81 feet-per-second impact velocity and the 42 feet-per-second exit velocity, the peak acceleration was calculated at 15 G's horizontal over a period of 0.08 seconds.

Without knowing the vertical velocity, the vertical accelerations cannot be calculated directly. However, head movement is usually considered an indication of the direction of the acceleration loads. In this case, the heads of the occupants struck the panel so that the motion would have to be about 10 degrees down from the normal head position. Adding that to the fully stroked pitch attitude of 22 degrees nose down, the head motion was about 30 degrees down (earth reference). The vertical component would have to be 15 G's times the tangent of 30 degrees, or 9 G's vertical load (earth axis). Converting to the airplane axis at 22 degrees pitch down, the longitudinal loads would be about 17 G's and the vertical loads would be about 2 G's (airplane axis). The velocity change in the airplane axis was about 45 feet per second longitudinal and was small in the vertical axis.

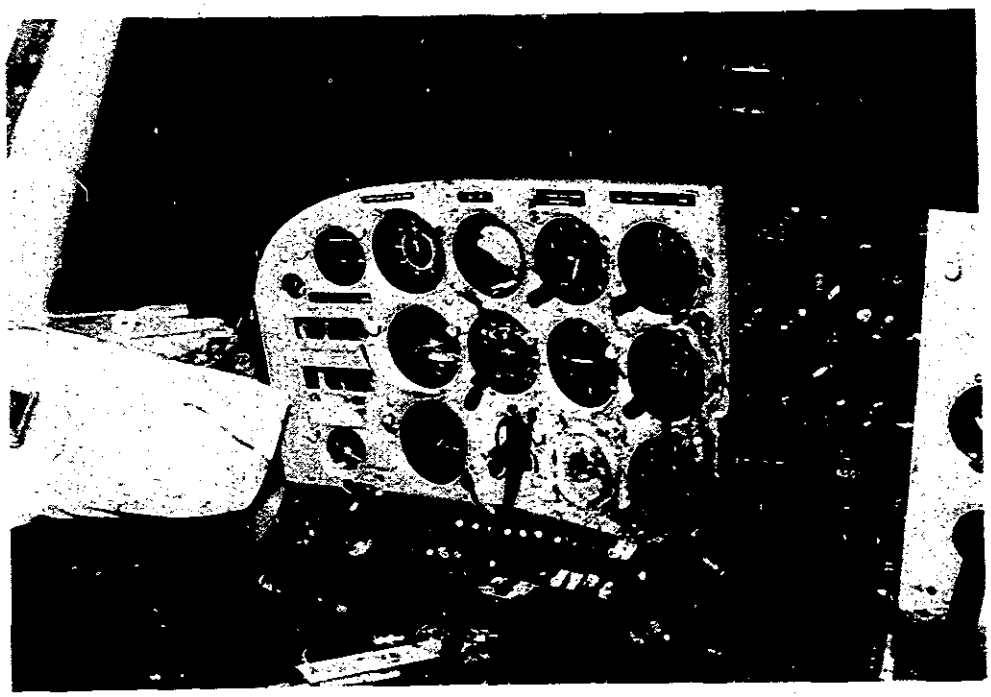


5-1. Impact depiction.

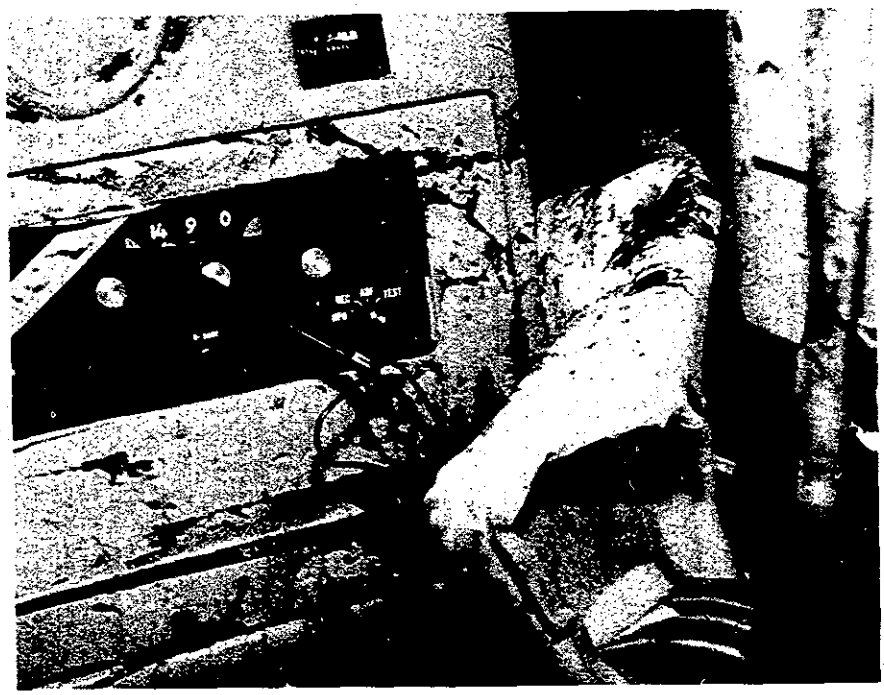
5-2. Wreckage.



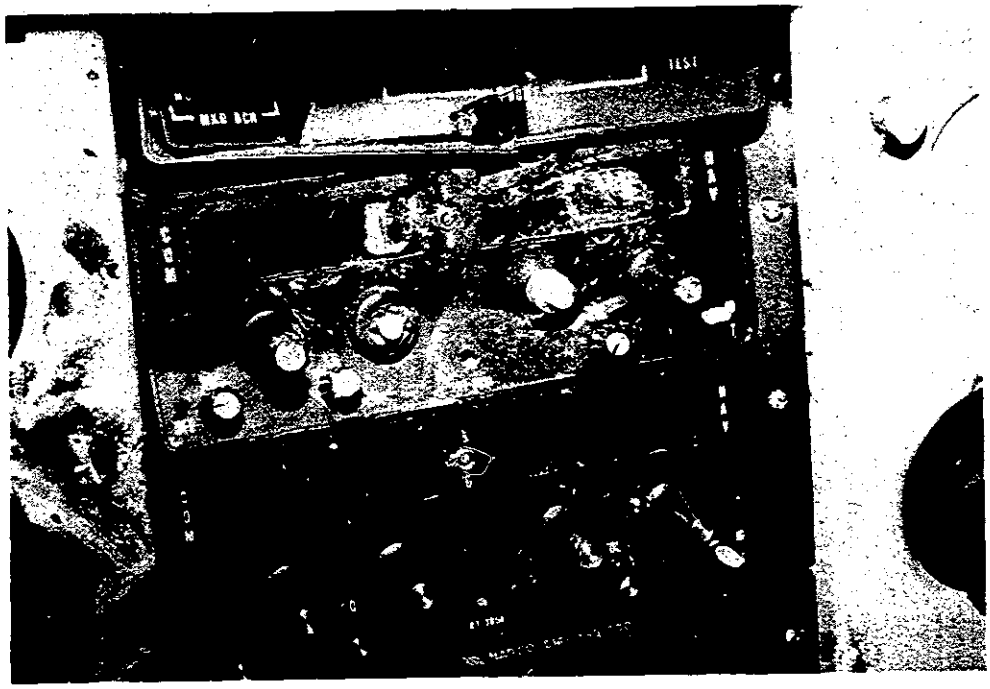
5-3. Wreckage - crush line.



5-4. Pilot's head contact area.



5-5. Right front passenger's head contact area.



5-6. Pilot's head contact area.

Case 6

SYNOPSIS

This high-wing, single-engine airplane attempted a downwind landing on a turf runway. The airplane touched down past midfield with insufficient runway remaining. The airplane ran off the end of the runway and into a ditch and embankment. The pilot and his two passengers were seriously injured. The airplane received substantial damage.

INJURIES

The pilot was wearing a lapbelt and a shoulder harness. His injuries were predominantly facial lacerations which required closure. These lacerations were the result of impact of his face onto the top of the instrument panel.

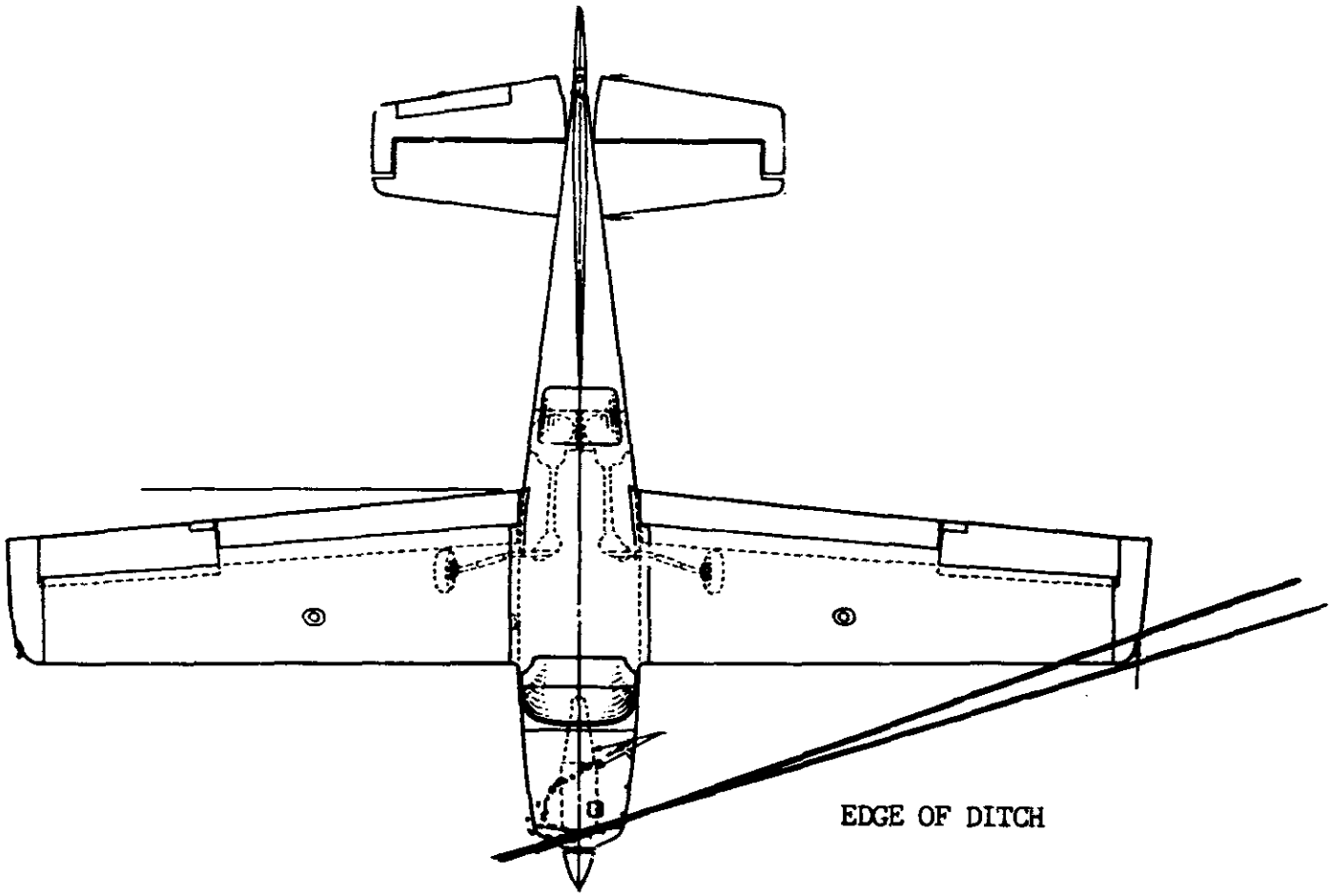
The passenger seated in the right front seat was wearing a lapbelt. She sustained a severe blow to her face when she impacted the top edge and front of the instrument panel. (See photograph 6-3.) Her injuries included several large and disfiguring facial lacerations, a fractured nose and a fractured rib. These injuries would have been prevented or would have been much less severe had she worn a shoulder harness. The seat tracks of her seat were badly deformed and the seat legs were bent and buckled (photograph 6-4).

The passenger in the left rear seat also was wearing a lapbelt but not a shoulder harness. She received minor facial lacerations. The side brackets on the right front seat had started to score or weaken the outboard portion of the lapbelt.

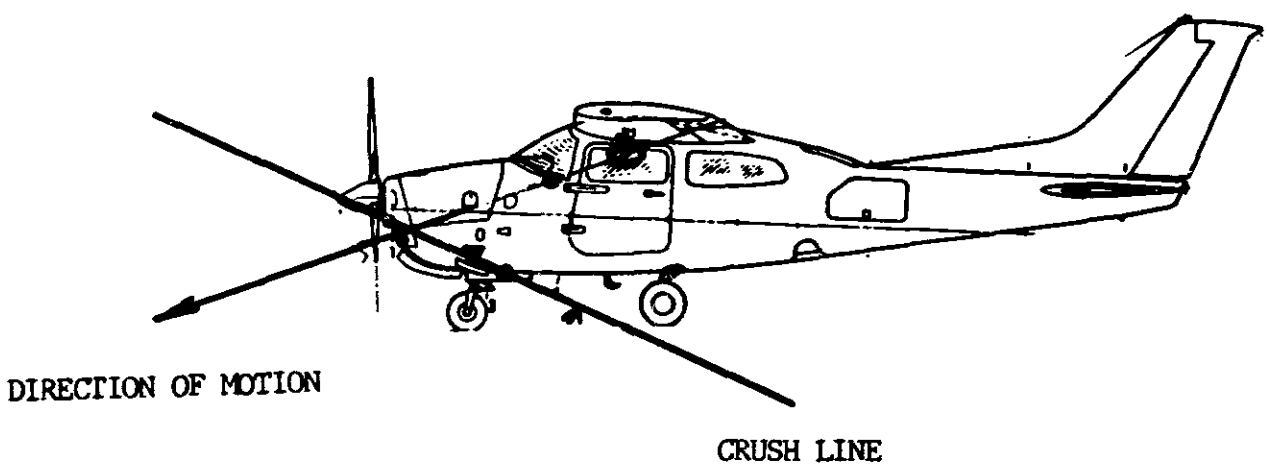
G-PULSE

From the point where the main gear left the top side of the ditch, the airplane traveled forward 21 feet and dropped 7.5 feet. The time required to drop 7.5 feet is about 0.68 seconds with a vertical velocity of 22 feet per second. The speed required to travel 21 feet in 0.68 seconds is 33 feet per second. The total velocity is calculated to be about 40 feet per second at a downward angle of 35 degrees.

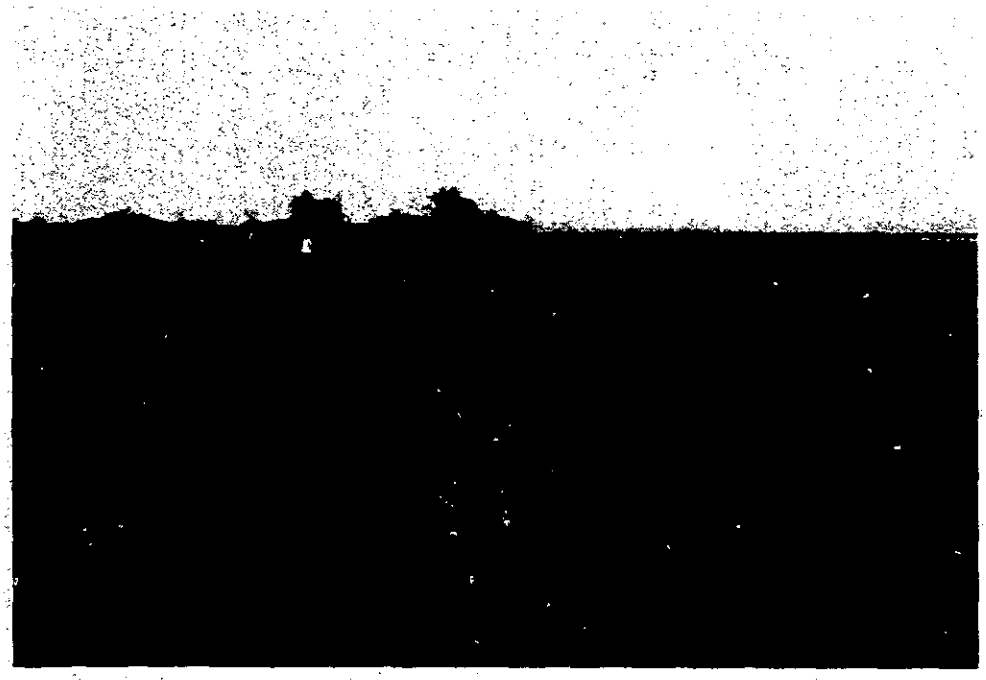
Since the airplane hit the bank and stuck there, the total velocity was dissipated in the 1 1/4 feet stopping distance. There was about one foot of crush and evidence of about 1/4 foot of elastic compression. The total average acceleration load of 19 G's average seems to be appropriate to the injuries and the damage to the airplane. A peak of 38 G's appears to be too high. The average value may be more appropriate because of the simultaneous impacting of the engine and the firewall/floorboard areas. The triangular peak values are normally associated with an impact involving an increasing amount of structure. Such was not the case here.



6-1. Top view depiction of airplane at impact.

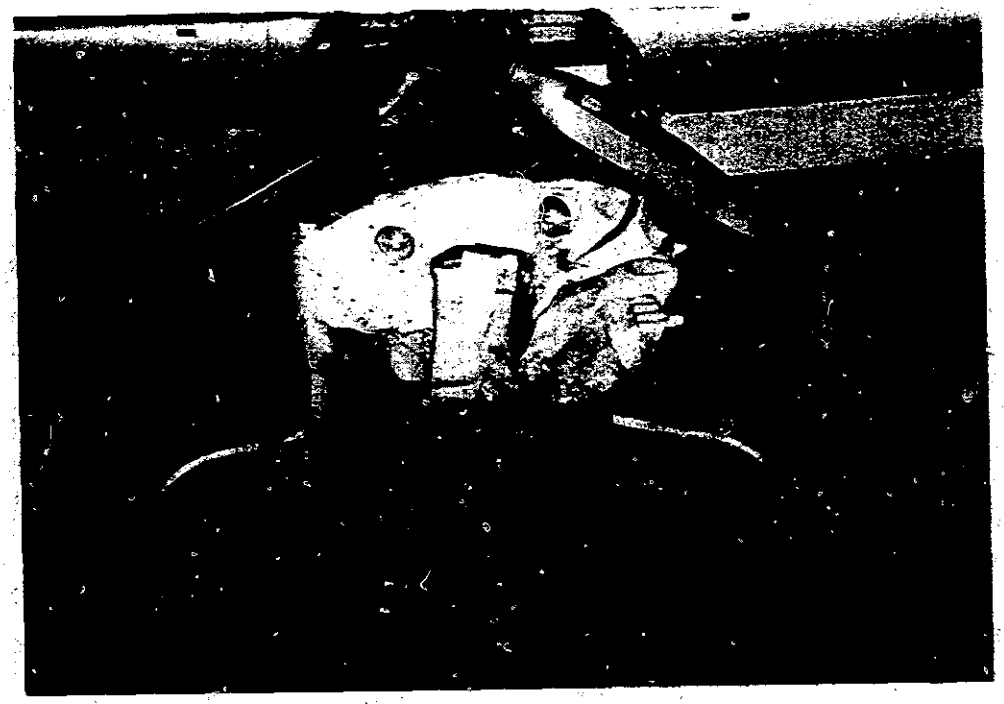


6-2. Side view depiction of airplane at impact.

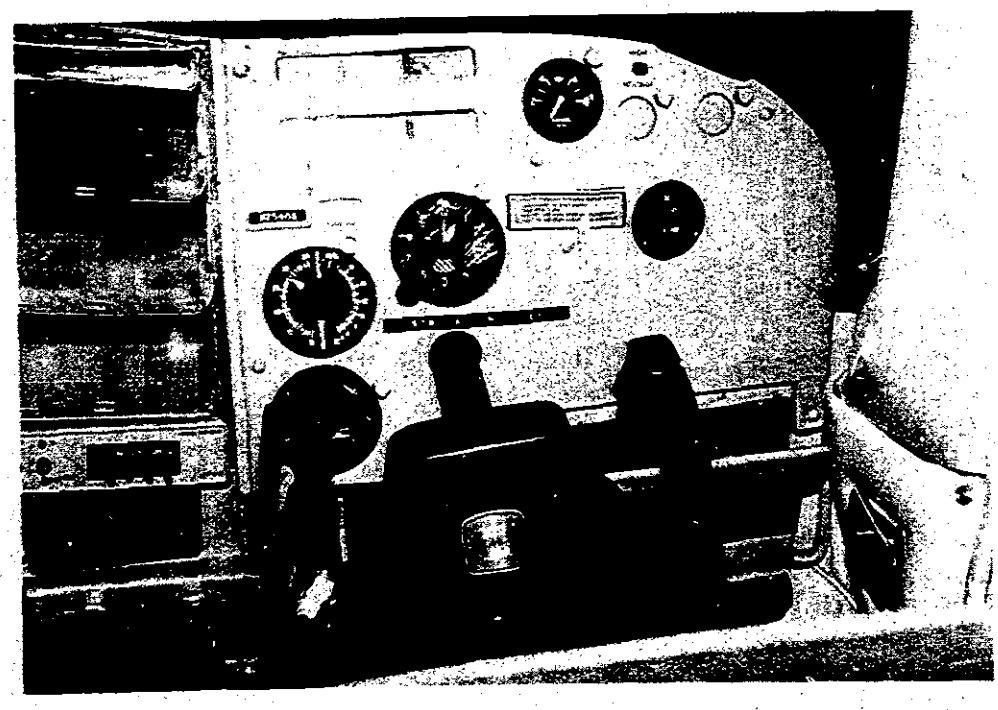


6-3. View of tire marks.

6-4. View of aircraft.



6-5. Crushing damage.



6-6. Head strike area of passenger.

6-7. Lapbelt holder that started scoring lapbelt.

Case 7

SYNOPSIS

This accident involved a 2-seat, high-wing, single-engine airplane which was being flown at low altitudes over a camping area. Following an inadvertent stall the airplane descended into a heavily wooded area, knocking down large trees as well as impacting upside down, destroying the airplane.

INJURIES

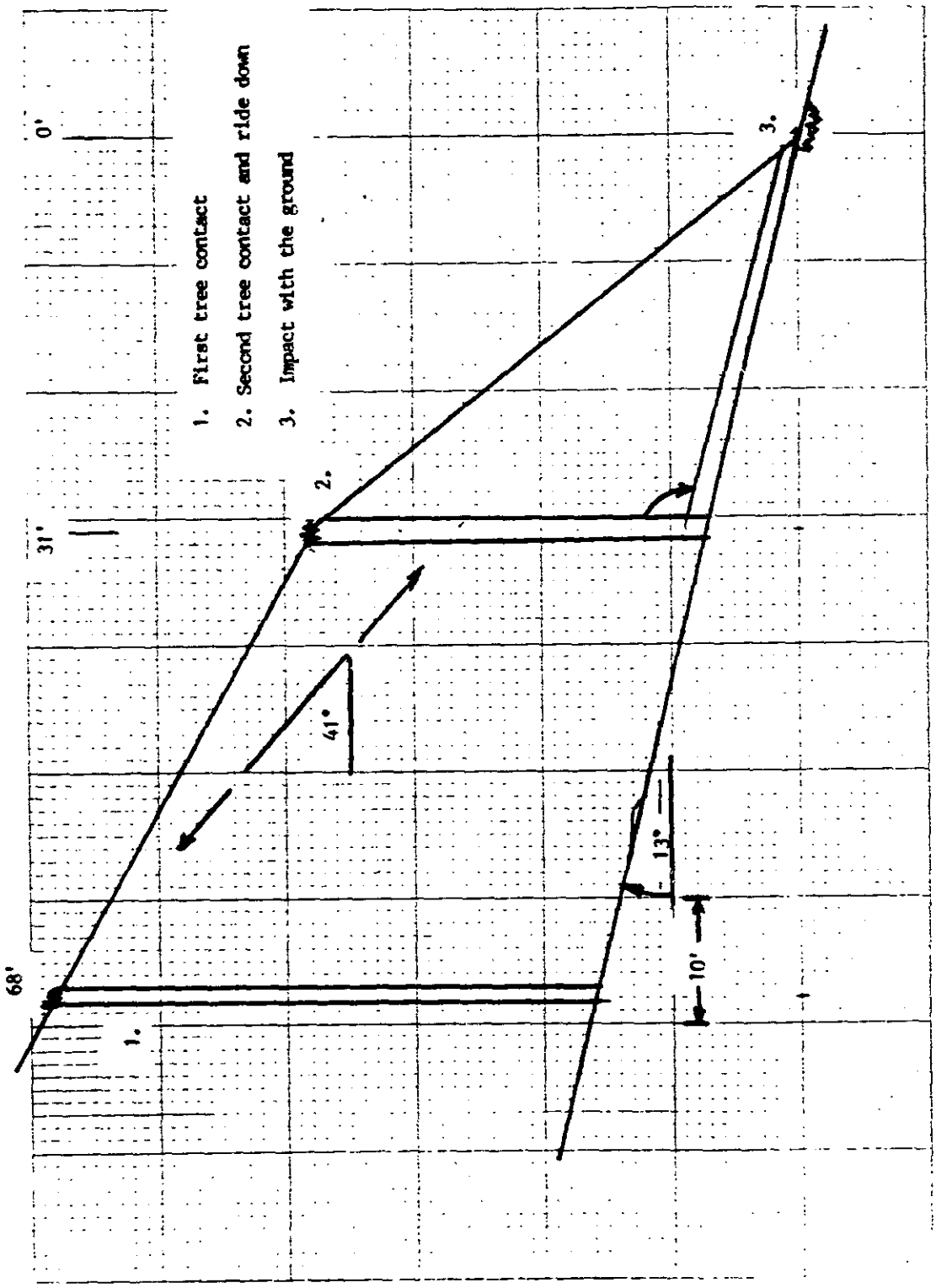
The pilot was fatally injured by the impact, although he was wearing a lapbelt and a shoulder harness. His injuries included numerous contusions, abrasions, and lacerations as well as hemorrhage within the brain structures. These were the result of pilot impact with the windshield and instrument panel and the control yoke. The legs of his seat and the seat track were bent and buckled as a result of the impact.

The passenger seated in the right seat survived with serious injuries. These included cerebral concussion, basilar skull fractures, fractures of the left clavicle, right proximal fibula, left tibia and fibula, as well as multiple abrasions and lacerations. These were the result of impact with the airplane structures and equipment. He was wearing both a lapbelt and a shoulder harness. His seat was relatively undamaged, but both tracks were buckled.

Photograph (7-2) demonstrates the severe loss of cabin volume during this accident, due to multiple tree strikes. It is unlikely that any of these multiple impacts could have generated the high acceleration loads that are associated with severe, single impact crashes.

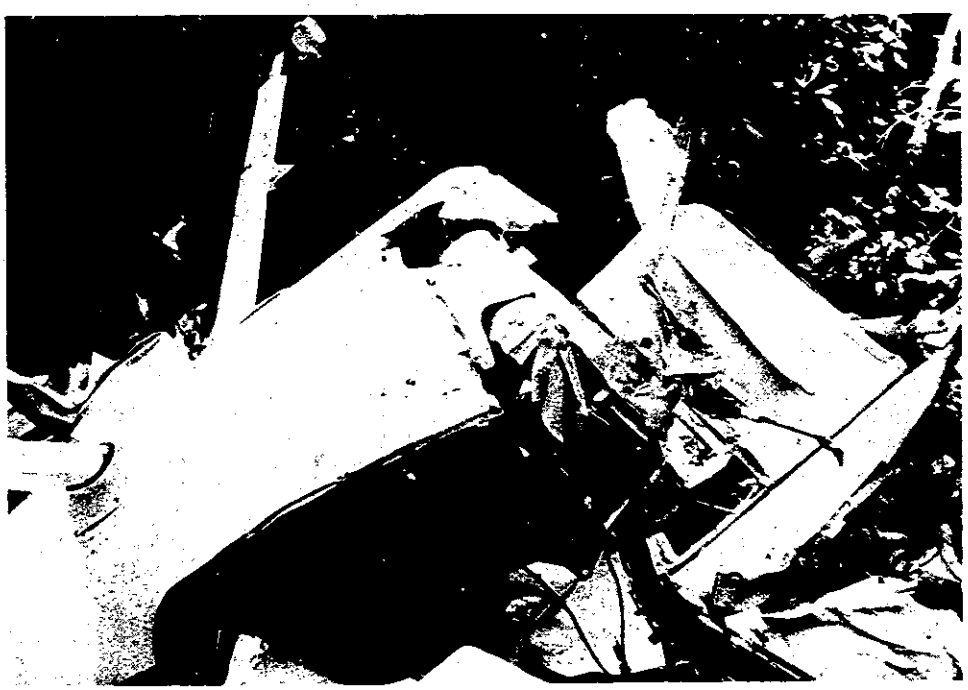
G-PULSE

No acceleration loads could be calculated because the impact speed with the ground could not be estimated. At point 2 on the diagram (7-1), the airplane hit a tree and it remained with the tree until reaching the ground.



7-1. Airplane's final approach before impact.

7-2. Airplane is inverted. Seat back top is pointing towards camera, and passenger seat is in view.



7-3. Pilot seat inverted.

Case 8

SYNOPSIS

This accident involved a turbocharged, twin-engine airplane making an approach for a night landing when the pilot lost visual contact with the runway environment and began a go-around. A positive rate of climb was not established, and the airplane impacted rising terrain.

INJURIES AND RESTRAINTS

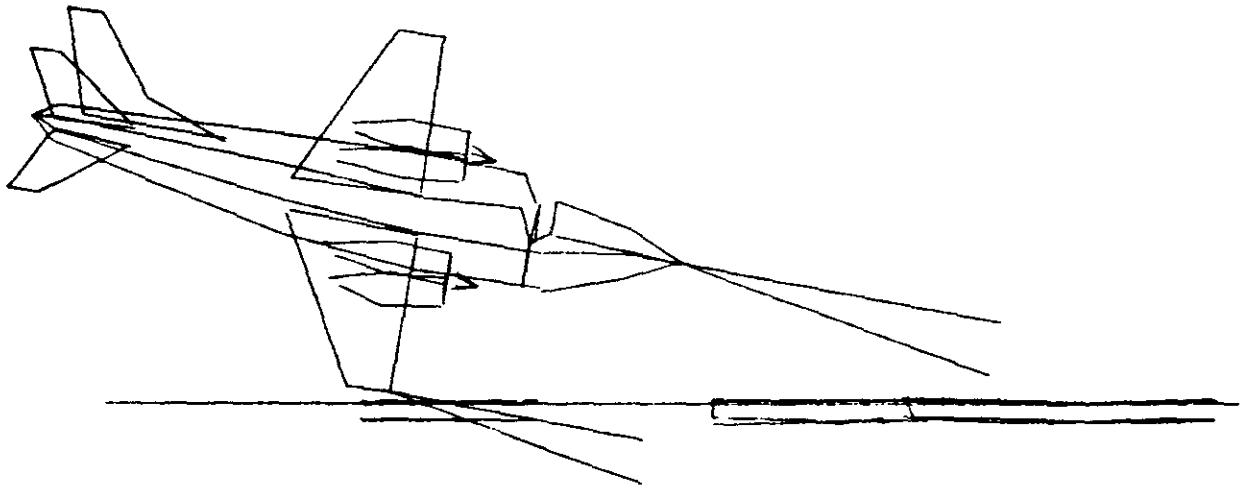
The pilot was not wearing the available shoulder harness. During the impact, his head contacted numerous lights and knobs on the instrument panel and other interior surfaces, fracturing his nose in several places and cutting his right cheek and scalp. In addition, he had a fractured right ankle, sprained left ankle, and back spasms caused by compression of a thoracic vertebra. A shoulder harness could have prevented the serious head injuries. The seat pan of the unoccupied right front seat had a small tear which was easily propagated to the full width of the seat by pulling at the tear with one finger. The pilot's seat pan was torn in similar manner.

G-PULSE

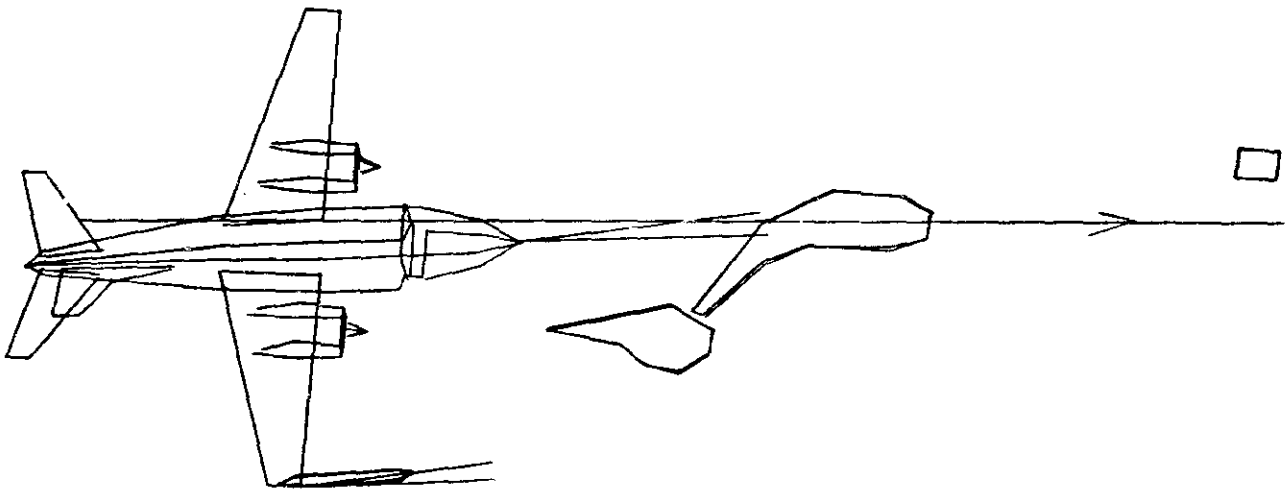
The impact speed of 67 knots was estimated from the airplane's landing configuration stall speed corrected for weight. The impact conditions were derived by matching the airplane components to the ground scars. At initial impact, the pitch attitude was about 10 degrees nose down with a right roll of about 30 degrees. The flight path was about 20 degrees down.

The total crush and stopping distance was about three feet, of which two feet were attributed to the engine nacelle contact and one foot was attributed to the crushing of the fuselage. The vertical impact velocity was calculated as 38 feet per second. The crushing of the nacelle area was estimated to be at an acceleration level of about half that of the fuselage. The minimum peak value would then be around 16 to 18 G's, but it could have been as high as 24 G's (earth axis).

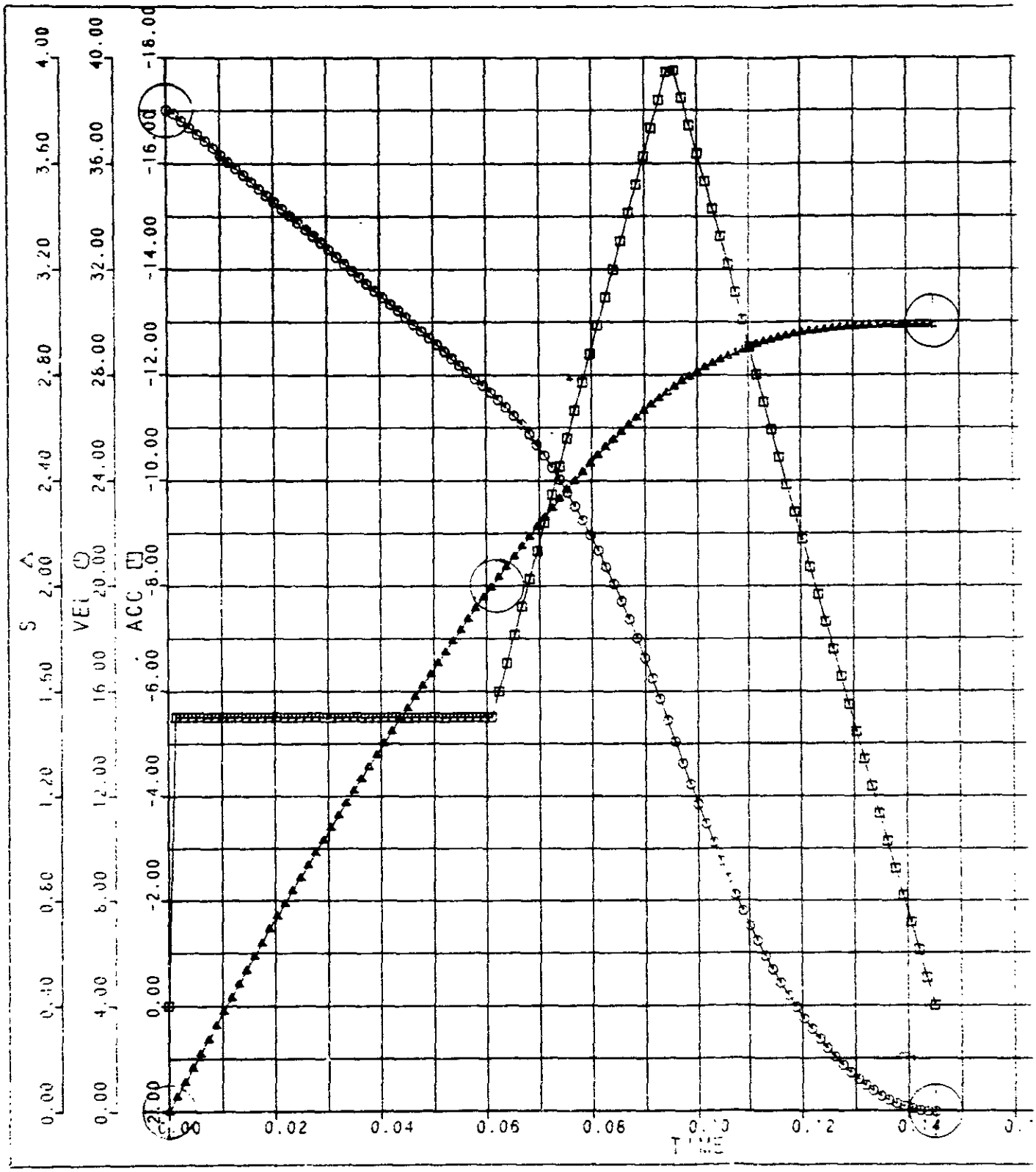
Since there was a long slide, exit velocity estimates were not made. The direction of head movement was used to estimate the longitudinal loads. Evidence showed that the head contacted the panel by moving 30 to 40 degrees down. With the fuselage in a 10-degree pitch down attitude, the head moved down at an angle of 40 to 50 degrees (earth axis). Using the 16 G vertical estimate, the total vector would be in the range of 25 G's. Converting into airplane axis would yield a vertical peak of 12 G's and a longitudinal peak of 22 G's. The horizontal velocity change of 50 feet per second is consistent with a 22 G peak pulse and a duration of 0.14 seconds. Referenced to the airplane axis, the vertical pulse was 12 G's with a velocity change of 21 feet per second. The horizontal pulse was 19 G's with a velocity change of 30 feet per second.



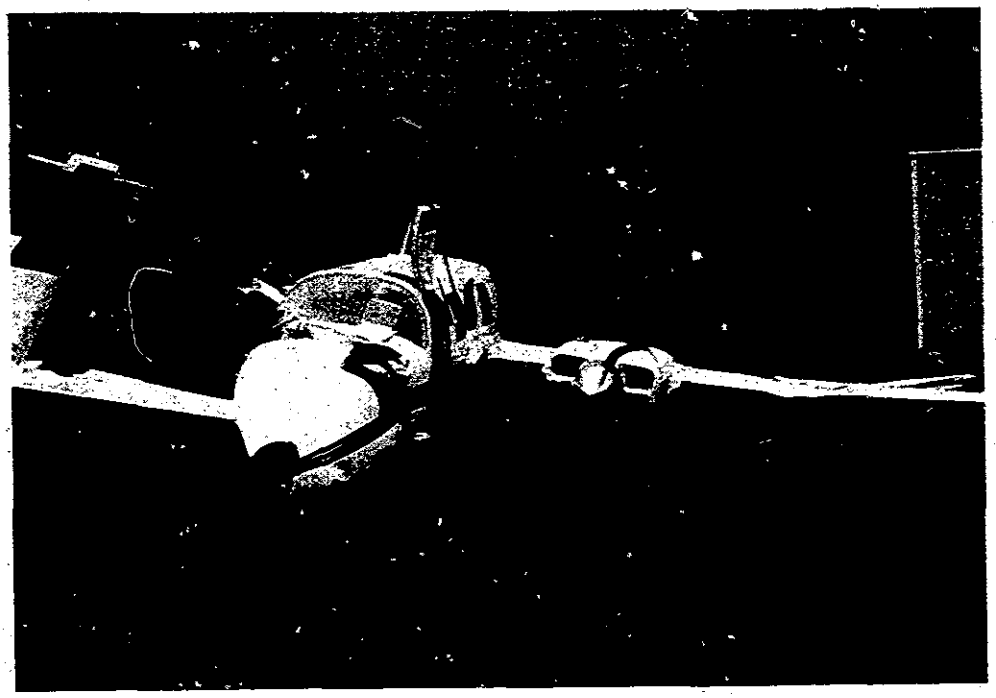
8-1. Side view, right wing down.



8-2. Top view.



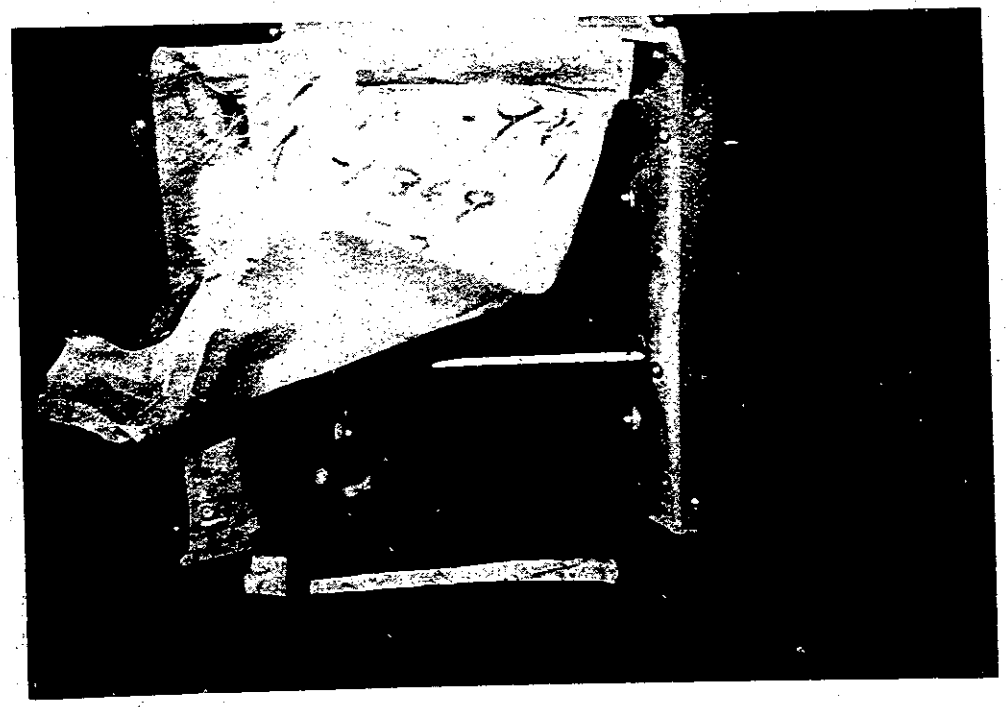
8-3. Crash pulse.



8-4. Wreckage.

8-5. Wreckage - crush line.

8-6. Pilot's seat as found.



8-7. Pilot's seat as torn by hand.

8-8. Pilot's head contact area.

Case 9

SYNOPSIS

This high-wing, single-engine airplane experienced an engine failure after takeoff as a result of fuel contamination. During the ensuing forced landing, the airplane impacted into a creek bank, continued 106 feet further, and ultimately came to rest in the creek. The airplane was destroyed.

SEATS, RESTRAINTS, AND INJURIES

The pilot, seated in the right-front seat, received serious but survivable injuries during the crash, but he drowned; his seat separated, allowing him to be ejected from the airplane into shallow water. The occupant in the left-front seat, who was the owner of the airplane, received facial lacerations, head and neck injuries and a severe concussion. The rear bench seat was occupied by a female passenger and her 2-month-old infant. Although an automobile child safety seat was found in the baggage area of the airplane, the child was being carried in a soft fabric papoose-type infant carrier (see photograph 9-6). The adult female received chemical burns as a result of being splashed with aviation fuel, as did the infant. The airplane was not equipped with shoulder harnesses, but each adult was wearing a seatbelt.

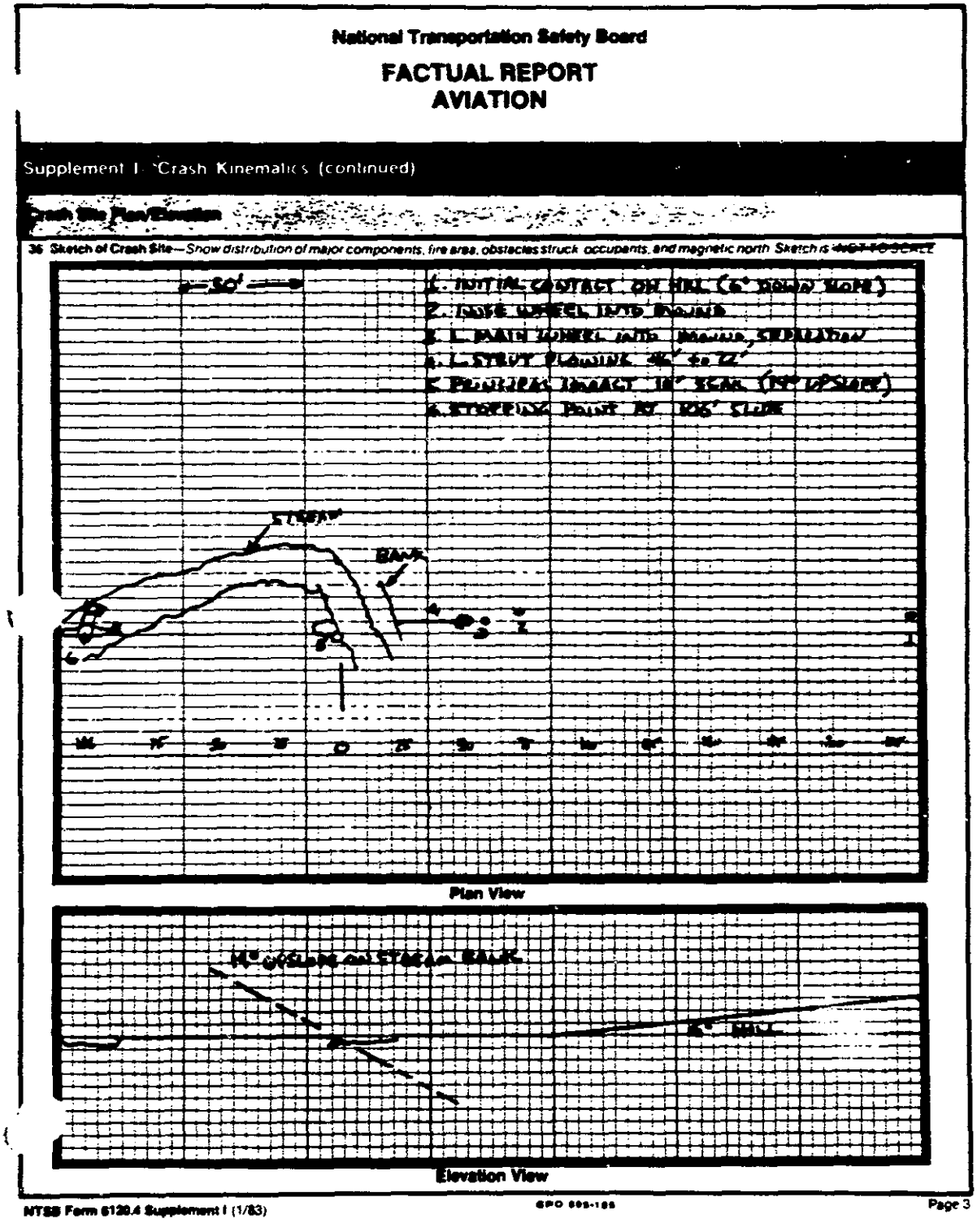
G-PULSE

The airplane made slight contact on the top of a hill and then flew down the 6-degree hill. It contacted the level ground at the bottom of the hill. The left wing strut plowed a groove for 24 feet to the creek bank edge, and the left main wheel was knocked off. The airplane crossed the creek and impacted the bank on the far side (the principal impact) into a 14-degree upslope. The fuselage made a gouge 10 feet long. The airplane continued on for another 106 feet.

The long slide would normally preclude an accurate estimate of the exit velocity, but in this case a large value of friction coefficient was assumed. By utilizing the largest reasonable value of friction, the calculated estimate of acceleration loads is conservative.

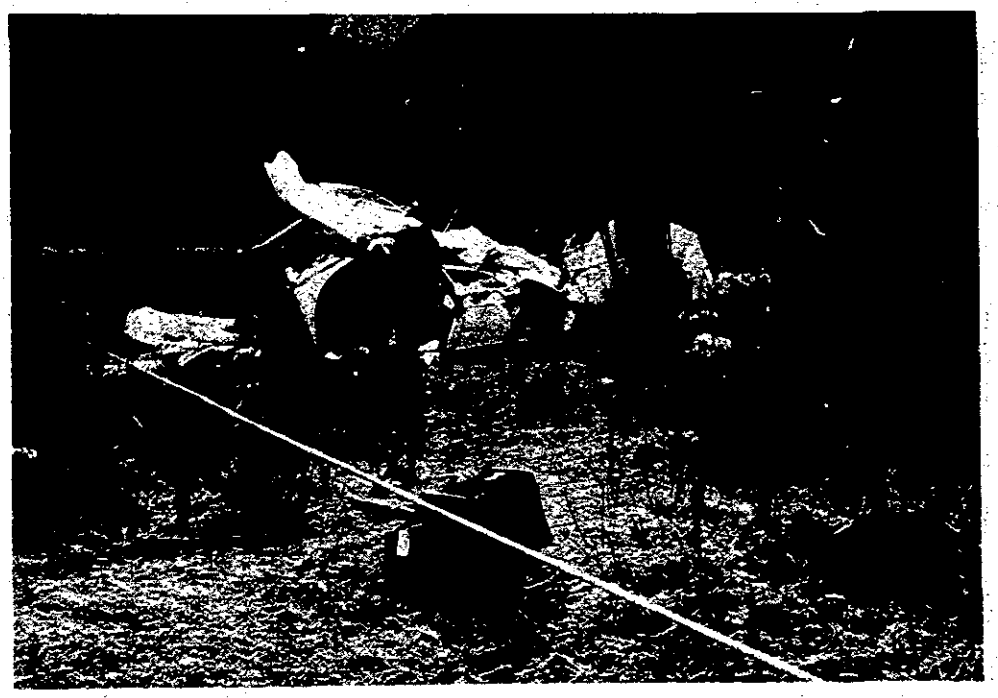
The 62-knot impact speed was derived from the airplane's landing configuration stall speed corrected for weight, the flaps up condition, and the tail wind. No velocity change was included for the "flight" down the hill. At the bottom of the hill the vertical motion was arrested and the airplane was considered going 110 feet per second. The left strut dragging for 24 feet would have slowed the airplane down to 104 feet per second (impact speed). A friction coefficient of 1.0 was assumed and the velocity change for the 106 feet of slide would be about 83 feet per second. A 12 G peak acceleration load was then calculated using the velocity change from 104 to 83 feet per second over the 10 feet ground scar distance.

It is believed that 12 G's is the smallest force that would be possible for the noted conditions. If a sliding friction coefficient of 0.8 is used, an acceleration load of 16 G's peak is possible. In this case, the injuries are consistent with the calculated acceleration loads but the damage appears more extensive. This is probably the result of a rolling action that occurred during the slide. A point of interest is that the infant was retained in the papoose-type carrier with straps around the mother. At the end of the sequence, the baby was still in the carrier and the carrier was still attached to the mother, although separation appeared imminent because of the tearing of the carrier.

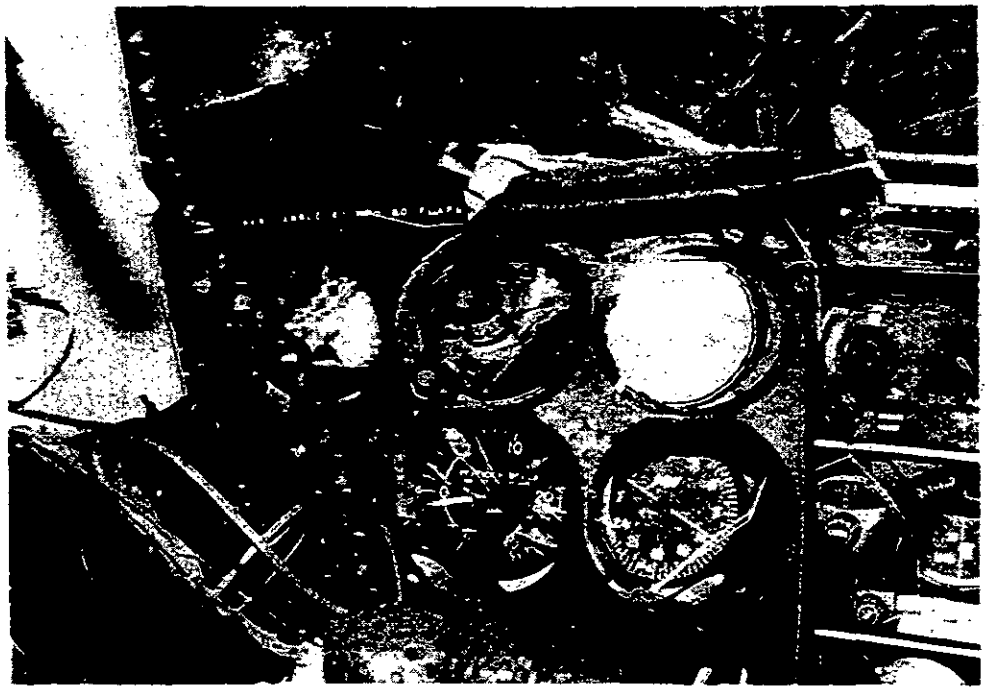


9-1. Impact progression.

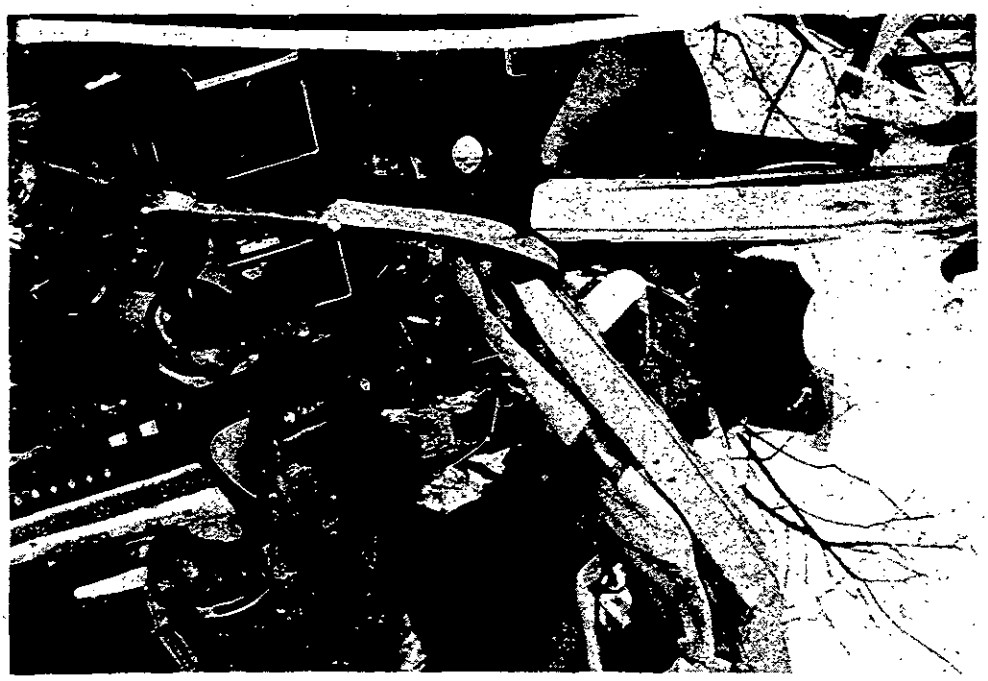
9-2. Wreckage.



9-3. Wreckage.

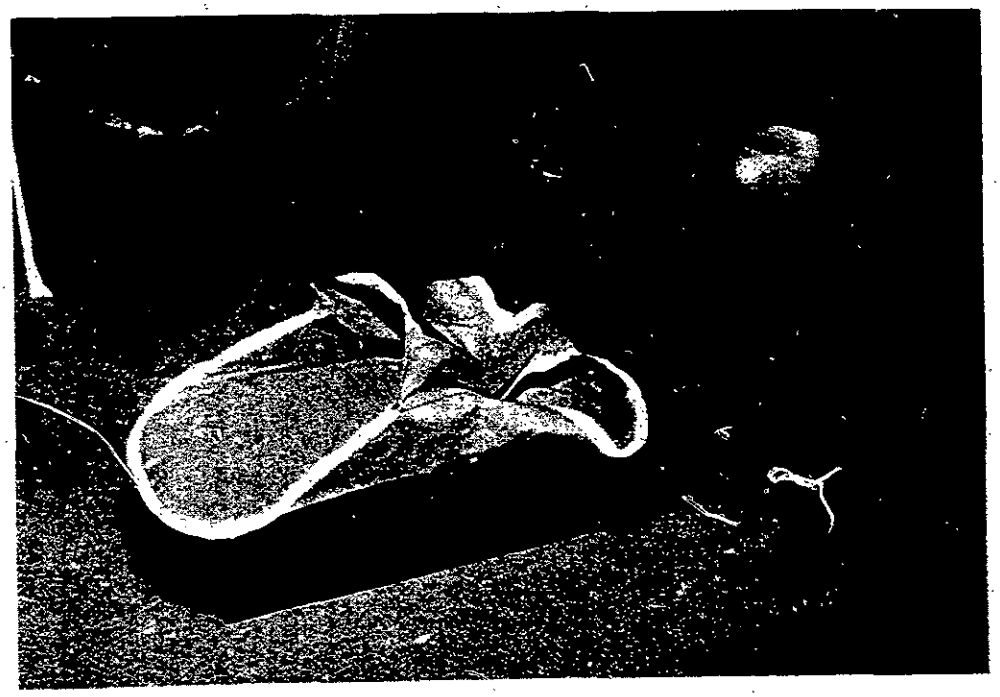


9-4. Pilot's head contact area.



9-5. Area near right front occupant; note door post over control column.

9-6. Principal impact area.



9-7. Child carrier that retained baby.

Case 10

SYNOPSIS

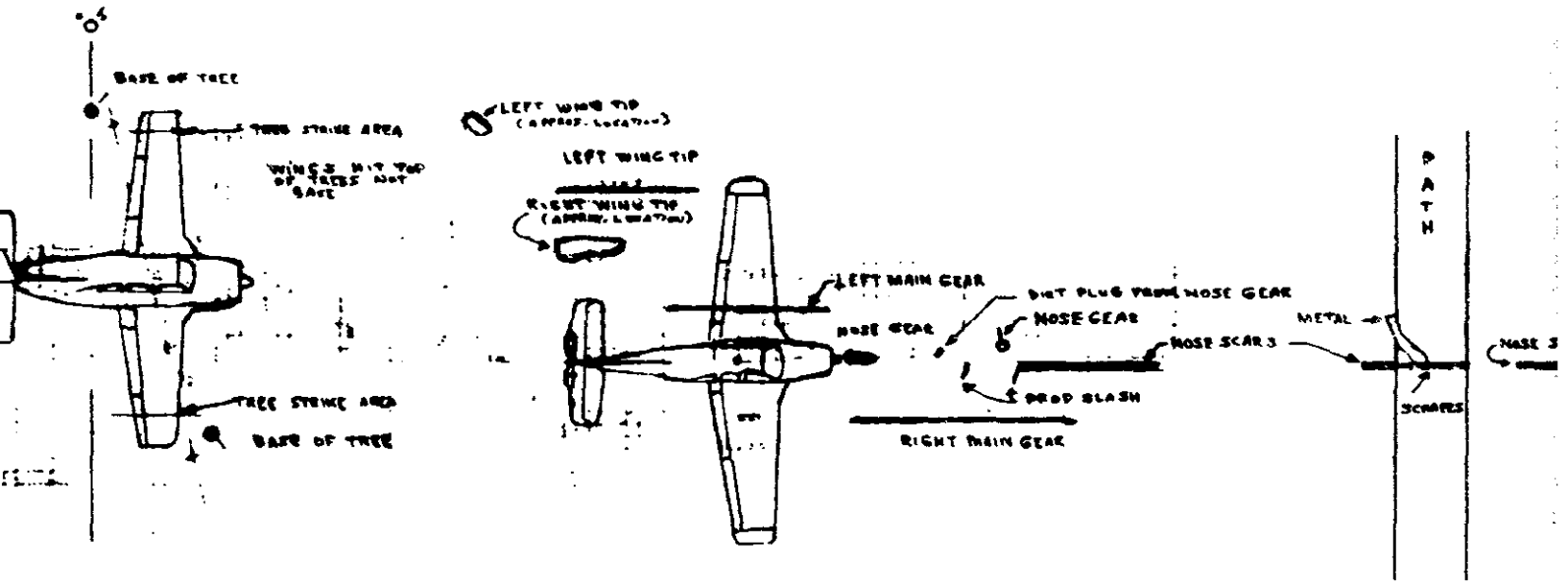
This accident involved a single-engine airplane making an off-airport forced landing on a golf course. In the last stages of descent the airplane hit several trees. During the post- impact slide, the airplane's right wing hit another tree, demolishing the wing.

SEATS, RESTRAINTS, AND INJURIES

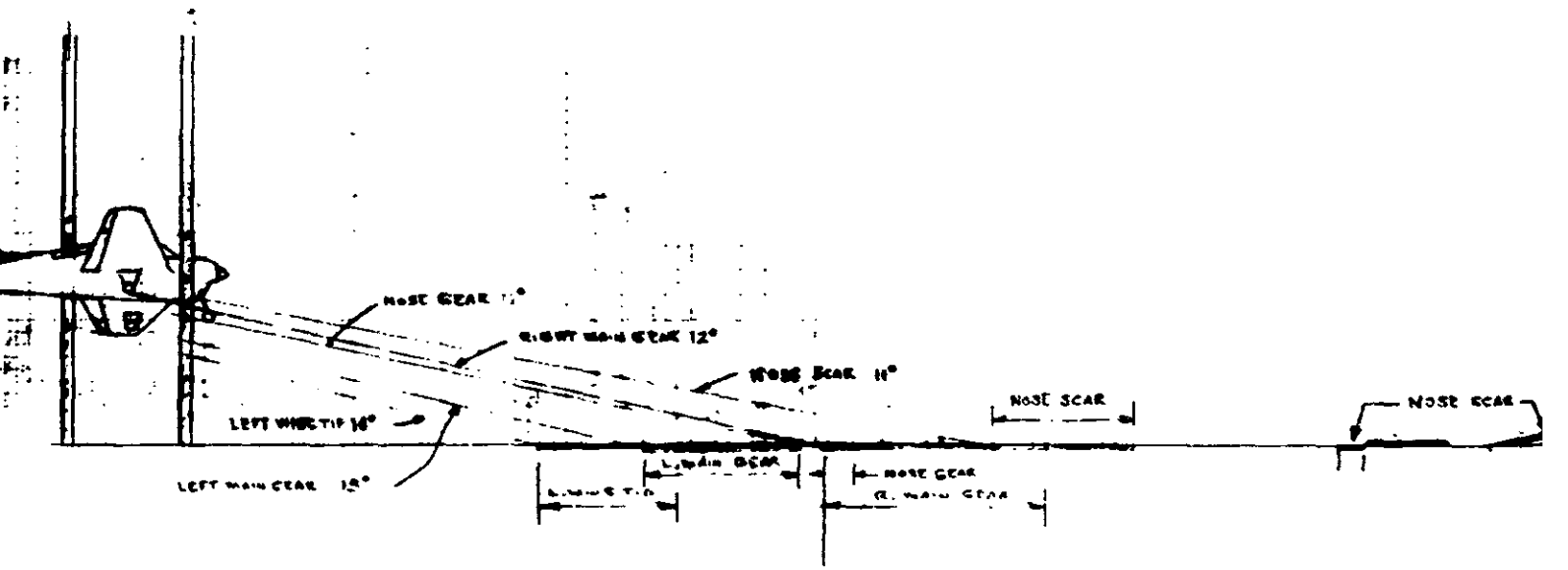
Of the four occupants in the airplane, only one suffered minor injuries; the others were not injured. All occupants were wearing lapbelts. Although shoulder harnesses were available to front seat occupants, they were not being used. The pilot contacted the altimeter knob, cutting his head. The rear seat pans, which were of a sling construction mounted to the side of the airplane, came loose. The wing root movement caused disruption of the seat/sidewall area, allowing the seat pans to come loose.

G-PULSE

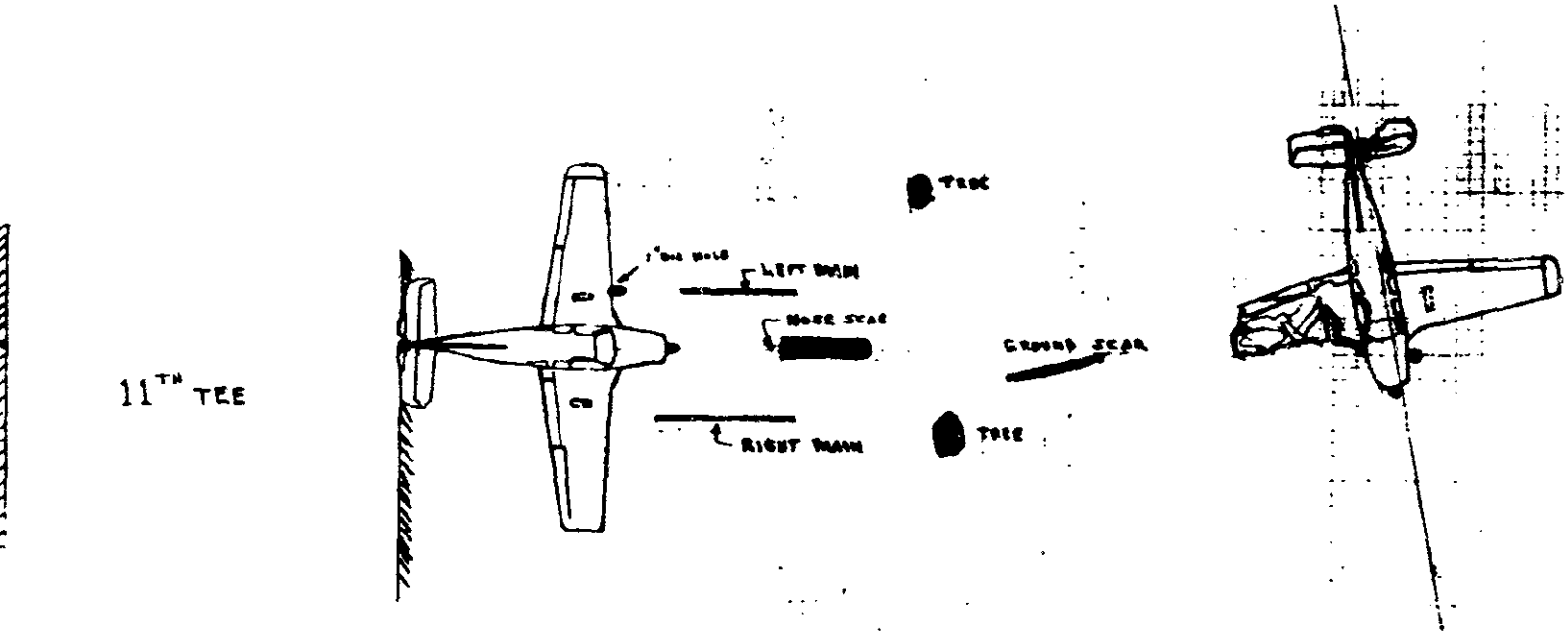
Because the airplane struck several trees and the ground prior to the major impact, it was difficult to determine the actual velocity losses in this accident. However, these small initial velocity losses cumulatively absorbed a substantial amount of energy, a little at a time. The net result was that the major impact was much less catastrophic than it might otherwise have been. The principal impact was at the secondary tree strike where the left wing was sheared in two and the right wing was heavily damaged. The airplane was substantially slowed prior to this impact, and the resultant acceleration loads were calculated at about 3 G's average using a decrease in velocity from 46 feet per second to 32 feet per second over the 5 feet of wing crushing. The average load is considered to be reasonable since an increasing amount of structure was not involved. The relative lack of occupant injury was also considered.



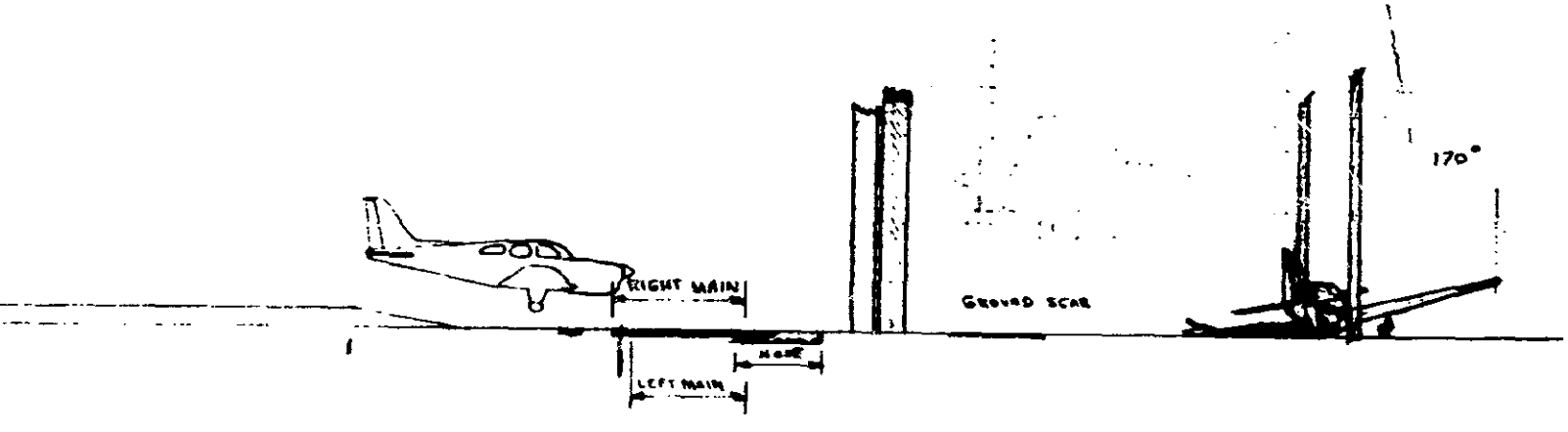
10-1. Flight path and impact



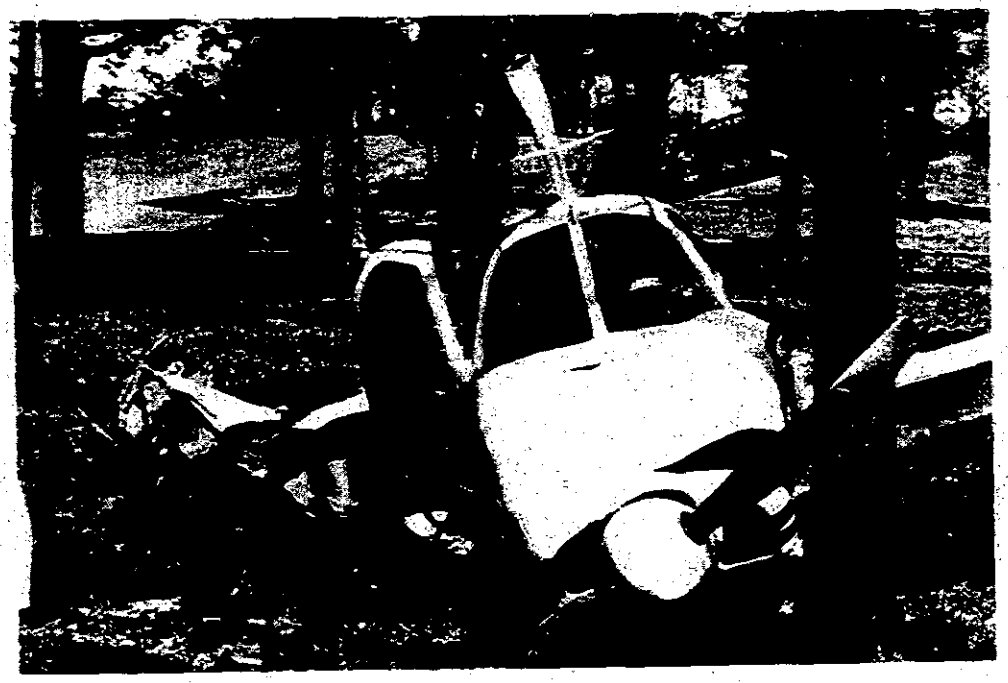
10-2. Flight path and impac



ction (top view)..



ction (side view).



10-3 Wreckage.

10-4 Wreckage.

Case 11

SYNOPSIS

This accident involved a single-engine, low-wing airplane that crashed off-airport at night following fuel exhaustion. The airplane impacted in a nose down nearly inverted attitude, displacing the engine and rupturing the cockpit and cabin areas. The cabin volume was reduced and the occupants were exposed to torn metal and other injury-producing debris. The impact attitude was 40 degrees nose down and the airplane was in a 145-degree (partially inverted) right roll. The airplane was destroyed.

SEATS, RESTRAINTS, AND INJURIES

The fatally injured pilot, who had a shoulder harness but was not wearing it, was subjected to multiple extreme traumatic injuries as a result of his head impacting the instrument panel. He received multiple skull fractures, rib fractures, facial lacerations, and other injuries. Even though the cockpit roof was crushed, the pilot's injuries all resulted from contact with the instrument panel and the sidepost. His injuries might have been substantially less serious with the use of a shoulder harness. His three passengers were all seriously injured. The right-front passenger, who was wearing a shoulder harness, had a fracture-dislocation of the left forearm and a fracture of the scapular process as well as multiple facial lacerations. The right-rear passenger suffered a facial fracture and mesenteric tear (possibly as a result of seatbelt loads) which required resection of the small bowel. Injuries which may have been the result of excessive loads on the seatbelt could have been less severe with the use of a shoulder harness. The left rear passenger, who was also wearing a seatbelt, received multiple fractures of her right arm and other flailing injuries. In addition, she sustained a blowout-type rupture of the small bowel and multiple facial lacerations. Her abdominal injuries probably were the result of seatbelt loads, and if so, could have been prevented or made less severe by shoulder harness usage.

G-PULSE

An impact speed of 53 knots was estimated by using the airplane's power off stall speed, correcting for the flaps up condition and the actual weight.

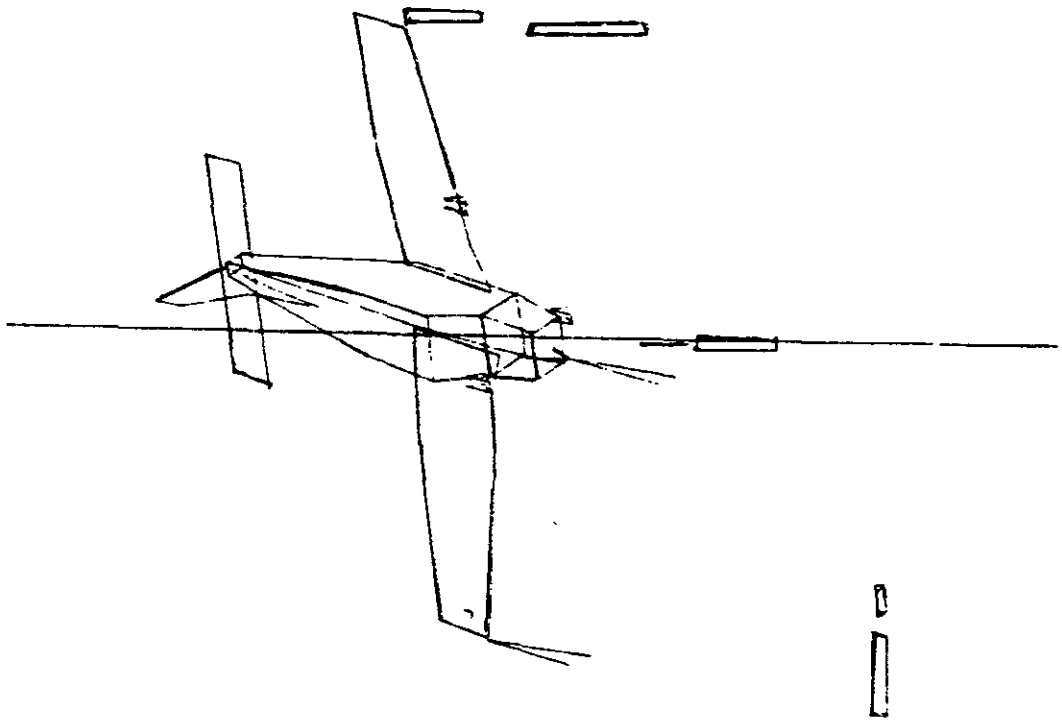
The airplane hit some trees at an altitude of about 34 feet and then continued on 104 feet to hit the ground in a 10-degree nose down pitch attitude and a 145-degree right roll. The flight path/impact angle was reconstructed at about 30 degrees.

The engine rotated up relative to the airplane, so that the propeller contacted the cabin top above the front seat occupants. Examination of the occupant head strikes on the cabin structure showed that the acceleration loads were predominantly longitudinal. Longitudinal crushing was about 5 feet. The vertical component of crushing was estimated at about 3 feet.

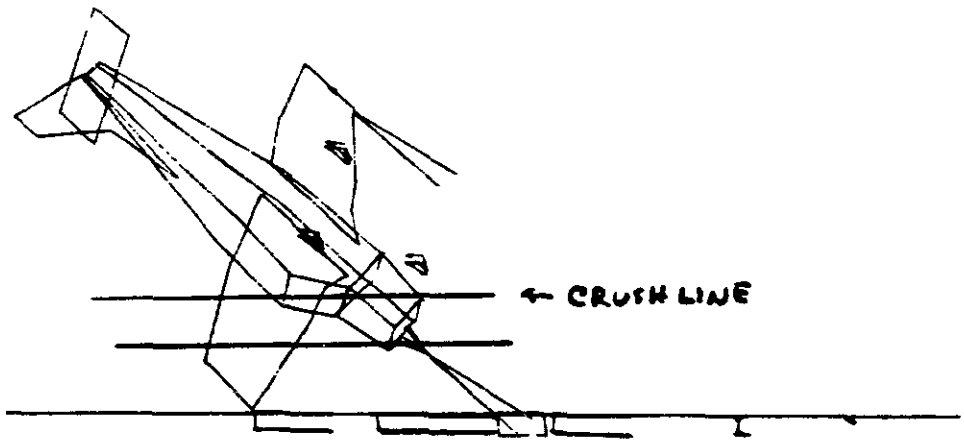
The vertical velocity component was estimated at 44 feet per second and the horizontal component at 77 feet per second. The exit velocity was calculated at 32 feet per second by using the 31 feet slide and a 0.5 friction coefficient. A vertical load of 20 G's peak was derived from the 44 feet per second vertical velocity and the 3 feet of crush. This load lasted for 0.137 seconds.

The airplane drawing was rotated through the impact sequence and it appeared that the total stopping distance at the principal impact was seven feet (5 feet of ground scar and about 2 feet of airplane motion). Slowing from 77 to 32 feet per second in 7 feet would result in a 22 G peak horizontal load over a period of 0.127 seconds.

The resultant vector sum of the loads is nearly aligned with the fuselage, again indicating primarily longitudinal loads (airplane axis) to the occupants. The longitudinal loads would be about 30 G's peak for a 60 feet-per-second velocity change.



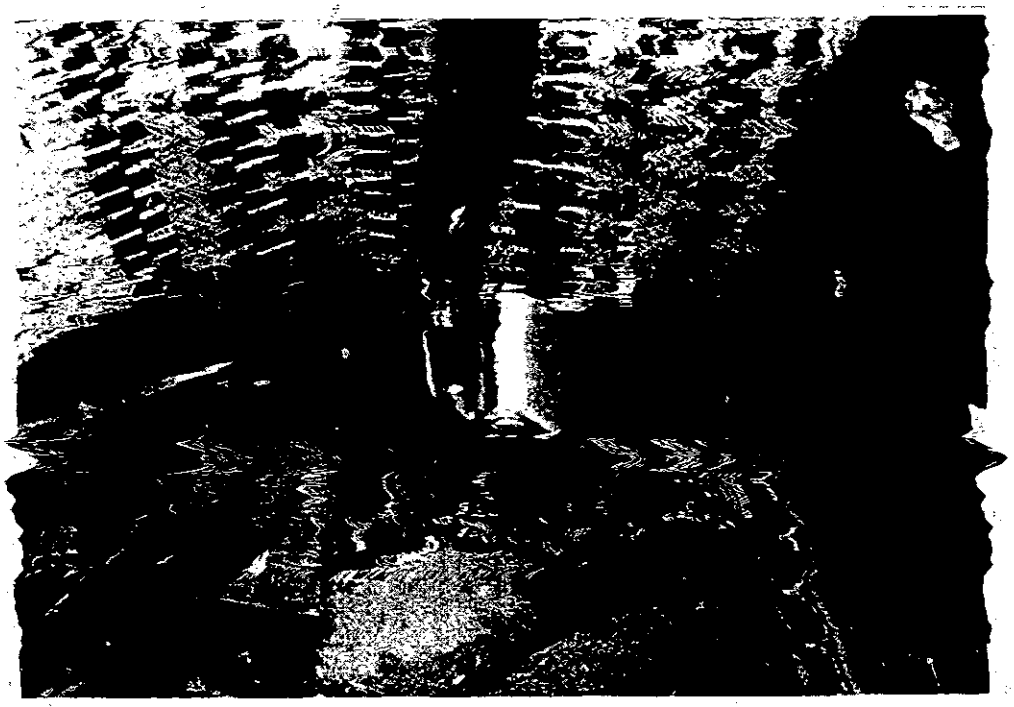
11-1. Top view depiction of airplane at impact.



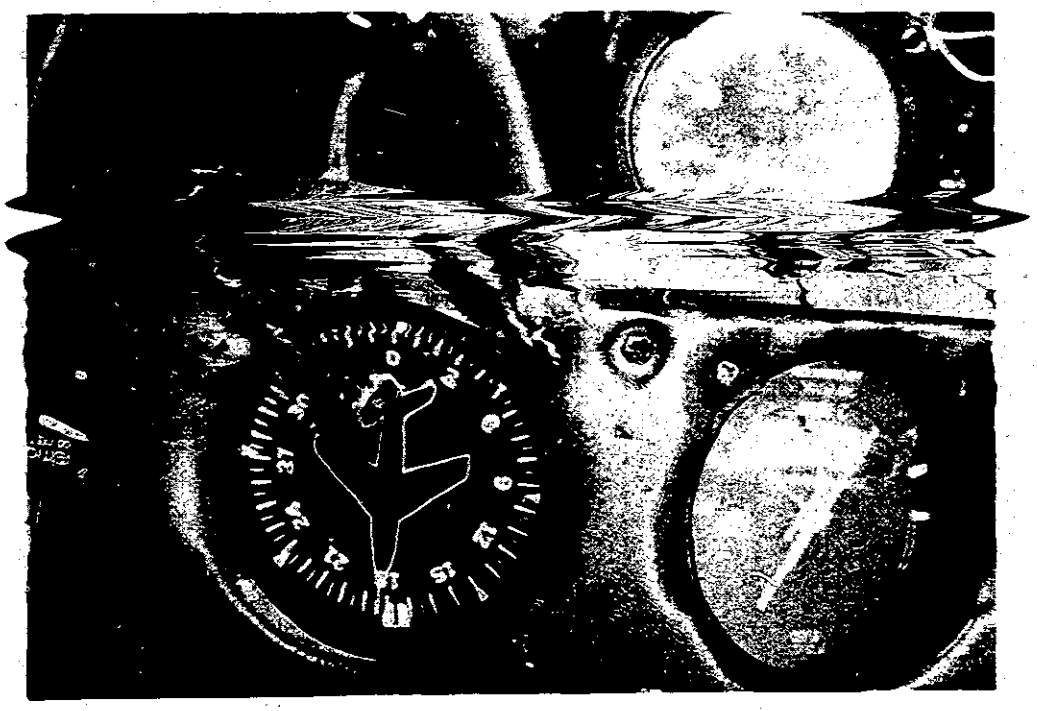
11-2. Side view depiction - airplane almost inverted.

11-3. Wreckage.

11-4. Wreckage.



11-5. Shoulder harness worn.



11-6. Pilot head strike area (one of multiple).

11-7. Pilot head strike area.

11-8. Circled area is pilot head strike area.

Case 12

SYNOPSIS

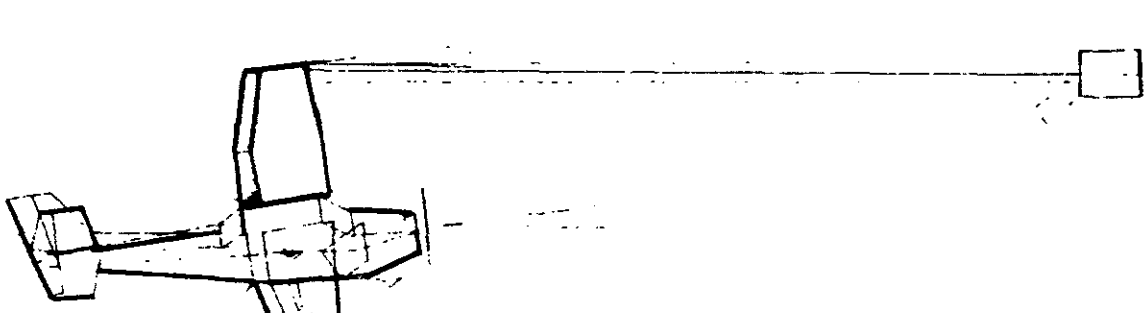
This accident involved a high-wing, single-engine airplane being flown VFR under IFR conditions. The pilot, who was instrument rated, attempted to conduct a VFR approach to the airport since he had ground contact, even though the forward visibility was nearly zero. During the approach, the airplane struck a utility pole shearing a portion of the left wing. Directional control could not be maintained, and the airplane entered a steep left bank. After turning about 135 degrees from its original flight path, the airplane crashed into a field, slid into a dirt bank, across an irrigation ditch, and onto a paved road.

SEATS, RESTRAINTS, AND INJURIES

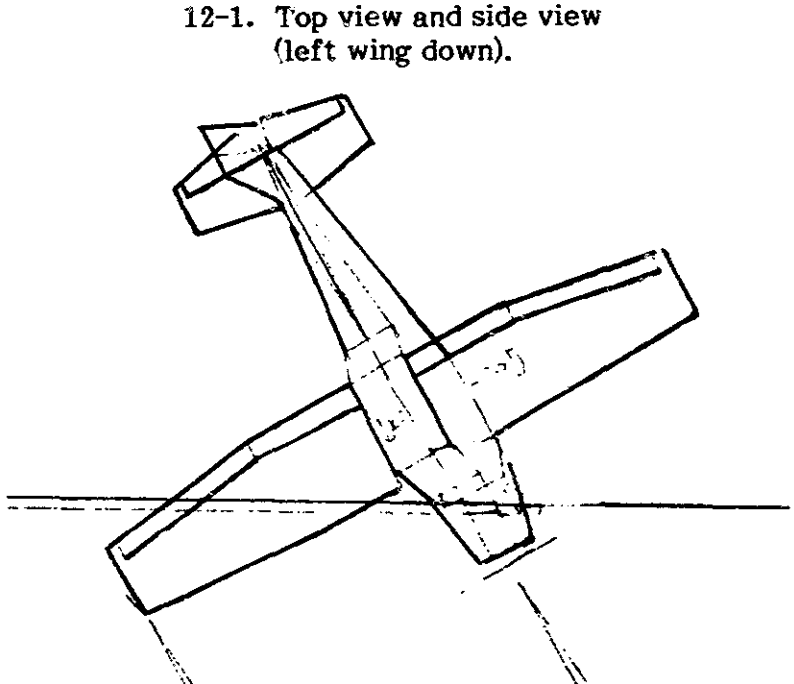
The pilot sustained multiple facial lacerations and a loss of consciousness, resulting in disorientation for several days following the accident. He also received a fractured ankle. A shoulder harness may have prevented his head injuries.

G-PULSE

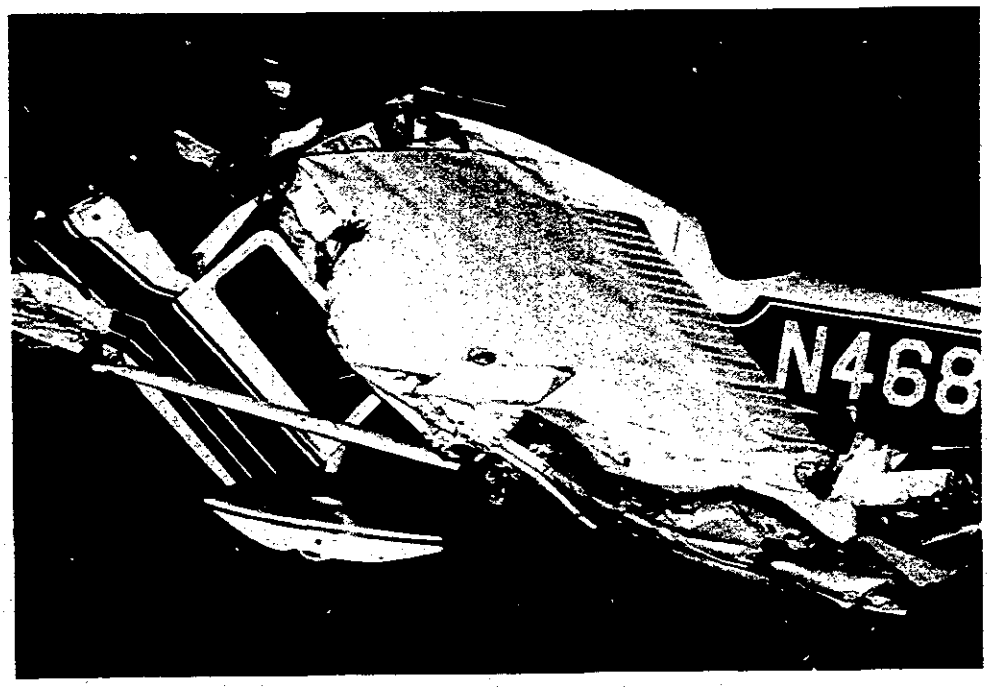
The exit velocity from the initial ground impact could not be determined because of the long slide and significant secondary impact into the side of the ditch. As a result, accurate reconstruction of the acceleration loads could not be made. The impact velocity of 55 knots was calculated by using the landing configuration stall speed corrected for weight and bank angle. The roll angle progressed from 60 degrees left wing down to 120 degrees of left roll. The pitch attitude changed from about level to 60 degrees nose-down. The impact angle was about 17 degrees.



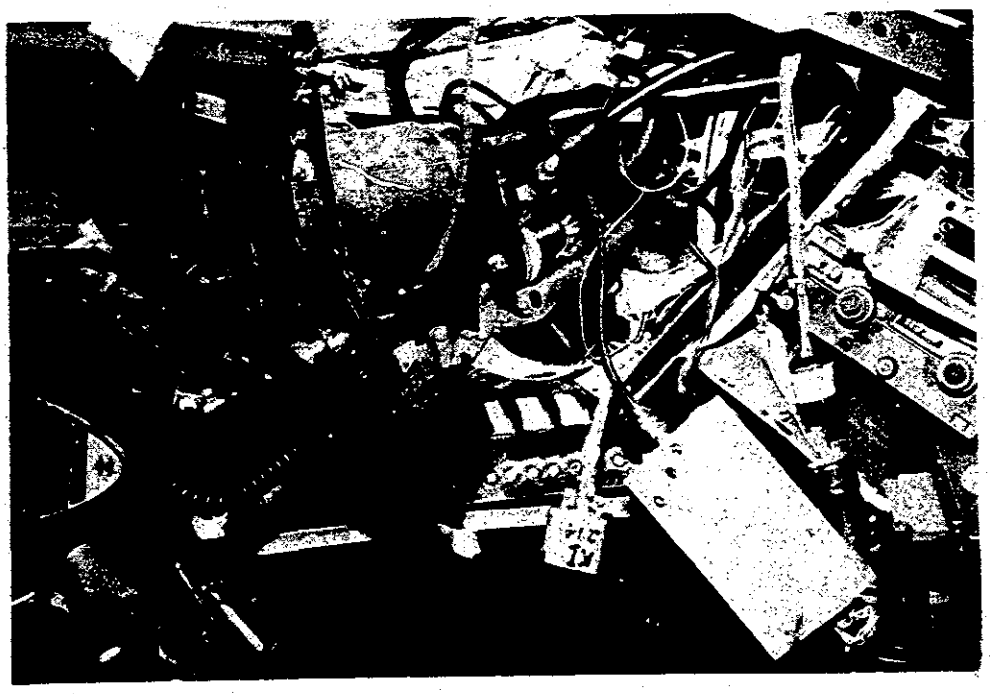
12-1. Top view and side view (left wing down).



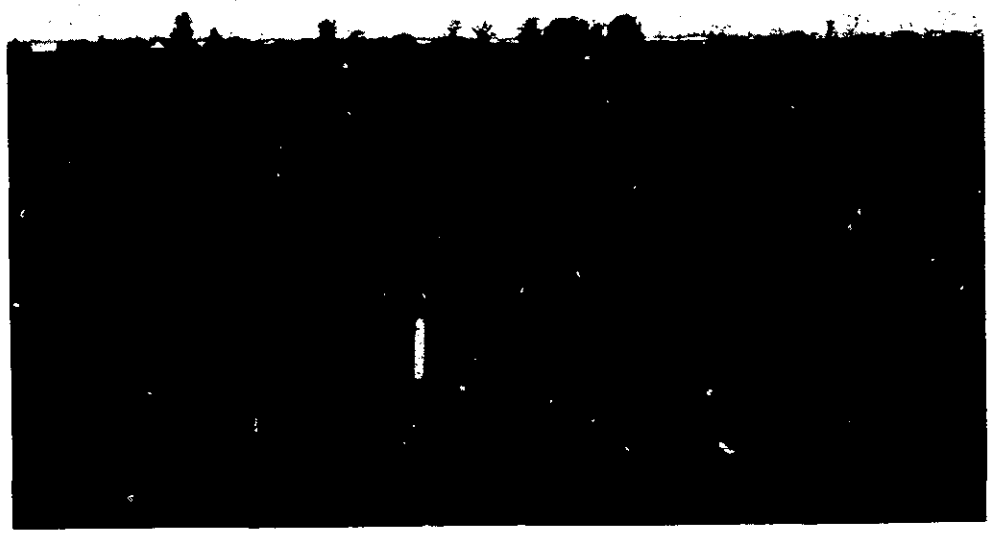
12-2. Side view - fully stroked position.



12-3. Wreckage.



12-4 Pilot's area.



12-6. Curving swath cut through crops, ending at side of irrigation ditch.

Case 13

SYNOPSIS

This accident involved a midair collision between a twin-engine airplane and a single-engine airplane. The twin landed without incident while the pilot of the single-engine airplane executed an emergency landing in a dry retention pond.

SEATS, RESTRAINTS, AND INJURIES

The two occupants of the single-engine airplane received serious injuries. The airplane was equipped only with the lapbelts worn by the pilot and the passenger.

The pilot received compression fractures of the cervical spine and two fractured ribs. The cervical spine injuries probably resulted when the seat pan split, allowing the pilot to impact the floor. The passenger received fractured ribs, a perforated chest, and a severely sprained ankle. The exact injury sources for this passenger could not be determined.

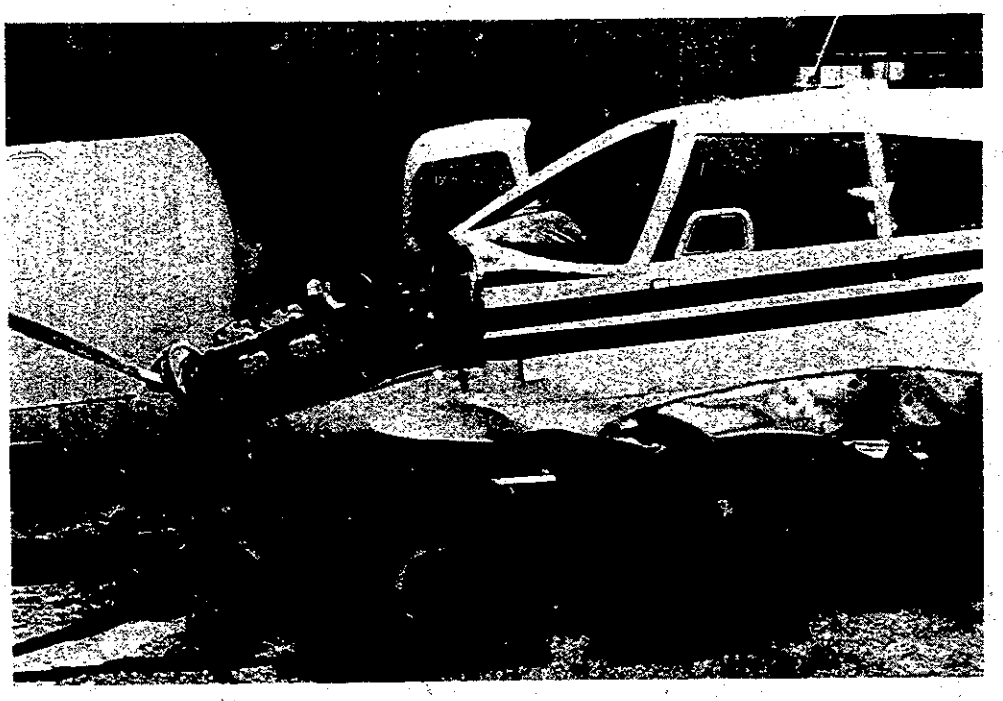
G-PULSE

The 51-knot impact speed was derived from the airplane's published landing configuration stall speed corrected for weight, flap position, and bank angle.

By matching ground scars and airplane components, it was determined that at impact the pitch attitude was about level with an 8-degree left roll relative to the ground; the ground sloped about 15 degrees. The resultant impact angle was about 10 degrees.

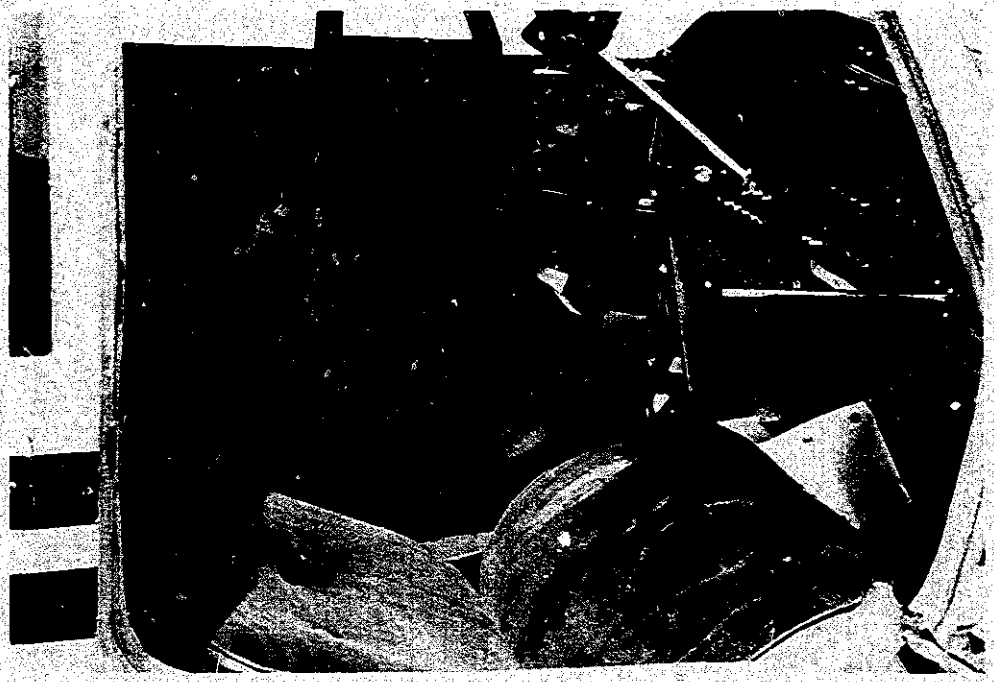
The vertical velocity at impact was 14.8 feet per second and the horizontal velocity was 84 feet per second. The exit velocity was not calculated because of the long slide and the rough, uneven terrain.

The vertical acceleration loads transmitted to the occupants were dictated by the effects of the gear and by the three inches of fuselage crush that could be measured. It was estimated that either the gear could slow the airplane down an equivalent of 8 feet per second or that the gear would break off and absorb no energy. If the gear did slow the airplane, it would slow the airplane from 14.8 feet per second to 12.5 feet per second. The peak vertical loads in these cases would have ranged from 15 to 20 G's. These loads are those imposed on the airplane. If the occupants' seats collapsed, the load to the occupants could be greater due to the secondary impact with the cockpit floor. The horizontal load was believed to have been small because occupants did not contact the instrument panel.

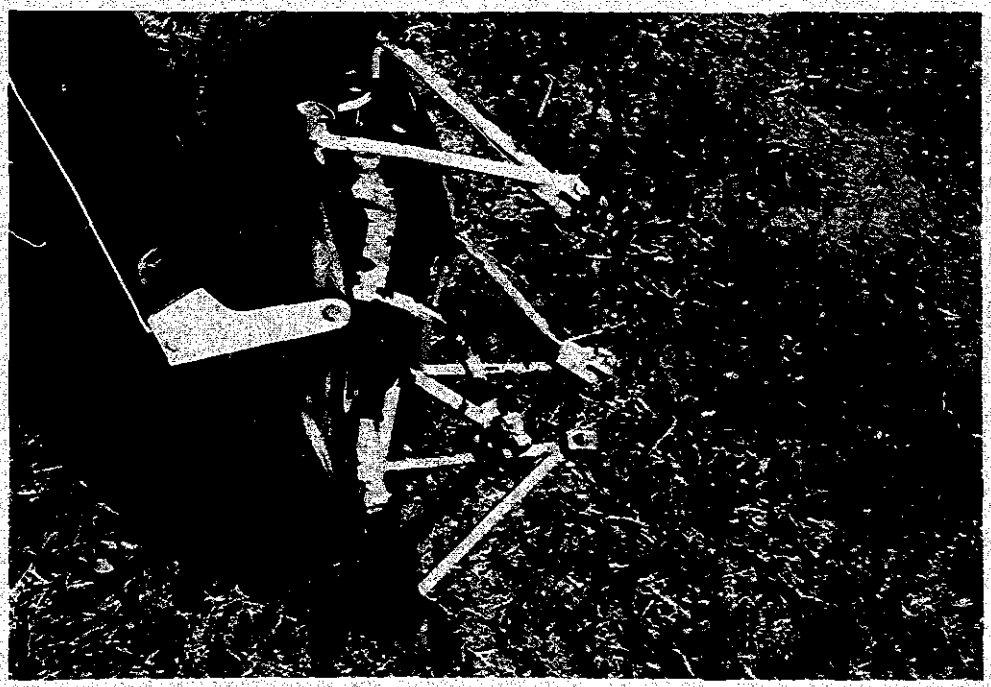


13-1. Wreckage - Crush line.

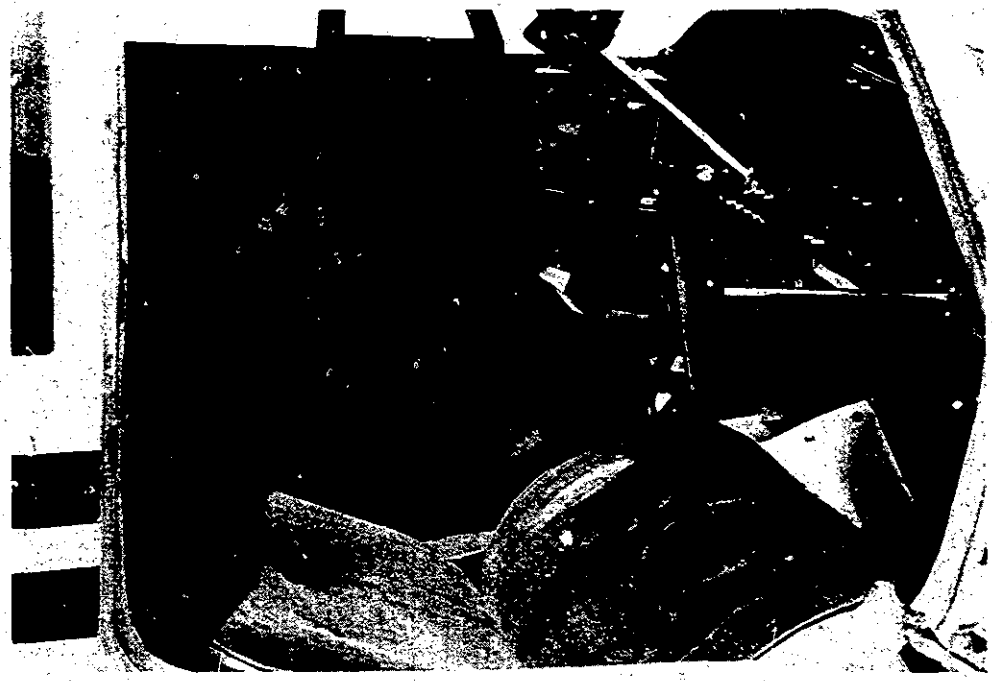
13-2. Impact points, general terrain.



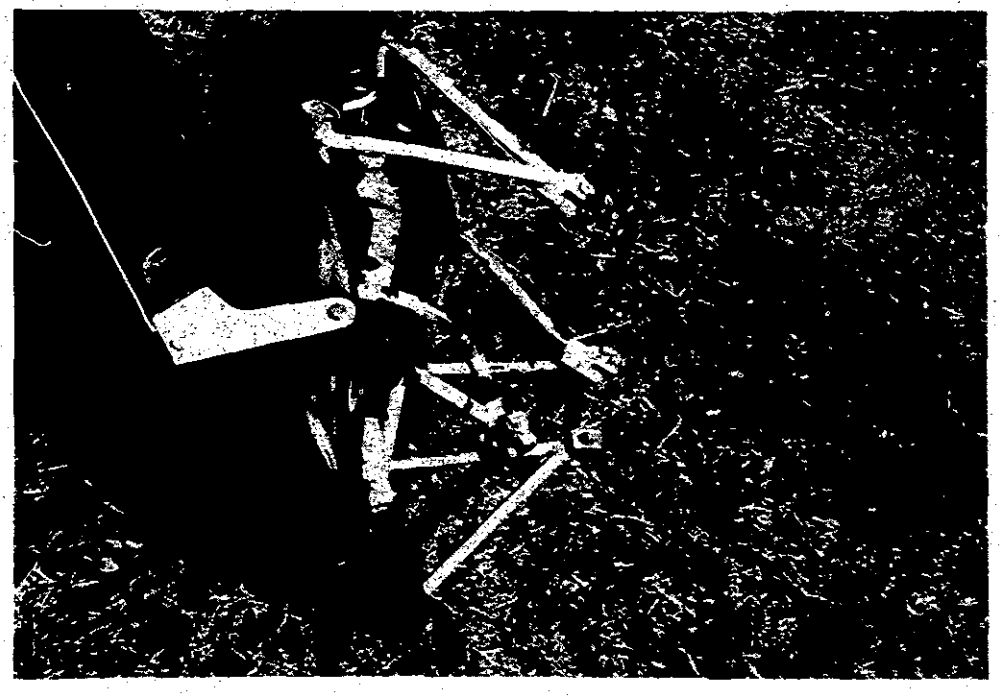
13-3. Seats rotated down to floor.



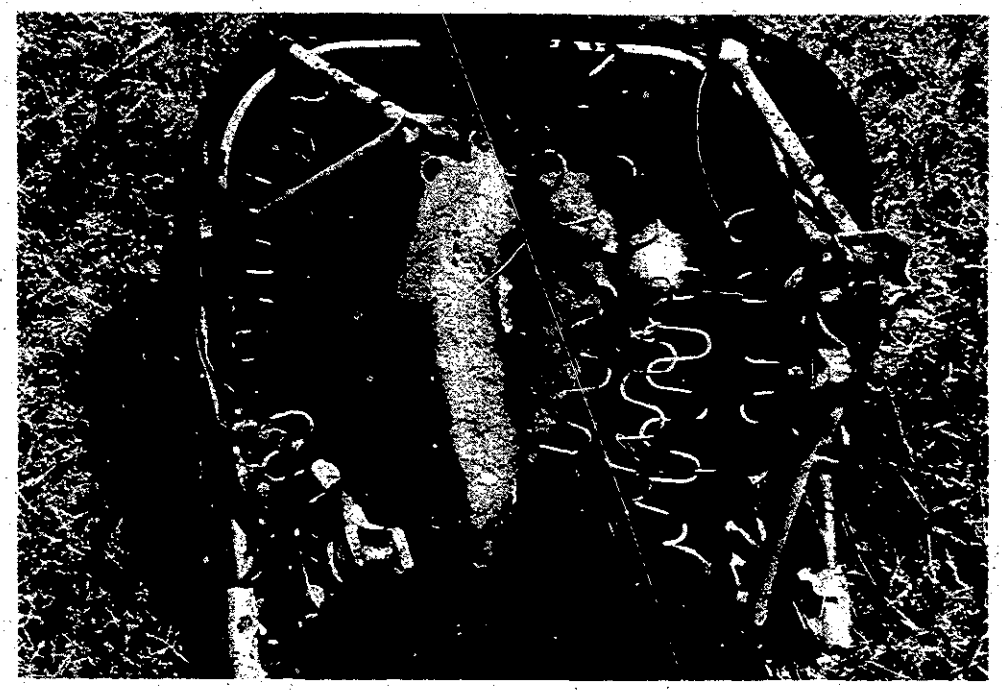
13-4. Pilot's seat - No stabilization between front and rear seat feet.



13-3. Seats rotated down to floor.



13-4. Pilot's seat - No stabilization between front and rear seat feet.



13-5. Springs pushed out of place.

13-6. Tie wires pulled loose.

Case 14

SYNOPSIS

This accident involved a twin-engine airplane which crashed at night in a heavily wooded area short of the runway following fuel exhaustion. The airplane received substantial damage. The pilot and his passenger were both injured.

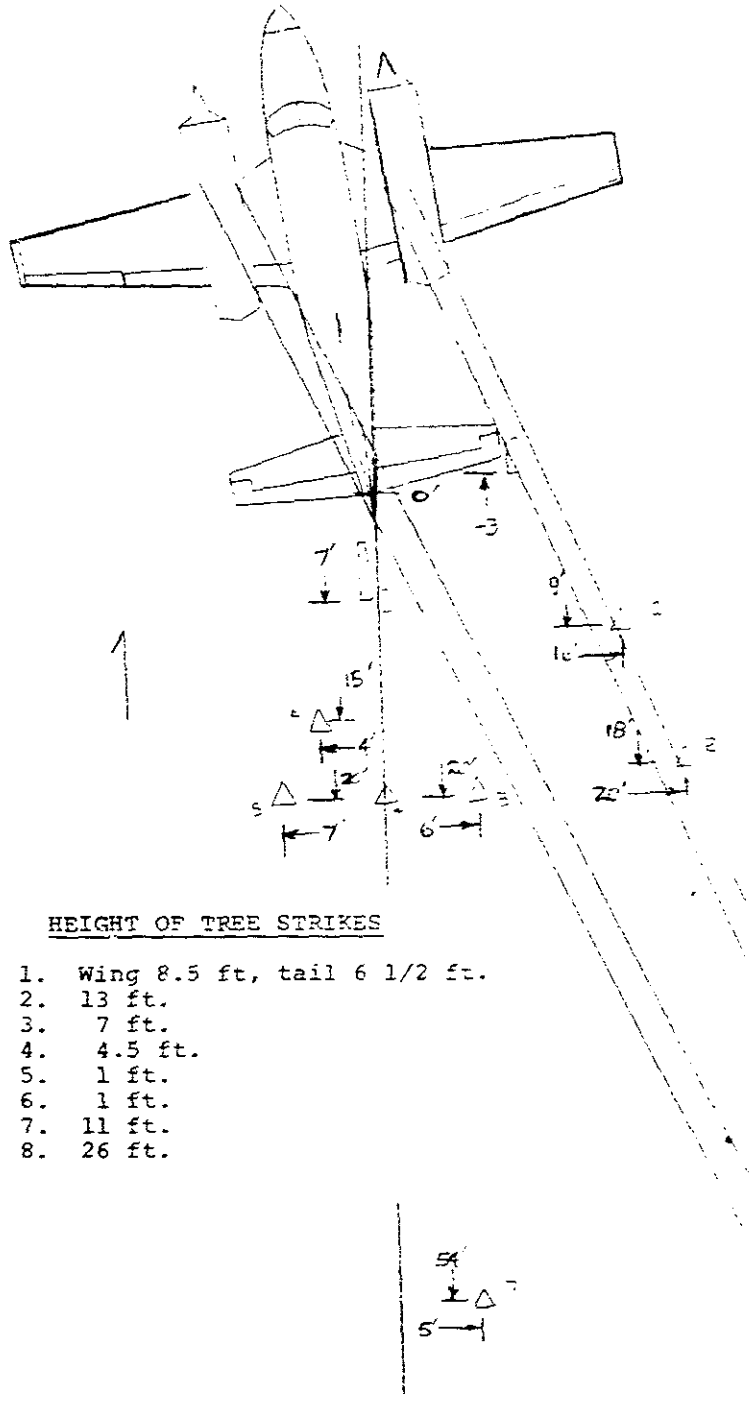
SEATS, RESTRAINTS, AND INJURIES

The pilot had removed his shoulder harness after takeoff and failed to put it back on prior to the crash. He was wearing his lapbelt. His seat was undamaged, and he received only minor injuries. The only passenger in this airplane was seated in a right rear seat. No shoulder harness was available for this seat, but the passenger was wearing a lapbelt. This seat is positioned over an enclosure for the air conditioning compressor and to the front side of the main spar. The entire seat was deflected downward during the impact, with a force sufficient to produce two dents in the cover of the air conditioner condenser, a position coinciding with the passenger's buttocks. Some equipment items inside the air conditioner were also deformed. The occupant suffered serious neck and back injuries in this accident.

G-PULSE

Acceleration loads could not be calculated because the multiple tree strikes and fragmenting of the structure precluded an accurate estimate of the impact velocity. However, the passenger had less than one inch of stroking distance because of the solid understructure in his seating area. The occupant contacted the understructure hard enough to leave a permanent dent in its metal cover.

This case provides an excellent example of the differences in back injuries as a result of differences in available stroking distance. If it is assumed that the vertical velocity at the final impact was 15 feet per second, then the vertical acceleration would be about 21 G's peak when 4 inches of measured fuselage crush is used. If an additional 4 inches of stroking distance had been available under the seat, the expected peak loads would have dropped to about 10.5 G's. The acceleration loads to the passenger were certainly as great as the acceleration loads to the airplane because there was no stroking distance available under his seat.



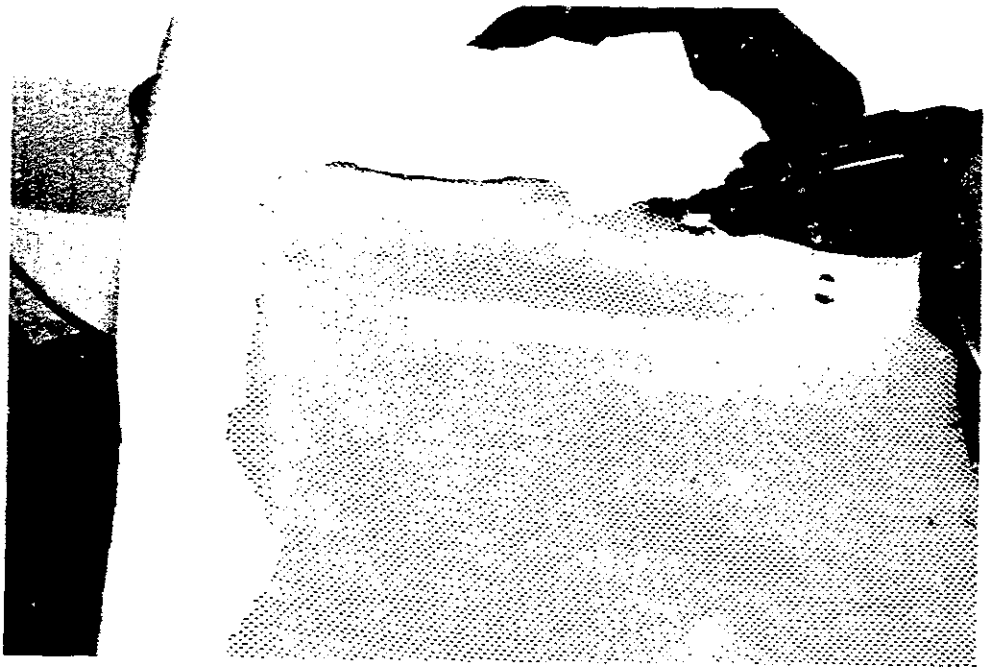
HEIGHT OF TREE STRIKES

1. Wing 8.5 ft, tail 6 1/2 ft.
2. 13 ft.
3. 7 ft.
4. 4.5 ft.
5. 1 ft.
6. 1 ft.
7. 11 ft.
8. 26 ft.

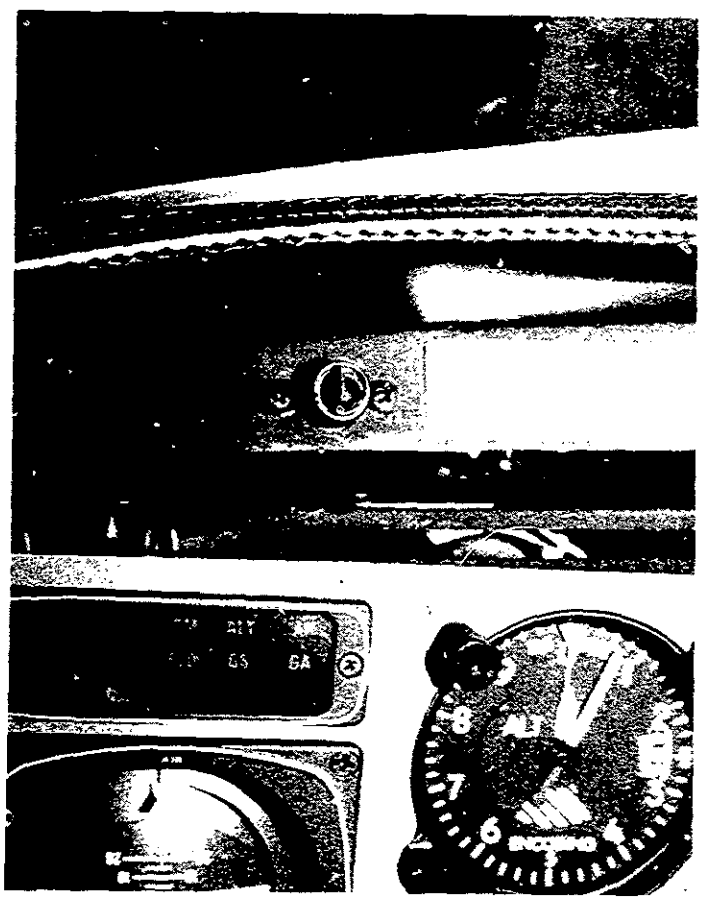
14-1. Final flight path through trees.

14-2. Wreckage.

14-3. The passenger seat and understructure that housed the air conditioning equipment.



14-4. The pan material that could be torn by hand (passenger seat).



14-5. Pilot's head contact area.

Case 15

SYNOPSIS

This accident involved a single-engine, low-wing airplane making a nonprecision approach at night over an area with few ground references. The airplane impacted the ground in a 9-degree nose-down attitude on the final approach course, about 1 1/4 miles from the landing threshold. Both occupants were seriously injured; the airplane was destroyed.

SEATS, RESTRAINTS, AND INJURIES

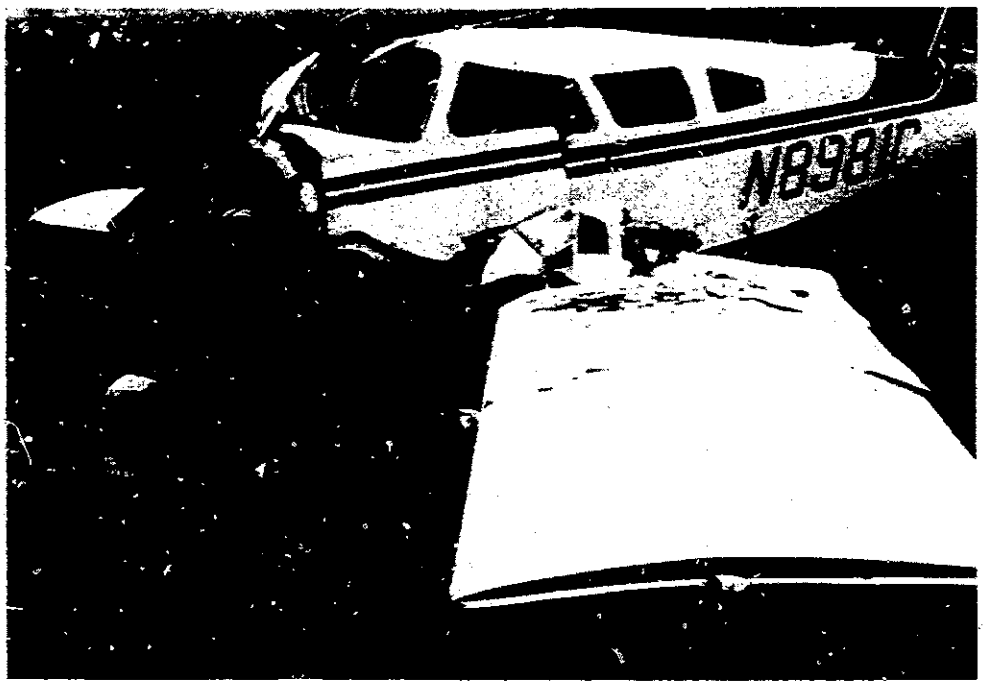
The occupants' seats were of an energy absorbing type. The seats were deformed and offered a significant amount of protection to the occupants. Both the pilot and his passenger were wearing lapbelts and shoulder harnesses and they remained in a snow-covered field for up to two hours before being rescued and transported to a hospital. The pilot received extensive lacerations of his face and a broken nose, broken ankles, and fractures of the third, fourth, and fifth ribs. The passenger also received multiple traumatic injuries, including extensive scalp lacerations, with the scalp peeled off the skull for a considerable distance. He also had a depressed skull fracture, fractures of both legs, and multiple bruises. In spite of the protection offered by the shoulder harnesses, both the pilot and the passenger impacted portions of the instrument panel as well as the side windows and side posts. Without shoulder harnesses, these impacts would probably have been fatal.

G-PULSE

Accurate G-loads could not be calculated in this case because of the long slide after initial impact. The slide actually consisted of a bounce of about 200 feet followed by a slide of about 200 feet. Small errors in estimating the sliding friction coefficient would result in large errors in the exit velocity estimates.

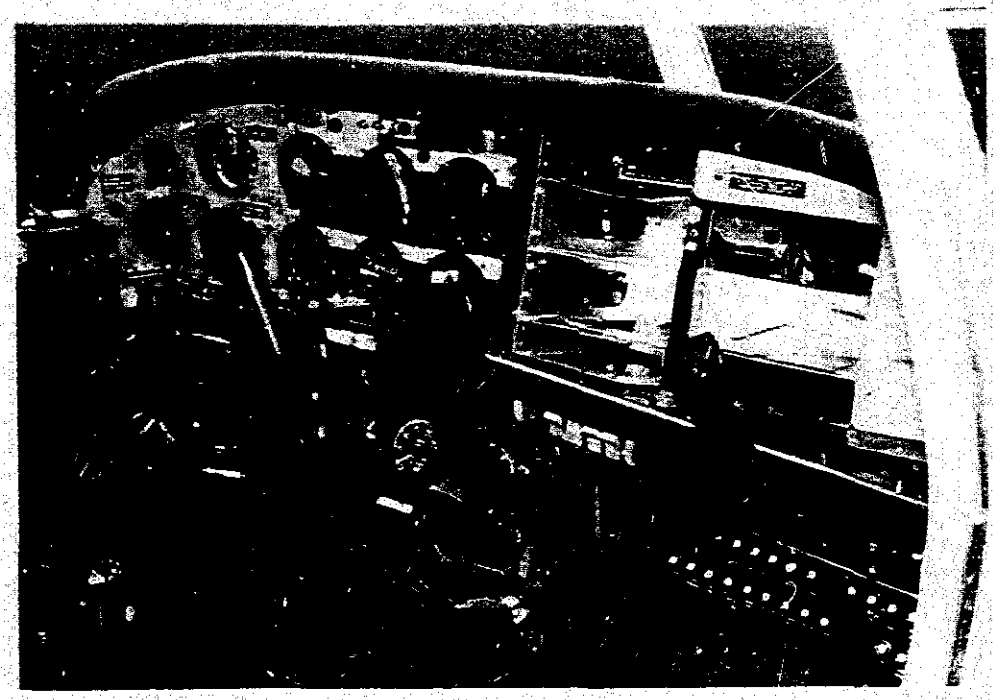
The pilot stated that the airplane was at 90 knots indicated airspeed; the ground scars indicate that the impact angle was under 10 degrees.

The acceleration loads were considered to be primarily longitudinal because of the occupant impact into the panel. The airplane's impact into the mud created greater longitudinal loads than if the impact had been on more firm ground.

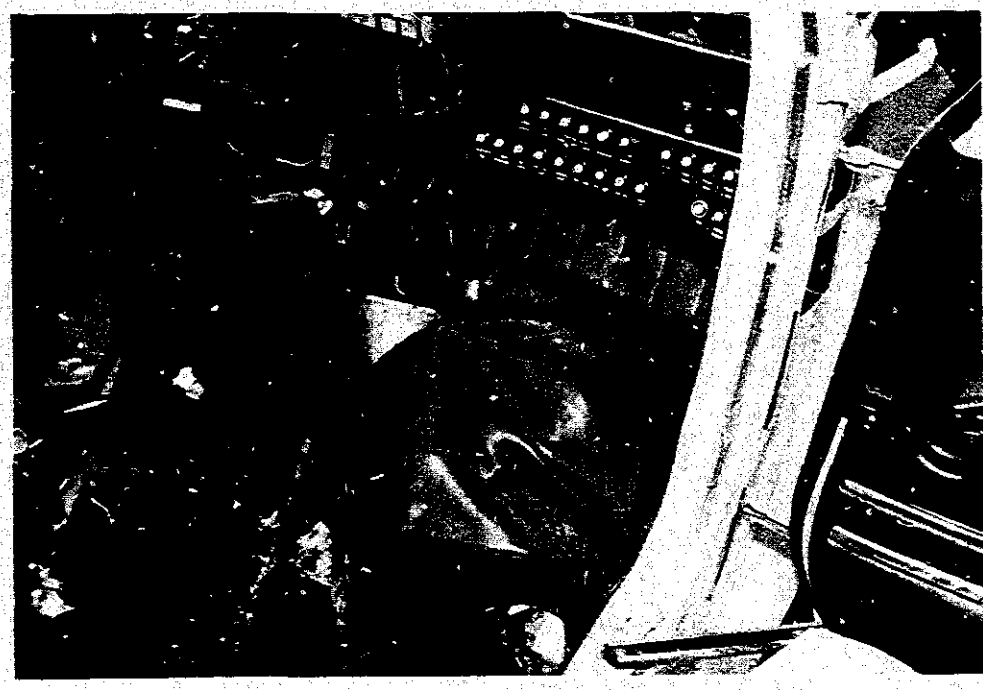


15-1. Wreckage.

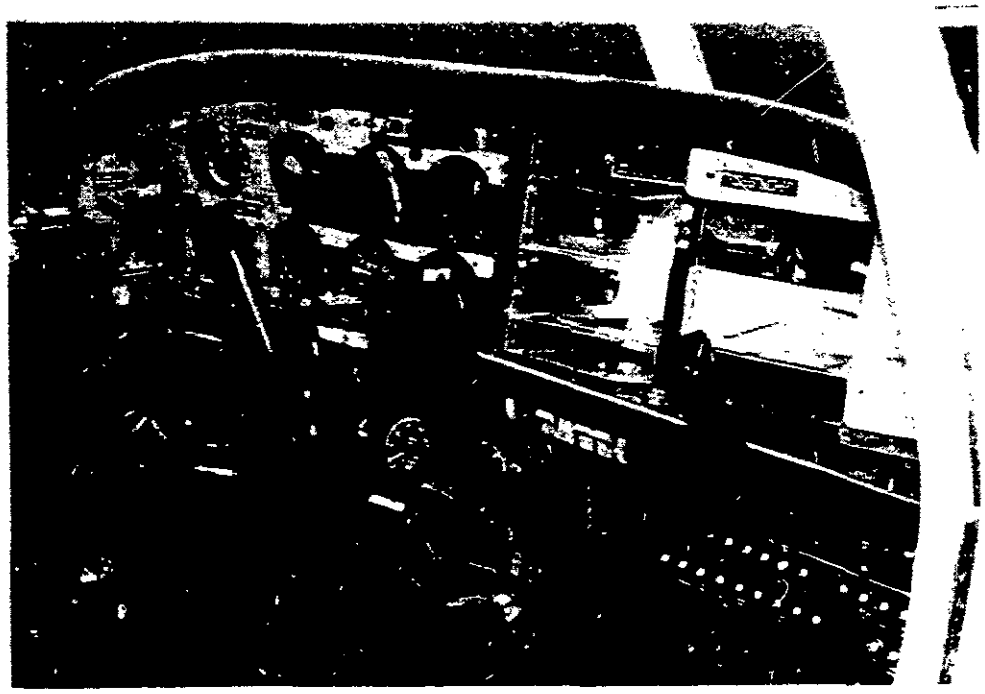
15-2. Wreckage.



15-3. Pilot contact area.



15-4. Floor upheaval under left front occupant.



15-3. Pilot contact area.

15-4. Floor upheaval under left front occupant.

Case 16

SYNOPSIS

This single-engine, low-wing airplane experienced engine problems and crashed in a clearing among tall trees. The airplane came to rest in an inverted position. The right wing and landing gear separated from the main fuselage. The fuselage received compression wrinkling throughout, but crushing was most prominent on the lower fuselage beneath the cabin.

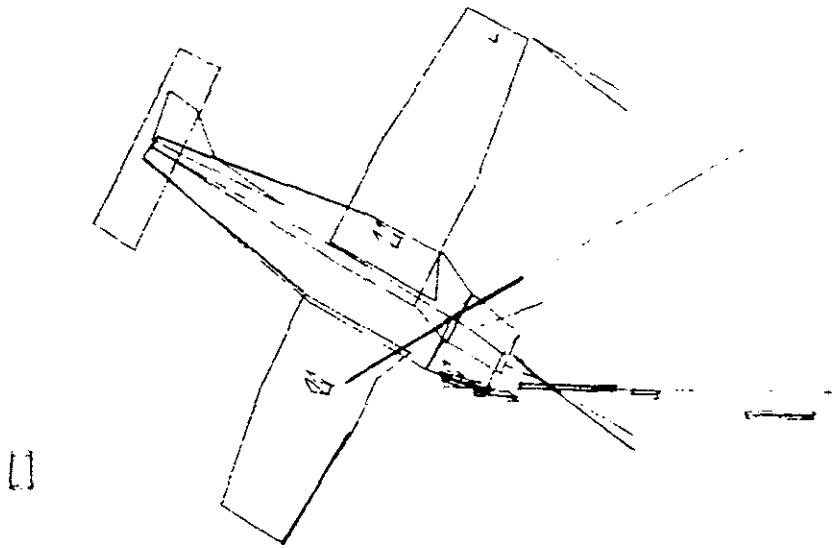
SEATS, RESTRAINTS, AND INJURIES

Although the pilot was killed, this accident was fully survivable. During the impact, his body and extremities contacted the instrument panel and control column. His chest was crushed and he received multiple brain contusions. There was no evidence of loading to the lapbelt which would be indicative of aft movement of the instrument panel. Passengers were seated in the copilot seat and in the right-rear seat, directly behind the copilot seat. Both passengers were seriously injured. At the time of impact, both were wearing lapbelts. The passenger in the right-front seat received lacerations to her face, ear, and left knee, caused primarily by impacts with the door post. She was unconscious when found and was not breathing because of an obstructed airway. She also fractured her right foot and coccyx. The legs of her seat bent to the right while the back frame and seat pan bent downward. The passenger occupying the right-rear seat received fractures of the lumbar vertebrae, and was also unconscious. The seat attach fittings separated.

G-PULSE

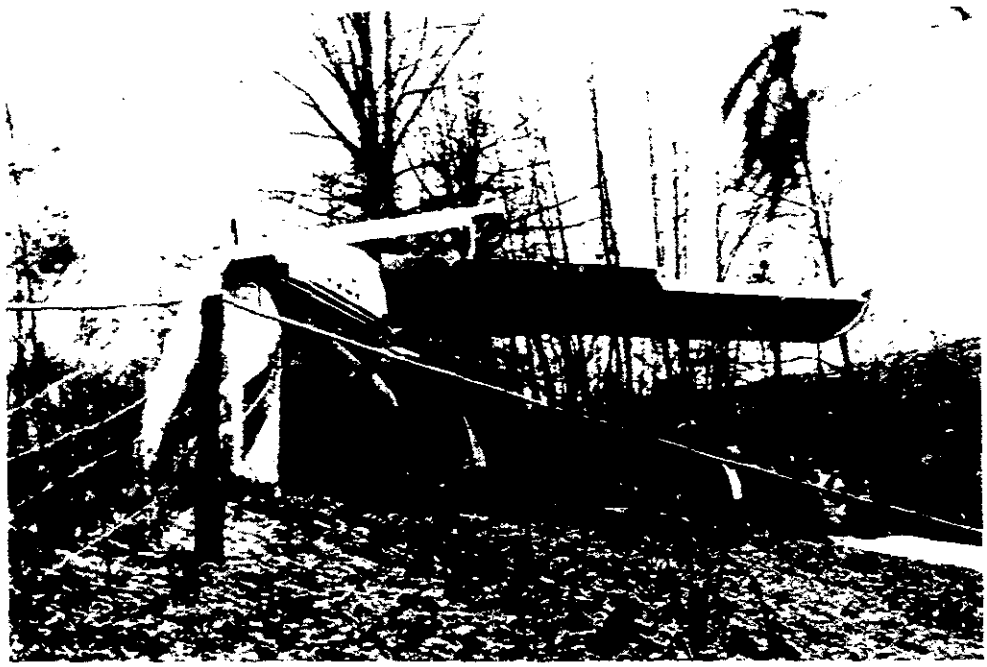
The airplane impacted the ground in a 30-degree nose-down pitch attitude with a 45-degree right roll. By the time the fuselage was fully crushed to the ground, the pitch attitude had increased to about 40 degrees. The airplane then slid 45 feet down an 18 percent slope. The initial impact speed was estimated to be 55 knots based on a flaps-up stall speed of 58 knots, corrected for weight, and adding 5 knots for acceleration to the ground after the stall.

The principal impact speed would have been less than the 55 knots because of the ride-down effect caused by the crushing of the wing. Assuming a 2 G average acceleration for 11 feet caused by the wing, the impact speed was calculated at 50 knots or 85 feet per second. The vertical velocity would have been 55 feet per second and the horizontal velocity would have been 65 feet per second. The sliding coefficient was about 0.5 (0.7 ground -0.18 slope). The velocity change during the 45-foot slide was from about 38 feet per second to zero. The velocity changes would then be 55 feet per second vertical and 27 feet per second horizontal (65 - 38). A crushing distance of about 3 feet in the vertical direction would yield a 31 G peak acceleration over a period of 0.11 seconds. The period of 0.11 seconds and the horizontal velocity change of 27 feet per second would yield a 17 G peak horizontal acceleration. The net acceleration of 35 G's would be about 60 degrees down (earth axis) and since the airplane attitude was 40 degrees down and rolled, the direction of the airplane axis acceleration would be predominately forward with some down and left loading. The velocity change in airplane axis was about 62 feet per second longitudinal and was small in the vertical direction.

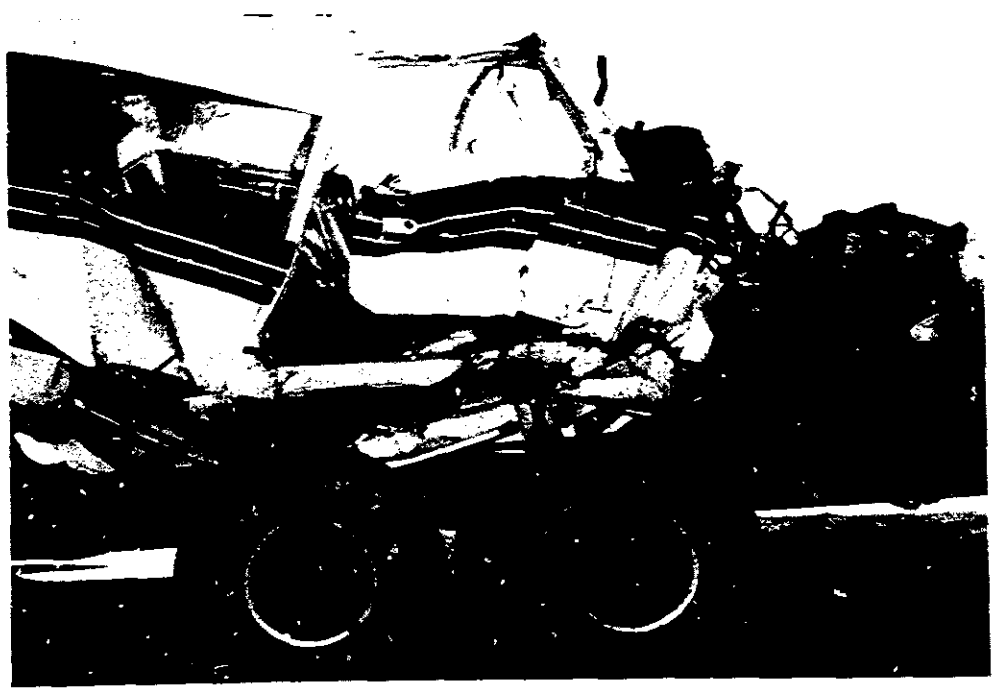


16-1. Impact angle (side and rear view).

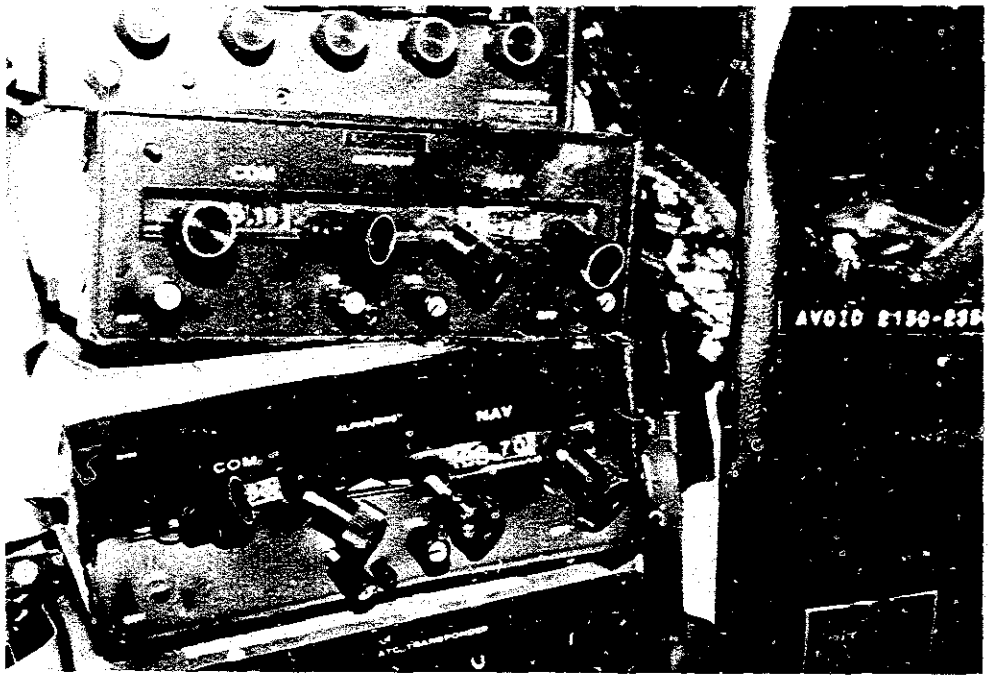
16-2. Wreckage.



16-3. Wreckage.



16-4. Crush angle.



16-5. Head impact area.

Case 17

SYNOPSIS

This single-engine, high-wing airplane crashed after the pilot executed a go-around maneuver in gusty winds. The airplane climbed over a line of trees in a steep right bank before losing altitude and impacting the ground. The airplane hit in a nose-low attitude, 800 feet to the right of the runway. It cartwheeled and came to rest in an upright position.

The airplane was destroyed. The nose was crushed back to the cabin. Both wings were bent downward and showed compression wrinkling throughout. The fuselage from the cabin forward was pitched downward. The fuselage was torn aft of the cabin.

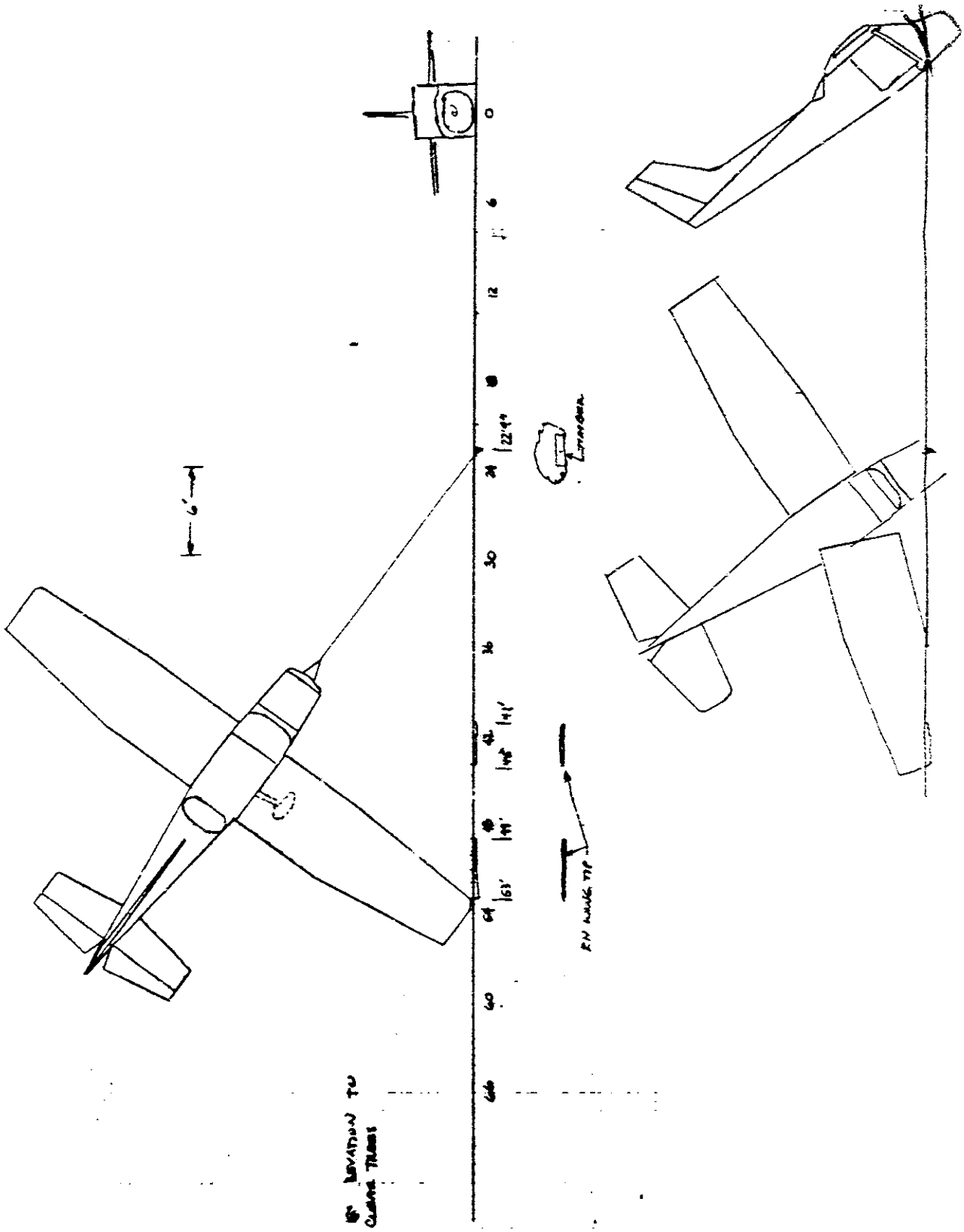
SEATS, RESTRAINTS, AND INJURIES

The accident was survivable. Of the three occupants of the airplane, the pilot was killed. Both passengers were critically injured. The pilot impacted the instrument panel and received multiple skull fractures that caused extensive hemorrhaging of the brain. He also received numerous lacerations and abrasions. The injuries probably could have been substantially reduced if the pilot had been wearing a shoulder harness. Although the aft movement of the instrument panel could still have produced contact, a shoulder harness would have prevented or reduced the velocity of impact into the panel. The passenger who occupied the copilot seat received multiple traumatic injuries that included depressed facial fractures, fractures of the left arm, left hand, and spinal column, and contusions to the left knee. The passenger wore the lapbelt. Her facial injuries could have been lessened or prevented had she used the shoulder harness. The other passenger occupied the right-rear seat. The back frame of his seat pan deformed downward and his lapbelt separated. He received lacerations and abrasions of his head and chest region, fractures to the right shoulder, left arm, and right leg, and a perforated small bowel. A shoulder harness could have prevented the lapbelt separation and the lapbelt injury by more evenly distributing the restraint system loads.

G-PULSE

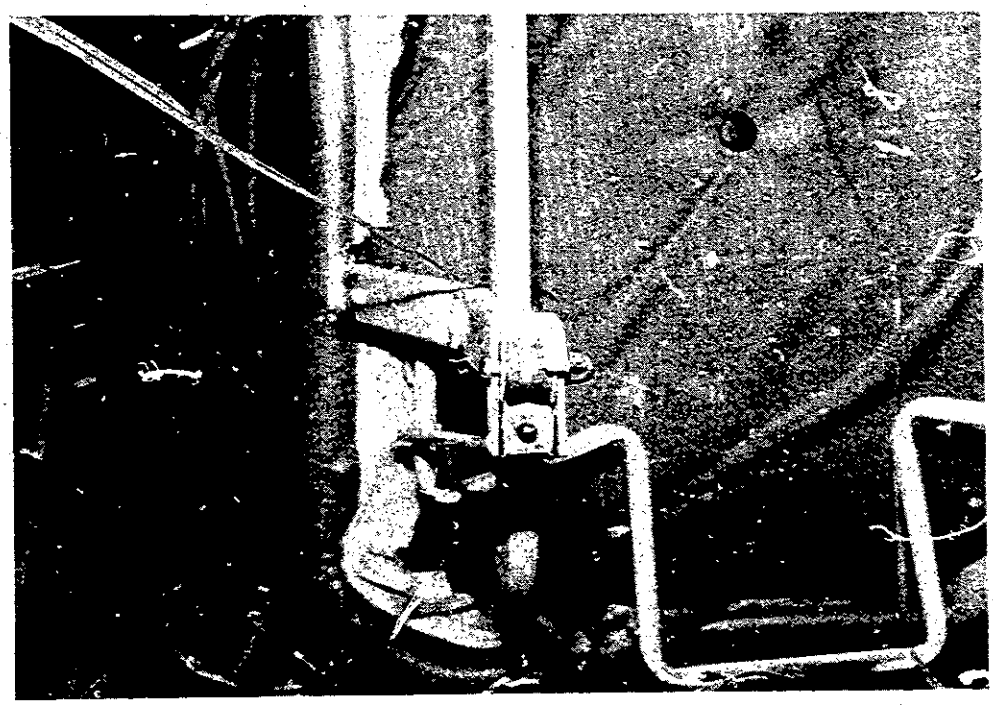
The airplane impacted the ground right wing first. By matching ground scars and airplane components, the attitude was reconstructed at 37 degrees nose-down with about 90 degrees right roll. An estimated impact speed of 41 knots was based on a landing configuration stall speed of 42 knots corrected for an estimated 60-degree roll, a weight of 2,000 pounds, and power on. It was assumed that the wing would create a ride down effect of 1 G acceleration for 19 feet, or a velocity change from 69 feet per second to 59 feet per second. The vertical velocity change would then be from about 30 feet per second to zero. A 23-foot slide and cartwheeling at a friction coefficient of 0.5 would create a 27 feet-per-second exit velocity. Therefore, the horizontal velocity change was estimated to be from 51 feet per second to 27 feet per second.

The general motion of the occupants was forward, so accleration was calculated by using a velocity change from 59 feet per second to 27 feet per second over a 4-foot stopping distance. The longitudinal load was about 22 G's peak with a velocity change of about 32 feet per second.

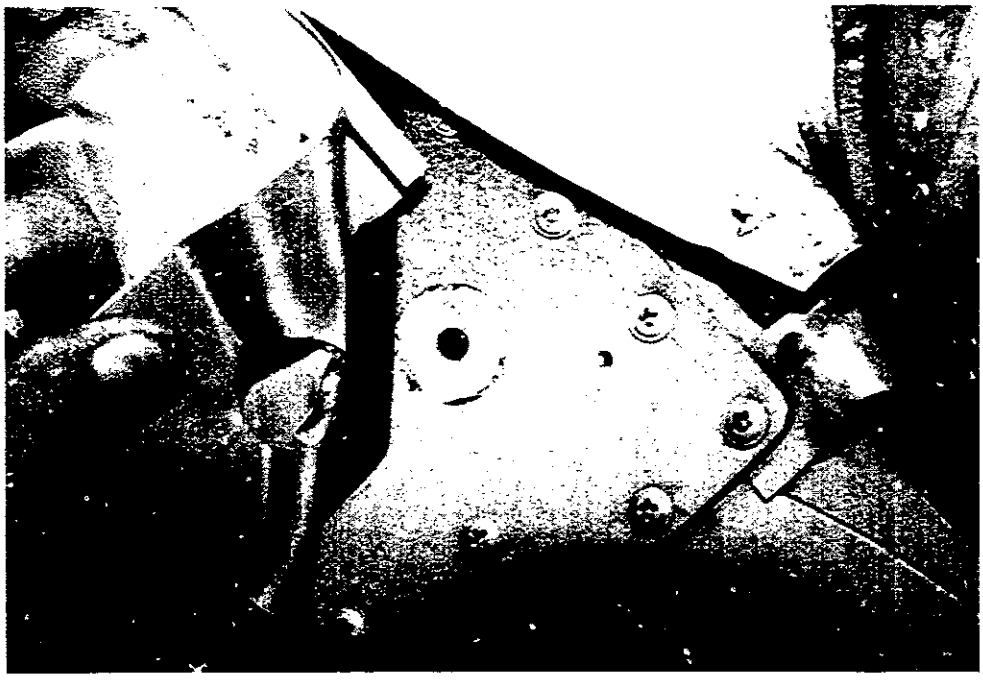


17-1. Impact angle.

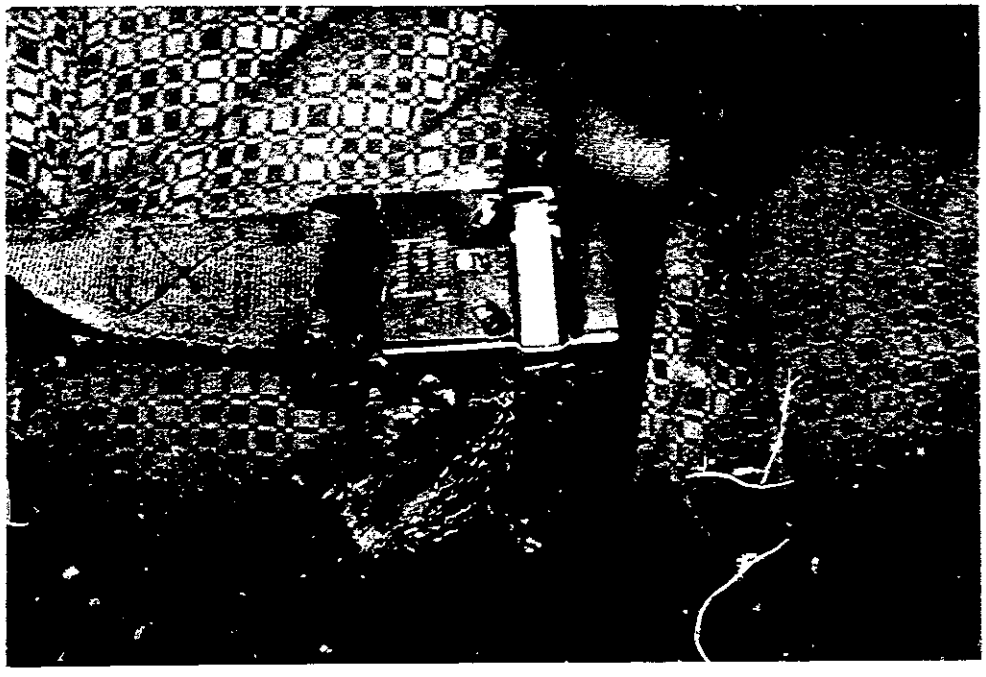
17-2. Wreckage.



17-3. Broken foot.



17-4. Area of separated shoulder harness bolt.



17-5. Buckle cam cut through webbing.

Case 18

SYNOPSIS

The single-engine, high-wing airplane crashed in an open field after the engine stopped running. The pilot had attempted to maneuver the airplane beneath power lines, but the airplane struck a telephone pole. The airplane yawed to the left before it impacted the ground 190 feet beyond the pole.

The airplane was demolished. The left wing outboard of the strut attachment was destroyed when the airplane struck the telephone pole. At ground impact, the engine was torn from the airplane. The empennage aft of the passenger cabin [redacted]hed and twisted 180 degrees.

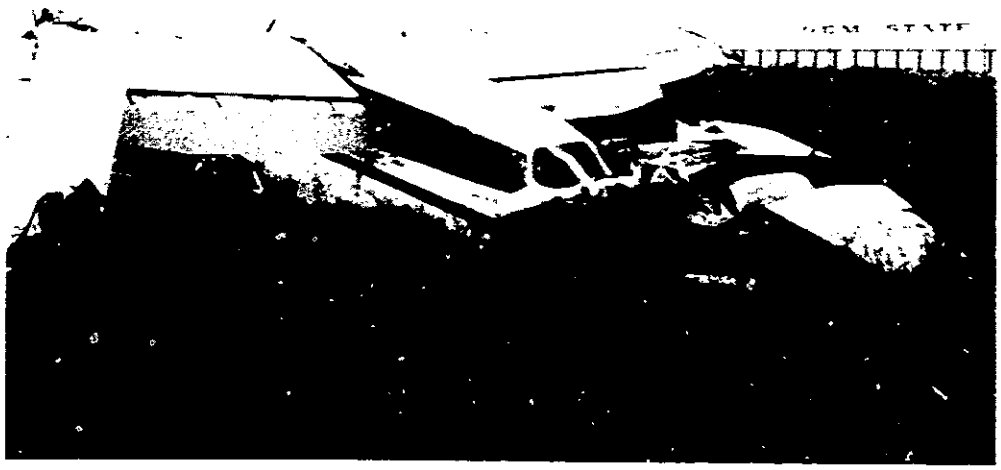
SEATS, RESTRAINTS, AND INJURIES

All seven seats separated from the floor tracks. The pilot and two passengers received minor injuries. The remaining four passengers were not injured. The pilot received a lacerated forehead. The passenger occupying the copilot seat received a scalp laceration and multiple minor contusions and abrasions on his arms and legs. The aft legs of the pilot's and copilot's seat separated. The pilot's seat track was distorted. The other injured passenger was seated on the right side of the third row of seats. She received multiple contusions of the chest. The seat pan frame and seat back tray of this seat deformed upward. The inboard forward seat leg as well as the two leg attach fittings were distorted to the right. Shoulder harnesses were available for the two front seats but were not worn.

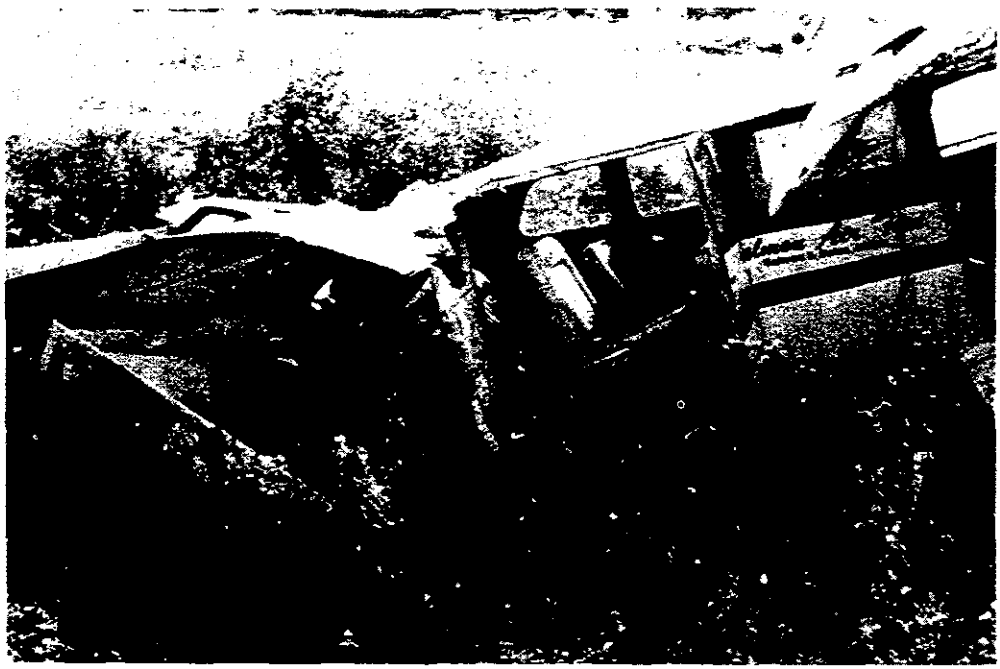
G-PULSE

Acceleration load calculations were not possible because of the relatively non-severe nature of this crash and because of the multiple strikes that occurred.

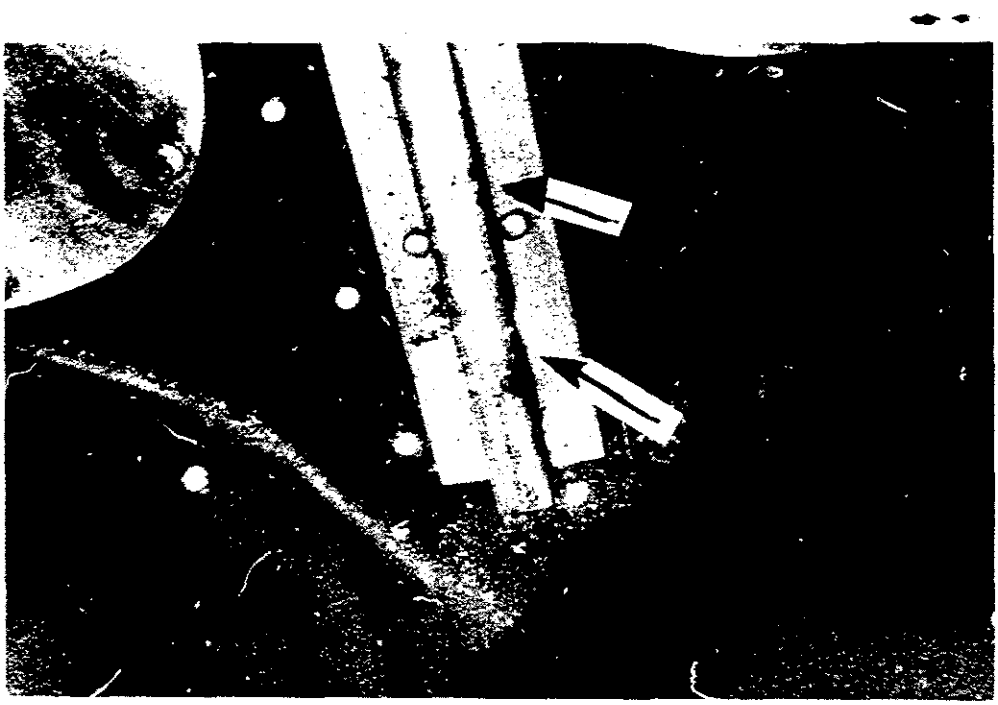
18-1. Wreckage.



18-2. Wreckage.



18-3. Rear seats.



18-4. Tracks torn out.

Case 19

SYNOPSIS

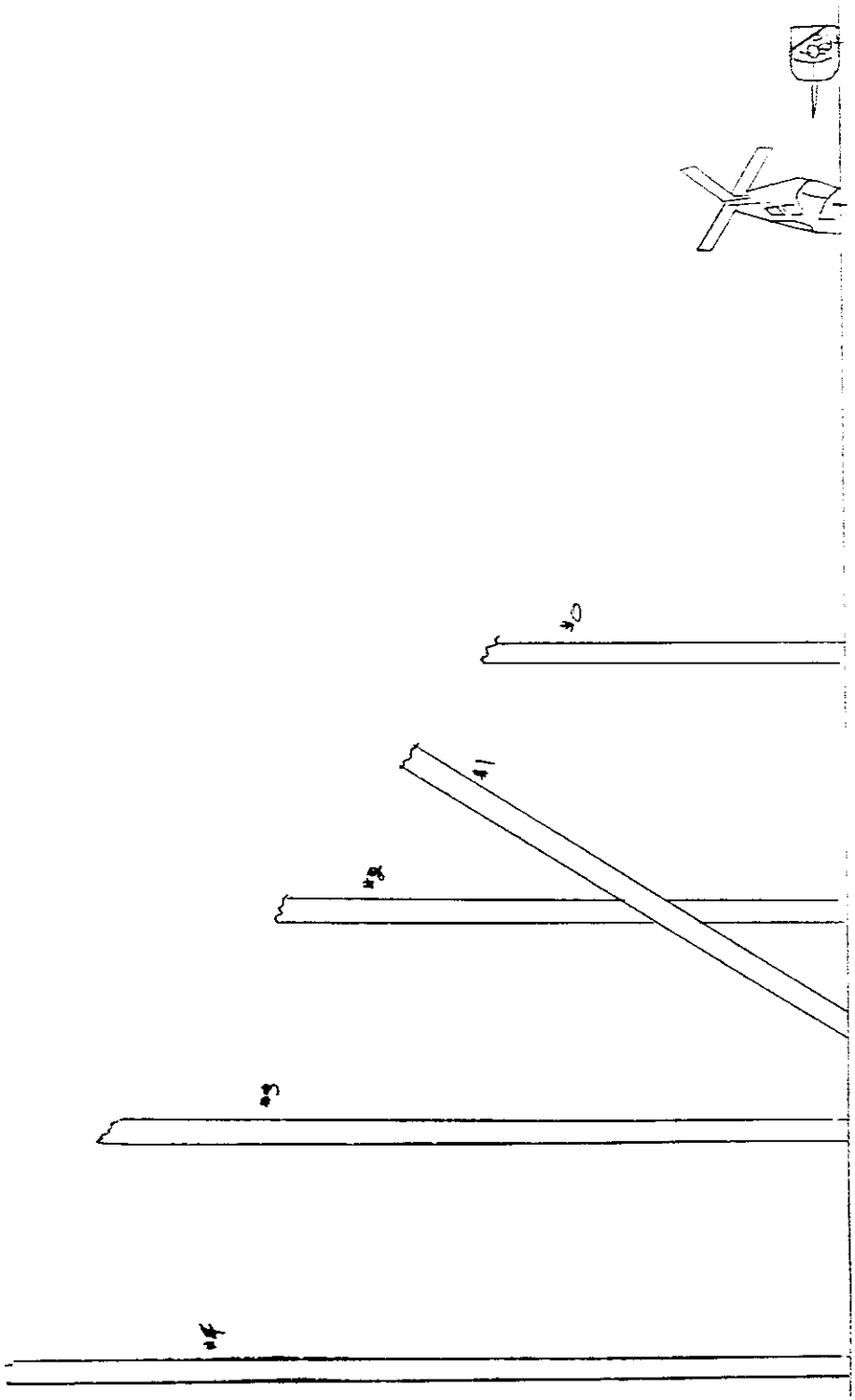
The single-engine, low-wing airplane crashed after takeoff about two miles from the end of the 2,900-foot runway. Witnesses saw the airplane take off and climb 100 to 150 feet above the ground before it disappeared from sight about a mile from the end of the runway. The airplane then struck trees, pitched over, and crashed in an open field. The airplane was demolished. The entire left wing, the outboard section of the right wing, and the left landing gear were torn from the airplane as it shredded through trees. The airplane impacted the ground in a 90-degree right yaw, 25 degrees nose-down, and 30 degrees left roll, with acceleration loads to the left. The fuselage received compression wrinkling throughout, and the remainder of the right wing separated from the airplane. The cabin was crushed inward in various locations, particularly on the left side.

SEATS, RESTRAINTS, AND INJURIES

This was a nonsurvivable accident. The airplane was equipped with lapbelts and shoulder harnesses, however, shoulder harnesses will not adequately restrain an occupant who is subject to strong side loads, as were the four occupants of this airplane. These persons all contacted the left sidewalls and/or the ground, and died of multiple traumatic injuries.

G-PULSE

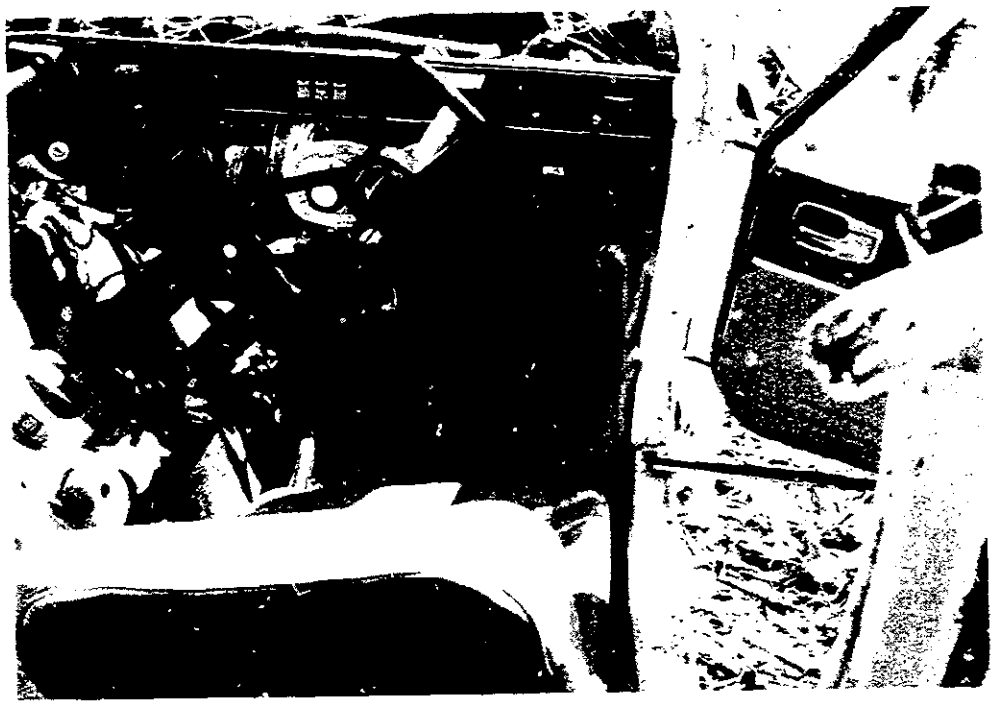
The flight path angle of 39 degrees was reconstructed from the tree strikes and the ground scars. A minimum vertical velocity of 46 feet per second was assumed, based on the 34-foot drop. The total velocity of 74 feet per second was based on the 46 feet per second velocity and the 39-degree impact angle. The airplane moved only 12 feet after impact with the movement being a rolling motion so no corrections were made for the slide. It is assumed that most of the energy was dissipated during the principal impact because of the low energy slide out. The crush to the fuselage was measured at 2.7 feet. Therefore, the peak acceleration loads were calculated to be about 63 G's, using the 74 feet per second velocity change and the 2.7 feet stopping distance.



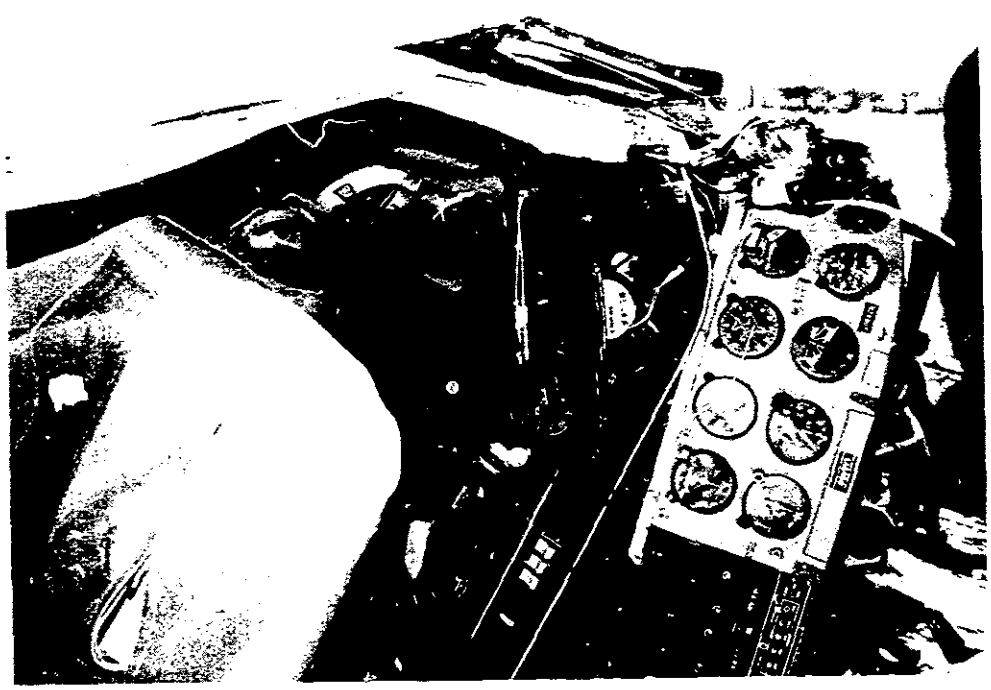
19-1. Impact angle.

19-2. Wreckage-crushline.

19-3. Wreckage-crushline.



19-4. Crush damage to pilot's side of cockpit.



19-5. Occupant contact area of left sidewall.

Case 20

SYNOPSIS

This single-engine, low-wing airplane crashed when the pilot attempted to make an emergency landing following a power loss due to fuel starvation. The airplane crashed on an embankment just inside the airport boundary.

The airplane received substantial damage. The nose gear was forced upward into the fuselage, and the left and right landing gears sheared off at impact. The right wing separated from the fuselage.

SEATS, RESTRAINTS, AND INJURIES

The pilot was the only occupant aboard the airplane. The pilot was wearing a lapbelt, but not the available shoulder harness. The pilot received serious injuries when he impacted the instrument panel and sidewall. His injuries included a scalp laceration, intercerebral hemorrhaging, and a fracture of the second lumbar vertebra.

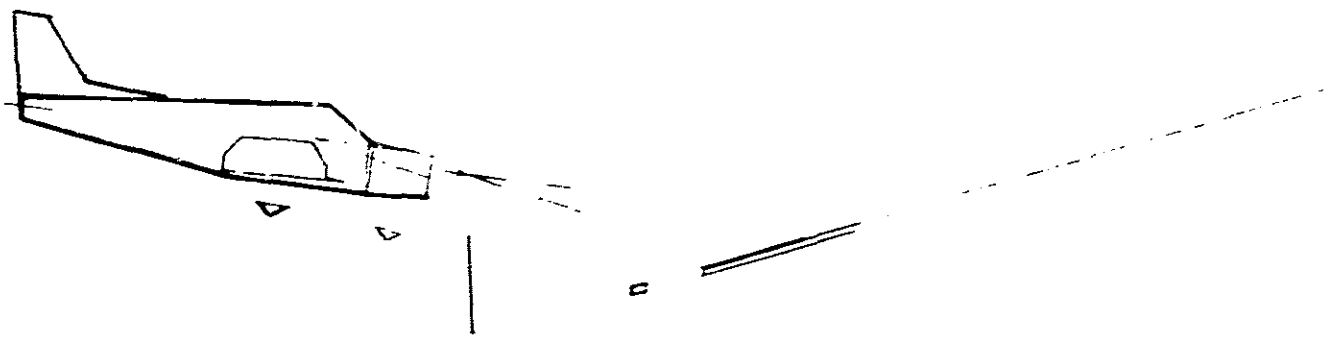
The airplane was equipped with energy absorbing seats. The pilot's seat stroked, absorbing energy which protected the pilot from higher vertical loads. Had the shoulder harness been worn, the pilot probably would not have received head injuries and may have been seated in a more upright position, thus preventing the flexion injuries to his back.

G-PULSE

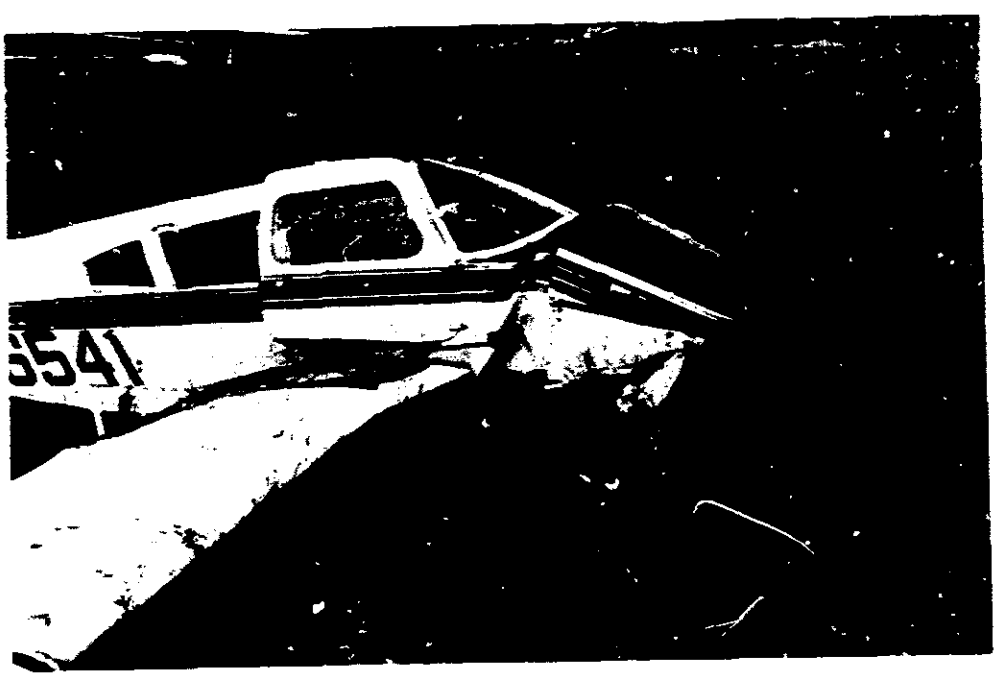
The acceleration loads were based on an impact angle of between 24 and 29 degrees and an impact speed of about 52 knots. The impact angle was reconstructed by aligning ground scars and airplane parts. The impact speed was based on a stall speed of 64 knots, flaps up, corrected for an actual weight of 2,000 pounds.

The vertical velocity would have been between 36 and 44 feet per second and the horizontal velocity was about 77 to 80 feet per second. A slide of 29 feet, a slope of 23 percent, and a friction coefficient of 0.7 would yield an exit velocity of 42 feet per second.

A 2-foot crush and a vertical velocity change of 36 or 44 feet per sceond would result in a peak acceleration of 20 to 30 G's. The horizontal load was calculated at about 18 G's peak, based on a velocity change of from 80 feet per second to 44 feet per second over about an 8-foot acceleration distance. Using the period of 0.11 seconds from the vertical load calculations would result in about a 22 G horizontal peak acceleration. Correcting for the airplane attitude, the airplane axis acceleration loads would be abcut 27 G's longitudinal and about 24 G's vertical. The energy absorbing seat, with a stroking distance of about 6 inches, would reduce the vertical loads to about 18 G's. The airplane axis velocity changes were about 43 feet per second in the horizontal direction and 38 feet per second in the vertical direction.

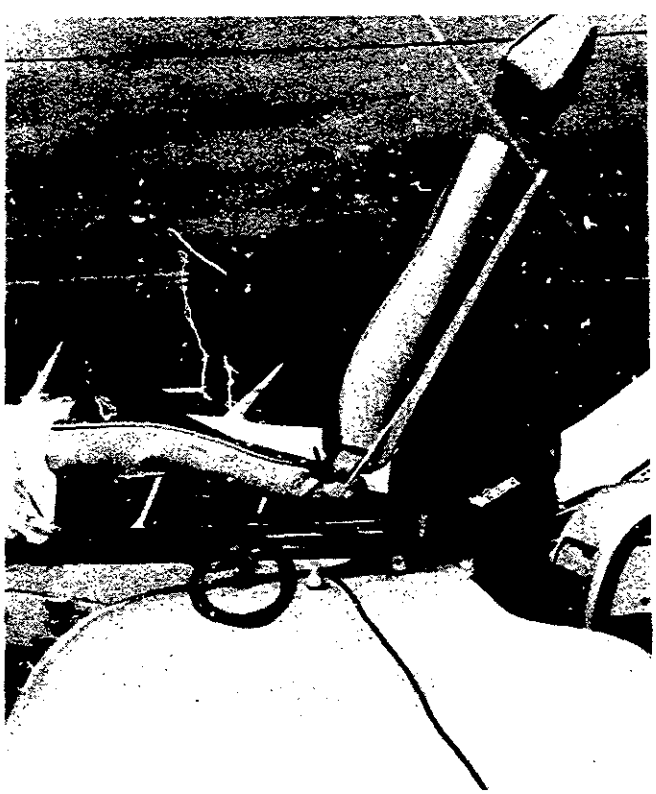


20-1. Impact angle.



20-2. Wreckage.

20-3. Energy absorbing seat in place.



20-4. Partially stroked energy absorbing seat.

Case 21

SYNOPSIS

The single-engine, high-wing airplane crashed following a power loss as a result of fuel exhaustion. The pilot executed an emergency landing, narrowly avoiding a busy freeway. The airplane hit a tree and then hit the ground with high vertical loads and slid up a grassy embankment. The airplane was substantially damaged.

SEATS, RESTRAINTS, AND INJURIES

The four occupants of the airplane received fractured vertebrae. At the time of the accident, all four occupants were using their lapbelts. The airplane was not equipped with shoulder harnesses. The pilot received fractures to the first lumbar vertebra, right wrist, and femur. The passenger seated in the copilot seat received a scalp laceration and fractures of the first lumbar vertebra and right humerus. The passenger seated directly behind the pilot received a compression fracture of the spinal cord and a ruptured small intestine. The passenger seated in the second row right side seat received a compression fracture of the thoracic region of the spine and a mesenteric tear.

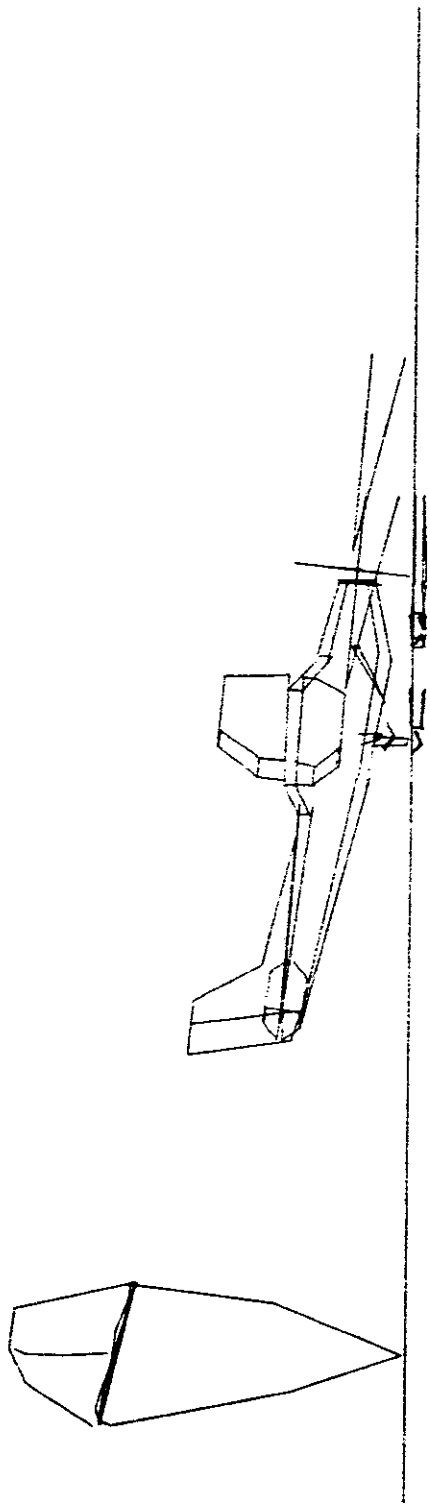
All occupied seats received structural damage. The inboard forward seat leg to the pilot's seat separated and bent in an aft direction. The seat track buckled upward but remained affixed to the floor. A forward leg to the copilot's seat separated and the seat track buckled upward. The two seats occupied in the second row showed leg and track damage similar to the damage found in the first row of seats. In addition, the seat pan and frame were deformed downward in both seats.

If shoulder harnesses had been available and worn, they would probably have prevented or reduced the injuries of three of the four airplane occupants. Energy absorbing seats could have prevented the lower back injuries. The seat pans were made from "S"-shaped springs stabilized laterally by tie wires. The springs in the two rear seats spread apart when the tie wire separated, allowing the occupants to contact the floor.

G-PULSE

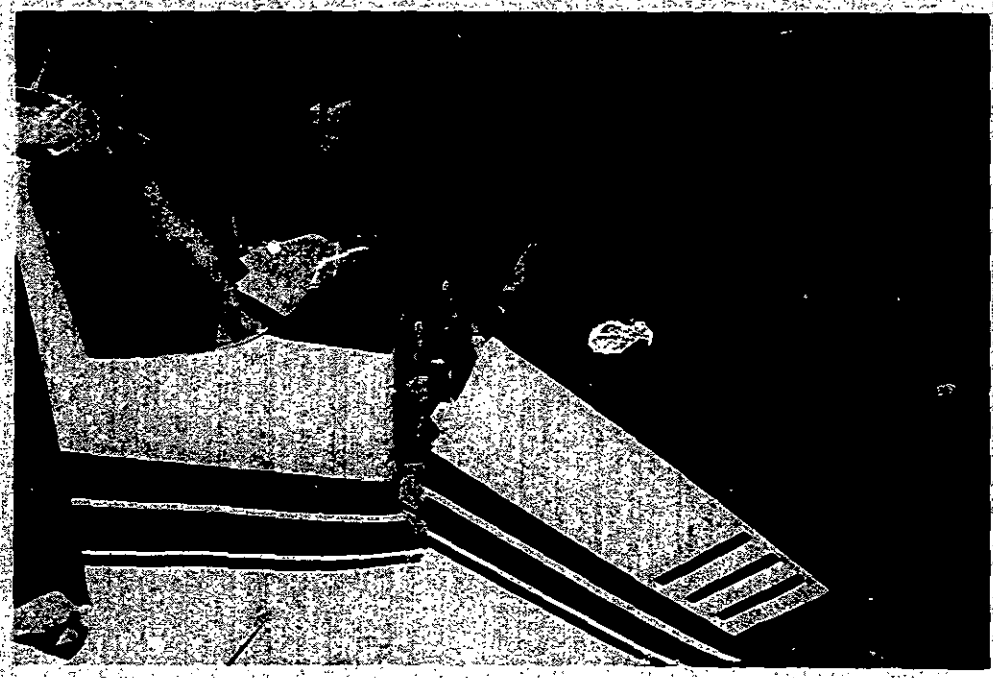
The airplane hit the ground with about a 17-degree impact angle, based on a 14-degree flight path angle and a 3-degree upsloping terrain. The impact speed was assumed to be about 48 knots, based on the published stall speed of 43 knots and corrected for the weight and flaps up configuration. The vertical velocity was calculated at 24 feet per second and the horizontal velocity was 78 feet per second. After impact the airplane slid up a 36 percent slope for about 30 feet. The sliding resistance was estimated at 1.06, based on the 36 percent slope plus a 0.7 friction coefficient. The velocity change during the slide would have been from about 64 feet per second to zero.

It was assumed that the main gear could slow the vertical descent from the 24 feet per second to about 21 feet per second. Since the actual stopping distance could not be reconstructed, a maximum stopping distance of about 8 inches was assumed. The result was a minimum peak vertical acceleration of about 20 G's at a period of about 0.06 seconds. The horizontal velocity change of about 14 feet per second and a period of 0.06 seconds would result in a peak acceleration load of 14 G's.



21-1. Impact angle.

21-2. Wreckage.



21-3. Nose cone dented forward.

Case 22

SYNOPSIS

An unlicensed pilot flying this twin-engine airplane made a steep approach to the runway, bounced the airplane three times on the runway before losing directional control, and crashed the airplane into the side of a shallow ditch. The airplane was demolished. The fuselage, including the extended nose gear, was crushed inward toward the cabin. The engines remained affixed to the wings but were substantially displaced.

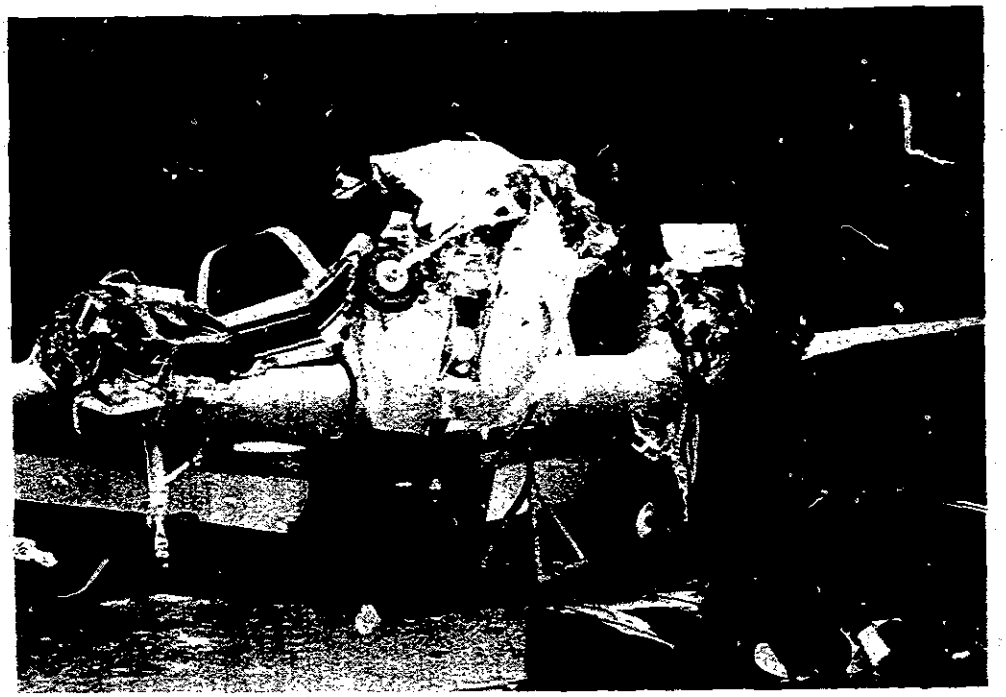
SEATS, RESTRAINTS, AND INJURIES

The four occupants of the airplane received serious injuries. The uncertificated pilot and the passenger occupying the copilot seat both moved forward into the instrument panel and glareshield. They also moved down in their seats, impacting the structure under the seat. The pilot seat pan was torn when it contacted the center seat track. Both front seat occupants received head injuries that consisted of lacerations and abrasions of the scalp and forehead. The pilot also received a lacerated eye, fractured right orbit, severe crush to the right side of his face, and abrasions of the chest. Passengers occupying the second row of seats received less serious injuries. The passenger occupying the seat directly behind the copilot seat received a superficial laceration of the forehead which did not need suturing. The passenger seated directly behind the pilot's seat received multiple abrasions of the back, abdomen, and legs. At the time of impact, all four occupants of the airplane were using their lapbelts. The airplane was not equipped with shoulder harnesses.

The cam on the right rear seat that holds the seat back in position was missing. When the occupant of that seat rebounded into the seatback, the missing cam caused extra loads to be placed on the bolt that holds the seatback and seatbelt. The bolt sheared, allowing the seat back to separate. This problem was noted on another seat in this airplane, indicating that maintenance was not proper.

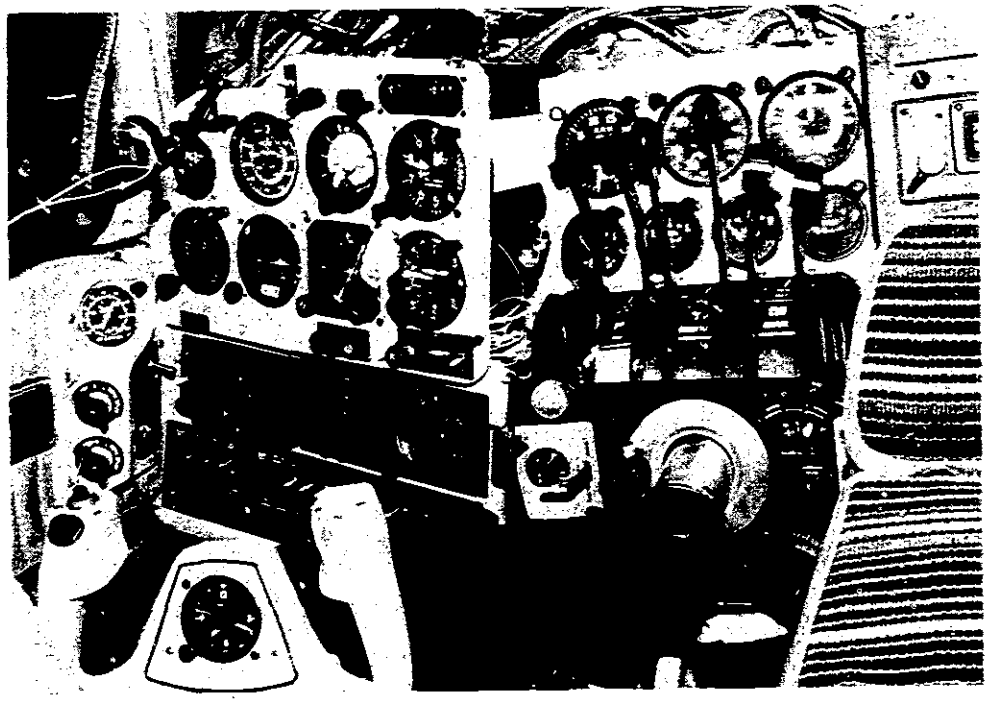
G-PULSE

The velocity of the airplane when it contacted the side of the ditch could not be estimated. Therefore, acceleration loads were not calculated.

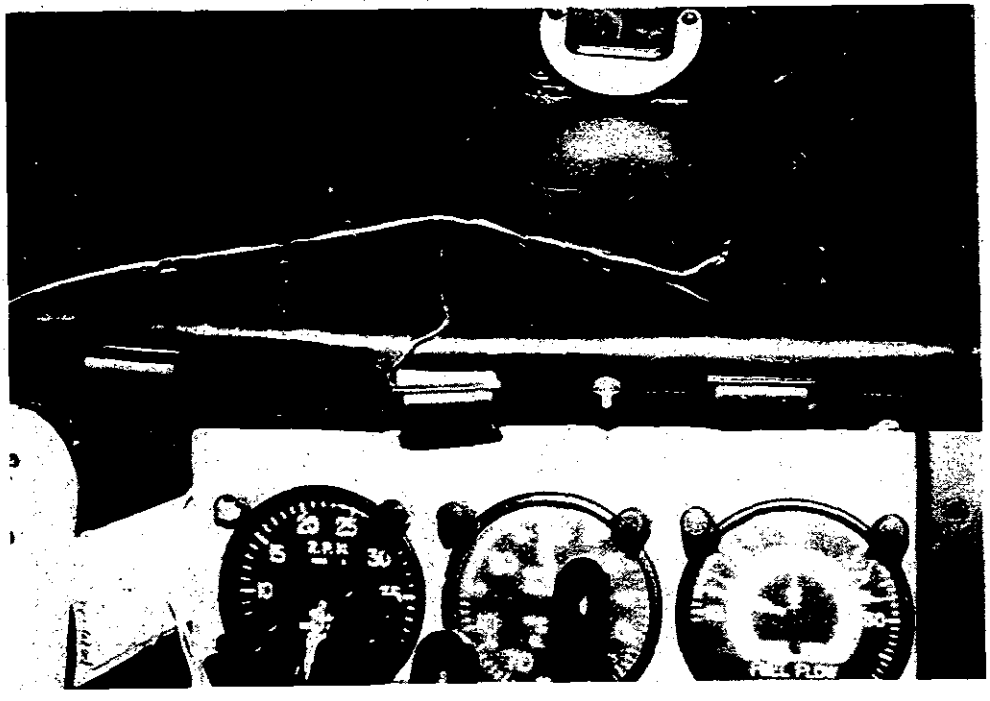


22-1. Wreckage.

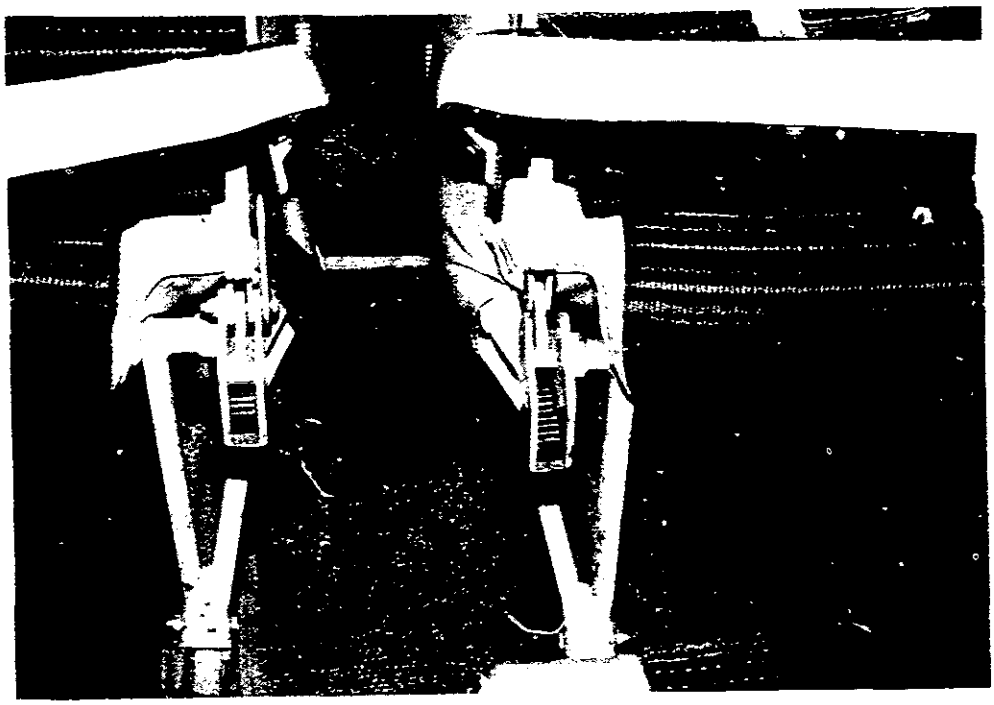
22-2. Crushline.



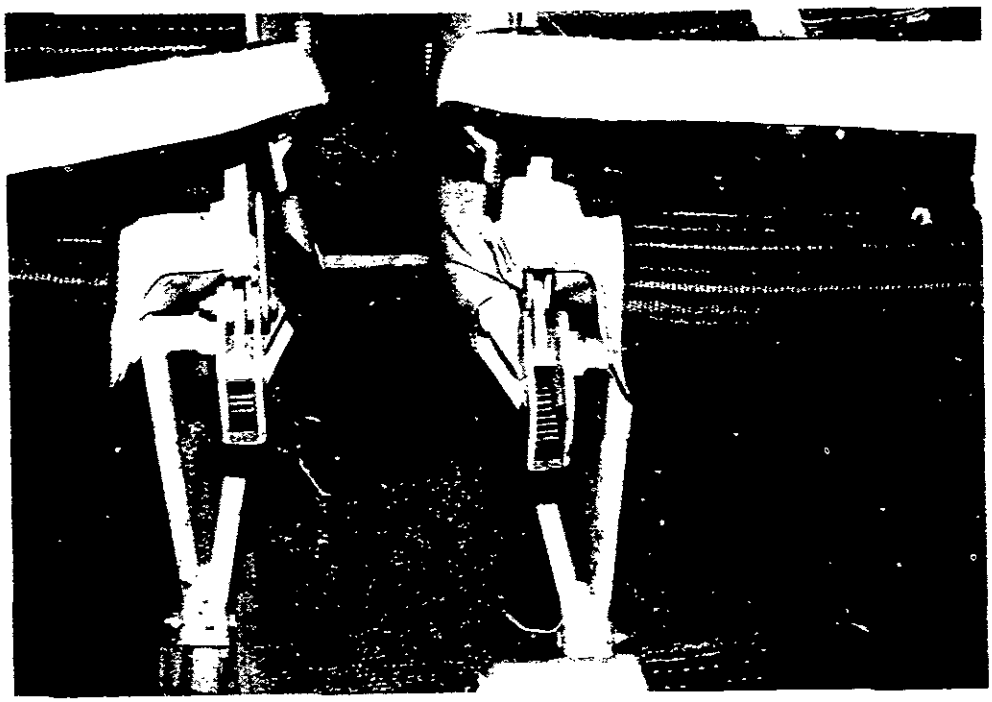
22-3. Pilot's panel.



22-4. Pilot's head contact area.



22-5. Seatback cam missing, causing bolt to shear.



22-5. Seatback cam missing, causing bolt to shear.

Case 23

SYNOPSIS

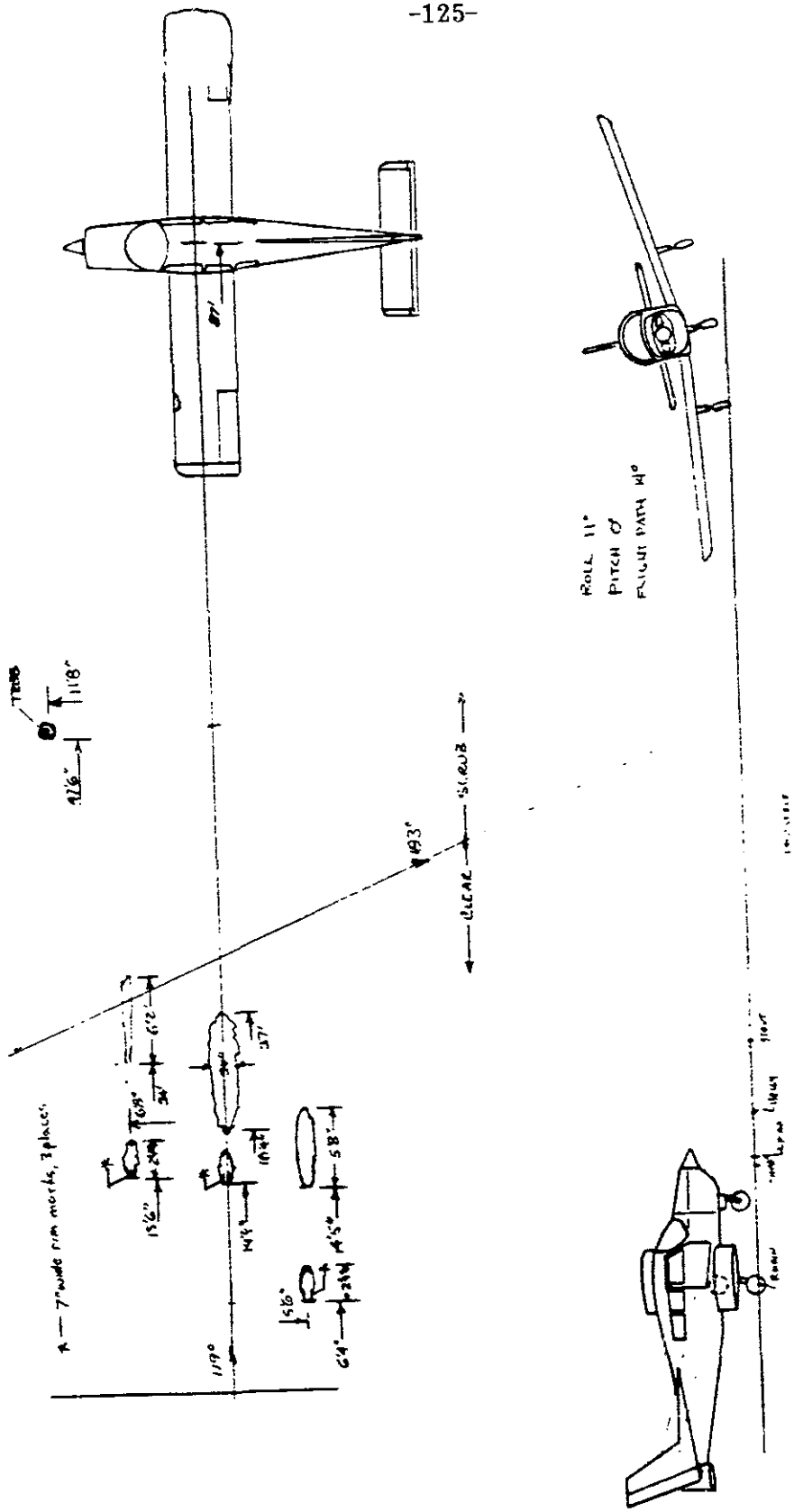
A solo student pilot was practicing touch-and-go landings when the engine lost power. He made a power-off landing in an open field adjacent to the runway. The single-engine, low-wing airplane sustained substantial damage. During the impact the nose landing gear caused upheaval of the fuselage belly, warping the seat tracks.

SEATS, RESTRAINTS, AND INJURIES

The student pilot received fractures of two lumbar vertebrae. Consistent with this type of injury, the seat pan had distorted in a downward direction. The inboard and outboard forward seat legs were bent. The seat feet remained affixed to the tracks, but buckled upward with the floor displacement.

G-PULSE

The airplane was equipped with lapbelts and shoulder harnesses for the pilot and copilot seats. At the time of the accident, the student pilot was using both his shoulder harness and lapbelt. The airplane impacted the ground in about a 14-degree flight path, zero pitch attitude and about an 11-degree right roll angle. The velocity was estimated at about 43 knots based on a weight of 1,800 pounds and a 2,450-pound gross weight stall speed of 51 knots. It was assumed that the landing gear could slow the vertical velocity from 18 to about 14 feet per second and, with a 4-inch stopping distance, the peak acceleration load would be about 17 G's. An estimated seat deflection of an additional 4 inches could have reduced the loads to about 9 G's. The horizontal acceleration load was considered small.



23-1. Flight path through trees and the impact angle.

23-2. Wreckage.

23-3. Crush damage to fuselage;
note where nose gear caused greater crush.

Case 24

SYNOPSIS

The single-engine, high-wing airplane was being operated for sightseeing when it crashed near the water's edge of a beach. The airplane had been about 100-200 feet above the water when it banked to the right in a steep climb. The airplane then rolled left, nose-dived, and crashed before it could be leveled off.

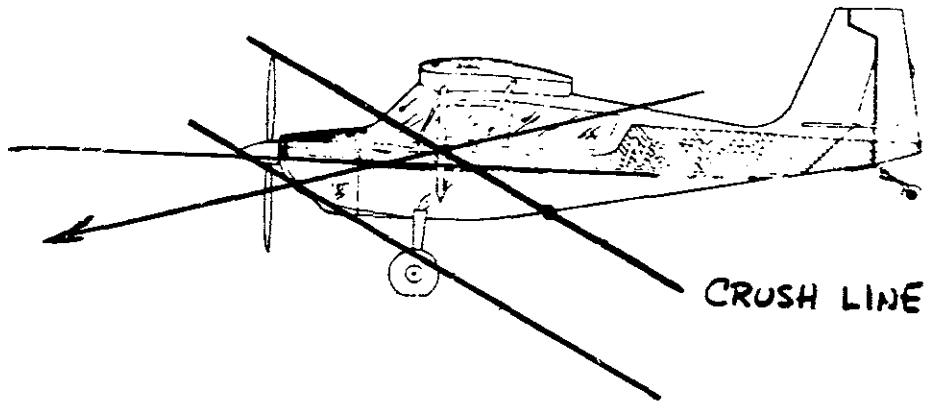
The airplane was destroyed on impact. The fuselage received compression buckling. Both wings partially separated. The cabin was crushed inward past the front seat position.

SEATS, RESTRAINTS AND INJURIES

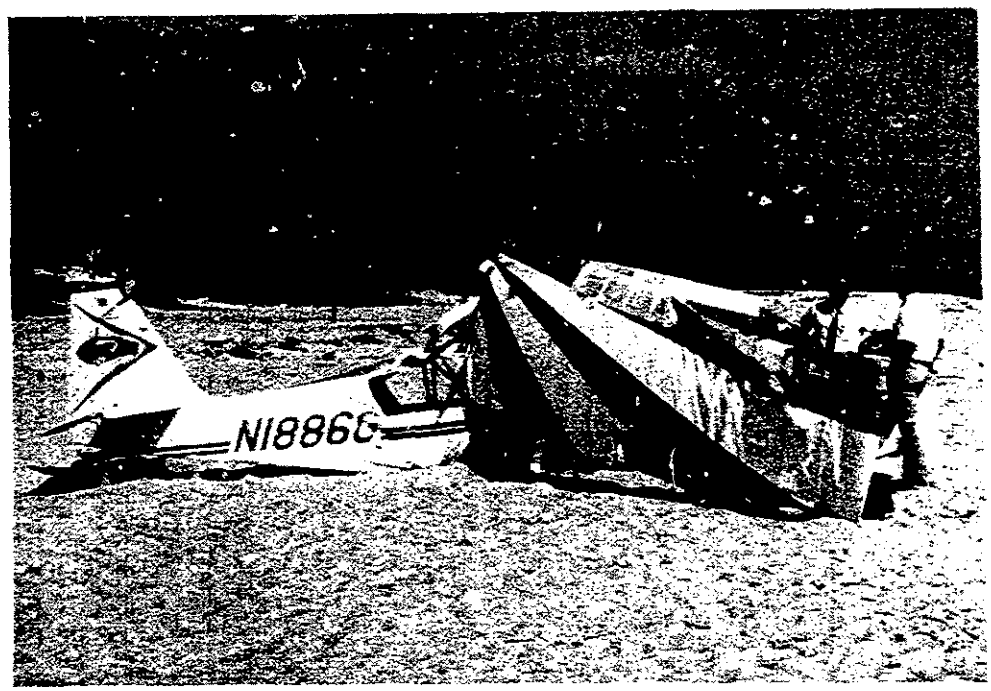
Although the two occupants were fatally injured, this accident may have been partially survivable. In this tandem seat airplane, the pilot's seat was located in the forward cabin, and the passenger seat was located directly behind the pilot's seat. The pilot received multiple severe traumatic injuries. The area of the pilot's seat received the most extensive structural damage. Restraint systems would not have prevented his death since a liveable volume was not retained in this area. The cabin space around the passenger's seat, however, remained relatively intact. The passenger used his lapbelt, but received a skull fracture when his upper body and head moved forward. A shoulder harness would probably have prevented his fatal head injury.

G-PULSE

The airplane impacted the ground with a 45-degree impact angle and a 30-degree nose-down attitude. The speed was estimated at about 50 knots, based on a 44-knot stall speed and allowing for some acceleration into the ground. The crushing extended about 5 feet aft, which would have caused very high acceleration loads to the front seat occupant as the crushline progressed through his position. The rear seat occupant would have had the advantage of the 5 feet of ride-down so that his acceleration loads could have been far less severe. The average acceleration load would be about 22 G's and the peak would be about 44 G's. It is believed that the actual load would be less than the peak because the crushing did not involve an increasing amount of structure throughout the crush distance. A 30 G acceleration was assumed, based on the lack of acceleration injuries to the rear seat occupant. The 30 G value must be considered a gross approximation.



24-1. The 45-degree impact angle.



24-2. Wreckage.

24-3. Wreckage.

24-4. Crushline.

Case 25

SYNOPSIS

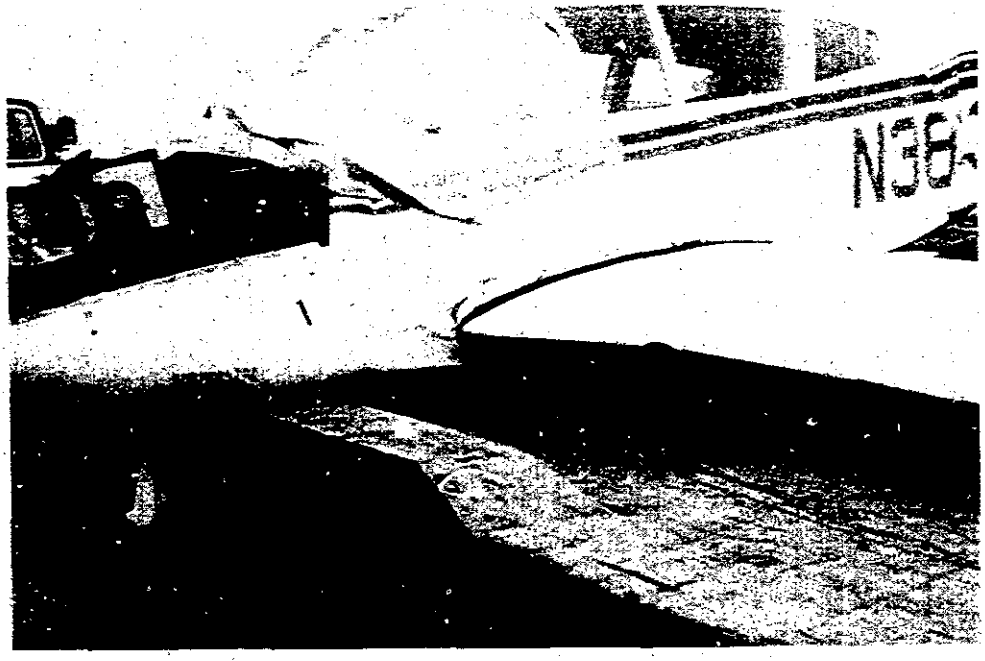
During the landing roll-out, this low-wing, single-engine airplane collided with a snowbank, and received substantial damage. The impact collapsed the landing gear. The nose gear sheared off. The fuselage received compression wrinkling in various locations, the windshield shattered, and both wings were damaged.

SEATS, RESTRAINTS, AND INJURIES

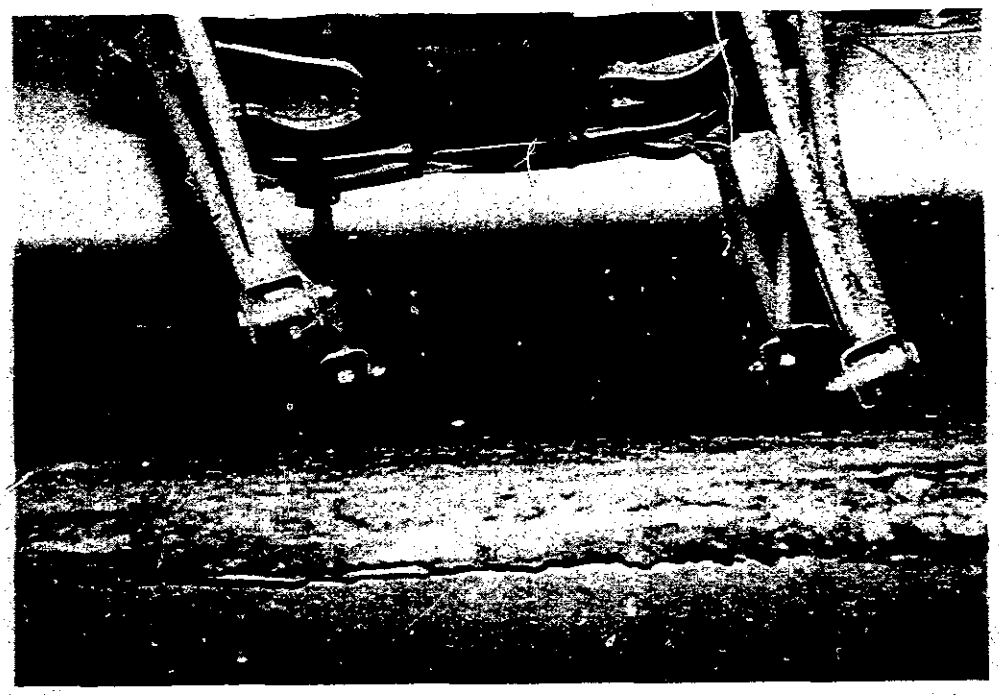
The pilot and copilot received minor injuries while the passenger seated in the second row left-side seat was seriously injured. The airplane was equipped only with lap belts. The seriously-injured passenger received a fractured shoulder when she impacted the window frame. The injuries would probably not have been prevented by a shoulder harness because the airplane was yawed 90 degrees when it hit the snow bank. The only seat to incur damage was the pilot's seat, when the seatpan frame distorted, and the seat legs and attach fittings buckled to the left, and the seat feet spread.

G-PULSE

Acceleration loads could not be calculated because the speed at impact with the snowbank could not be estimated.



25-1. Wreckage.



25-2. Seat loaded sideways which spread seat feet.

Case 26

SYNOPSIS

This accident involved a single-engine, low-wing airplane that crashed following fuel exhaustion when the pilot deviated from his flight plan to avoid poor weather.

The airplane was demolished. The fuselage and cowling were crushed aft to the cabin, and compression buckling was present on the top of the fuselage. The right wing was sheared off.

SEATS, RESTRAINTS, AND INJURIES

This accident was survivable. Of four occupants aboard the airplane, the two passengers occupying the right side seats were seriously injured. The passenger occupying the right front seat received head and chest injuries that included multiple facial lacerations, a concussion, and a fractured jaw and clavicle. The passenger seated in the right-rear seat received a vertebral compression fracture. The pilot received multiple facial lacerations and a fractured right thumb. The passenger behind the pilot received less severe back injuries. The injured passengers were using their lapbelts at the time of the accident. The front seats were equipped with shoulder harnesses and energy absorbing seats. The pilot stated that the shoulder harnesses were not used because he did not see them.

At impact, the occupants moved forward. The two occupants in the front seats impacted into the control yokes and instrument panel. The pilot hit the glareshield; the right front passenger's injury was caused by his contact with the radio group. Both front seats were stroked about 1 inch. The passengers seated in the second row impacted the seat backs directly in front of them. The rear seat occupant sustained lower back injuries and there was evidence of vertical loading on the seat where the seat pan is only several inches above the floorboard. The floorboard under the right rear seat was bent down from occupant loading.

Had the shoulder harnesses been worn, the front seat occupants probably would not have sustained their upper body injuries. Had energy absorbing seats been available for the rear seats, or had a greater stroking distance been available, the rear seat occupants probably would not have received their lower back injuries.

All four seats that were occupied received structural damage. The back frame and forward seat legs of the pilot and copilot seats were buckled in a forward direction. The seats in the second row showed impact damage to the attach fittings, and were bent forward.

G-PULSE

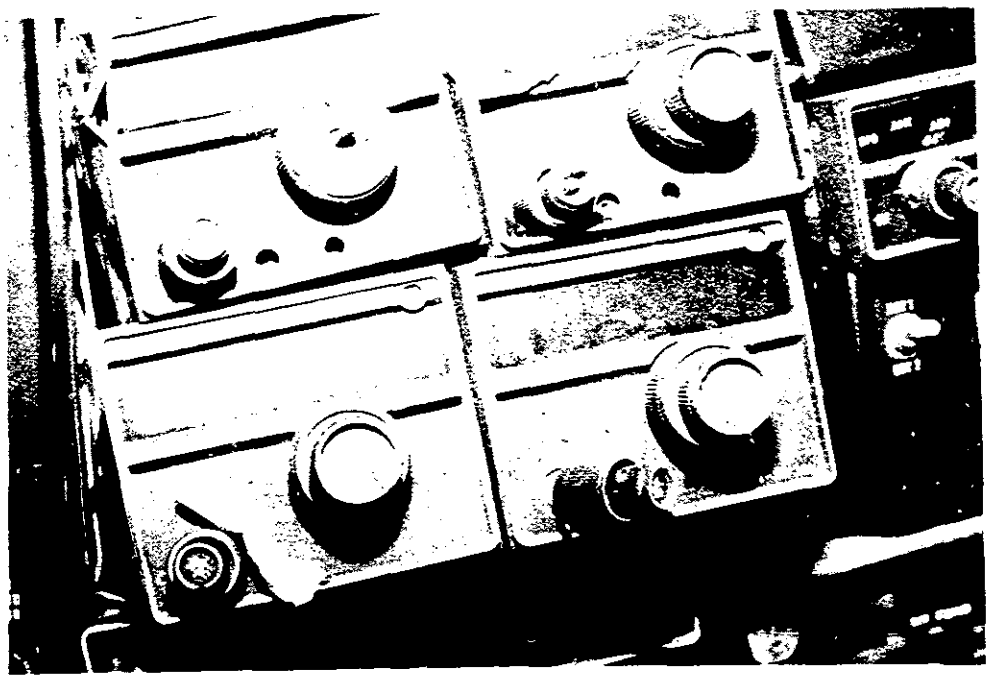
The pilot stated that he was at 70 knots indicated airspeed when he hit the first tree, shearing off the right wing. The airplane hit the tree 19 feet high and continued on for 102 feet before impacting the ground. A reconstruction using ground scars was not possible, but the pilot said the airplane hit the tree and then pancaked on the ground. The damage to the airplane fuselage indicated both significant vertical and horizontal loads consistent with the injuries.

By evaluating a possible ballistic trajectory of the airplane, it was concluded that the vertical velocity at ground contact could be about 35 feet per second and the time from tree contact to ground contact would be about 1.2 seconds. That would yield an average horizontal velocity of about 88 feet per second. The total velocity would be about 95 feet per second with an impact angle of 22 degrees. An exit velocity of 45 feet per second was based on a 45-foot slide and a 0.7 friction coefficient. The total stopping distance of 6 to 8 feet was based on the length of the ground scar and allowed for some fuselage crush. Since the attitude of the airplane could not be determined, the acceleration loads could not be broken into vertical and horizontal axes. Slowing from 95 to 45 feet per second over 7 feet would yield a 30 G peak acceleration. The velocity change would be about 50 feet per second.

26-1. Wreckage.

26-2. Cockpit area.

26-3. Battery pulled loose.



26-4. Head contact area.

Case 27

SYNOPSIS

This accident involved a single-engine, low-wing airplane that crashed when the pilot attempted to make a forced landing. The first and principal impact was with the top of a small hill, and the airplane became airborne again for a short distance. The airplane skidded on its belly before coming to rest in an open pasture. The fuselage was crushed and the engine was forced upward, distorting the cowling.

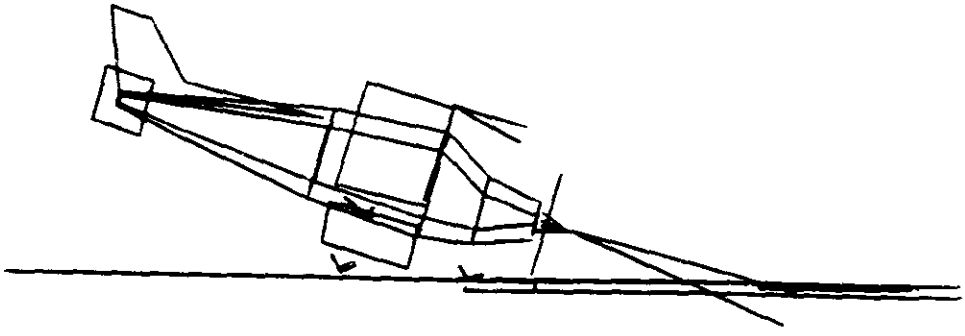
SEATS, RESTRAINTS, AND INJURIES

There were two occupants aboard the airplane. Based on the damage to the airplane and the occupant injuries, the vertical acceleration loads were judged to be the predominant loads. The horizontal loads were judged to be small because there was no evidence of occupant contact with the instrument panel. The seats were stroked down and the fatal injury appeared to be caused by vertical loads which drove the skull down onto the spine. The pilot's weight was 270 pounds and the passenger's weight was 180 pounds. At impact, the pilot and passenger were using their lapbelts. The airplane was not equipped with shoulder harnesses.

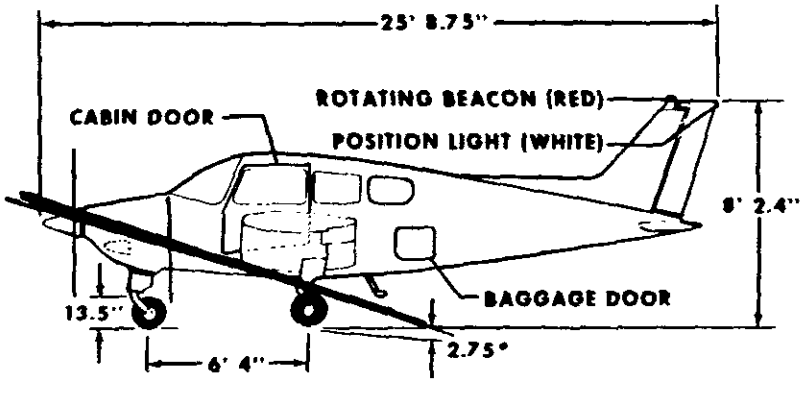
Both occupant seats incurred damage. The pilot's seat was partially separated from the seat track. The seat pan was distorted downward, and the back frame was collapsed rearward. The seat track was bent. The copilot's seat, which was occupied by the passenger, was similarly damaged except that the back frame, which collapsed on the pilot's seat, remained intact. The pilot's seat was fully stroked to the floor and the copilot's seat was almost fully stroked. It is believed that the energy absorbing nature of the seats protected the passenger by preventing him from slamming into the floor. The pilot did not receive this same protection becasue his extra weight (energy) exceeded the capabilities of the seat. For additional information concerning the effect of weight on energy absorption, see the section regarding Vertical Pulse and Velocity Change in the main body of this report.

G-PULSE

The crushline on the fuselage indicated that the nose of the airplane was 20 degrees nose-down relative to the ground. By matching ground scars and airplane components, the impact angle was reconstructed as about 25 degrees and the roll angle as about 15 degrees. The published 51-knot stall speed at 2,350 pounds was corrected for a 2,000 pound weight, yielding a calculated speed of 48 knots. A 34 feet-per-second vertical velocity and a 1-foot crushing distance would yield a 36 G peak vertical acceleration. Adding another foot of stopping distance because of the stroking seat would lower the peak acceleration to 18 G's. The passenger apparently had the full advantage of the seat because his seat was almost fully stroked. The heavier pilot appeared to fully stroke his seat and probably bottomed out on the floor, thus creating far greater acceleration loads to himself. His seat was not capable of dissipating the extra energy because of the additional weight.

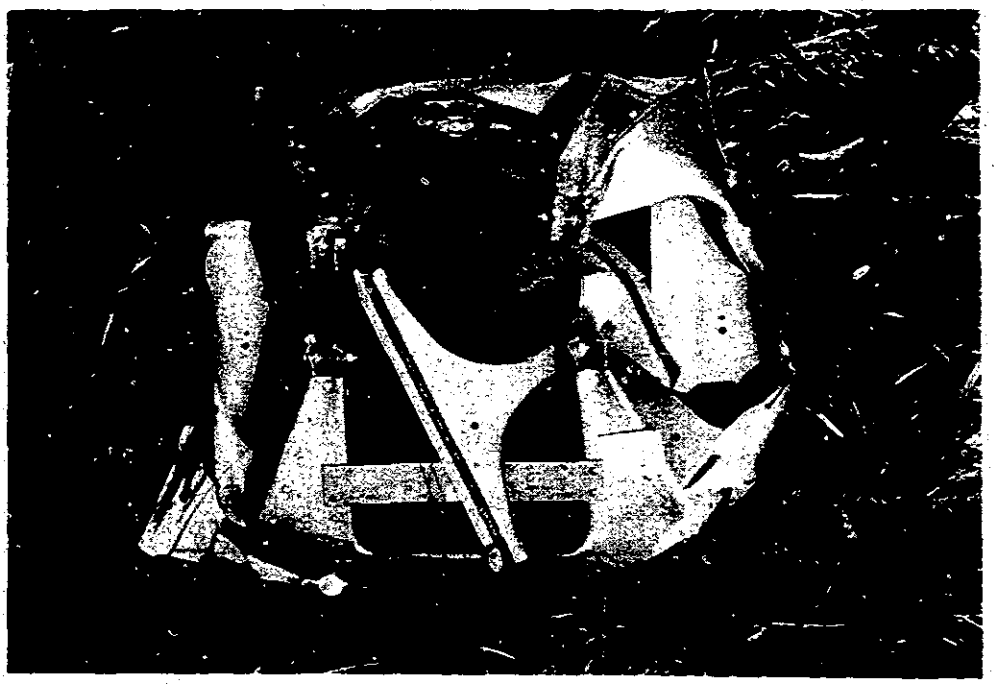


27-1. Impact angle.



27-2. Crushline.

27-3. Wreckage.



27-4. Crushed seat - spread seat feet.

27-5. Relative crush of each seat.

Case 28

SYNOPSIS

In this accident a student pilot was taking a check ride for a private pilot certificate with an FAA-designated examiner. The single-engine, high-wing airplane contacted some power lines and crashed in an open field. The airplane was demolished as it pitched forward in a near-vertical attitude when it hit the ground. The fuselage, in addition to buckling, tore just forward of the cockpit and just aft of the baggage compartment. The left wing and left landing gear strut were bent rearward. The instrument panel was displaced aft.

SEATS, RESTRAINTS, AND INJURIES

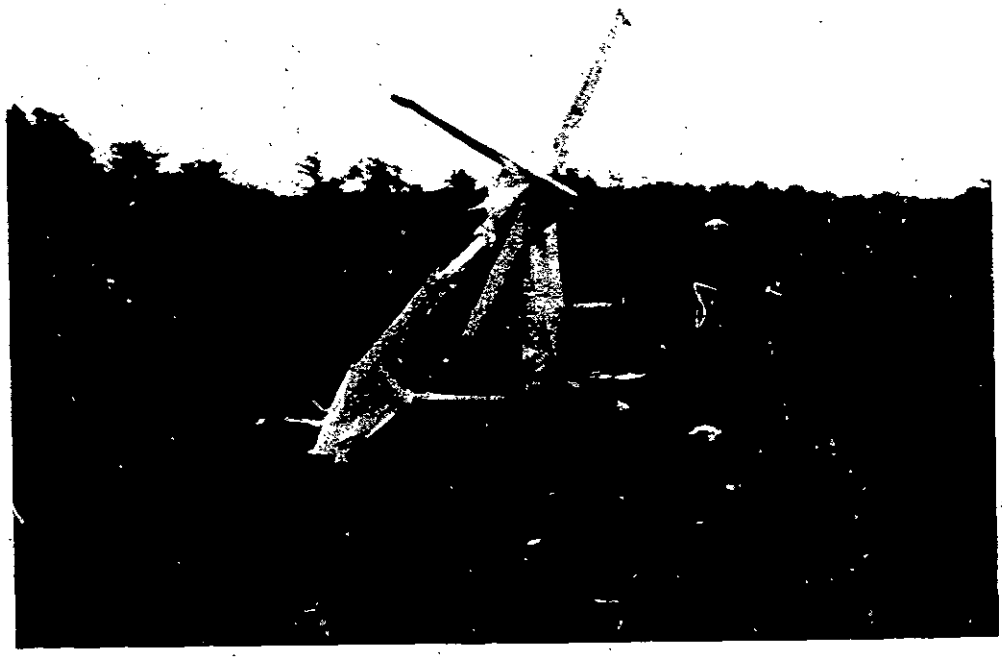
The student pilot was critically injured while the FAA-designated examiner riding in the right front seat was killed. Although the airplane was equipped with both lapbelts and shoulder harnesses, the student pilot was wearing only the lapbelt. Her most serious injuries included lacerations of the skull, a concussion, fractures of the ribs and extremities, and an avulsed liver. The examiner used both the shoulder harness and lap belt. His injuries were similar to the student pilot's injuries, however, the control column caused a penetrating wound to the chest which resulted in a lacerated heart.

At impact, both occupants impacted into the instrument panel and control yokes. Both control yoke columns snapped. The pilot's seat, occupied by the student pilot, showed downward distortion to the seat pan frame and the seat bottom enclosure. The copilot's seat, occupied by the examiner, showed no visible damage.

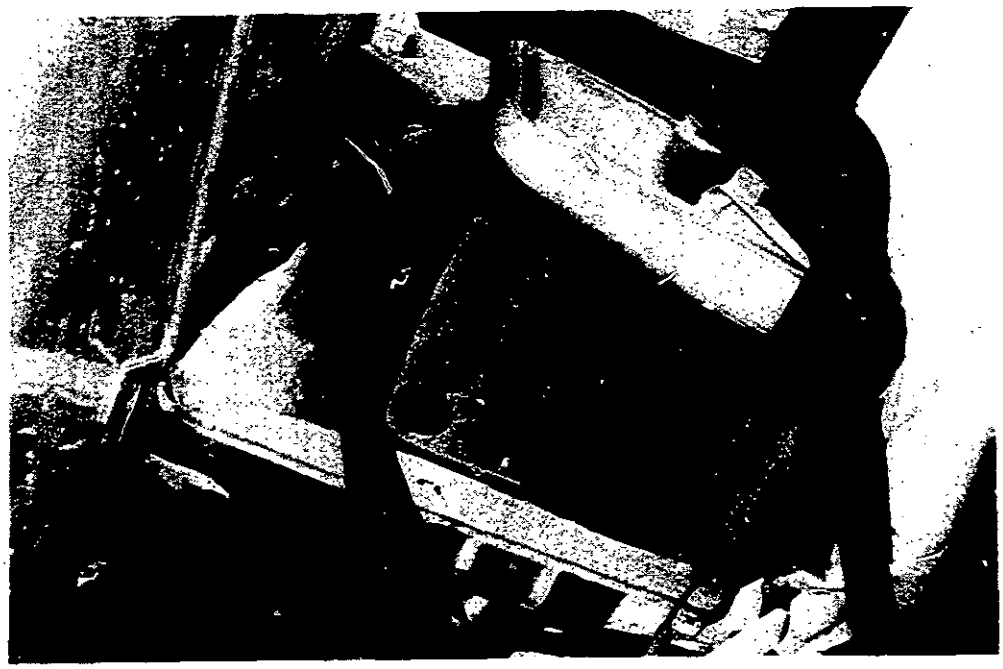
The FAA-designated examiner suffered less severe head injuries than the student pilot because his shoulder harness helped minimize upper torso movement at impact. Panel contact was not precluded completely, however, because of the instrument panel movement. The livable volume for the examiner was further violated by the broken control column that caused his fatal chest wound. A shoulder harness and lap belt are not designed to protect the user from objects penetrating from outside the livable volume, but instead are designed to prevent or minimize secondary impacts as was done in this case.

G-PULSE

The nature of the injuries and the occupant impact damage to the instrument panel indicate that the acceleration loads were primarily longitudinal in nature. Since the exact attitudes could not be reconstructed, a total acceleration load was calculated. Based on a ballistic reconstruction and the stall speed, it was estimated that the airplane impacted the ground at about 41 knots. The airplane hit and stuck, so the total velocity change was about 69 feet per second. The total stopping distance was about 6 feet, which would yield a peak acceleration of 25 G's.



28-1. Wreckage.



28-2. Cockpit area.

28-3. Control column length that penetrated copilot.

Case 29

SYNOPSIS

This accident involved a single-engine, high-wing airplane that collided with several large trees while attempting to land in heavy fog conditions. The main wreckage came to rest in an upright position 455 feet beyond the impact with the first tree. Both wings were damaged extensively. The fuselage was compressed and dented in various locations. The empennage compressed and separated from the fuselage.

SEATS, RESTRAINTS, AND INJURIES

Of the three occupants aboard the airplane, the pilot and one passenger were killed. The other passenger received serious injuries. The pilot's most significant injuries were a crushed chest and complete transection of the thoracic aorta. Other injuries included fractures of the face, ribs, sternum, and right knee. He also incurred lacerations and abrasions to the face, head, and thorax. Main contacts were with the yoke and instrument panel. The fatally injured passenger received fractured ribs and extensive lacerations of the head. The sole survivor of the accident was seated in the left-rear seat directly behind the pilot. He received contusions of the chest and thoracic injuries that included a broken hip and torn digestive organs.

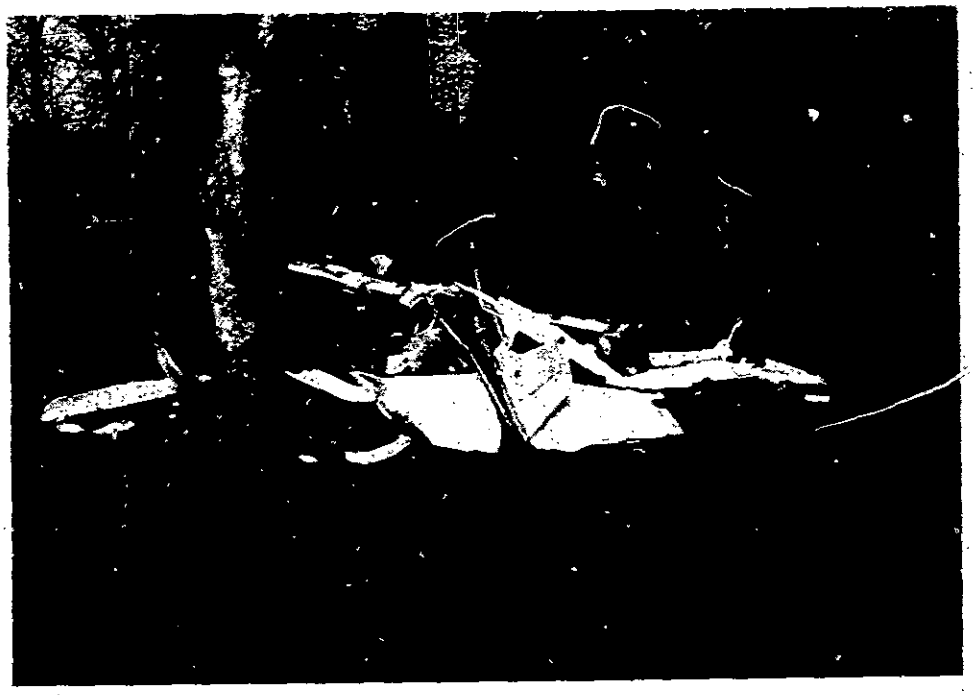
The airplane was equipped with lap belts and shoulder harnesses in the front seats. Other seats were equipped with lapbelts only. All occupants used the lapbelts but no one used the shoulder harnesses. During the impact sequence, the pilot struck the inwardly-crushed fuselage sidewall, the control yoke, the instrument panel, and the windshield. Similarly, the passenger who was killed impacted the control yoke, instrument panel, and windshield. The survivor, seated behind the pilot, was struck from the side by the fuselage sidewall.

The three occupied seats were damaged. The leg attach fittings of the pilot's seat were knocked off the seat track, and the seat track separated from the floor. The seat back was bent to the right and rearward. The copilot's seat received similar damage. The seat track separated from the floor, and the seat frame was cracked. The left-rear passenger seat was subjected to impact forces from the left side. The seat track stayed intact, but the two forward leg attach fittings were knocked off the track. This seat was deformed forward and to the right.

Use of the shoulder harnesses could have prevented or reduced the severity of the upper body injuries of the two front seat occupants. Also, shoulder harnesses could have more evenly distributed the impact loads to the rear seat occupant, preventing the tearing of the digestive organs.

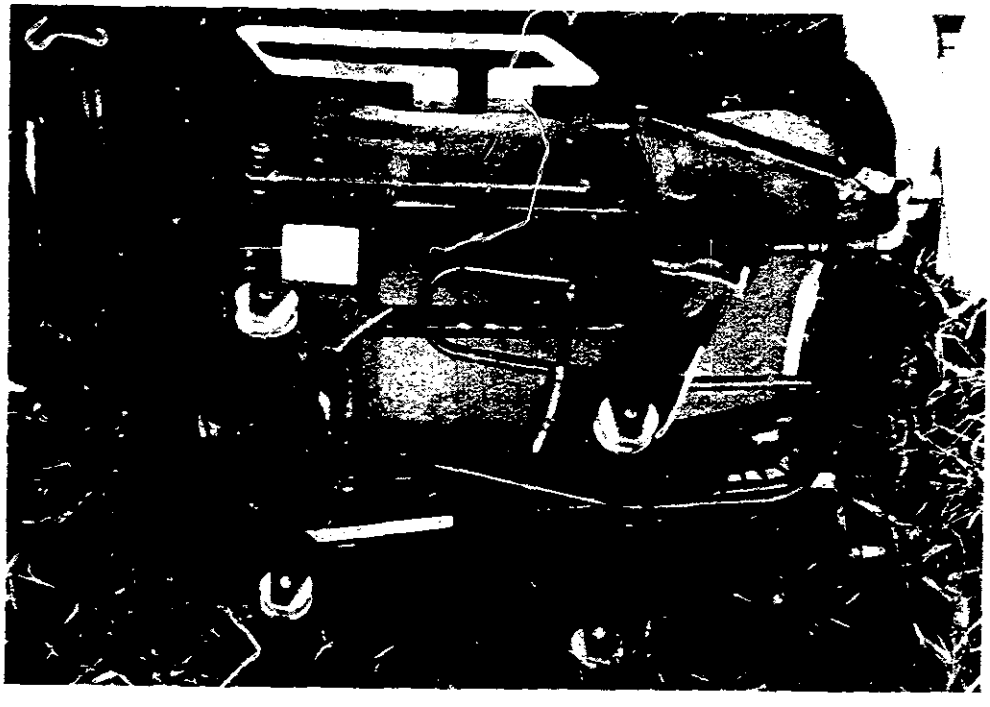
G-PULSE

Acceleration loads could not be calculated for this case because the airplane cruised into trees at about 130 knots. The velocity change for the 450-foot slide could not be calculated with any degree of confidence.



29-1. Wreckage.

29-2. Wreckage.



29-3. Multiple fracture to stiff seat structure.

Case 30

SYNOPSIS

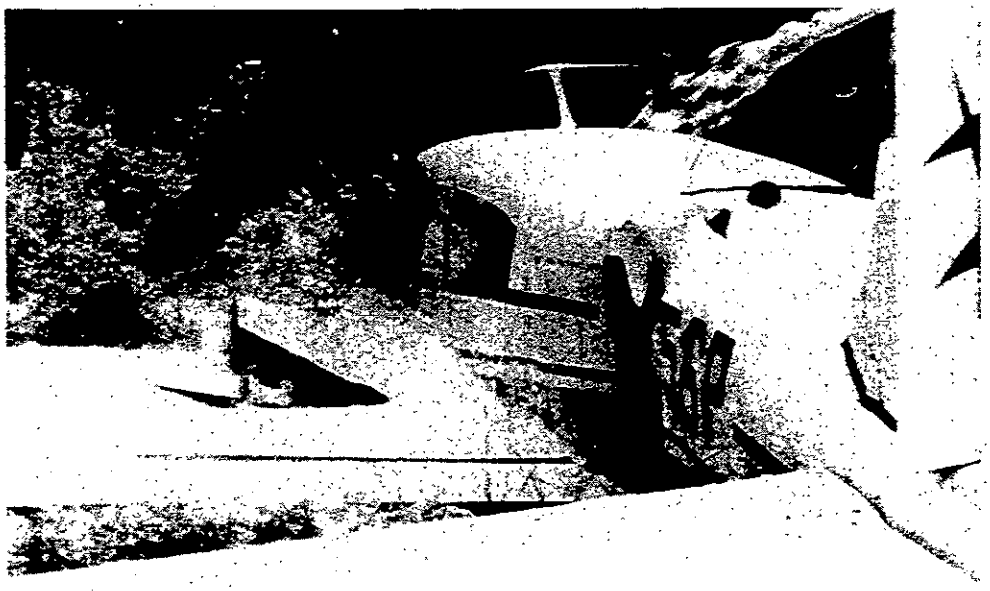
This accident involved a single-engine, low-wing, airplane that skidded off the runway and temporarily became airborne before crashing to the ground in a near vertical attitude. The airplane was destroyed. The nose gear was sheared off and the left main landing gear was driven upward by the impact, rupturing the left fuel tank. There was no fire. The fuselage was split open on the right side just forward of the baggage compartment. Compression damage resulted on the opposite side. The engine broke off at the firewall. The right wing was bent upward.

SEATS, RESTRAINTS, AND INJURIES

The pilot was killed and the only passenger received serious injuries. The pilot, who was wearing a lapbelt but no shoulder harness, received a fractured skull, multiple rib fractures, massive internal injuries, and superficial abrasions, contusions, and lacerations to the head, body. and extremities. A shoulder harness, if available and used, would probably have prevented the pilot's fatal injuries. The right horn, of the pilot's control yoke was broken, probably as a result of impact from the pilot's head or chest. The passenger in the copilot seat received serious injuries, which included fractures of her pelvis and ribs, as well as a perforated lung and ruptured digestive organs. Like the pilot, the passenger was wearing her lapbelt. A shoulder harness could have prevented the pelvic injuries and internal rupturing of the digestive organs by reducing the lapbelt loads.

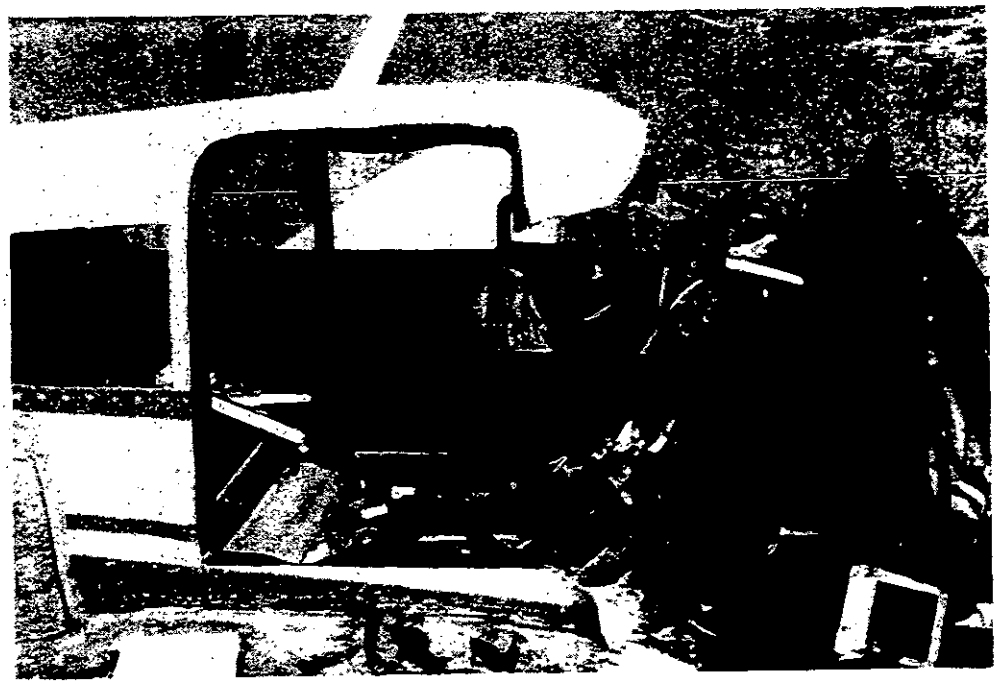
G-PULSE

The airplane left the runway and traveled about 109 feet horizontally and dropped about 40 feet. After ground impact, there was an 18-foot slide down a 7-degree slope. After several iterations using different speeds, the resultant lift and corresponding vertical accelerations (lift-weight), the vertical velocity was calculated to be 40 feet per second and the horizontal velocity was 61 feet per second with a flight path angle of 33 degrees. The impact angle into the 7-degree downslope would then be about 26 degrees. The velocity lost during the slide was based on an 18 foot slide down a 7-degree or 12 percent slope with a 0.7 friction coefficient. The velocity change was from 31 feet per second to zero. The principal impact would then be from 73 feet per second to 31 feet per second over an estimated 4-foot stopping distance. The peak longitudinal acceleration load was calculated to be about 34 G's.



30-1. Wreckage.

30-2. Wreckage.



30-3. Compression damage to cockpit area.

30-4. Control yoke damage.

Case 31

SYNOPSIS

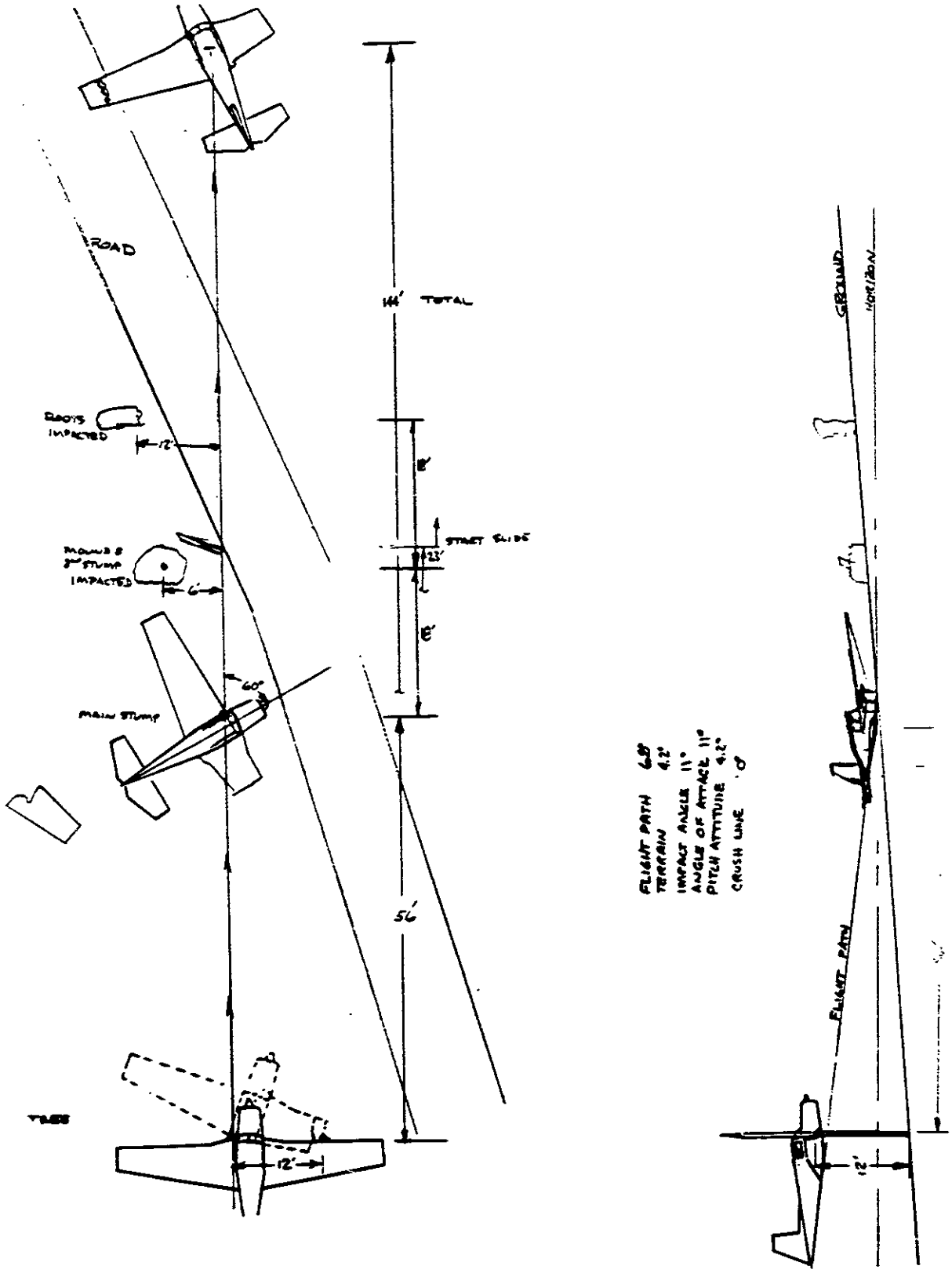
This accident involved a single-engine, low-wing airplane that crashed in an open field which had been logged and partially burned. Aboard the airplane were the pilot and his wife, who was seated in the copilot's seat. During the flight, the pilot lost consciousness and slumped over. His wife executed a crash landing. Skid marks on the ground indicated the airplane slid for about 70 feet. The engine and engine cowling were bent down, and the fuselage and both wings were damaged. A stump penetrated the cabin at the pilot seat position.

SEATS, INJURIES, AND RESTRAINTS

The pilot never regained consciousness; he apparently died inflight from a heart attack. Although the pilot probably died from a heart attack, his impact injuries consisted of a basilar skull fracture, lacerated liver, fractured pelvis and fractured ribs. His wife received serious injuries, including fractures of the pelvis, and ribs. The diaphram was ruptured. She also suffered contusions to her face and neck. At the time of the accident, she was wearing her lapbelt. The airplane was not equipped with shoulder harnesses. Shoulder harness use could have prevented the upper body injuries of both occupants and possibly the pelvic and internal injuries of the passenger. The pilot's pelvic injuries could not have been prevented by either shoulder harness use or energy absorbing seats because of the damage caused by the penetrating tree stump.

G-PULSE

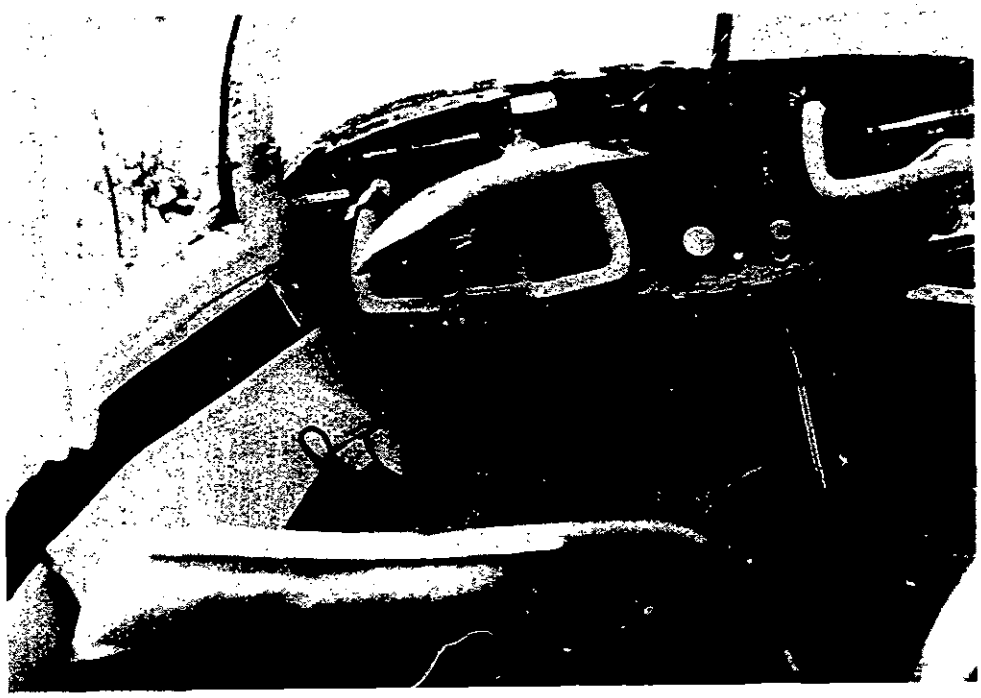
Acceleration loads could not be calculated because of the multiple tree strikes and the long slide over rough terrain.



31-1. Final flight path.

31-2. Wreckage - Area where tree stump penetrated fuselage.

31-3. Wreckage.



31-4. Sidewall pushed in on pilot's side by tree stump.

31-5. Wing damage.

Case 32

SYNOPSIS

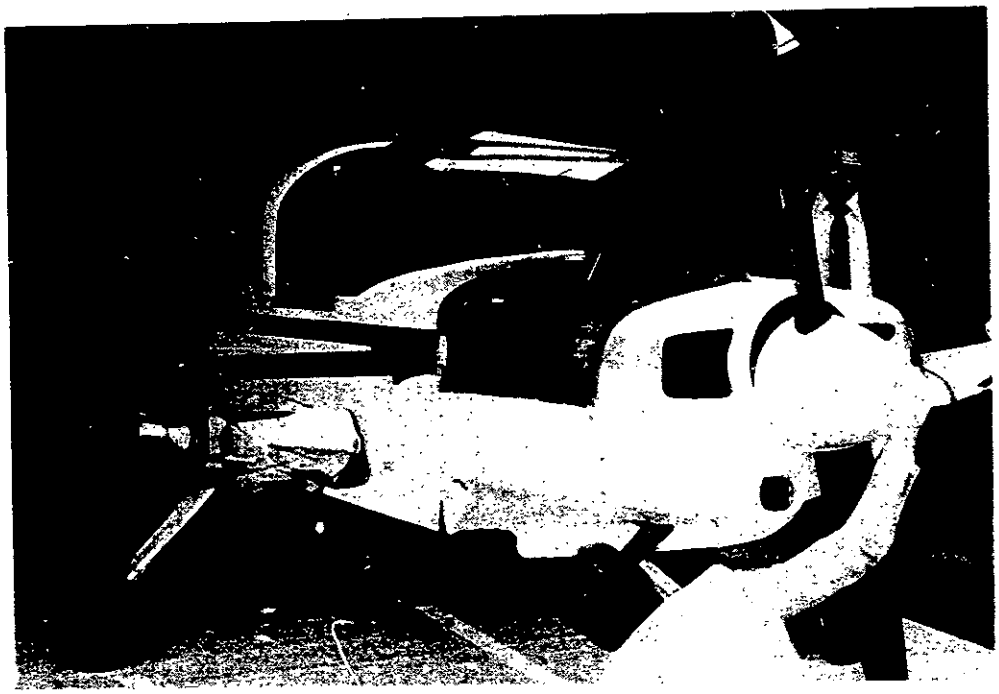
This accident involved a low-wing, single-engine airplane. The pilot had been practicing takeoffs and landings. On his third landing, the pilot attempted a go-around, but the airplane did not gain sufficient altitude and it crashed into a grove of trees. The airplane was destroyed. The right wing separated on impact and the left wing was dented and bent. The tail section and empennage were twisted. The airplane came to a stop suspended in the trees.

SEATS, INJURIES AND RESTRAINTS

The pilot was wearing his shoulder harness and was not injured.

G-PULSE

The airplane flew into a number of 6-inch diameter trees, breaking the trees and shearing one wing. Seven trees were contacted sequentially over a total of 12 feet. The loading was primarily longitudinal, and the pulse was assumed to be an average pulse because of the sequential tree strikes. At an impact speed of 52 knots, the average acceleration load was calculated at 10 G's. There were probably higher spikes, but the loading would not have approached the peak loads of a triangular pulse.



32-1. Wreckage.

32-2. Tree strike to wing.

Case 33

SYNOPSIS

The twin-engine airplane was on an instrument landing system (ILS) approach to an airport in fog and light turbulence. The copilot stated that while on final approach, the "bottom dropped out." The airplane crashed on an ice-covered bay, and slid about 350 feet before coming to rest on the shore. The airplane was destroyed. The nose section of the airplane was crushed and partially torn from the fuselage. The fuselage was distorted and torn in various places. The landing gear struts of the left and main landing gears were broken off. Both engines were deflected rearward under each wing. There was no fire.

SEATS, RESTRAINTS, AND INJURIES

Two crewmembers and five passengers were injured. The most extensive injuries, which were received by the captain, included compression fractures of vertebrae, fractured lower legs, and head and internal injuries. The copilot received minor injuries. The passengers received flail-type injuries, including a fractured arm, fractured knee, head and facial injuries, and various contusions and lacerations. The more seriously injured passengers were in seats that separated. The pilot and copilot were wearing their shoulder harnesses at the time of the crash. Shoulder harnesses were not available to the passengers.

The pilot received the most serious injuries of the crew because he was in the area of the crushed fuselage. His seat was totally separated from the fuselage due to complete fragmenting of the fuselage structure. The acceleration loads would have loaded the pilot down into the seat, but the crushing fuselage broke the seat pan in an upward direction. The copilot's seat was loaded in a downward direction. The use of the shoulder harness probably saved the pilot's life and prevented serious injury to the copilot.

G-PULSE

Photographs taken at the accident site show the crushline and general fuselage damage. The crushline in the photographs and the three-view drawing were consolidated into a separate drawing in which the plane of the crushline was rotated to the horizontal position. Parallel lines, labeled 1 through 5, were drawn to represent the crush levels at which different parts of the structure became involved during the crash (photograph 33-5). The airplane attitude, measured directly from the drawing, showed a roll angle of 21 degrees left wing down and a nose-down pitch attitude of 9 degrees.

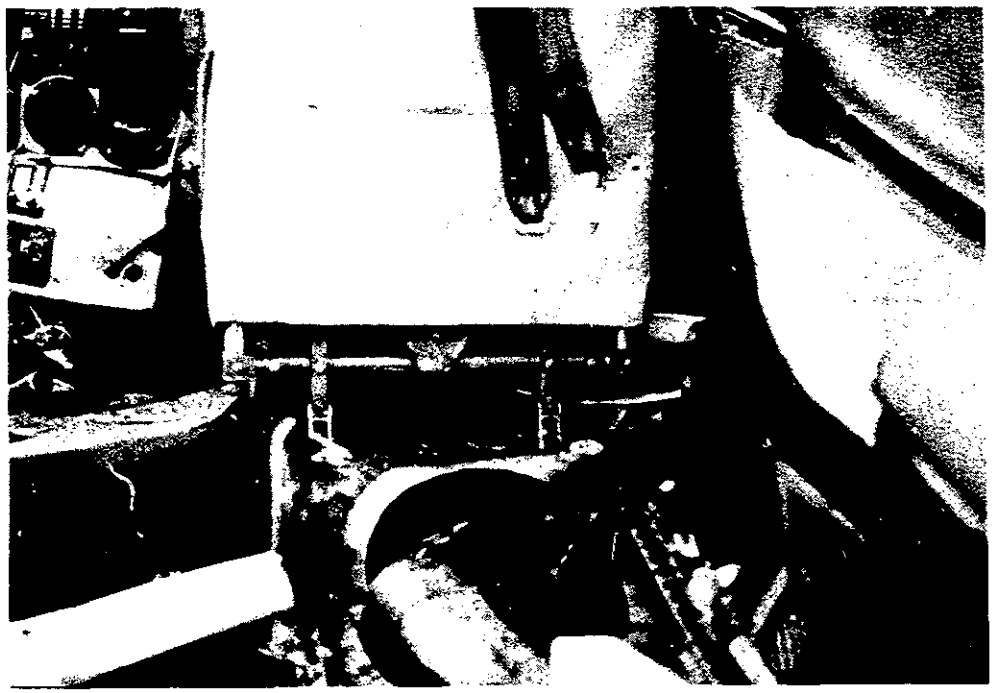
The airplane was assumed to be near stall speed, based on the copilot's statement that the "bottom dropped out." Since the wind was near zero, it was assumed that the ground speed and airspeed were the same, near stall speed. Stall speed for the airplane with the power off and 30 percent flaps, is 86 ktas. A stall angle of attack near 12 degrees with an estimated pitch rotation of 2 degrees and a pitch angle measured at 9 degrees yielded a possible flightpath angle of 23 degrees where the flightpath angle is equal to the sum of the pitch angle, angle of attack, and the pitch rotation. Since there were no supporting data, such as ground scars or tree strikes, the estimates of angle of attack and pitch rotation were not used with the same degree of confidence as were the crushline measurements.

A flight path angle of 23 degrees and an 86 knot velocity would yield a 57 feet-per-second vertical velocity. The acceleration, velocity change, and distance plot (photograph 33-6) was completed using the vertical velocity of 57 feet per second and a total stopping distance of 6.12 feet, resulting in a period of 0.157 seconds and a possible peak acceleration of 30 G's.

33-1. Damaged seat.

33-2. Left side crushline.

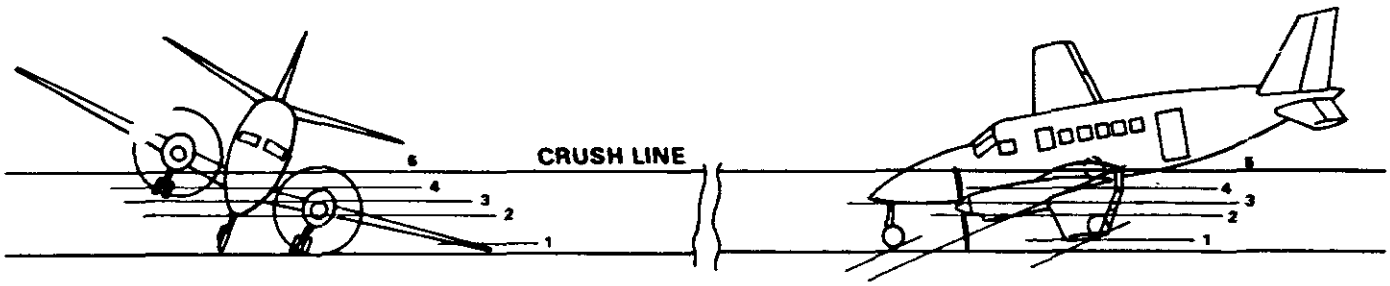
33-3. Pilot's seat in area that was totally fragmented.



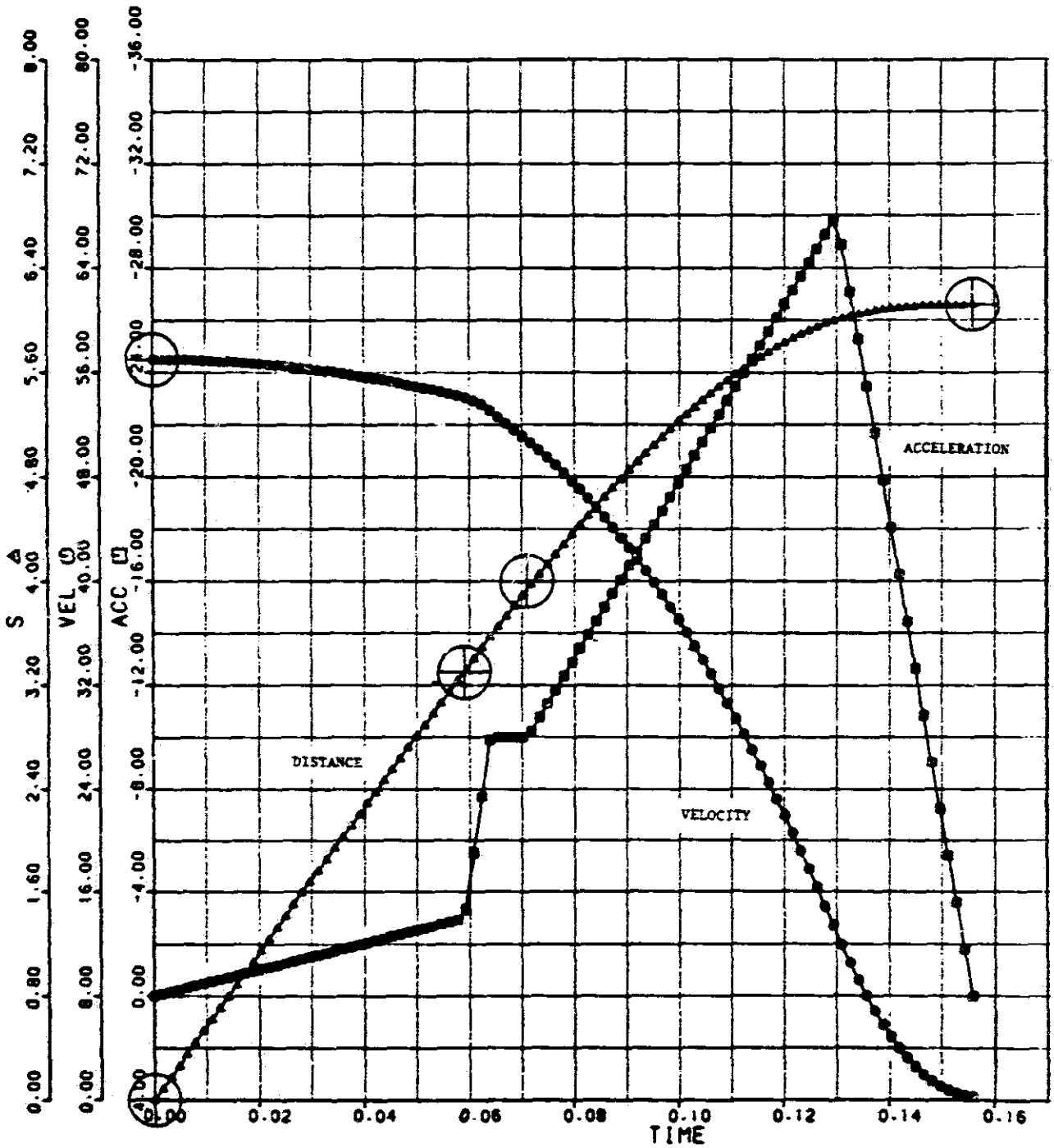
33-4. Copilot's seat in undamaged area.

CRASH INVOLVEMENT
1. WING TIP — 0 FT
2. ENGINE — 2.28 FT
3. FUSELAGE — 3.30 FT
4. COCKPIT — 4.00 FT
5. FULL STROKE — 6.12 FT

SCALE = 144 in/in
PITCH = -9°
FLIGHT PATH = -2° -9° -12° = -23°
STALL SPEED — POWER OFF, 30% FLAPS = 82 KCAS = 86 KIAS = 86 KTAS
ROLL = 21° LEFT
Vv = 145 FT/SEC sin 23° = 57 FT/SEC



33-5. Drawing showing crushline.



33-6. Shaped crash pulse.

Case 34

SYNOPSIS

This accident involved a single-engine, low-wing airplane that operated as a tour airplane in the Mount St. Helen's National Volcanic Area. After experiencing engine problems, the airplane made a forced landing and crashed on the mud flats of the Toutle River in a relatively flat and open area. The airplane initially touched down among boulders that were about 1 to 3 feet in diameter. After hitting the boulders, the airplane slid for about 110 feet before coming to a stop. During the impact progression, the fuselage was crushed inward at various locations, the right wing sheared from the fuselage, and the cabin floor separated in places. The airplane was destroyed.

SEATS, RESTRAINTS AND INJURIES

The pilot and a passenger who was seated at the left window seat of the third row were fatally injured. The pilot is believed not to have worn his shoulder harness. He received a chopping wound to the forehead, skull fractures, neck fractures, hemothorax, pelvic fractures, and internal rupturing of the digestive organs. These injuries resulted from the pilot's unrestrained impact into the instrument panel and control yoke. The lapbelt caused the rupturing of the pilot's digestive organs. The passenger who was killed received injuries to the head, a fractured pelvis, and ruptured digestive organs. He wore a lapbelt, but his head and upper torso impacted the seatback directly in front of him. Like the pilot, this passenger's internal injuries were probably caused by the use of a lapbelt only. A shoulder harness was not available at this seat location.

The other five passengers received serious injuries in the accident. An adult male passenger seated in the copilot's seat received a concussion, a facial fracture, and contusions to the chest. He used the shoulder harness and lapbelt. The other four passengers were seated in the second and third rows of the cabin. At these seat locations, lapbelts were the only means of restraint. It is believed that these passengers used their lapbelts at the time of the accident. One passenger received a fractured vertebra and a mesenteric tear. Another passenger had a compression back fracture, pneumothorax, and internal injuries due to lapbelt loads. A third passenger had a compression back fracture and neck strain. The fourth passenger had a cervical fracture. There was a mix of back, upper body, and internal injuries. All seven occupants had upper body injuries, five had back injuries, and four had internal injuries possibly due to lapbelt loads. Shoulder harnesses and energy absorbing seats could have reduced or prevented most of the occupant injuries.

G-PULSE

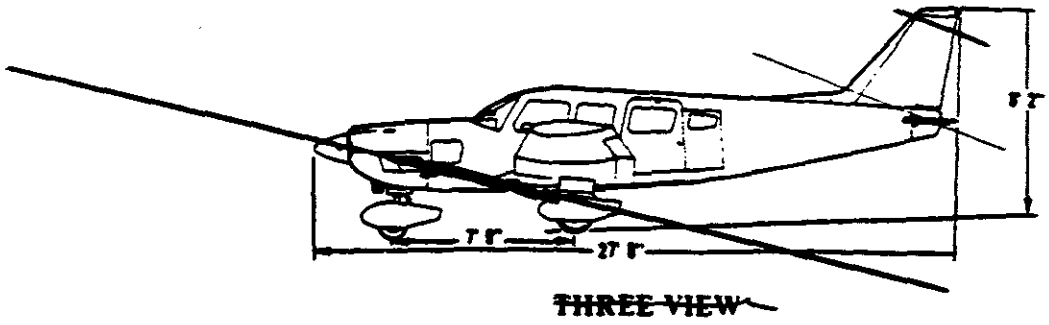
The airplane had a crushline indicating that the attitude at impact was at least 10 degrees nose-down. The flaps were down, so the angle of attack was estimated at about 12 degrees. Adding the angle of attack and the pitch attitude would result in an impact angle and flight path angle of 22 degrees. The gross weight stall speed is 55 knots; based on witness descriptions; a bank angle of about 45 degrees was assumed for the calculation of the 65-knot stall speed, which was also assumed to be the impact speed.

The vertical impact velocity was then calculated at 41 feet per second and the horizontal velocity was 102 feet per second. The slide of 110 feet at a 0. 7 friction coefficient results in an exit velocity of 70 feet per second. The vertical velocity change of 41 feet per second over 1.8 feet of crush would yield a 30 G peak. The period would be 0.084 seconds. The horizontal velocity change of 32 feet per second (102-70) in the period of 0.084 seconds would yield a peak 24 G load. The resultant 38 G load would be at 51 degrees down. Correcting for a 41 degree angle to the airplane axis (51 degrees-10 degree pitch) yields a 25 G peak vertical acceleration and a 29 G peak horizontal acceleration. The equivalent velocity changes were 40 feet per second horizontal and 34 feet per second vertical.

34-1. Wreckage.

34-2. Crush area.

34-3. Copilot's panel.



34-4. Crushline.

Case 35

SYNOPSIS

The single-engine, high-wing airplane made a series of bounces when it touched down on the last third of the runway. The pilot attempted a go-around maneuver, but the airplane never gained sufficient altitude to clear several tree tops. The airplane crashed on the airport in a partially wooded field.

The airplane was destroyed in the crash. The fuselage was extensively deformed and the cowling was wrinkled and buckled from the propeller to the forward section of the cabin. Aft of the cabin, the fuselage was twisted and partially torn. Both wings received compression damage and eventually sheared off as the impact progressed.

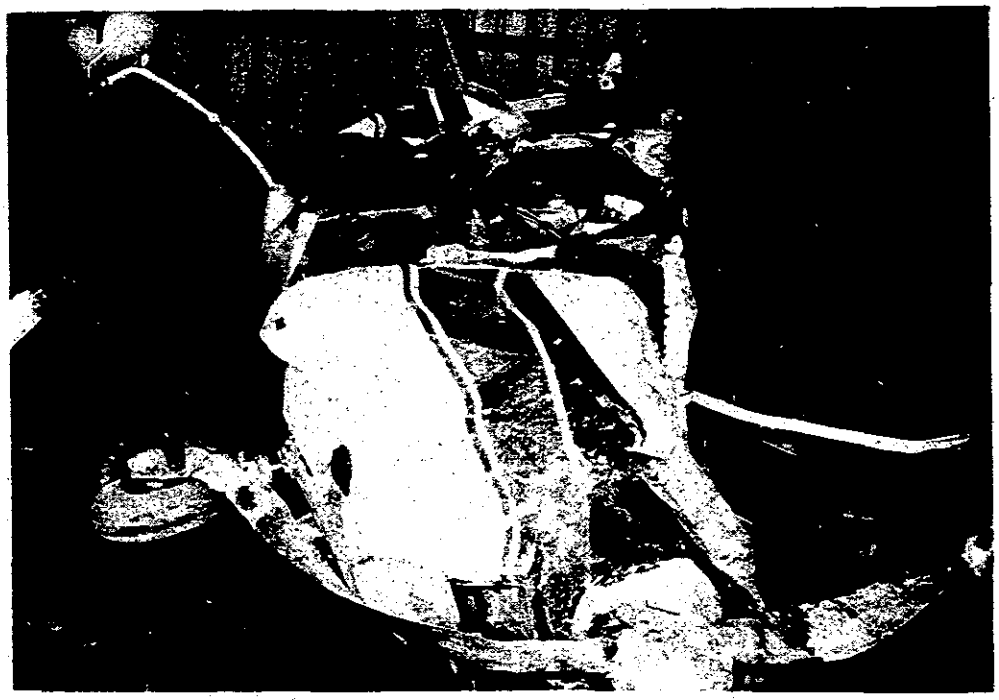
SEATS, RESTRAINTS, AND INJURIES

The pilot and two passengers received serious injuries. The pilot's injuries included lacerations of the forehead and knees, a fractured leg, and ruptures of the small bowel and colonic mesentary. The passengers received similar injuries. One passenger received lacerations to the forehead and right ankle, and fractures of his forearm, left elbow, and both upper arm bones. The other passenger received lacerations to the thigh and chest. In addition, he fractured his left wrist, foot, and several ribs.

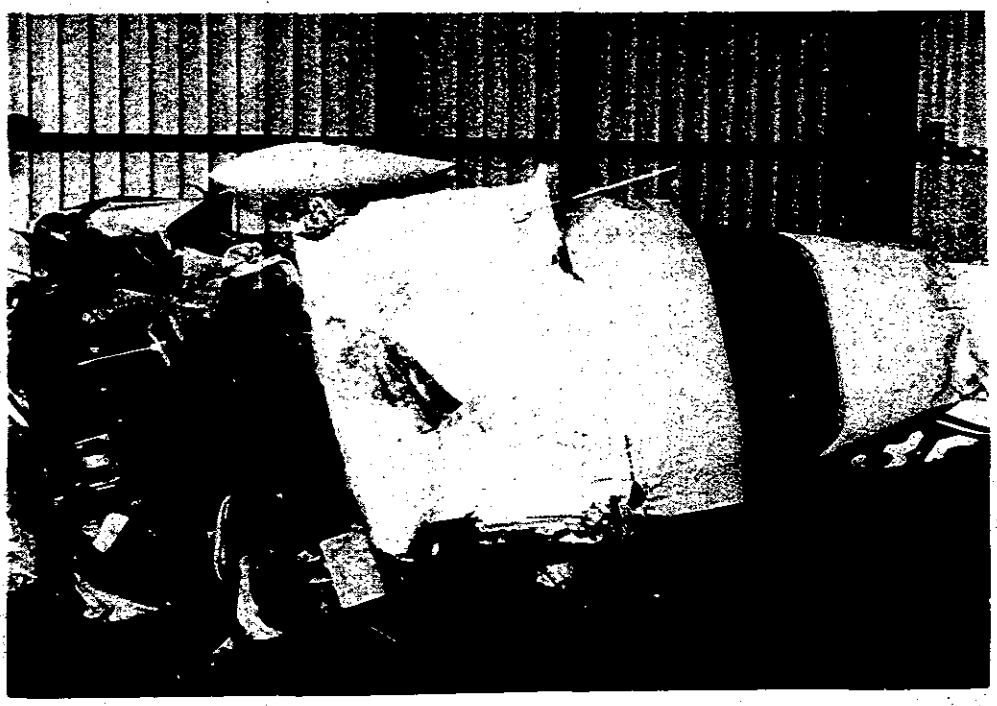
The airplane was equipped with lapbelts only. At the time of impact, all occupants were using their lapbelts. The facial injuries that all three occupants received would have been prevented or reduced had shoulder harnesses been available and used. The pilot's internal injuries could also have been prevented if the lapbelt loads could have been distributed to the shoulder harness.

G-PULSE

The airplane initially contacted the trees at about a 50-foot altitude and in about a 28-degree right roll attitude. The airplane continued on for 170 feet before striking the ground. The ending slide was about 30 feet. It was assumed that the airplane hit the trees at or near stall speed, which was calculated to be about 46 knots based on the published stall speed of 48 knots, corrected for a weight of 2,300 pounds and a bank angle of about 30 degrees. Since the acceleration loads appeared longitudinal based on the occupant contact areas, the gouging of the ground, and the nature of the fuselage crushing, a single acceleration was calculated. If the airplane was slowed to 40 knots because it went through the trees, crushing the right wing, the impact speed would be about 68 feet per second. The 30-foot slide at a 0.7 friction coefficient would yield an exit velocity of about 36 feet per second for a velocity change of about 32 feet per second. The stopping distance of 4.5 feet was derived by using the crush to the front of the airplane. The acceleration load would then be about 23 G's peak.



35-1. Wreckage.



35-2. Wreckage.

Case 36

SYNOPSIS

During approach to landing, a twin-engine turbojet showed signs of engine problems when the fire warning lights activated for both engines. When the landing gear was lowered, the passengers began to smell smoke. The pilot initiated a steep descent to the runway and had no elevator control when he tried to flare. Using the trim, the sink rate was slowed. All landing gear broke off at impact. The airplane became airborne again before touching down and sliding to a stop off the edge of the runway. The forward part of the fuselage received several inches of crushing. A ground fire started underneath the airplane aft of the wings.

SEATS, RESTRAINTS, AND INJURIES

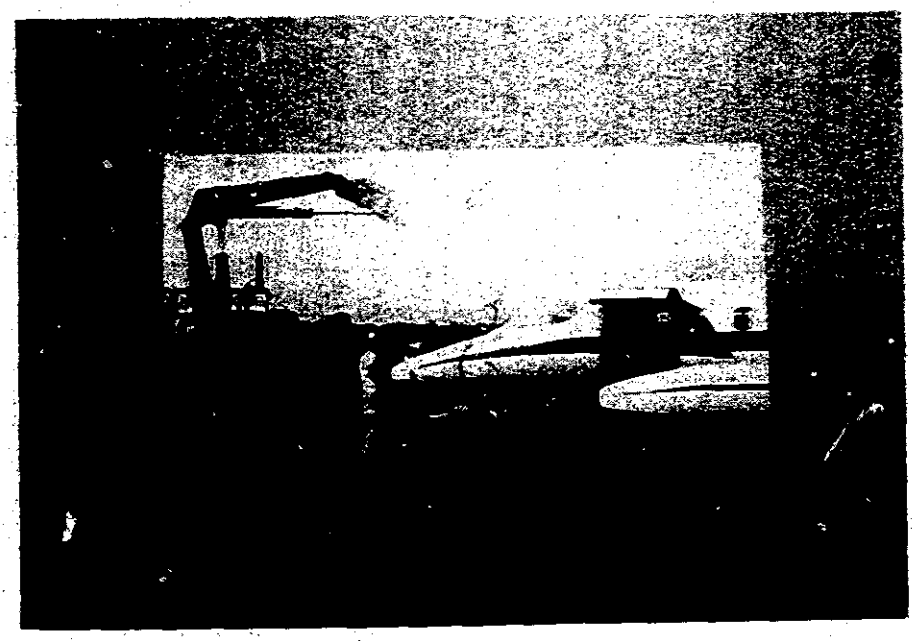
Both crew members were wearing their shoulder harnesses at the time of the crash. The aluminum seat pans for their seats tore down incrementally, absorbing a great amount of energy. They were not injured. It was reported that the passengers were leaning toward the aisle at impact, and sustained lower back injuries.

It was discovered that the passenger seats did not have a structural type of seat pan, only foam and a plastic type material, which was suspended from the seat frame. The pan was positioned over a steel ring that allows the seat to swivel. In this case, the reported misposition of the rear seat occupants, rather than the lack of a seat pan, probably contributed to their injuries. There was no evidence that the occupant had bottomed out on the steel ring.

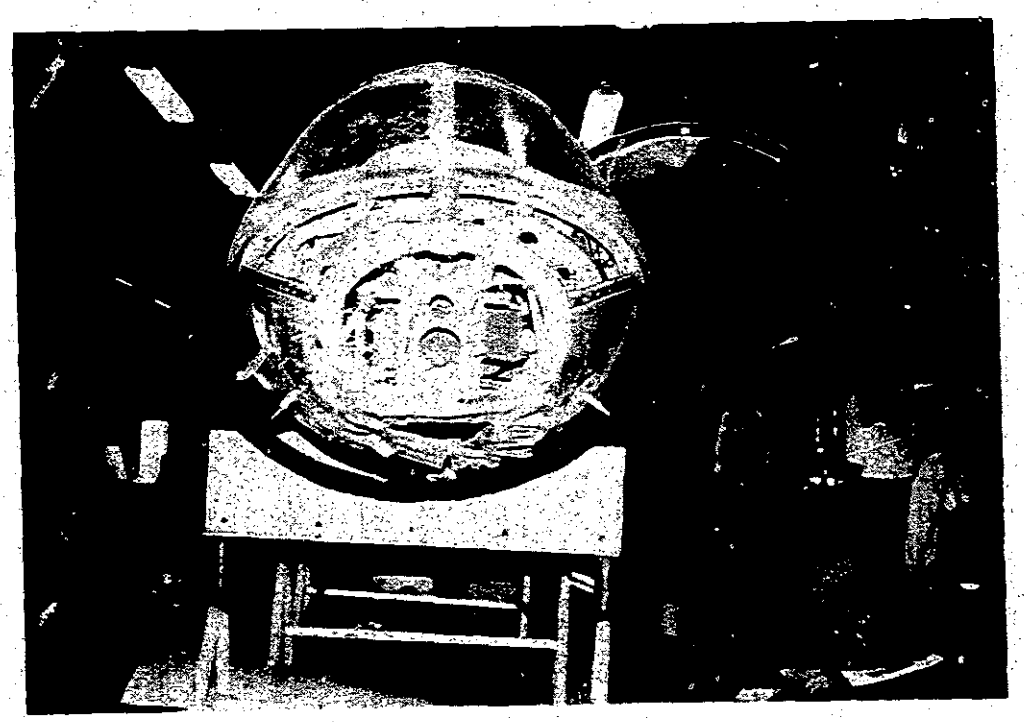
The front seat absorbed energy as the pans tore out incrementally. The crew were probably protected from injury because of the seat pans tearing. Had the passengers remained seated in an upright position, their injuries may have been lessened. It is possible, however, that the lack of a seat pan would have caused them further injury had they contacted the steel ring.

G-PULSE

The impact speed could not be estimated accurately. Also, small errors in the impact angle would create large errors in the vertical loading calculations. Acceleration load calculations were not made.



36-1. Wreckage.



36-2. Crush to nose area.

36-3. Incrementally torn seat pan.

36-4. Crack in plastic-type seat pan.

Case 37

SYNOPSIS

The single-engine high-wing airplane crashed approximately 2,000 feet from the departure end of the runway. The pilot had been practicing touch-and-go landings when a witness observed the airplane starting to zigzag. The airplane descended toward the ground in a nose-low attitude. Before it could recover, the airplane impacted the ground in a cleared field.

The airplane was demolished. The fuselage was compressed from the engine back to the cabin. The fuselage was torn and twisted aft of the cabin. Both wings had compression buckling. In addition, the right wing separated from the fuselage.

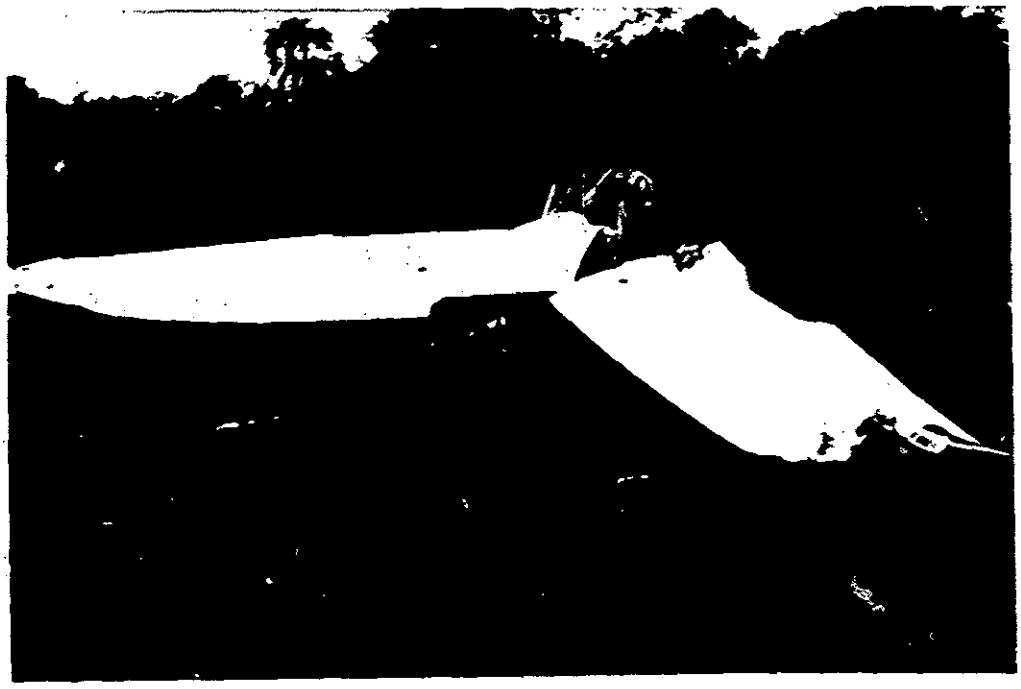
SEATS, RESTRAINTS, AND INJURIES

This accident was survivable. The pilot died and the passenger seated in the copilot seat received serious injuries. At impact, both occupants were wearing lapbelts and shoulder harnesses. The pilot received a circumferential skull fracture and the passenger received a severe concussion when his head hit the instrument panel. It appeared that the pilot's shoulder harness was at an excessive length, possibly allowing excessive forward movement. Also, the panel moved aft a great amount reducing the effectiveness of the shoulder harness.

G-PULSES

The airplane initally contacted the ground in about a 90-degree left roll and at an impact angle of about 43 degrees. After the impact, the airplane moved another 15 feet, mostly just falling down. The acceleration loads were in a predominantly longitudinal direction. The estimated impact speed was based on a gross weight stall speed of 42 knots, corrected for a weight of 1,450 pounds and a bank angle of about 30 degrees. The impact speed was considered to be about 46 knots or 78 feet per second. The airplane was slowed by the crushing of the left wing and the 4 feet of crush to the front of the fuselage. Eight feet of wing ridedown at 2 G's would slow the airplane from 78 feet per second to 71 feet per second. The exit velocity would be about 26 feet per second for a velocity change of about 45 feet per second. Using the 4 feet of fuselage crush would yield a peak longitudinal acceleration of about 34 G's.

37-1. Wreckage.



37-2. Wreckage.

Case 38

SYNOPSIS

A twin-engine, low-wing airplane was making an approach to landing. Witnesses observed that the right propeller had stopped. The airplane was making a left turn to the final when it appeared that the pilot lost directional control. The airplane rolled completely to the right then nosed over, impacting the ground in a grassy field in a 90-degree nose-down attitude.

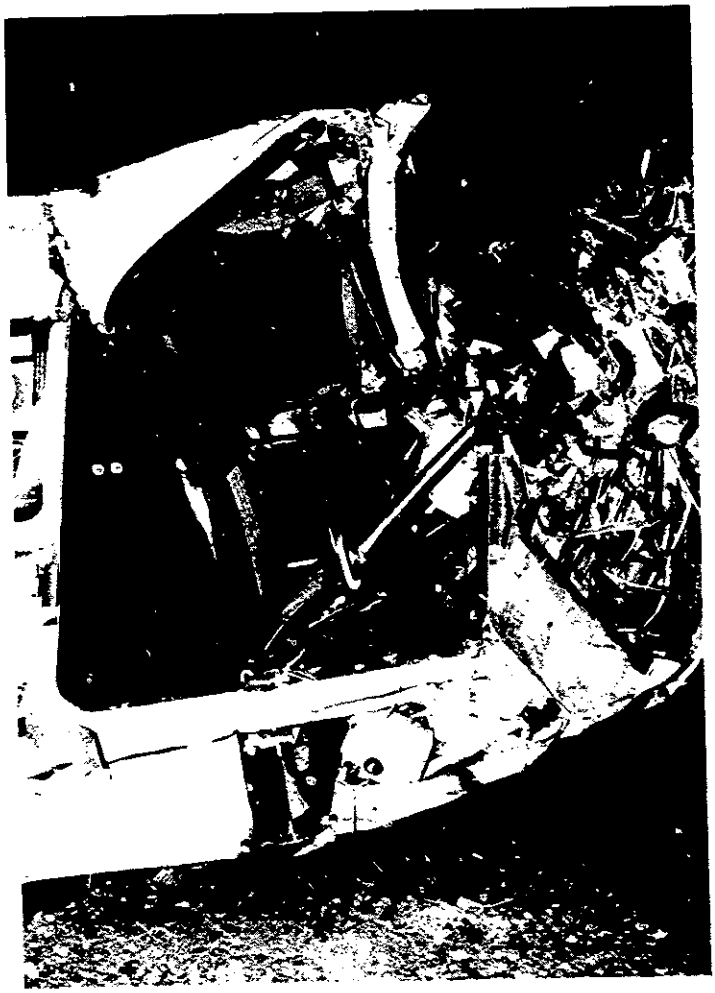
The airplane was crushed up to the cabin. The cabin roof buckled and was bent aft and upward. Both wings were crushed and buckled aft. The landing gear remained attached but was displaced rearward.

SEATS, RESTRAINTS, AND INJURIES

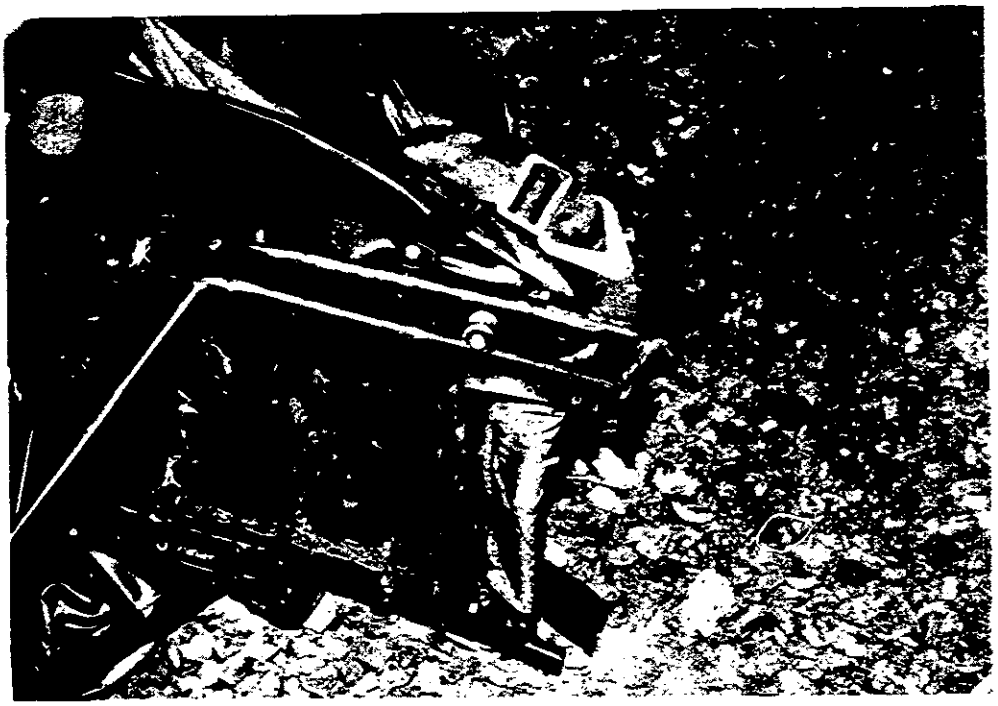
The front seat occupants were in a non-survivable portion of the airplane because of the severe crushing to the cockpit. An 8-year-old boy in the rear seat sustained a fatal, open head wound, when he pitched forward into a steel tube that was exposed. The tube formed part of the seat back of a crew chair directly ahead of the boy. A shoulder harness may have prevented his fatal injury.

G-PULSES

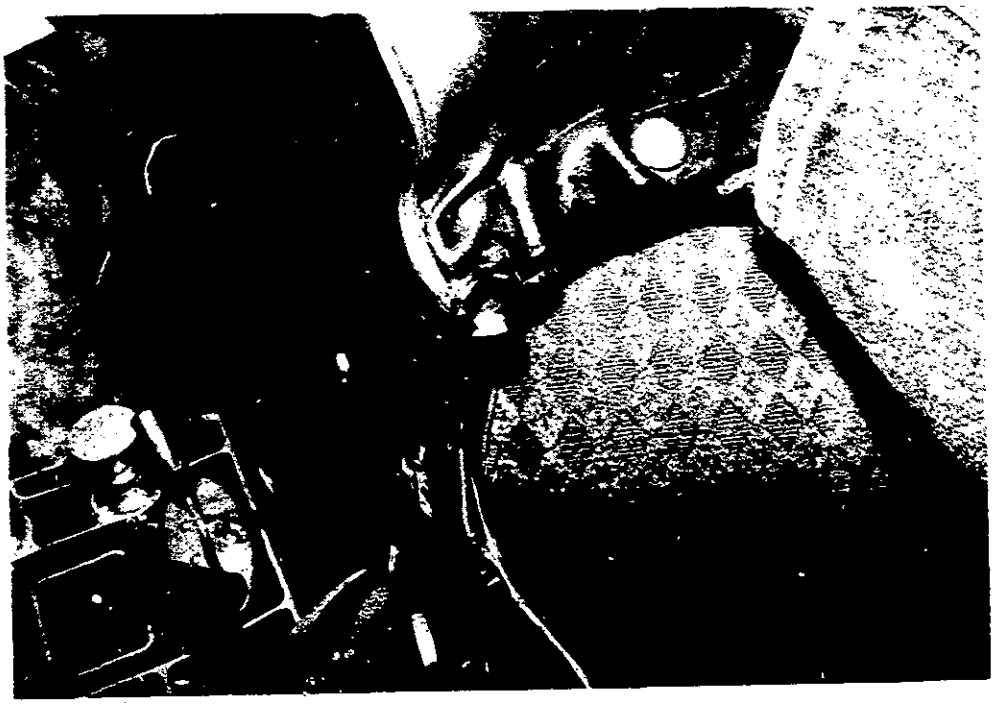
The acceleration loads could not be calculated because the impact velocity could not be estimated.



38-1. Wreckage - Crushed nose.



38-2. Separated seat.



38-3. Head strike area of rear seat occupant.

Case 39

SYNOPSIS

This single-engine, low-wing airplane made a forced landing following an engine failure that occurred at an altitude of 1,400 feet; the pilot attempted to land the airplane on an open field. However, it landed short on the upslope of a river bank. The airplane impacted the ground at about 65 knots in a nose-high attitude.

The airplane was substantially damaged. At impact, all three landing gears collapsed aftward. The fuselage belly and both wings incurred crushing damage. The occupiable cabin space was not compromised except for slight upward displacement of the floor under the front seats.

SEATS, RESTRAINTS, AND INJURIES

The four occupants aboard the airplane received serious injuries. The pilot, who was critically injured, received fractures of his skull, facial bones, jaw, and lower extremities. He also received compression fractures of the L-2 and L-4 vertebrae. Teeth were aspirated into the right lung. He survived, but remained unconscious for several months. The passenger occupying the copilot seat received comminuted fractures to the L-1 and L-5 vertebrae, the left humerous, and numerous facial bones. She also received simple fractures of four ribs. The two rear seat passengers received lumbar compression fractures. Additionally, the left seat passenger suffered lacerations of the face, right forehead, and right knee as well as a ruptured small bowel. The right rear seat passenger received simple fractures of the face, nose, left wrist, left radius, both ankles, and a bilateral fracture of the pelvis.

The injuries sustained by the occupants could have been reduced or prevented by shoulder harnesses and energy absorbing seats. At impact, both the pilot and the passenger in the copilot seat pitched forward into the control columns and yokes. The two rear seat passengers pitched forward into the seatbacks of the front seats. As a result of this unrestrained forward movement, all four occupants received serious head injuries.

The severity of the injuries sustained by the two rear-seated occupants may have been enhanced because their lapbelts broke at impact. The cable, which anchors the fabric material to the floor, broke in both cases. The cables had rusted and been wrapped with electrical tape. Although the cable strength had been reduced, they still exceeded the 1,500-pound minimum strength required by the Technical Standard Order under which they were manufactured.

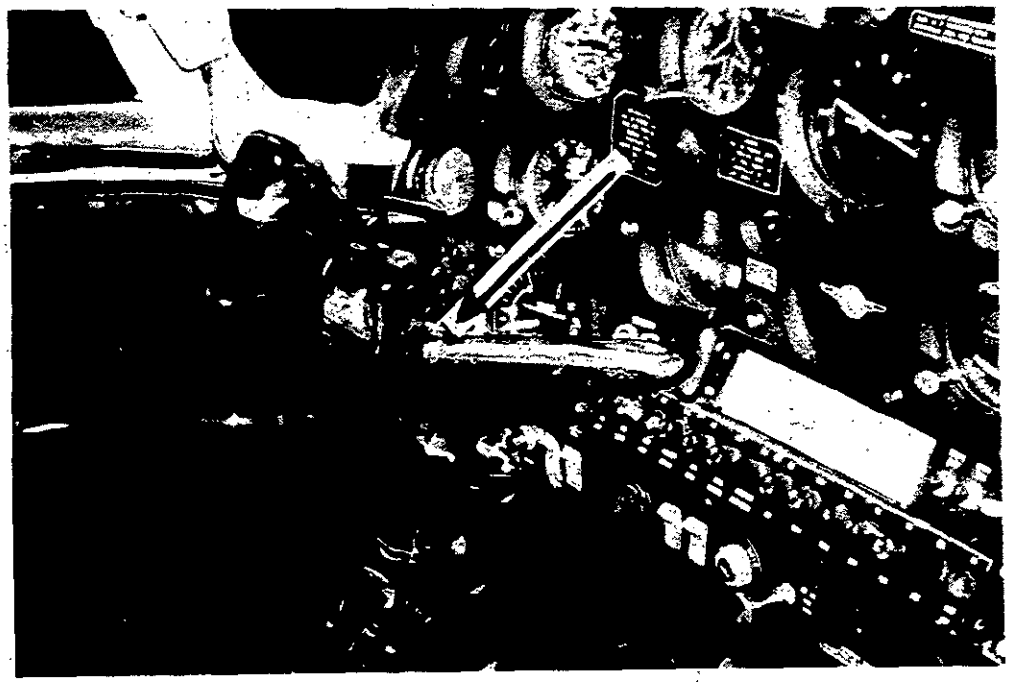
All occupied seats exhibited signs of impact damage. The most severe seat damage occurred in the front seats. The seat pan of the pilot's seat deformed downward. Prior to the accident, the pilot had reupholstered the seat cushion beneath the seat pan frame with lawn chair webbing. The webbing was secured with household staples. When the seat pan deformed, the lawn chair webbing tore. A fire extinguisher bottle located under the pilot's seat also crushed two inches inward. The seat track and attach fittings to this seat distorted outward. The front right seat was similarly damaged. The seat pan collapsed downward, and the seat attach fittings and seat track bent outward.

The two occupied rear seats exhibited signs of deformation but to a lesser extent. The seat legs of both these seats distorted rearward, and the seat track and attach fittings were distorted upward.

G-PULSES

The airplane was in a zero degree pitch attitude and a 26-degree roll attitude at impact. The 12-degree flight path angle combined with the 30-degree terrain angle would result in a 42-degree impact angle. The 3,400 pound gross weight stall speed of 54 knots was corrected for an actual weight of 2,500 pounds for a stall speed of 47 knots. The head wind of 4 knots reduced the impact speed to 43 knots or 71 feet per second. The vertical velocity would be 47 feet per second and the horizontal velocity would be about 53 feet per second. The friction coefficient of 0.7 and the grade of 0.6 percent combines with the 12 feet of slide for an exit velocity of 32 feet per second to zero. A 3-foot crushing distance and the 47 feet per second velocity change would result in a 23 G peak load during a period of about 0.13 seconds. The horizontal velocity change of 21 feet per second (53 - 32) and the period of 0.13 seconds result in a 10 G peak load. To correct to the airplane axis, the ground axis system would have to be rotated 30 degrees, resulting in a 25 G total acceleration at an angle of 36 degrees below the nose of the airplane. (66-30) In airplane axis, the vertical load would be about 15 G's and the horizontal load would be about 20 G's. The equivalent airplane axis velocity change would be 31 feet per second vertical and 42 feet per second horizontal.

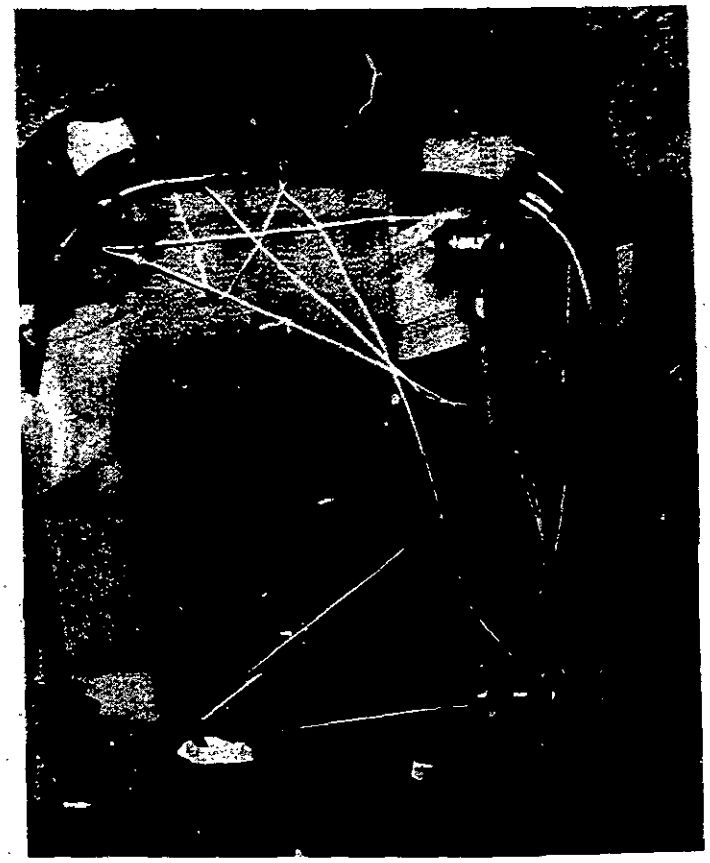
39-1. Wreckage.



39-2. Control column damage.

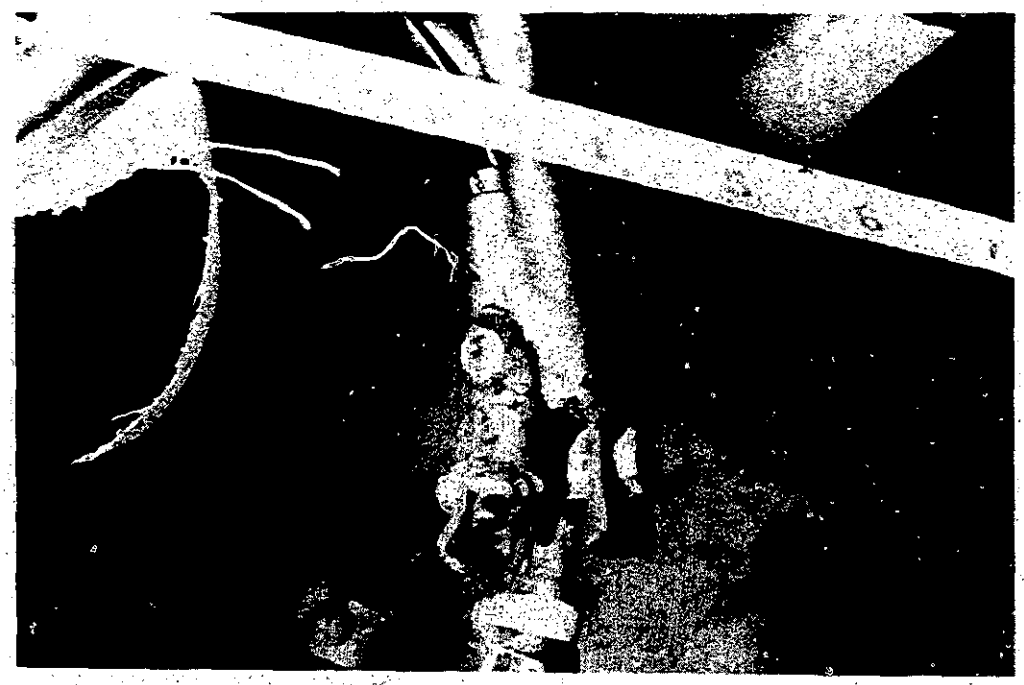
39-3. Bottom of seatpan with lawnchair webbing and add-on equipment.

39-4. Bottom of seat pan.



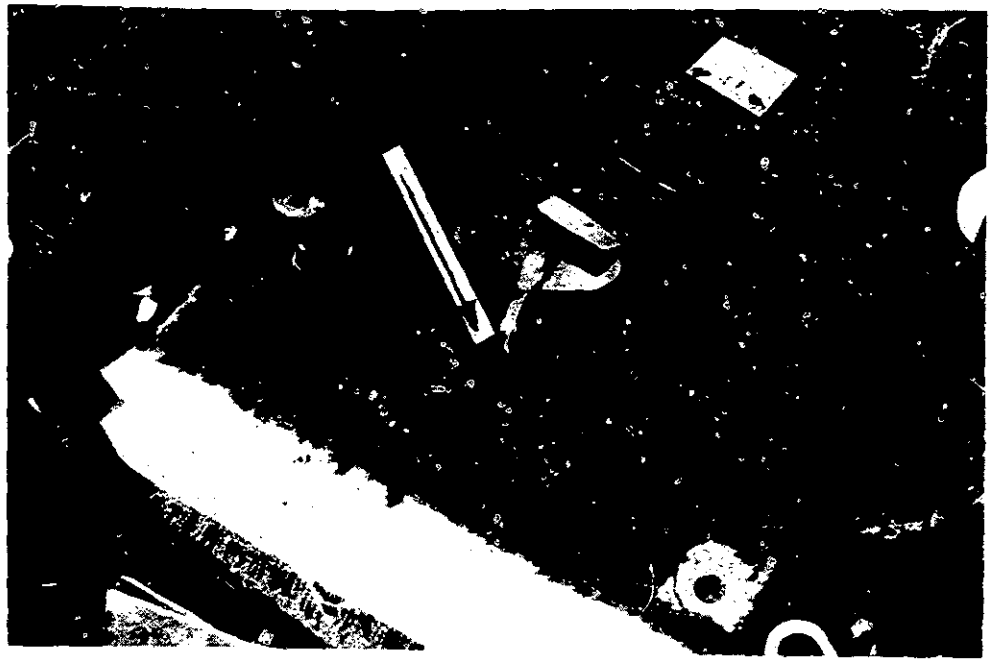
39-5. Original seatpan that had been repaired.

39-6. Lawnchair webbing.



39-7. Spread seat feet.

39-8. Separated lapbelt cable.



39-9. Separated lapbelt cable.

APPENDIX B

DATA SUMMARY

Data Summary

Case No.	Accident No.	Injuries	Those Who Would Have Improved with SH	Those Who Would Have Improved with E/A Seats	Impact Angle (Degrees)	Impact Speed (Knots)	GH Peak	GV Peak	ΔV_H A/C Axis (Feet per sec.)	ΔV_V A/C Axis (Feet per sec.)	Issues (F) Front (R) Rear: No SH - High Lap Belt Load Injuries	SH Not Available (F) Front (R) Rear	SH Not Worn	E/A Seats Not Available	Seats Coming Loose	Poor Seat Pan Design	Equipment Add to Seats	Comments
1	DEN 83 LAO 72	1F 1S	1F 1S	1S	10°	90+	–	–	–	–	1(F)	–	2(F)	–	1(F)	–	–	Forgot to put shoulder harness back on in emergency.
2	LAX 82 FA 337	1S 2M	1S	–	24°	56	21	3	46	Small	–	1(R)	2(F)	2(F) 1(R)	1(F)	–	–	
3	SEA 82 FA 122	1F 4S	1F 4S	1F 3S+	48°	62	27	30	48	53	1(R)	3(R)	1(F)**	3R	2(F)	–	–	Lap belt separated. Forgot to put shoulder harness back on in emergency. Floor warped.
4	ATL 82 FA 126	1S 1M	1S	–	11°	43	11	6	22	12	*	2(F)	–	2(F)	–	2(F)	1	Seat pans rotten.
5	DEN 83 FTI 02	2F 1S 1M	2F 1S	–	22-30°	53	17	2	45	Small	–	2(R)	2(F)	2(F) 2(R)	*(F)	–	–	Did not have time to put shoulder harness back on in emergency.
6	CHI 83 FA 007	2S 1M	2S	–	62°	22	19	0	40	Small	–	1(R)	1(F)	2(F) 1(R)	1(F) 1(R)	–	–	
7	CHI 82 FA 213	1F 1S	1S	–	41°	–	–	–	–	–	–	*	–	2(F)	1(F)	–	–	
8	CHI 83 LA 040	1S	1S	1S	20°	67	19	12	30	21	–		1(F)	1(F)	** 2	*	–	Forgot to put shoulder harness back on. **Unoccupied.* No ripstop seat pan.
9	ATL-83 FA 095	1F 2S 1M	1F 1S	–	14°	62	16	0	21	Small	–	2F 1R	–	–	2	–	–	
10	ATL 82 DA 127	4N	–	–	90°	27	3	0	14	0	–	–	–	–	–	2(R)	–	Seat pan attached to sidewall. When sidewall buckled, seat pan separated.
11	ATL 83 FA 014	1F 3S	1F 3S	–	30°	53	30	0	60	Small	2(R)	2(R)	1(F)	–	2(F)	–	1	
12	LAX 83 LA 058	1S	1S	–	17°	55	–	–	–	27	–	1(F)	–	1(F)	1(F)	–	1	
13	FTW 82 DA 275	2S	–	2S	10°	51	–	15-20	Small	15	–	2(F)	–	2(F)	2(F)	2(F)	–	Seat pan springs spread, seat frame not stable.
14	DCA 83 AAO 19	2S	1S	1S	80°	45-60	–	*Estimated 21	Small	*Estimated 15	–	1(R)	1(F)	1(R)	–	1	1	*No stroking distance in 2nd row of seats, nylon pan could be torn by hand.
15	MKC 83 FA 066	2S	2S	1S	10°	90+	*	*	*	*	–	–	–	–	–	–	–	Shoulder harness and energy absorbing seat offered protection.

Data Summary

Case No.	Accident No.	Injuries	Those Who Would Have Improved with SH	Those Who Would Have Improved with E/A Seats	Impact Angle (Degrees)	Impact Speed (Knots)	GH Peak	GV Peak	ΔV_H A/C Axis (Feet per sec.)	ΔV_V A/C Axis (Feet per sec.)	Issues (F) Front (R) Rear: No SH - High Lap Belt Load Injuries	SH Not Available (F) Front (R) Rear	SH Not Worn	E/A Seats Not Available	Seats Coming Loose	Poor Seat Pan Design	Equipment Add to Seats	Comments
16	ATL 82 FA 065	1F 2S	1F 2S	–	30°	55	35	Small	62	Small	–	2(F) 1(R)	–	2(F) 1(R)	1	1(F)	–	Luggage hit seat back.
17	MIA 83 FA 014	1F 2S	1F 2S	–	30°	35	22	Rolled 90° Loads Small	32	N/A	1(R)	1(R)	2(F)	1(F)	2	–	–	Lap belt induced perforated small bowel. Lap belt separated
18	SEA 82 FA 019	3M 4N	1M	–	–	–	–	–	–	–	–	5(R)	2(F)	–	2(F) 5(R)	–	–	
19	ATL 82 FA 067	4F	–	–	39°	44	633*		Sideways		–	2(F) 2(R)	–	2(F) 2(R)	2(F) 2(R)	–	–	Nonsurvivable. *Total.
20	DEN 82 DA 167	1S	1S	1S	29°	52	27	24* (to 18)	43	38	1(F)	–	1(F)	–	1(F)	–	–	
21	ATL 83 LA 027	4S	–	4S	17°	48	14	20	14	21	1(R)	2(F) 2(R)	–	2(F) 2(R)	2(F) 2(R)	2(R)	–	"S springs seatpan separated
22	CHI 83 LA 006	4S	2S	–	9°	–	–	–	–	–	–	2(F) 2(R)	–	2(F) 2(R)	–	–	–	Lack of vertical stroking distance. Maintenance problem.
23	ATL 82 DA 222	1S	1S	1S	14°	44	–	17 (to 9)	Small	14	–	–	–	–	–	–	–	Seat performed as energy absorbing seat.
24	NYC 82 FA 203	2F	1F		42°	50	30	–	54	Small	–	1F 1R	–	1(F) 1(R)	–	–	–	The front seat occupant could not have survived because of proximity to crush line.
25	ATL 82 FA 054	1S 2M	–	–	–	–	–	–	–	–	–	2(F) 1(R)	–	2(F) 1(R)	2(F) 1(R)	–	–	Seat feet spread.
26	ATL 82 DA 162	2S 1M 1N	1S 1M	1S	20°	56	30	–	50	–	–	2(R)	2(F)	2(R)	-	–	–	*Total G's - energy absorbing seats helpful in front.
27	ATL 83 FK 601	1F 1M	–	–	30°	48	–	36 G 18 G w/ seat	–	34	–	2(F)	–	2(F)	2(F)	–	–	Energy absorbing seats helpful.
28	NYC 82 FA 116	1F 1S	1S	–	70°	42	25	–	69		–	–	1(F)	2(F)	–	–	–	Shoulder harness helped.
29	DEN 83 FA 027	2F 1S	2F 1S	–	–	–	–	–	–	–	1(R)	1(R)	2(F)	2(F) 1(R)	1(F) 1(R)	–	–	
30	DEN 82 AA 132	1F 1S	1F 1S	–	23°. 26°	39	34	0	66	Small	1(F)	2(F)		2(F)	–	-	1	

Data Summary

Case No.	Accident No.	Injuries	Those Who Would Have Improved with SH	Those Who Would Have Improved with E/A Seats	Impact Angle (Degrees)	Impact Speed (Knots)	GH Peak	GV Peak	ΔV_H A/C Axis (Feet per sec.)	ΔV_V A/C Axis (Feet per sec.)	Issues (F) Front (R) Rear: No SH - High Lap Belt Load Injuries	SH Not Available (F) Front (R) Rear	SH Not Worn	E/A Seats Not Available	Seats Coming Loose	Poor Seat Pan Design	Equipment Add to Seats	Comments
31	ATL 82 FA 032	1F 1S	1S	–	11*	58	–	–	–	–	1(F)	2(F)	–	2(F)	2(F)	–	–	
32	ATL 83 FA 036	1N	1	–	90*	52	10*	–	88	Small	–	–	–	1(F)	–	–	–	*Average. Shoulder harness helpful.
33	NYC 82 AA 026	5S 2M	2S-3S	–	23*	86	–	30	–	57	–	5(R)	–	2(F) 5(R)	4(R)	–	–	Shoulder harness helped.
34	SEA 82 FA 155	2F 5S	2F 5S	1F 3S	22*	65	29	25	40	34	1(F) 3(R)	5(R)	–	2(F) 5(R)	1(F) 3(R)	–	1	*If 3R
35	NYC 83 FH A02	3S	3S	–	20	40	23		36		1F	2(F) 1(R)	–	2(F) 1(R)	–	–	–	
36	Foreign	1S 1M 2N	2F	2F 2R	12	–	–	–	–	–	–	2R	-	2(R)	–	–	–	*The crew benefitted from shoulder harnesses and energy absorbing seats.
37	NYC 84 FA 216	1F 1S	1S 1F	–	43	46	34	–	45	–	–	–	–	2(F)	–	–	–	*Had shoulder harnesses on. Pilot's may have been improperly worn.
38	DCA 83 AA 024	3F	1F	–	90	–	–	–	–	–	–	2(F) 1(R)	–	2(F) 1(R)	–	–	–	
39	NYC 83 FA 012	4S	4S	4S	42	42	20	15	42	31	–	2(F) 2(R)	–	2(F) 2(R)	•	–	••	*The seat belts broke. Pilot struck fire extinguisher.

APPENDIX C

EXCERPTS FROM THE GENERAL AVIATION SAFETY PANEL PROPOSAL TO THE FEDERAL AVIATION ADMINISTRATION

Dynamic Testing of Seats

Recommended seat criteria for small general aviation aircraft applying for initial type certification after December 31, 1985, for operations with fewer than 10 passenger seats.

(a) Each seat, bench or other device for crew or passenger occupancy must successfully complete dynamic tests with an occupant weight of 170 pounds in accordance with each of the conditions stated below.

(1) A change in velocity of not less than 31 feet per second when the seat, bench or other seating device is oriented in its nominal position with respect to the aircraft's reference system and the aircraft's longitudinal axis is canted upward 60 degrees with respect to the impact velocity vector and the aircraft's lateral axis is perpendicular to a vertical plane containing the impact velocity vector and the aircraft's longitudinal axis. For the aircraft's first row of seats, peak deceleration must occur in not more than .05 seconds after impact and must reach a minimum of 19 g's. For all other seats, peak deceleration must occur in not more than .06 seconds after impact and must reach a minimum of 15 g's.

(2) A change in velocity of not less than 42 feet per second when the seat, bench or other seating device is oriented in its nominal position with respect to the aircraft's reference system and the aircraft's longitudinal axis is yawed 10 degrees either right or left of the impact velocity vector (but in such a way as to cause the greatest load on the upper torso restraint system), the aircraft's lateral axis is contained in a horizontal plane containing the impact velocity vector and the aircraft's vertical axis is perpendicular to a horizontal plane containing the impact velocity vector. For the aircraft's first row of seats, peak deceleration must occur in not more than .05 seconds after impact and must reach a minimum of 26 g's. For all other seats, peak deceleration must occur in not more than .06 seconds after impact and must reach a minimum of 21 g's.

(Note: The aircraft's reference system is defined as consisting of three mutually perpendicular axes where the vertical axis is perpendicular to a waterline reference system of the aircraft and parallel to the station reference system and the longitudinal axis is perpendicular to the station reference system. The velocity change shall be pure translation with no angular acceleration considered.)

(3) The floor rails used to attach the seating device to the airframe must be misaligned with respect to each other by at least 10 degrees vertically (i.e. out of parallel), with the direction at the option of the manufacturer, to account for floor warp.

(4) Dynamic tests in accordance with the conditions stated in paragraph (a), subparagraphs (1), (2) and (3) are considered to be successfully completed when the performance measures (4a) through (4f) are demonstrated.

(4a) Loads in individual upper torso straps do not exceed 1,750 pounds. If dual straps are used for retaining the upper torso, the total strap loads do not exceed 2,000 pounds.

(4b) The maximum pelvic load as measured in a 11 CFR 572 dummy does not exceed 1,500 pounds.

(4c) The occupant's upper torso strap or straps remain on or in the immediate vicinity of the occupant's shoulder during the impact.

(4d) The lap belt remains on the occupant's pelvis during the impact.

(4e) the occupant's head either does not contact any portion of the cockpit or cabin or if it does, the head impact does not exceed a Head Impact Criteria (HIC) of 1,000, as determined by the test procedures defined in SAE J921.

(4f) The attachment between the seating device and the aircraft's structure remains intact (although the structure can have exceeded its limit load) and the restraint system remains intact (although it also can have experienced separation that is intended as part of its design) as long as the conditions contained in (4a), 4b), (4c), (4d) and (4e) are met.

(b) In addition to the dynamic tests and criteria defined in paragraph (a) and its subparagraphs (1) through (4f), all seats, benches, or other seating devices and its supporting structure must be designed to withstand the static loads imposed by a 215-pound occupant when subject to the aircraft's design loads as defined in the aircraft's approved flight/ground envelope.

(c) Paragraphs (a) and (b) above specify a minimum standard for new aircraft with application for type certification dated after December 31, 1985. An applicant for a type certificate has the option to depart from the criteria presented in paragraphs (a) and (b) above provided an alternate approach that achieves the same or equivalent level of occupant crash tolerance can be substantiated on a rational basis.

Mandatory Equipage of Shoulder Harnesses

The General Aviation Safety Panel affirms its earlier recommendation that all FAR Part 23 general aviation aircraft manufactured after December 31, 1984 be equipped with upper torso restraint systems. We further recommend that the the FAA consider ways to facilitate the installation of upper torso restraint systems in older general aviation aircraft, and that the FAA work with the SAE Upper Torso Restraint Committee to formulate acceptable standards for harness material and attachments to be used in aircraft manufactured after December 31, 1985.

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