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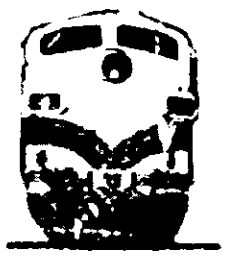

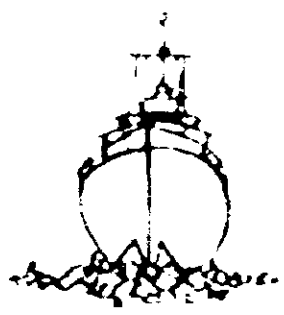

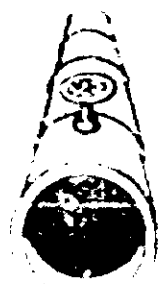

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SAFETY REPORT

GENERAL AVIATION CRASHWORTHINESS PROJECT: PHASE TWO - - IMPACT SEVERITY AND POTENTIAL INJURY PREVENTION IN GENERAL AVIATION ACCIDENTS

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16. Abstract This report is the second in a series of reports to be 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 presented a methodology for documenting impact severity. This Phase Two report presents specific data on survivable accidents. The data developed in this study suggest that the survivable envelope is defined by impact speeds of 45 knots at 90 degrees of impact angle, 60 knots at 45 degrees, and 75 knots at zero degrees. Data are presented which demonstrate that if all occupants wear shoulder harnesses, fatalities are expected to be reduced by 20 percent and 88 percent of the seriously injured persons in survivable crashes are expected to experience significantly fewer life-threatening injuries. Thirty-four percent of the seriously injured occupants of survivable accidents are expected to be less seriously injured if energy-absorbing seats are available.

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SAFETY REPORT

Adopted: March 15, 1985

GENERAL AVIATION CRASHWORTHINESS PROJECT: PHASE TWO--IMPACT SEVERITY AND POTENTIAL INJURY PREVENTION IN GENERAL AVIATION ACCIDENTS

INTRODUCTION

In the years 1972 through 1981, 36,466 accidents occurred involving general aviation airplanes. Of the 73,596 occupants of these airplanes, more than 18,614 (25 percent) were killed or 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 using shoulder harnesses and had been seated in energy-absorbing seats.

The Safety Board began a General Aviation Crashworthiness Program in 1980 to gather data to be used to further support previous Safety Board recommendations for improved crashworthiness 1/ in general aviation airplanes. Two basic approaches were taken to compile these data. One approach was for a team of trained crashworthiness investigators to complete detailed onscene investigations of selected survivable accidents 2/ to document the structural deformation of the airplanes, the impact severity of the crash, and the resultant injuries to the occupants. Acceleration loads were then calculated for each accident. The methodology for these analyses was described in the Safety Board's report, "General Aviation Crashworthiness Project, Phase One". 3/ Analyses of these selected accidents will be presented later as part of a Phase Three report. The other approach was to compile, beginning in 1982, more detailed kinematic 4/ and injury information for all general aviation accidents. This was the information used as the basis for this report.

This report places emphasis on, and provides support for, efforts to improve the crashworthiness of general aviation airplanes. It presents specific data which help to define survivable accidents, including information on impact severity and estimates of the potential benefits that are expected to result from the use of shoulder harnesses and energy-absorbing seats. In this report, "real world" occupants (actual survivors and potential survivors) define the limits of impact severity in survivable accidents.

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

2/ 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 accelerations 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.

3/ "General Aviation Crashworthiness Project, Phase One," June 27, 1983 (NTSB/SR-83/01).

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

Federal standards for occupant protection in general aviation airplanes essentially have remained unchanged for the last 30 years, despite major advances in crashworthiness technology, many of which resulted from government/industry research and investigative projects which began in the late 1950's and early 1960's. These projects, which included full-scale crash testing of a variety of aircraft, addressed all areas of crashworthiness, including postcrash fires, seats/restraints, cockpit/cabin environments, and crash acceleration environments. However, the new technology has been used only in a very limited way, primarily in agricultural application airplanes. 5/

The Federal Aviation Administration (FAA) has been testing upgraded seat and restraint systems since 1970, but to date there has been only one substantive change in the relevant regulations for general aviation airplanes--shoulder harnesses have been required on front seats of airplanes manufactured after July 18, 1978, and on some older models used in commercial operations. 6/ Appendix A presents a synopsis of the more important recommendations issued by the Safety Board to the FAA addressing various issues of crashworthiness, and the FAA's responses to them.

The National Aeronautics and Space Administration (NASA) recently 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. (Additional information on this important program is provided in appendix B.)

During the last several years, there have been increasing efforts to promote improvement in general aviation crashworthiness. In February 1983, a government/industry group, including representatives of the General Aviation Manufacturers Association (GAMA), met at NASA's Langley, Virginia, facility to study issues related to general aviation airplanes. The findings of the group regarding crashworthiness included:

- the mandatory availability and use of upper torso restraints (shoulder harnesses) in small aircraft could provide an immediate improvement in crashworthiness;
- there currently is an adequate body of knowledge for the issuance of initial rules pertaining to structural crashworthiness for small airplanes; and
- additional research is needed to define a crash scenario representative of survivable accidents on which crashworthiness performance standards can be based.

All GAMA airplane manufacturers have pledged to install voluntarily shoulder harnesses on all seats of newly manufactured airplanes. The organization has petitioned the FAA to require such installation on all small airplanes manufactured in the United States.

5/ Walhout, G. J., "Crashworthiness Observations in General Aviation Accident Investigations--A Statistical Overview", Aircraft Crashworthiness, University Press of Virginia, 1975.

6/ Title 14 Code of Federal Regulations (CFR), Section 23.785, published on June 16, 1977 (42 FR 30603).

In February 1983, the General Aviation Safety Panel (GASP), an industry task force convened at the invitation of the FAA, issued a position paper containing several recommendations dealing with crashworthiness. Like the earlier government/industry group, the task force recommended mandatory installation and use of shoulder harnesses as soon as practicable. Also, it recommended that the development of new crashworthiness design standards be expedited. One of the immediate goals of this recommendation was to ". . . provide a means for collecting meaningful accident data on the effectiveness of seat restraints and harnesses. Such 'real-world' data would be compared with experimental results in order to provide a broader basis for creating design criteria."

The Safety Board had been gathering the "real-world" crashworthiness data since January 1982. With that data and the release of the GASP recommendations, the Safety Board approached both the manufacturers and the FAA and suggested that parties cooperate to resolve the technical stumbling blocks which had plagued past efforts to secure crashworthiness improvements. The FAA, manufacturers, and other representatives from the industry responded by reconvening the GASP.

Beginning in July 1983, the GASP held a series of meetings to explore the general aviation crashworthiness issues. The Safety Board presented the data gathered in its crashworthiness program which supported heavily the GASP's efforts to develop its recommendations. As a result of the meetings, the GASP forwarded a proposal to the FAA on May 2, 1984, that defined 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. 7/

METHODOLOGY

To define the impact severity of survivable accidents and to estimate the benefits to be derived from the availability and use of shoulder harnesses and energy-absorbing seats, the Safety Board used data available in the investigative reports of 535 selected accidents that occurred in 1982 to perform a detailed analysis of crash kinematics and occupant injuries. Accidents selected as suitable for this examination were general aviation airplane accidents in which at least one occupant was fatally or seriously injured. 8/ Certain airplanes such as aerial application airplanes, homebuilt airplanes, and older airplanes of fabric and tube construction were excluded. The selected accidents also were limited to airplanes which are expected to continue to be in production and hence would be the most likely candidates for improved crashworthy designs.

Data available concerning each of these accidents were evaluated by investigators experienced in the analysis of patterns of injury causation in general aviation airplane accidents. A detailed analysis was made by examining completed investigative forms, narratives, photographs, witness statements, and medical information in order to estimate

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7/ General Aviation Safety Panel, Proposal to the Federal Aviation Administration, May 2, 1984. (For excerpts, see appendix C.)

8/ Title 49 CFR 830.2 defines "serious injury" as any injury which: (1) Requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns, or any burns affecting more than 5 percent of the body surface.

the extent to which each accident was survivable and to compile information on impact speeds and impact angles. For the purpose of this study, an accident was considered to be survivable when a livable cabin volume was maintained throughout the crash sequence and the forces transmitted to the occupant through the seat and restraint system did not appear to have or should not have exceeded the limits of human tolerance to abrupt accelerations. Therefore, an accident was considered to be survivable when at least one occupant either survived or could have survived if shoulder harnesses or energy-absorbing seats had been used.

A partially survivable accident is a survivable accident in which at least one fatality occurred that could not have been prevented. Potential survivors were identified in each accident by examining accident data describing the damage to the airplane and the injuries of each occupant. First, the "livable volume" was evaluated for each seat. Photographic documentation was the primary source of this information. To be considered livable, each space where an occupant was seated had to have remained large enough for survival throughout the crash sequence. Individual locations considered nonsurvivable were those where the livable volume had been reduced drastically or had been destroyed. An example of a nonsurvivable accident is one in which the volume had been reduced during the crash by a crushing structure that had rebounded, thus giving a final appearance of a livable volume. Secondly, the injuries of each of the occupants were evaluated separately, taking into account the availability and use of occupant restraints and the retention of seat structures in their normal positions, postcrash fires, and other important factors. An assessment was made, wherever possible, of the degree to which injuries could have been lessened by the use of shoulder harnesses or energy-absorbing seats. (A more detailed discussion of the procedures used is presented in appendix D. Appendix E presents five accident examples and the evaluation results.)

ANALYSIS

The study group for this report is comprised of 535 accidents involving 1,268 occupants, of which 391 accidents resulted in at least one fatality. In these 391 accidents, there were 859 fatalities, 74 occupants who survived with serious injuries, and 19 occupants who survived with minor or no injuries. All occupants were fatally injured in 85 percent of the 391 fatal crashes. In 144 accidents in which no one was fatally injured, 228 occupants were seriously injured and 87 occupants received minor injuries. One occupant's injuries could not be determined.

The analysis for this study group is presented in two sections: first, impact severity is discussed in terms of impact angles and impact speeds, and the impact severity envelope (referred to in this report as the survivable envelope) is determined for survivable accidents. Second, the potential for injury prevention, made possible by shoulder harnesses and energy-absorbing seats, is presented.

Impact Severity

Impact severity was defined in terms of impact angle and impact speed, the most readily available parameters that can be related to the survivability of an accident. Each accident was determined to be survivable or nonsurvivable, and, for most of the accidents, impact speeds and impact angles were estimated. After the impact severity estimates were made, each accident and occupant were represented on the polar plots which follow.

The impact severity increases with impact angle because the velocity change during the principal impact becomes greater at increasingly higher impact angles. At shallow

impact angles, the airplane "hits and skips" with relatively small velocity changes. At high impact angles, the airplane "hits and sticks," which results in a greater velocity change or a more severe impact.

The distributions of impact speeds and impact angles for survivable accidents versus nonsurvivable accidents are presented in figure 1. 9/ Each data point represents one airplane. There were a significant number of survivable accidents at impact speeds of less than 90 knots and at impact angles of less than 45 degrees. There were very few survivable accidents outside this range. In contrast, there were proportionally fewer nonsurvivable accidents at impact speeds of less than 90 knots and at impact angles of less than 45 degrees.

The occupants of the survivable accidents depicted in figure 1 are plotted individually in figure 2. The survivor plot (top) includes all occupants who survived or who could have survived. The nonsurvivor plot (bottom) represents occupants of partially survivable accidents who could not have survived even if they had been using shoulder harnesses and/or had been seated in energy-absorbing seats. These fatalities typically resulted from tree penetration at a specific seat location in the cabin or from localized cabin disruptions.

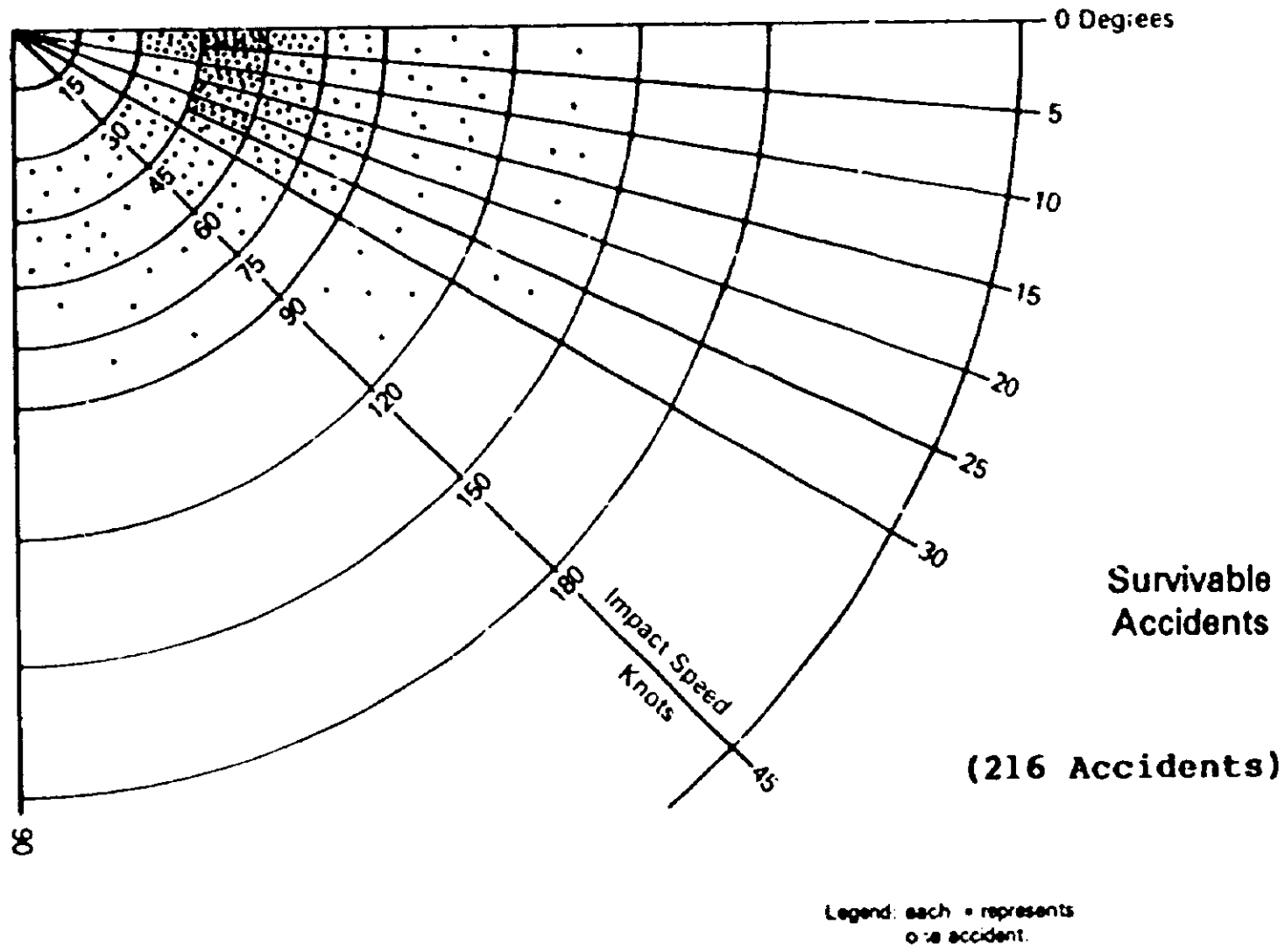
The occupants of the nonsurvivable accidents depicted in figure 1 are plotted individually in figure 3. Relatively few occupants in nonsurvivable accidents are in the area defined as an impact speed of less than 90 knots and an impact angle of less than 45 degrees. Nearly all of the occupants who did not survive were in accidents in which either one or both of those parameters were exceeded.

Figures 2 and 3 were compared to establish whether the difference between survivable accidents and nonsurvivable accidents was one of impact severity. Any difference which could be demonstrated would define the limits of the survivable envelope. First, the density plots of figure 2 (top) and figure 3 were overlayed. In another comparison, the plots were redrawn as rectangular plots so that dot density of various sectors could be directly compared. These rectangular plots also were overlayed for comparison.

These comparisons produced a boundary, or visible difference, between the two groups. The difference was most clear as a line which extends from 0 degrees at 75 to 90 knots, to 45 degrees at 60 knots, and to 90 degrees at 60 knots. A special effort was made to evaluate nonsurvivable accidents which fell inside this limit and to evaluate survivable accidents which were outside this limit.

Most of the latter accidents differed from the other survivable or nonsurvivable accidents within their respective severity ranges in some of the following ways. In the lower speed, survivable region, nonsurvivable accidents included those involving inverted crashes or direct tree or other object strikes to single occupants. In the high-speed and/or low-angle impact region, a survivable accident would include an airplane cruising into gently rising terrain and sliding over some distance to a stop without generating significant loads.

9/ Comparisons of the dot density of a sector in the low-speed range to the dot density of a sector in the high-speed range can be misleading. For example, in figure 1 between the lines forming the angles of 30 and 45 degrees, the sector between 75 and 90 knots is twice as large as the sector between 30 and 45 knots, even though both represent equal changes in velocity and angle. As a result, the relative dot density in differing speed ranges cannot be compared directly. Comparisons of dot density for differing impact angles within a given speed range are valid, however, as are comparisons among individual sectors from figure to figure in this report.



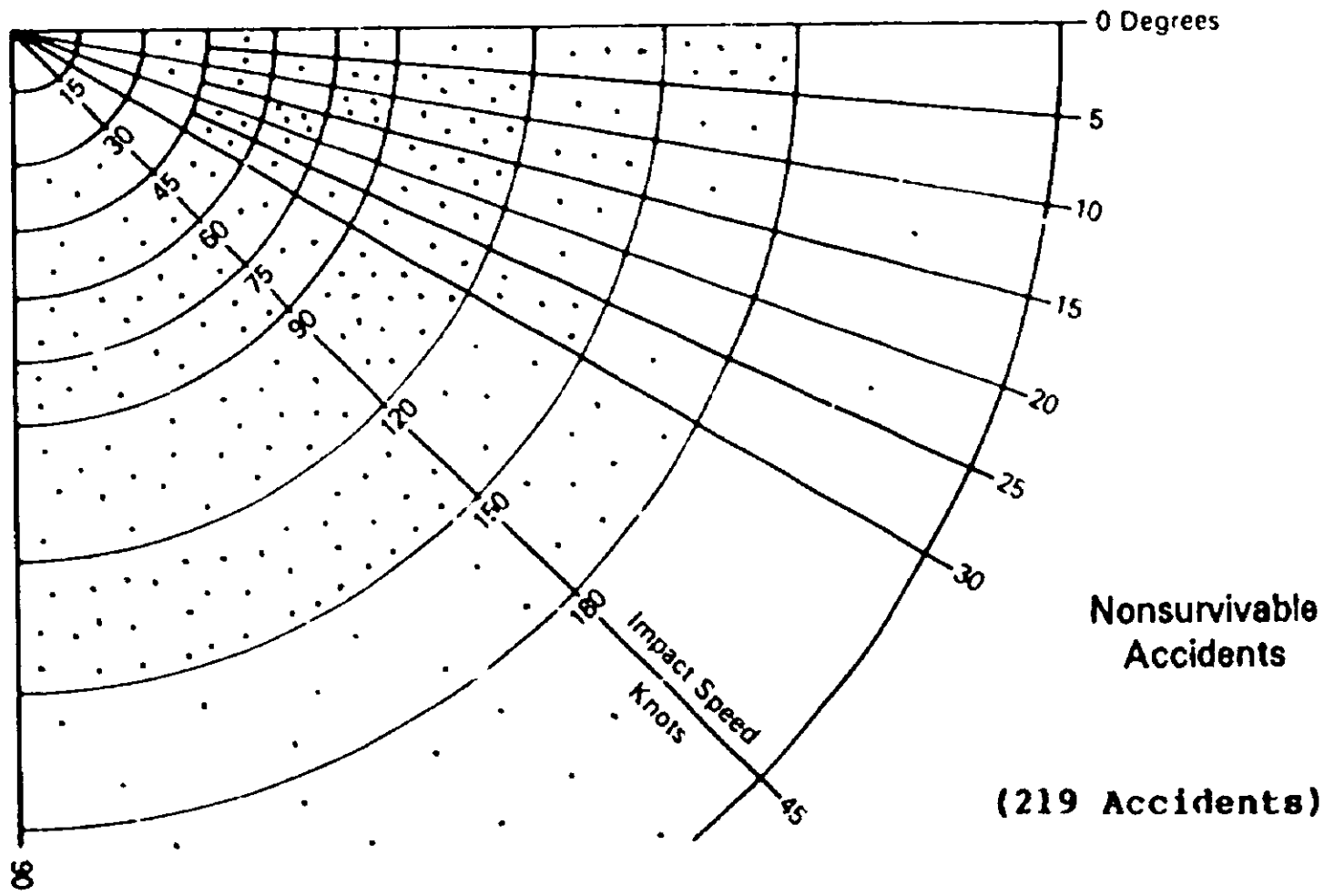
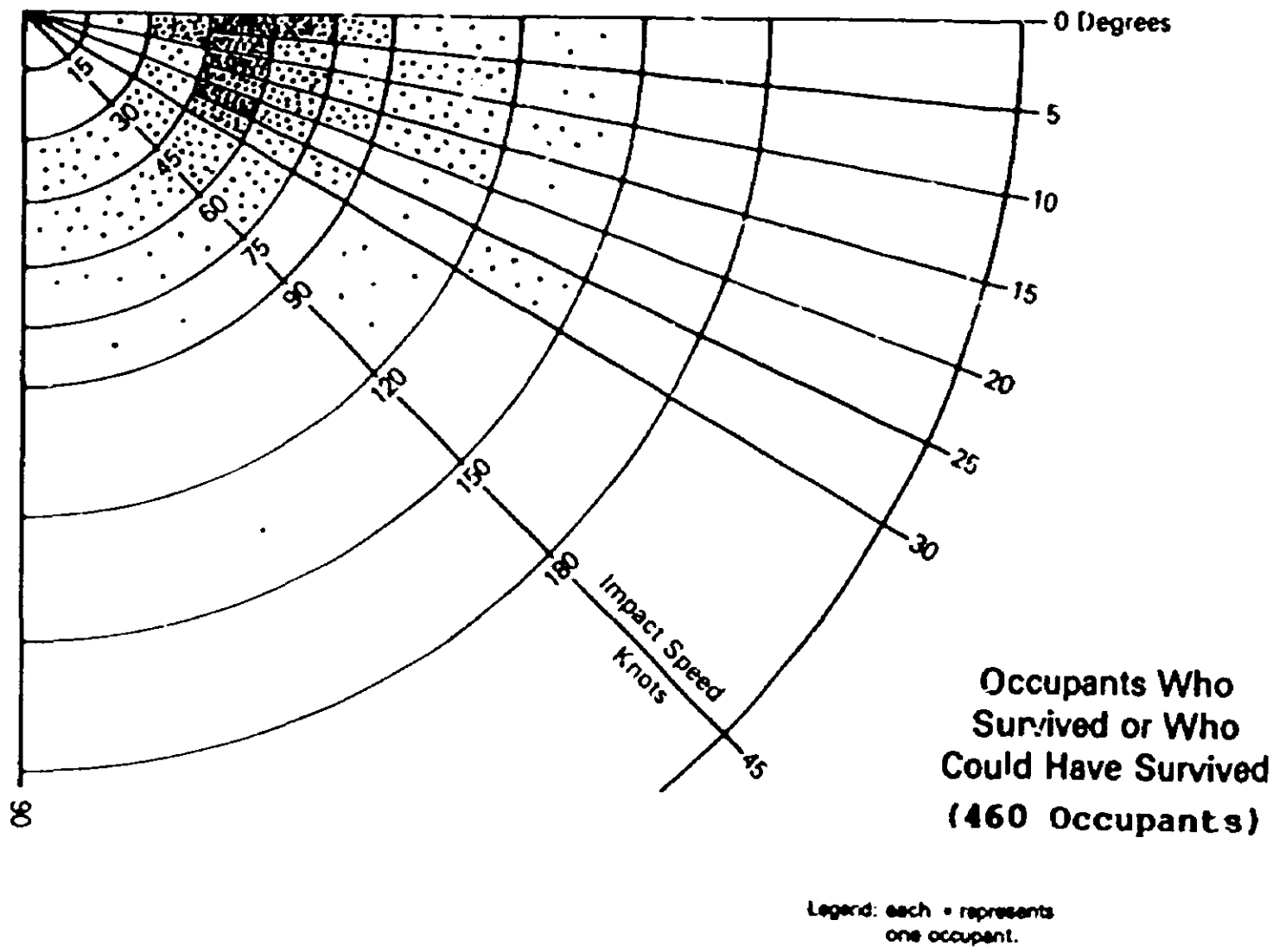


Figure 1.--Impact angles and impact speeds:
Survivable versus nonsurvivable accidents.



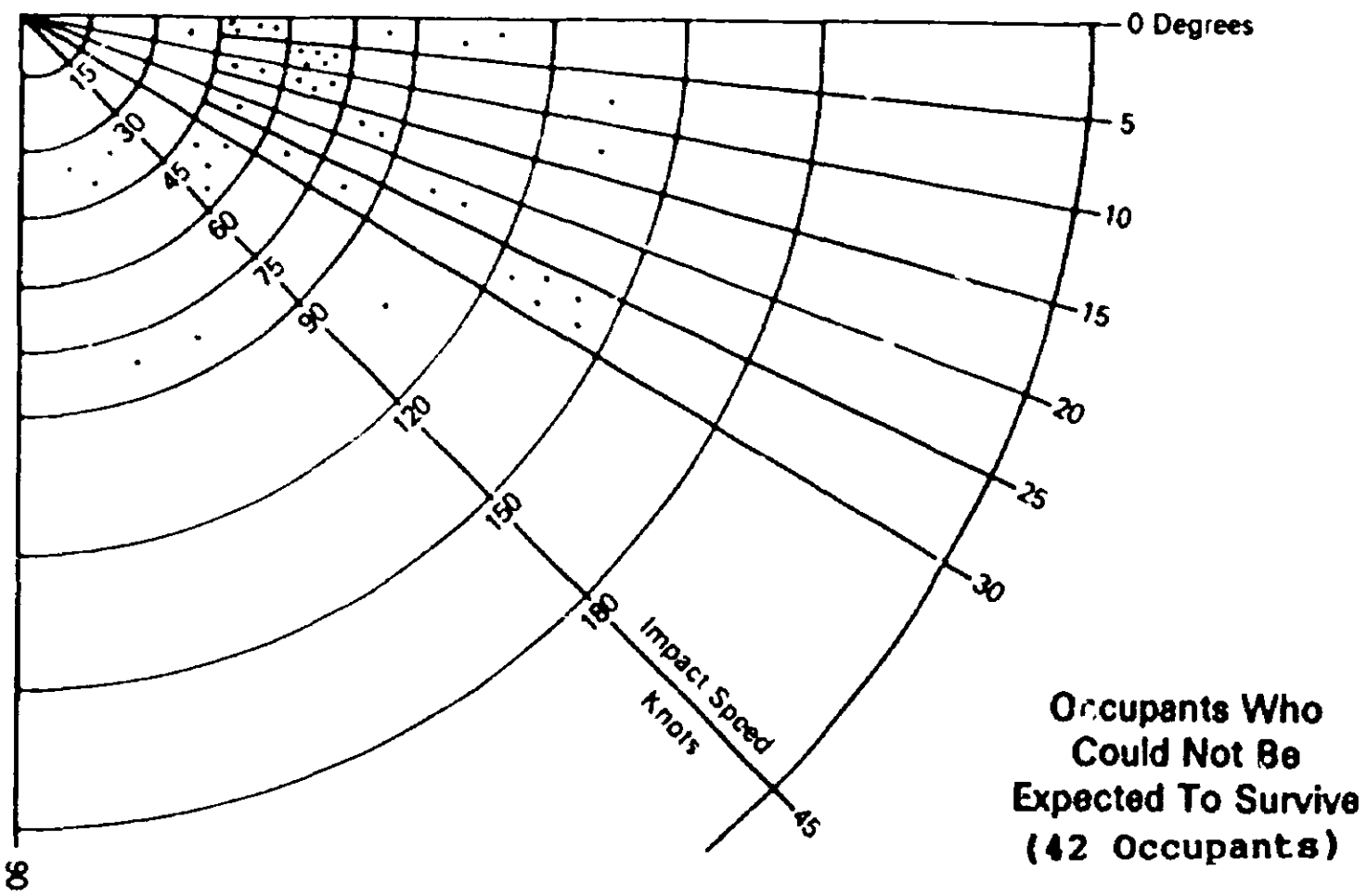


Figure 2.--Impact angles and impact speeds in survivable accidents: Occupants who survived or could have survived versus occupants whose survival was not expected.

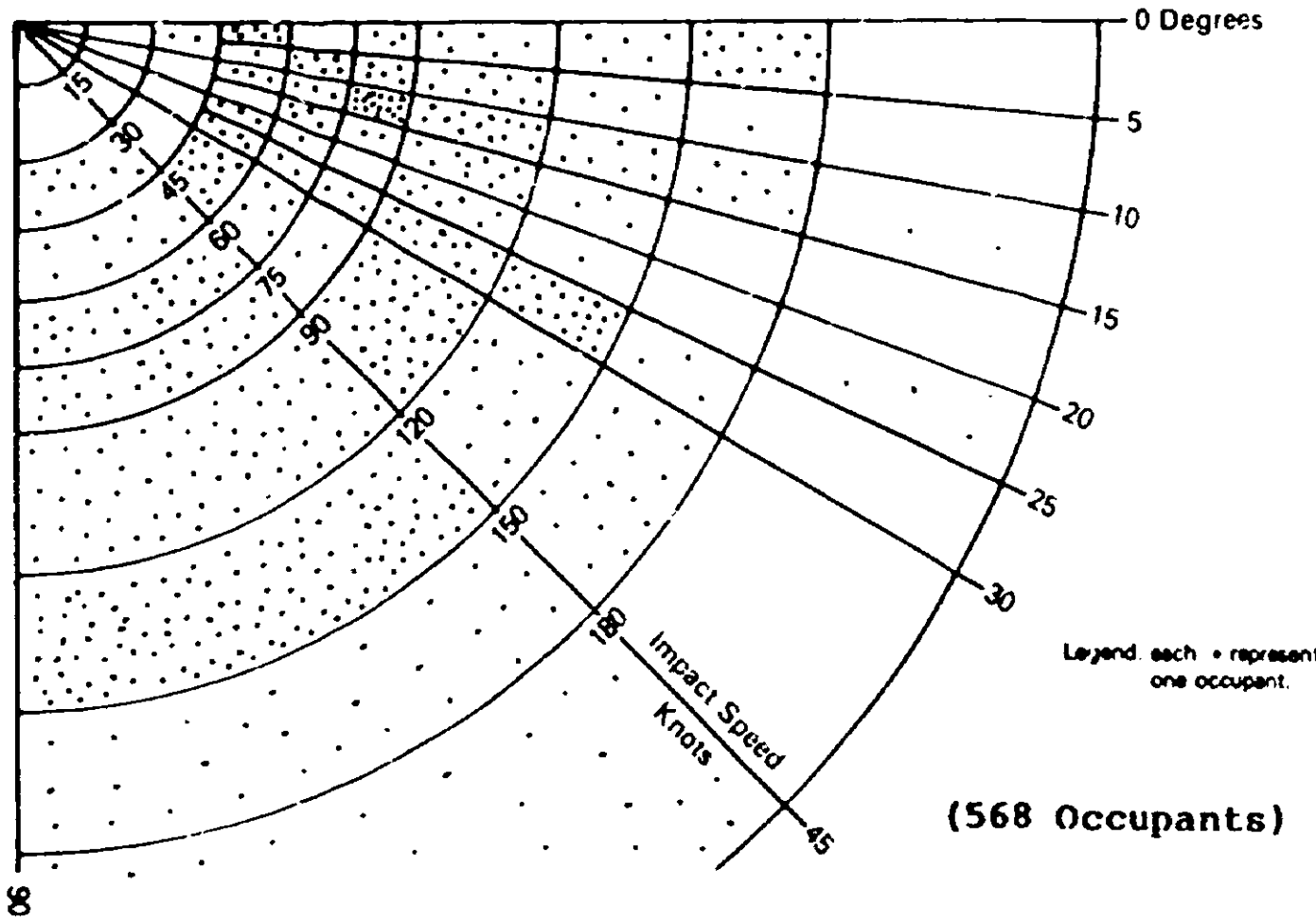


Figure 3.--Impact angles and impact speeds: Occupants in nonsurvivable accidents.

As plotted, an impact angle of 90 degrees appears to be the limit of the survivable envelope for a 60-knot impact. However, examination of the accident reports shows that the survivable impacts plotted in the 45- to 90-degree sector actually are distributed much more closely to the 45-degree line than is shown by the even distribution of the plot. Since the data in that sector are biased more toward the 45-degree line, the survivable impact speed limit at an impact angle of 90 degrees is more nearly 45 knots.

Similarly, many accidents in the impact speed range of 75 to 90 knots were only marginally survivable. The survivable occupant density depicted in figure 2 in the 75- to 90-knot sectors probably is actually aligned more closely with the 75-knot limit.

The resulting boundary of the survivable envelope is depicted in figure 4 by a line from zero degrees at 75 knots, to 45 degrees at 60 knots, and to 90 degrees at 45 knots.

Figure 5 compares impact severity for occupants who could have benefitted from using a shoulder harness with all occupants who actually survived. The top plot represents all occupants who actually survived, some of whom were wearing a shoulder harness. The bottom plot includes fatally and seriously injured occupants who could have been less seriously injured had they worn a shoulder harness. That the two presentations are so closely similar indicates that the benefits to be gained from shoulder harness use may not significantly expand the envelope in which accidents are survivable. Rather, the use of shoulder harnesses will reduce injuries and prevent fatalities in accidents which basically are survivable. The primary reason for this is that the limiting factor in expanding the survivable envelope, to include higher speeds, is cockpit and cabin integrity. The loss of cockpit/cabin integrity results in the loss of a "livable volume" in high-speed, high-angle impacts which precludes occupant survival regardless of the installation of shoulder

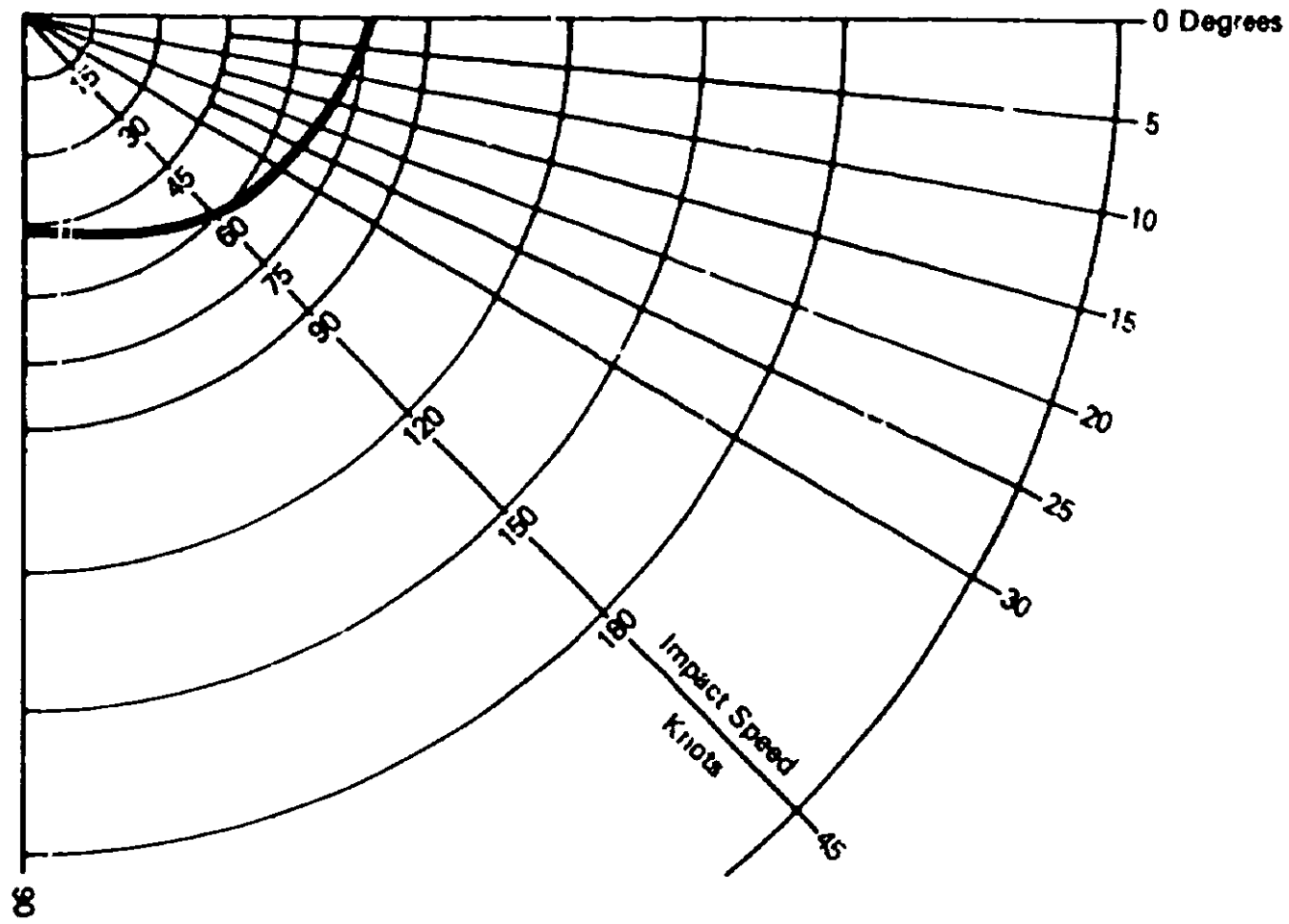


Figure 4.—Survivable envelope for general aviation accidents.

harnesses and other protective systems. To significantly expand the survivable envelope to include higher speeds, the airframe would need to be designed to higher structural limits.

Figure 6 depicts the impact severity for occupants whose injuries would have been less severe if energy-absorbing seats had been used. While the number of occupants who would have benefitted from these seats is relatively small compared to occupants who would have benefitted from shoulder harnesses, the pattern of impact speeds and impact angles in which benefit is obtained is similar. As with shoulder harnesses, the potential benefit of energy-absorbing seats requires the maintenance of a livable cockpit/cabin volume.

Potential Benefits of Shoulder Harnesses and Energy-Absorbing Seats

In addition to developing data on impact severity, an important part of this study was to assess the magnitude of the benefits that could be expected from the use of shoulder harnesses and energy-absorbing seats.

There were five survivable accidents in which shoulder harnesses were worn by only one of two front-seat occupants. A comparison was made of the relative injuries of each occupant. It was found in each case that injury severity was less for the occupant who wore the shoulder harness. The impact angles ranged from near zero degrees to 30 degrees, and impact speeds ranged from 30 to 75 knots. As expected, the higher speeds corresponded to impact angles under 15 degrees, and the higher impact angles (greater than 20 degrees) corresponded to the lower impact speeds. None of the accidents involved postcrash fire. (See table 1.)

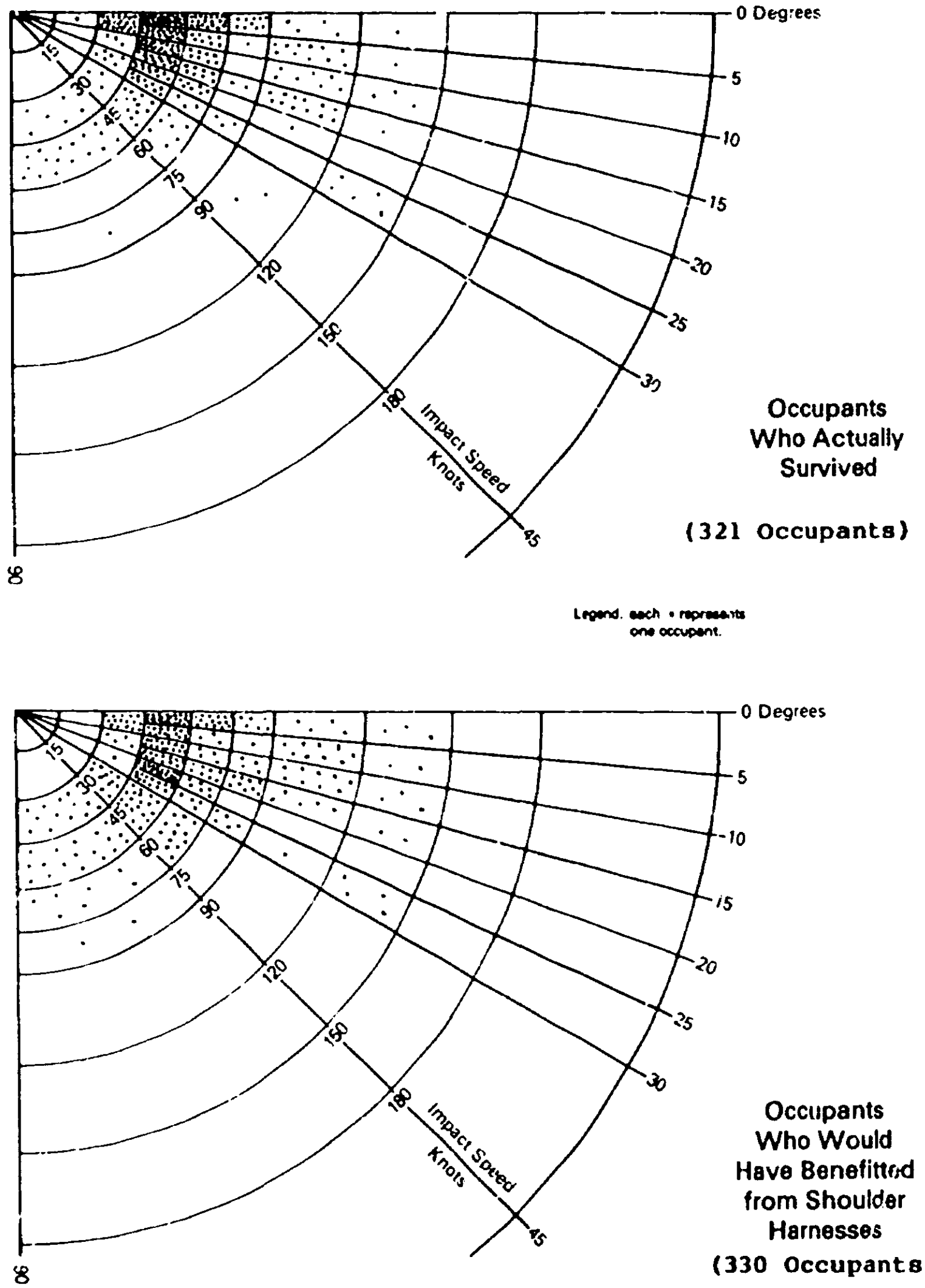


Figure 5.--Impact angles and impact speeds: Occupants who actually survived and occupants of survivable accidents who would have benefitted from using a shoulder harness.

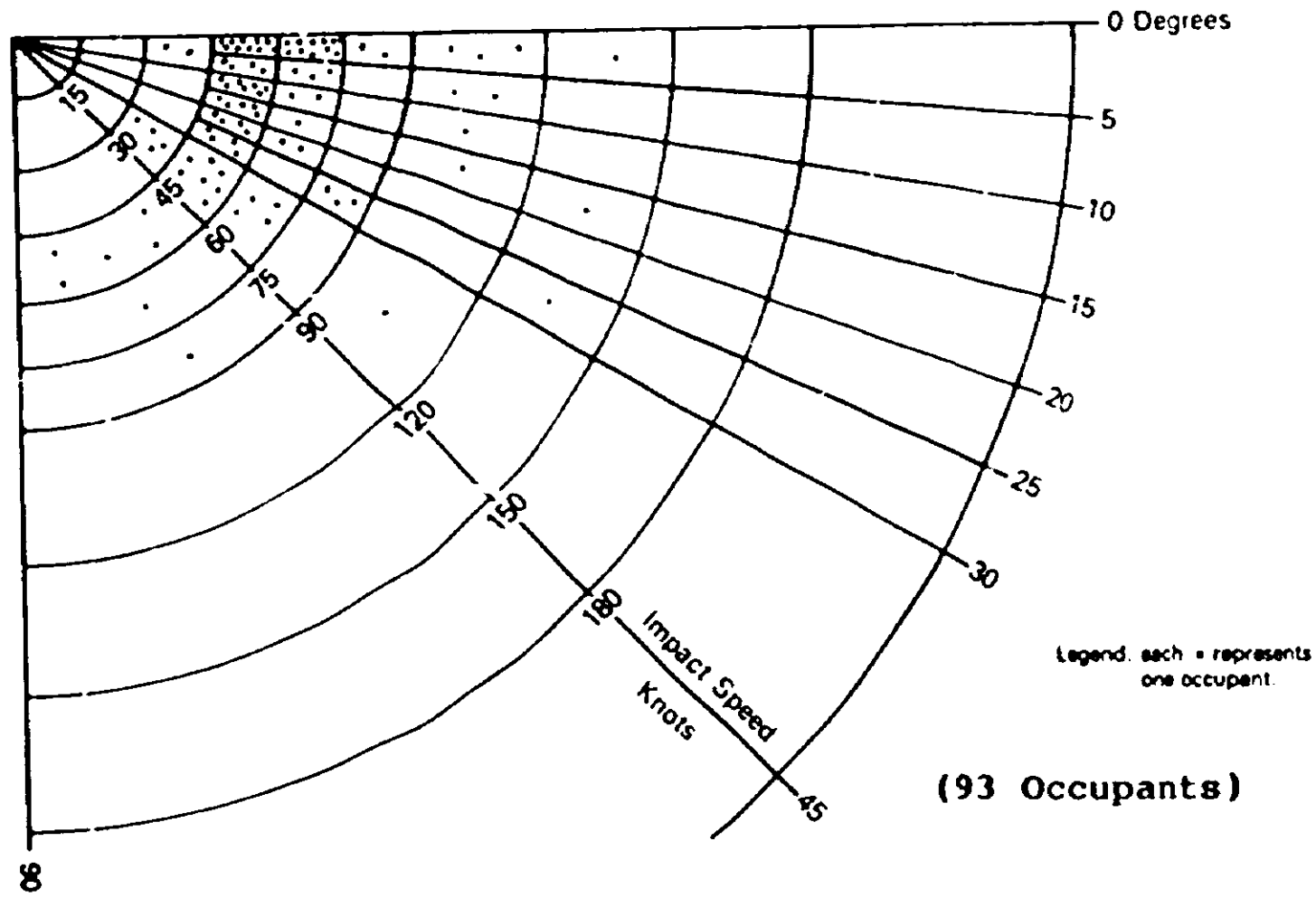


Figure 6.—Impact angles and impact speeds: Occupants who would have benefitted from energy-absorbing seats

Table 1.--Side-by Side Injury Comparison

	Injury level		Impact severity	
Example	With shoulder harness	Without shoulder harness	Impact speed (knots)	Impact angle (degrees)
1	Serious	Serious	45-60	5-10
2	Minor	Serious	60-75	0-5
3	Minor	Serious	45-60	0-5
4	Minor	Serious	30-45	25-30
5	Serious	Fatal	45-60	0-5

In each of these accidents, the occupant who wore a shoulder harness had fewer and less severe injuries than the occupant who did not. For example, in one accident each of two occupants sustained serious injuries, but the pilot, wearing a shoulder harness, sustained a broken leg and a slight concussion while the passenger without a shoulder harness sustained severe head injuries. The differences in the injuries in these comparisons were related to head and upper body injuries. Those persons who wore shoulder harnesses had markedly fewer head injuries. As would be expected, shoulder harnesses did not prevent injuries to the lower torso or to the extremities.

Estimates of Shoulder Harness Benefits.--Since this study did not evaluate accidents in which the injury levels were only minor and none, the estimates of shoulder harness benefits presented in this report are conservative. For example, there were a number of severe accidents in the 1982 data base in which occupants received only minor or no injuries, because they were wearing shoulder harnesses. While an analysis of these accidents would have further strengthened this study, there was no timely way to isolate those accidents. Further, the estimates of benefit presented in this report are based on the existing fleet of general aviation airplanes. Any improvements in airframes which are incorporated in the future that will result in improved preservation of the "livable volume" will increase the importance of shoulder harness use.

There are two important elements which must be satisfied in order to realize the full benefits of shoulder harnesses. First, the shoulder harness must be available for use. Only 40 percent of all airplane occupants examined in this study had shoulder harnesses available. The second element is that of use; a shoulder harness cannot protect an occupant from injury in a crash if it is not being worn. Of the 253 occupants whose shoulder harness use could be determined, only 100 persons, or 40 percent, actually used the available devices. (See figure 7.) Combining the availability rate (40 percent) and the usage rate (40 percent) indicates that 16 percent of the occupants were wearing shoulder harnesses.

Of the occupants examined in this study, 71 percent occupied front seats, and 97 percent of the persons wearing shoulder harnesses were front-seat occupants. This indicates that the use of a shoulder harness is confined almost entirely to front seats. Shoulder harness availability was determined for 771 of the 902 front-seat occupants. Fifty percent of those occupants (382 out of 771) had shoulder harnesses available. Shoulder harness use could be established for 240 of the 382 front-seat occupants. Forty percent of these occupants (97 out of 240) wore their shoulder harnesses.

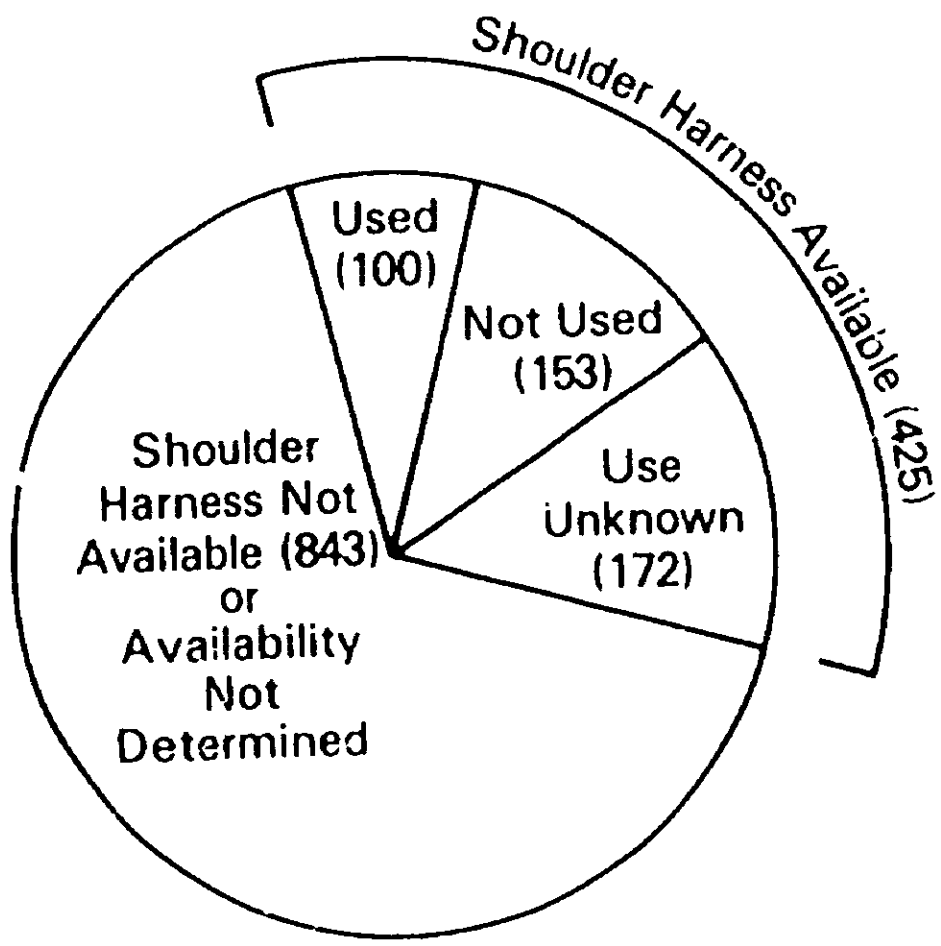


Figure 7.--Shoulder harness availability and use.

Fewer shoulder harnesses were available for rear seat occupants. Availability was determined for 304 of the 366 rear occupants. Fourteen percent of those occupants (43 out of 304) had shoulder harness available. Shoulder harness use could be established for 13 of the 43 rear seat occupants. Only 23 percent of these occupants (3 out of 13) wore their shoulder harnesses.

Many of the occupants who had shoulder harnesses available were not required to wear them. Although crewmembers are required to wear shoulder harnesses for takeoffs and landings, many did not. Some crewmembers forgot to put their shoulder harnesses back on when it became evident that an in-flight emergency would lead to a crash. These issues will be addressed in the next report of this series.

Each of the 1,268 occupants was evaluated separately. Potential benefits were established for 1,111 occupants. The potential for benefit for the 157 remaining occupants could not be determined. Detailed data were collected on specific injuries and on the extent to which these injuries either could have been prevented or could have been less serious through the use of a shoulder harness. Of the 859 fatally injured occupants in this study, the potential for benefit of shoulder harnesses could be established for 800 persons. There were 163 occupants who could have survived but did not. It is estimated that at least 13 percent (106) of the 800 fatally injured persons in these accidents would have been injured only seriously if they had been using shoulder harnesses and that an additional 7 percent (57) of the fatally injured persons would have had only minor or no injuries. The expected benefits are even more pronounced for those who were seriously injured. Fully 88 percent (201) of the 229 seriously injured persons who could be evaluated in this study probably would have received less severe head or upper body injuries, only minor injuries, or no injuries at all if shoulder harnesses had been worn. (See figure 8 and table 2.)

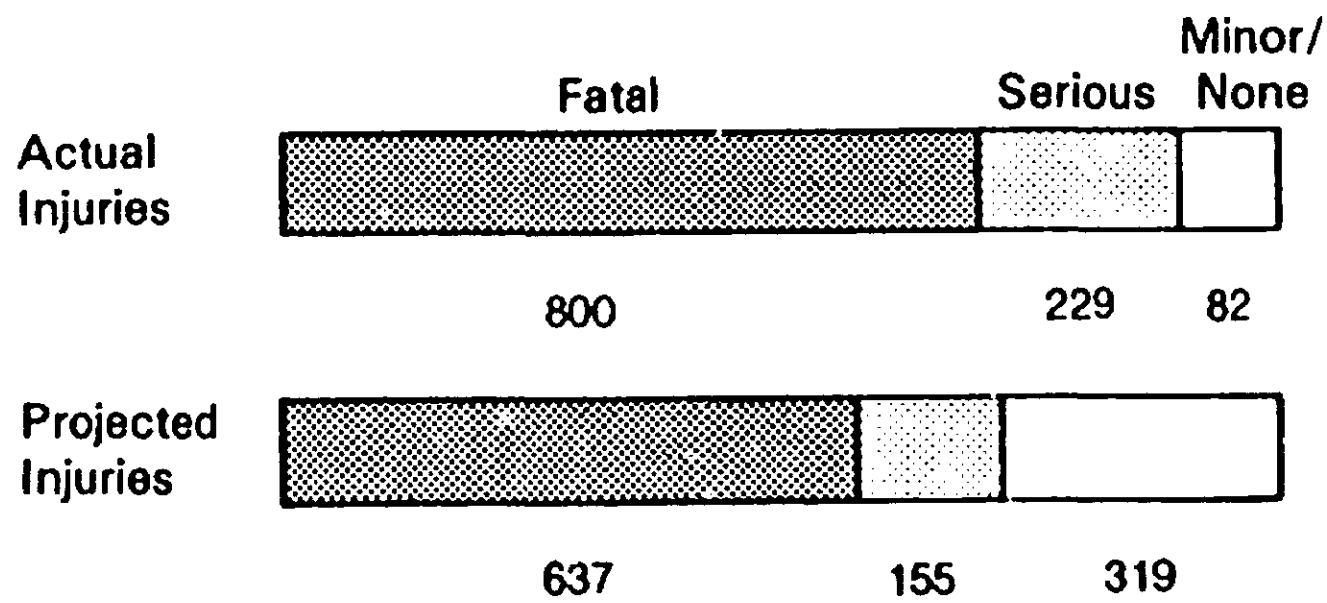


Figure 8.--Distribution of occupant injuries as actually occurring and as expected with full shoulder harness use.

Table 2.--Injury distribution as actually occurring and as predicted given full shoulder harness use.

Occupant injury level	Original injury distribution	Predicted injuries with shoulder harnesses	Percentage change
Fatal	800	637	-20
Serious	229	155	-32 (-41)
Minor/none	82	319	N.A.
	1,111	1,111	

Table 2 presents the net benefits of shoulder harness use. The 163 fatally injured occupants who would not have been injured fatally if a shoulder harness had been worn would have received, instead, serious, minor, or no injuries. Likewise, 180 of the persons (79 percent) who were injured seriously without shoulder harnesses would have had only minor or no injuries with a shoulder harness. As a result, the net change is a 20-percent reduction in fatalities and a 32-percent reduction of serious injuries. In addition to this benefit, 21 persons (9 percent) of the seriously injured occupants in this study, while still expected to have serious injuries even with a shoulder harness, would have had significantly less serious head or chest injuries. These additional benefits are presented in parentheses in table 2.

Because the data presented in table 2 include a large number of persons from nonsurvivable accidents, the percentage change in benefits of shoulder harness use is not as graphic as would be the case if only survivable accidents are considered. Table 3 presents the potential benefits of shoulder harness use for the occupants involved in survivable accidents only. For the purpose of this presentation, 584 of the fatally injured occupants were removed from the data base because they were involved in nonsurvivable accidents. Thus, in survivable accidents only, shoulder harnesses could have prevented 75 percent (163) of the 216 fatalities, and 79 percent of the 229 serious injuries. Overall, of all occupants of survivable accidents who had fatal or serious injuries, 82 percent could be expected to have received a significant benefit in terms of injury reduction through shoulder harness use.

Table 3.—Occupants in survivable accidents: Potential benefits of shoulder harness use.

Original injury distribution		Expected distribution with shoulder harnesses		Percentage
Fatal	216	Fatal	53	25
		Serious	106	49
		Minor/none	57	26
Serious	229	Serious	49 (21)	21
		Minor/none	180	79
Total of Fatal and Serious	445	Total who benefitted	343 (364) 1/	77 (82)

1/ The number 364 (82 percent) is compiled from the 106 occupants coded fatal to serious, the 57 occupants coded fatal to minor/none, the 180 occupants coded serious to minor/none, and the 21 occupants out of 49 who were coded serious to serious but would have had less serious injuries.

Estimates of Energy-Absorbing Seats Benefits.--Energy-absorbing seats cannot be expected to prevent many fatalities since the predominant injuries which they can prevent are spinal injuries. These injuries rarely result in a fatality except when they prevent timely egress. However, they usually are severe, long-lasting, and costly. Evaluation of the data in this study indicated that about 2 percent of the fatalities could have been prevented if energy-absorbing seats had been available. Many serious back and neck injuries can be prevented if vertical energy management is considered during seat design. This study found that about 34 percent of the occupants who had serious injuries could be expected to have had significantly fewer serious injuries if they had been seated in energy-absorbing seats.

An important consideration in achieving these potential benefits is that, in order for an energy-absorbing seat to provide occupant protection, the occupant must remain in an upright position and the seat must remain in place. This means that the occupant must be restrained by a lapbelt and shoulder harness. Installation of improved seats, in the absence of shoulder harness use, will not produce the improvements noted above. Moreover, it is important to note that nearly 27 percent of the seats in survivable accidents did not remain attached. 10/ When a seat does not remain securely attached to the floor, occupant injury protection offered either by the seat or by the lapbelt and shoulder harness is considerably reduced.

To summarize the benefits that could be expected from the use of shoulder harnesses and energy-absorbing seats, it was established that 20 percent of all fatalities could have been prevented by the use of shoulder harnesses and that 91 percent of the seriously injured occupants could have had less serious head, upper body, and/or back injuries with the use of shoulder harnesses and energy-absorbing seats combined. Shoulder harnesses alone could have prevented or minimized the severity of the head and upper body injuries for 88 percent of the seriously injured occupants; energy-absorbing seats could have prevented or minimized the severity of back injuries for 34 percent of the seriously injured occupants.

CONCLUSIONS

1. Shoulder harness use is the most effective method of reducing fatal and serious injuries in general aviation airplane accidents.

2. New crashworthy airframe design is the improvement which will most significantly expand the survivable envelope to higher impact speeds.

3. Impact severity, as defined by impact speed and impact angle, is a principal determinant of a survivable accident.

4. The accidents reviewed in this study generally were survivable within the envelope bounded by a line through an impact speed of 45 knots at an impact angle of 90 degrees, 60 knots at 45 degrees, and 75 knots at zero degrees.

5. A potential 20-percent reduction in fatalities could be realized if all occupants of general aviation airplanes were to wear shoulder harnesses.

6. Potentially, 88 percent of seriously injured occupants could be expected to incur significantly reduced injuries if shoulder harnesses were used.

10/ A seat attachment failure is defined in appendix D under "Seat retention."

7. A potential 2-percent reduction in fatalities could be realized with the installation of energy-absorbing seats.

8. Potentially, 34 percent of seriously injured occupants could be expected to have significantly reduced injuries if energy-absorbing seats were available.

9. Where shoulder harness availability and use could be determined, only 16 percent of the occupants were wearing a shoulder harness at the time of the crash. Shoulder harnesses were available to 40 percent of the occupants and, when available, were worn 40 percent of the time.

10. Twenty-seven percent of all seats in survivable accidents underwent some type of failure.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JIM BURNETT
Chairman

/s/ PATRICIA A. GOLDMAN
Vice Chairman

/s/ G. H. PATRICK BURSLEY
Member

March 15, 1985

APPENDIXES

APPENDIX A

NATIONAL TRANSPORTATION SAFETY BOARD GENERAL AVIATION CRASHWORTHINESS RECOMMENDATIONS WITH SUMMARIES OF FEDERAL AVIATION ADMINISTRATION RESPONSES AND SAFETY BOARD EVALUATIONS OF THESE RESPONSES

The Safety Board has issued a series of general aviation crashworthiness recommendations since 1970. A series of letters to and from the FAA discuss the various issues and anticipated actions generated by those recommendations. The last formal FAA response to those recommendations was a letter to the Safety Board that was dated March 21, 1983. That response and the current FAA crashworthiness efforts resulted in the Safety Board issuing a letter to the FAA dated September 5, 1984, excerpts of which follow.

Recommendation CY-70-42, Part 4

> [Initiate] regulatory action . . . to raise the "minor crash landing" inertia forces of 14 CFR 23.456 to a level comparable to those produced by a moderate-to-severe crash landing. Until a reasonable crash design condition is decided upon, including a specified crash acceleration pulse, it is suggested that the longitudinal inertia force be raised to 20 to 25 and the forces about other axes be similarly increased.

The FAA has responded that attempts at interim regulatory action without a technical data base would not be productive, and that energy management must be fully assessed since stronger seats have to be stiffer and thereby would transmit more crash loads to the occupant. Upon completion of its research activities concerning crash pulse definition and computer modeling, the FAA plans to initiate appropriate rulemaking.

Since its March 21, 1983, correspondence to the Safety Board, the FAA, at the GASP meeting of September 27, 1983, has made preliminary proposals for crash dynamic standards which were considered by the GASP committee. A GASP proposal for seat and restraint standards was agreed upon, and the proposal has been forwarded to the FAA. If adopted, it would fulfill the intent of Safety Recommendation CY-70-42, Part 4 for higher crash force requirements.

In view of the present FAA/industry effort toward the development of crash landing design standards and other general aviation crashworthiness requirements, the Safety Board has reclassified the status of Safety Recommendation CY-70-42, Part 4 from "Open--Unacceptable Action" to "Open--Acceptable Action" pending the outcome of these efforts.

Recommendation A-77-70

> Amend 14 CFR 23.785 to require installation of approved shoulder harnesses at all seat locations as outlined in NPRM [Notice of Proposed Rule Making] 73-1.

The FAA forwarded to the Safety Board a copy of a cost-benefit analysis for shoulder harness installation, and the FAA intends to consider this cost-benefit analysis, GAMA recommendations on shoulder harnesses, and the recommendations from the "Small Airplane Stall Speed Study" committee in determining what action to take on this issue.

Safety Recommendation A-77-70 encompasses two specific areas: (1) installing shoulder harnesses on all seats on newly manufactured airplanes, and (2) requiring existing airplanes to be retrofitted. GAMA has petitioned the FAA to require shoulder harnesses on all seats of small airplanes manufactured after 1984. Also, GAMA and the Society of Automotive Engineers (SAE) are working on shoulder harness design requirements which will facilitate such installations. Industry representatives also have voiced support for voluntary efforts to retrofit the current fleet with shoulder harnesses at most seats.

The recommendation for shoulder harness retrofitting at all seat locations should be addressed, and the GASP forum is an ideal one in which to discuss this issue. The Safety Board recognizes that the current GASP task of defining dynamic testing and installation requirements must be resolved first. The Board has submitted data to the GASP which clearly show that many lives can be saved if the current airplane fleet is equipped with shoulder harnesses. Until the FAA responds on the retrofit issue and takes action on the GAMA petition to require shoulder harnesses on all seats, the status of Safety Recommendation A-77-70 will remain in an "Open--Unacceptable Action" status.

Recommendation A-80-125

> Require that those general aviation aircraft manufactured to include attachment points for shoulder harnesses at occupant seats be fitted with shoulder harnesses no later than December 31, 1985, and, in the interim, require this modification as a requisite for change in FAA registration.

The FAA stated that Safety Recommendation A-80-125 was addressed in its cost-benefit analysis and that it will be evaluated with Safety Recommendation A-77-70. Therefore, pending further evaluation by the FAA of the retrofit issue and in view of the close relationship of this recommendation to Safety Recommendation A-80-127, the Safety Board will change the status of Safety Recommendation A-80-125 from "Open--Acceptable Action" to "Open--Unacceptable Action."

Recommendation A-80-126

> Develop, in coordination with airframe manufacturers, detailed, approved installation instructions for installing shoulder harnesses at each seat location in current models and types of general aviation aircraft in which shoulder harness attachment points were not provided as standard equipment. Publish and provide these instructions to owners of those aircraft by December 31, 1982.

The FAA states that design functions are the responsibility of the manufacturers or owners and that the provisions of Safety Recommendation A-80-126 are not within the scope of the FAA's responsibility.

As stated in its November 5, 1982, letter, the Safety Board recognizes that the FAA does not perform detailed design work; however, the FAA, on an almost daily basis, tests and evaluates crashworthiness designs at the Civil Aeromedical Institute (CAMI). The staff at CAMI has been constructive in suggesting improvements in seat and restraint designs developed by manufacturers. It is that type of coordination to which the Board refers. Members of GAMA are voluntarily involved in pursuing the intent of this recommendation. GAMA has stated that the three major manufacturers now have FAA-approved kits to retrofit shoulder harnesses to older airplanes and that it intends to promote the retrofitting of such restraint devices. The Safety Board recognizes that there may be some older airplanes in which retrofitting is not possible, but the majority of the fleet now can be retrofitted with existing kits. However, to be most effective, this effort will require FAA support if shoulder harnesses are to be installed in a large number of airplanes. The FAA has informed the GASP committee that it intends to publish an Advisory Circular to assist designers in developing better restraint and seat systems, and that it will promote the installation and use of shoulder harnesses in general aviation airplanes. The Safety Board considers the proposed FAA action as fulfilling the intent of Safety Recommendation A-80-126. Therefore, Safety Recommendation A-80-126 has been reclassified from "Open--Unacceptable Action" to "Open--Acceptable Alternate Action." The Board encourages the FAA to expedite the development of the Advisory Circular, and it requests that the FAA provide the Board its plans to support the voluntary retrofit effort as announced at the GASP meeting.

Recommendation A-80-127

Require that those general aviation aircraft for which FAA-approved harness installation instructions have been developed be fitted with shoulder harnesses at each seat location no later than December 31, 1985, and, in the interim, require this modification as a requisite for change in the FAA registration.

The FAA stated that Safety Recommendation A-80-127 was addressed in the cost-benefit analysis and that it will be evaluated with Safety Recommendation A-77-70. Therefore, pending FAA's further evaluation of Safety Recommendations A-77-70 and A-80-125, the status of Safety Recommendation A-80-127 also will remain "Open--Unacceptable Action."

Recommendation A-80-128

At established intervals, extend the application of all newly established occupant protection provisions of 14 CFR 23 to all newly manufactured general aviation aircraft.

The FAA has responded that the broad general scope of such a recommendation makes it difficult to determine what occupant protection provisions the Safety Board is addressing. The FAA believes that periodic Part 23 regulatory reviews, now part of its regular process, adequately address the intent of Safety Recommendation A-80-128. Moreover, retroactive application of new regulations must comply with Executive Order 12291 and cost-benefit analysis, "illustrates that retrofit schemes are typically very costly, with little identifiable benefit."

It was not the intent of Safety Recommendation A-80-128 that airplanes already manufactured be retrofitted. Rather, its intent was to eliminate the "grandfather" clause under which airplanes type-certificated many years ago still can be manufactured today without incorporating known safety improvements. Manufacturers repeatedly introduce

significant new features in aircraft during yearly model changes using the same type certificate. The Beech Bonanza, for example, has had many new seat designs during the 35 years since its type certificate was issued.

The Safety Board believes that newly established occupant protection provisions, such as improved seat designs in newly certificated airplanes or in new models of existing airplanes, should be extended by regularly scheduled Part 23 design reviews to all newly manufactured airplanes. Pending further FAA review, the status of Safety Recommendation A-80-128 will remain "Open—Unacceptable Action."

Recommendation A-80-129

Revise 14 CFR 23.785(j) to incorporate performance standards and test criteria to insure that an acceptable level of occupant safety is achieved through cabin "delethalization."

The FAA has restated its belief that it is not feasible to proceed in accordance with Safety Recommendation A-80-129 because of its broad general scope. Moreover, the FAA suggests that advisory material developed in the FAA general aviation crash dynamics program will be sufficient to supplement regulatory actions.

Both Safety Board and FAA accident investigations have identified numerous areas where present cabin delethalization measures did not work. No standards exist to define acceptable methods to prove that the delethalization designs perform as intended. The Safety Board is not attempting to limit the many ways in which these problems can be solved; it only seeks to limit the manufacturing of aircraft with inadequate safety provisions. If the FAA will not specify test and performance standards that ensure adequate safety designs, so called "delethalized airplanes" that cause injury will continue to be manufactured. Since the FAA will not act on this recommendation, Safety Recommendation A-80-129 has been placed in a "Closed—Unacceptable Action" status.

Recommendation A-80-130

Revise current standards for seat and restraint systems to incorporate needed crashworthiness improvements identified in FAA Research Project reports.

Although the FAA concurred with the intent of Safety Recommendation A-80-130, it planned no definitive action without specific information concerning crashworthiness improvements. Since this response, the Safety Board has learned informally that the FAA is in the process of developing an Advisory Circular for crashworthy seat design because investigations have disclosed that there are deteriorated seat pans in the fleet which rip easily when a tear starts. Although the FAA's staff has stated that Part 23 will never provide the standards to solve crashworthiness problems, the Board believes that seats and restraints need to be designed to standards other than just strength requirements. However, based on the FAA staff's proposed development of an Advisory Circular to establish broader guidance, the status of Safety Recommendation A-80-130 has been changed from "Open--Unacceptable Action" to "Open--Acceptable Alternate Action." The Board encourages the FAA to expedite the development of the Advisory Circular and would like to receive a timetable for its development as well as an outline of its proposed content.

Recommendation A-80-131

Establish standards for the dynamic testing of occupant protection devices required in general aviation aircraft.

The FAA stated in a response of April 3, 1982, that it was waiting to determine dynamic load characteristics, and it asked the Safety Board to identify other "devices" to which it might have had reference. Based on the Safety Board's further clarification in its letter of November 5, 1982, the FAA stated on March 21, 1983, that it appears that the intent of Safety Recommendation A-80-131 would require testing of all immediate components of the cockpit/cabin environment without sufficient rationale or justification. The FAA concluded that testing would be an enormous undertaking and inconsistent with the Regulation by Objective concept the FAA was then advocating, and that the Safety Board should reconsider its position.

The Safety Board recommended that dynamic testing of occupant protection devices be required in general aviation aircraft. The reason the word "devices" was used is that there are many ways to protect occupants. The most straightforward approach led to the design of the seats and seatbelts and shoulder harnesses as we know them today. However, in the future, a manufacturer may opt to use energy-absorbing cabin structures to reduce occupant crash loads. Such energy-absorbing devices should be proven by dynamic testing. For instance, an effective energy-absorption device could be a better landing gear design.

A manufacturer's representative at the GASP meeting agreed that standards for dynamic testing are needed. The CAMI has been testing full-scale fuselages for years, and many deficiencies have been found in occupant protection devices that would not have surfaced except for dynamic testing. This type of testing of new aircraft models would not be an enormous undertaking; it is the only valid way to test the effectiveness of devices that are to function in a dynamic environment.

Again. with the formation of the GASP crashworthiness committee, the upcoming Part 23 regulatory review, and the FAA's crashworthiness program plan, the Safety Board looks forward to progress in increased occupant protection in general aviation airplanes. Therefore, in view of these positive steps, the status of Safety Recommendation A-80-131 has been changed from "Open—Unacceptable Action" to "Open--Acceptable Action" pending the results of these activities.

APPENDIX B

COMPARISON OF STUDY DATA WITH NATIONAL AERONAUTICS AND SPACE ADMINISTRATION CRASH TEST DATA

In 1973, the National Aeronautics and Space Administration (NASA) initiated full-scale crash testing of general aviation airplanes in an effort to define the dynamic response of airplane structure, seats, and occupants during survivable crashes. The 24 tests, which were concluded in 1982, were accomplished by crashing airplanes into concrete or dirt under controlled flight conditions. The impact angles and impact speeds for the tests were chosen to closely approximate impact speeds and angles of actual general aviation airplane crashes. These tests provided data about structural and occupant response which are useful to designers involved in the development and testing of new crashworthy systems. A comparison of the NASA data with data from the actual crashes of general aviation airplanes described in this report is useful in confirming that the tests were representative of actual survivable accidents. The current Safety Board study of impact data confirms that the NASA testing series represented real-world general aviation survivable crashes. Impact severity data presented in NASA Technical Paper 2083 11/ was compared with the data in this study.

The 24 sets of impact speeds and impact angles generated by the NASA tests are shown in figure 9. This figure shows that most of the NASA tests fall within the impact severity envelope of survivable accidents presented in this study. The three tests outside the envelope were considered survivable because the impacts to concrete resulted in small velocity changes and small accelerations. One test within the survivable envelope (45 degrees and 52 knots) was only partially survivable because of the crushing in the cockpit area. Another test within the survivable envelope was considered nonsurvivable because of the high accelerations and extreme crushing (loss of a livable volume). That test consisted of an airplane impacting soft dirt. The dirt impact resulted in an abrupt stop and high accelerations instead of the typical impact and slide exhibited in other tests which impacted concrete.

In summary, the NASA tests and the results of this Safety Board crashworthiness study combine to provide a foundation for future crashworthiness design efforts. The present Safety Board study has yielded real-world data concerning the limits of the impact severity envelope of survivable accidents, and the NASA test results provide the precise engineering data which are the basis for the mathematical models needed for designing better crashworthy equipment.

11/ National Aeronautics and Space Administration (NASA) Technical Paper 2083. "Correlation and Assessment of Structural Airplane Crash Data with Flight Parameters at Impact, 1982."

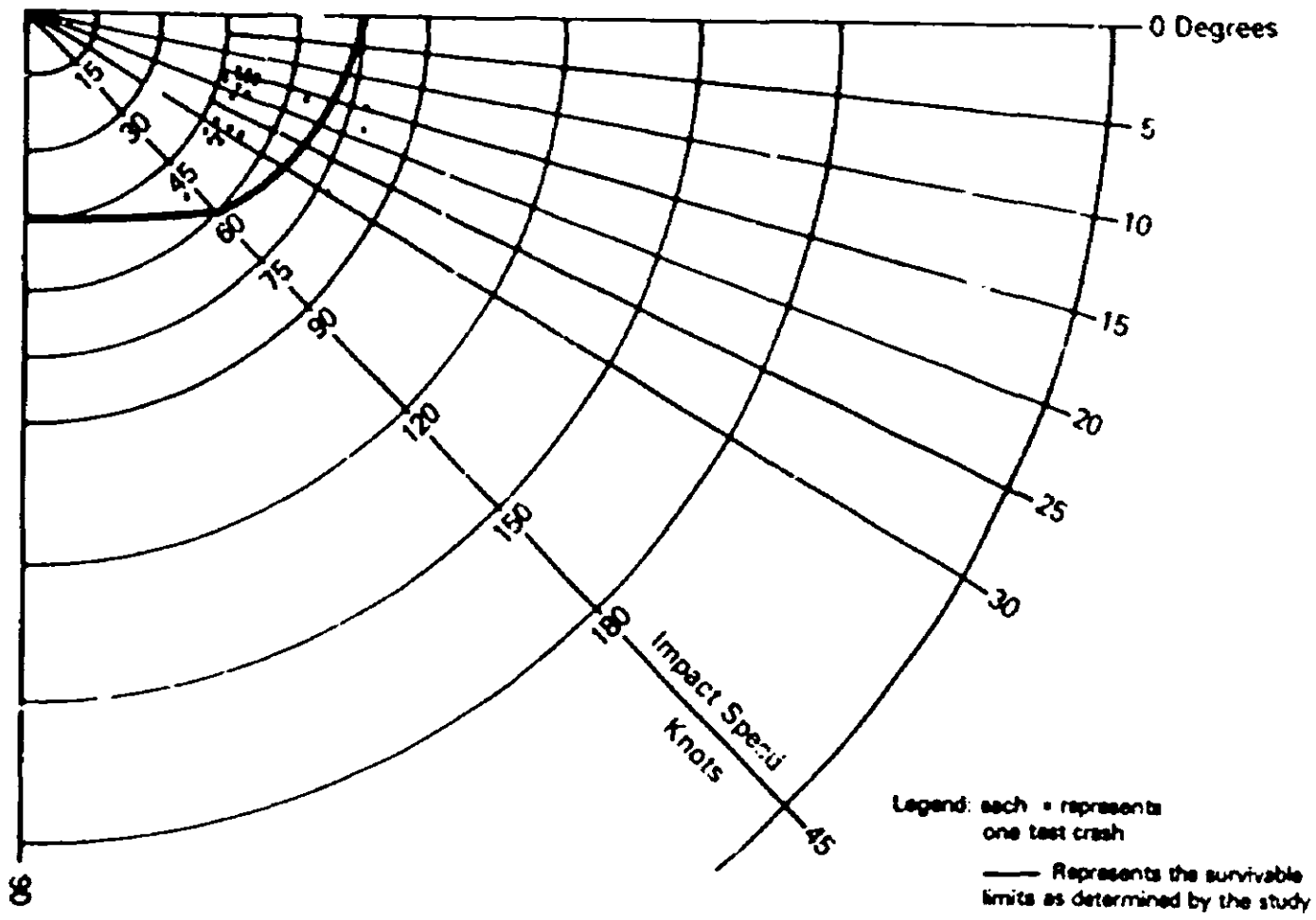


Figure 9.—Impact angle and impact speed:
Comparison of NASA test crashes and limits of the survivable envelope.

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 decleration 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.

APPENDIX D

METHODOLOGY

General

In 1982, the Safety Board began collecting substantially more detailed information on general aviation accidents than it had in the past, which could be used to define crash severity and injury causation factors. For the first time, more complete information on airplane speed, impact angles, and terrain condition was available for analysis as was more complete documentation of seats, restraint systems, and occupant injuries.

In order to select accidents particularly suited for a study on the potential for injury reduction, the Safety Board's most recently completed general aviation data base (1982) was examined. A subset of accidents in this data base was selected which represented only fixed-wing airplanes in which at least one occupant sustained fatal or serious injuries. From this subset, certain accidents were eliminated: principally those which involved older airplanes of fabric and tube construction, home-built airplanes, and agricultural application airplanes (crop dusters). Also eliminated from this study were aircraft involved in on-ground collisions. The remaining airplanes were those which are or could continue in production and which would not be expected to be eliminated from the general aviation fleet in any substantial numbers in the next few years.

The resulting set of 535 accidents was evaluated by Safety Board investigators experienced in the patterns of injury causation in general aviation accidents. All records pertaining to each of these accidents were collected, including reporting forms, narratives, photographs, witness statements, and medical information. A detailed analysis was made of this information and qualitative estimates were made of the extent to which the accident was survivable. The injuries of each of the 1,268 occupants were evaluated separately, taking into account the availability and use of occupant restraints, the retention of seat structures in their precrash position, postcrash fires, and other important features. The formats used for recording the occupant injury and airframe impact severity information are presented on the next two pages.

Potential survivors were identified by examining injuries and airplane damage. This examination was applied on a seat-by-seat basis for each occupant in each airplane. First, it was determined whether a livable volume was available around each seat. Each space where an occupant was seated had to remain esentially uncompromised throughout the crash sequence. Photographic documentation was the primary source of this information. Seat locations considered nonsurvivable were those where the livable volume had been destroyed or where the volume had been violated severely during the crash by a crushing structure that had rebounded, thus giving a final appearance of a livable volume. Some spaces were considered nonsurvivable while the rest of the airplane was considered survivable. For example, a tree impinging into one seat location may render that position nonsurvivable while other seat locations are not affected. Proximity of an occupant to the crush line (flat spot on the airplane caused by ground contact) also affects survivability. Investigative experience has shown that an occupant located near or below the crush line normally will receive fatal accelerative injuries.

Kinematics Study - Airplane Data As of Jul-13-1983 Page 1397

File	Date	Location		Injuries Fat	Ser	Min	Non	Unk	Damage	Make Model
1603	Aug-21-1982	ARTHUR	ND	0	0	0	4	0	DEM	MOONEY M20F

Accident Number	Phase	Fire	Not Applicable	N/A Reason	Initl.
DEN82DA170	LAN	UNK	---	---------	- -

Fire	Flight Path Angle	Terrain Angle	Impact Velocity
1. YES	1. UP	1. UPSLOPE	1. 0 - 15
2. NO	2. DN	2. DNSLOPE	2. 15 - 30
3. UNRELATED	3. 0 - 5	3. 0 - 5	3. 30 - 45
	4. 5 - 10	4. 5 - 10	4. 45 - 60
	5. 10 - 15	5. 10 - 15	5. 60 - 75
	6. 15 - 20	6. 15 - 20	6. 75 - 90
	7. 20 - 25	7. 20 - 25	7. 90 - 120
	8. 25 - 30	8. 25 - 30	8. 120- 150
	9. 30 - 45	9. 30 - 45	9. 150- 180
	10. 45 - 90	10. 45 - 90	10. 180+

Keywords :

Notes :

000030

Kinematics Study - Occupant Data

File	Occupant Position	Shoulder Available	Harness Used	Seats Energy Absorber	Stayed in Place
		1. Yes 2. No 3. Unk.	1. Yes 2. No 3. Unk.	1. Yes 2. No 3. Unk	1. Yes 2. No 3. Unk.

Region of Injury	Reduced by Harness EA				Table of injury improvements	
					Shoulder Harness	Seat (EA & Retention)
	yes	no	yes	no		
	___	___	___	___	1. Fatal to Fatal	1. Fatal to Fatal
	___	___	___	___	2. Fatal to Serious	2. Fatal to Serious
	___	___	___	___	3. Fatal to Minor	3. Fatal to Minor
	___	___	___	___	4. Fatal to None	4. Fatal to None
	___	___	___	___	5. Serious to Serious	5. Serious to Serious
	___	___	___	___	6. Serious to Minor	6. Serious to Minor
					7. Serious to None	7. Serious to None
					8. Minor to Minor	8. Minor to Minor
					9. Minor to None	9. Minor to None
					10. None to None	10. None to None
					11. Fatal to Unknown	11. Fatal to Unknown
					12. Serious to Unknown	12. Serious to Unknown
					13. Minor to Unknown	13. Minor to Unknown

Initials

_____

Notes

Injury information came primarily from medical reports and autopsies. Injuries that could have been reduced or eliminated by the use of shoulder harnesses or energy-absorbing seats were noted. The evaluator then attempted to determine whether the occupant could have survived if the injuries had been less severe or eliminated.

Each accident was evaluated by examining occupant injury and evidence supporting estimates of impact speed and impact angle. Data were documented that detailed shoulder harness availability and use, seat retention, and shoulder harness and energy-absorbing seat effectiveness. These data were recorded on an occupant injury form and an airplane impact severity form.

Occupant Injury

An occupant injury form was completed for each occupant even if the injuries of that occupant were minor or none.

Shoulder harnesses available.--Shoulder harnesses were considered available if the accident report so stated or for front seats of airplanes manufactured after July 18, 1978. All seats on Beechcraft airplane models from 1975 on were considered to be equipped with shoulder harnesses. While some models of general aviation airplanes had shoulder harnesses installed as options before 1978, the number was considered to be small. Data recorded from the older airplanes confirmed that few older airplanes had shoulder harnesses.

Shoulder harness use.--In many cases it could not be determined whether shoulder harnesses were used. Determinations were made predominantly on the strength of written documentation of the investigation and on occupant or rescue personnel statements, when available.

Energy-absorbing seats.--The only seats that were considered energy absorbing were Piper's "S" tube seats. In fact, other seat designs, such as the Beech Musketeer seats, can absorb significant amounts of energy, but they were not coded as energy absorbing since energy absorption was not a part of the seat design concept.

Seat retention.--If a seat separated from its attachment points, or if several of the seat feet or legs became detached, the seat was classified as loose. A seat that is loose, even if it stays close to its normal position, offers little protection. Loose seats were coded as "not staying in place."

Actual Injuries Versus Predicted Injuries

Table of predicted injuries.--These data were compiled under the assumption that shoulder harnesses were not worn and energy-absorbing seats were not available. The available data were evaluated to determine the original injury index and the predicted injury index if shoulder harnesses and energy-absorbing seats were used. 12/

12/ Injury index: The level of injury--fatal, serious, minor, and none.

In cases where shoulder harnesses or energy-absorbing seats were used, the level of injury which would have occurred had these devices not been used was determined. For example, if a seriously injured occupant would have received fatal injuries if that occupant had not worn a shoulder harness, "fatal to serious" would have been coded.

For a complete evaluation of the benefits of shoulder harnesses and energy-absorbing seats, it is necessary to go beyond the injury index level. Serious injuries range from a fractured bone to severe internal injuries. An occupant's skull fracture and broken leg would result in an injury index of serious. If a shoulder harness would have prevented the critical head injury, the occupant still would have a broken leg and the injury index would remain "serious." Such a circumstance would be coded as "serious to serious," thus ignoring the significant head injury improvement provided by the shoulder harness. Therefore, a further breakdown of injuries was required.

Region of injury reduced by shoulder harness and energy-absorbing seat.--Body regions of injury were given numerical codings when a significant injury was documented. The injury then was evaluated to determine whether shoulder harnesses or energy-absorbing seats would have prevented the injury. The evaluations were done even though the overall injury level might not have been reduced.

Airplane Data

Fire.--Information about fires was examined to determine whether each fire was the result of a crash or was an unrelated fire such as that from a dropped cigarette.

Flight path angle.--The flight path angle is the angle of the path of the airplane as it descends or climbs relative to the horizon. Flight path information data is a direct entry item in the Safety Board accident investigation forms. When these data were not recorded, photographs, drawings, witness statements, and the accident report's narrative were reviewed to determine the flight path angle.

Terrain angle.--Terrain angle is the angle of the terrain relative to the horizon with reference to the direction of airplane travel. When an airplane impacts sloping terrain, the terrain is considered to have an "up" angle, if the airplane impacts into rising terrain relative to the direction of flight.

Impact angle.--The impact angle is the difference between the flight path angle and the terrain angle. A 30-degree impact angle could result from a level flight impact into 30-degree rising terrain or from a 30-degree dive into flat terrain.

Impact Speed.--Impact speed is the airplane's speed in knots during the principal impact. 13/ The velocity was estimated based on the aerodynamic properties of the airplane, such as stall speed and cruise speed, and also was based on airplane configurations, such as power setting, flap and gear positions, and aircraft weight. In most cases, there was sufficient information to establish whether the airplane was in a stall, near stall, or cruise immediately before impact. It was more difficult to estimate impact speed in some cases, in particular high-speed dives, intermediate speeds between stall and cruise, and impacts involving multiple strikes.

13/ Principal impact occurs when the most severe decelerative forces are experienced and the most damage is sustained by the fuselage. The principal impact may not be necessarily the initial impact.

APPENDIX E

FIVE ACCIDENT EXAMPLES AND EVALUATION RESULTS

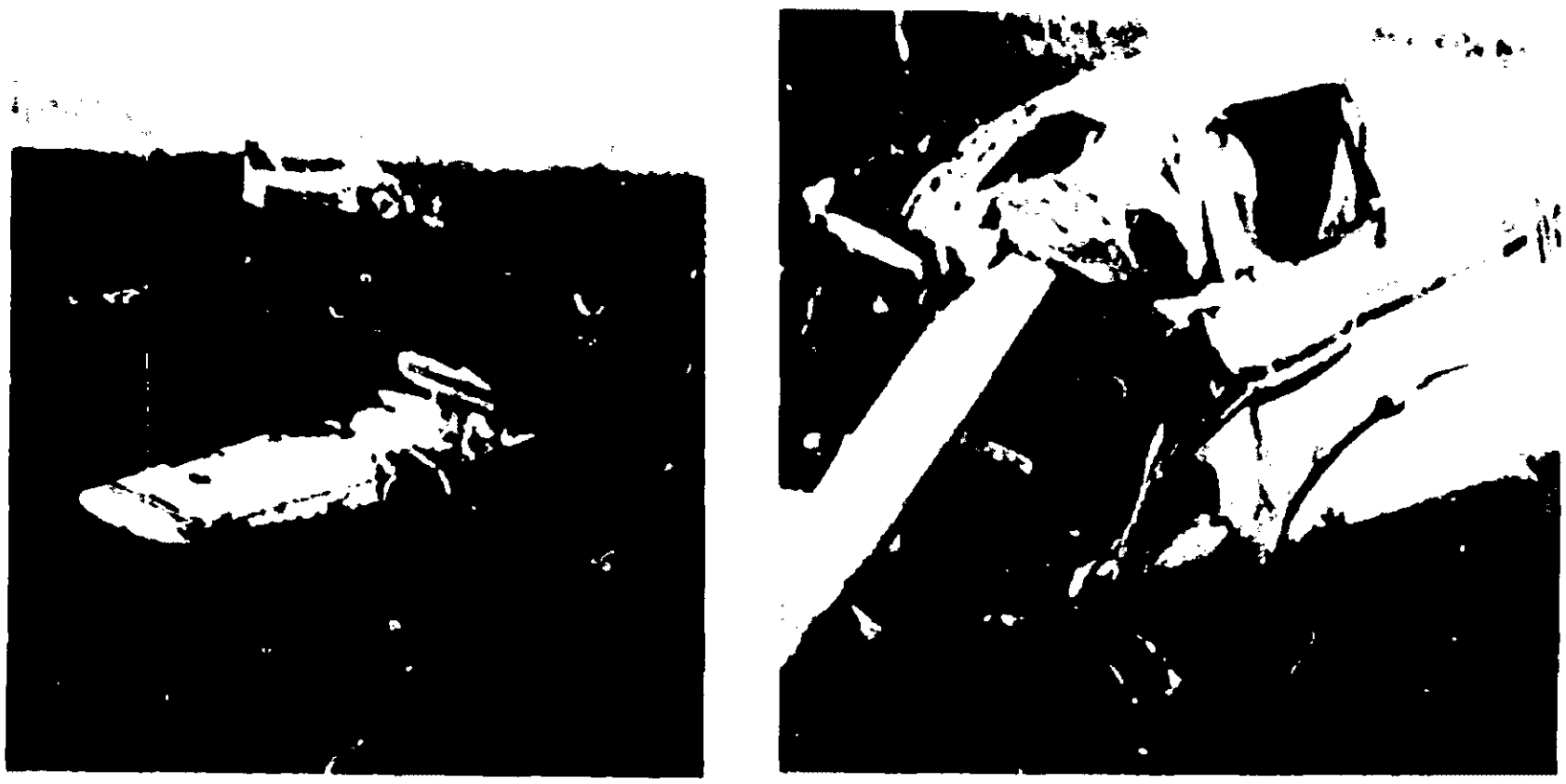
Five accidents are presented as examples to show the coding procedures that were used during the course of this study. These accidents ranged in severity from survivable to nonsurvivable.

These analyses show the various considerations involved in a crashworthiness evaluation. In each case, occupant movement must be evaluated with respect to the existing or desired occupant protection system. However, the ultimate consideration in predicting the benefits provided by crashworthy occupant protection systems rests in the definition of survivability, i.e., a livable volume must be maintained and the accelerative forces must be survivable.

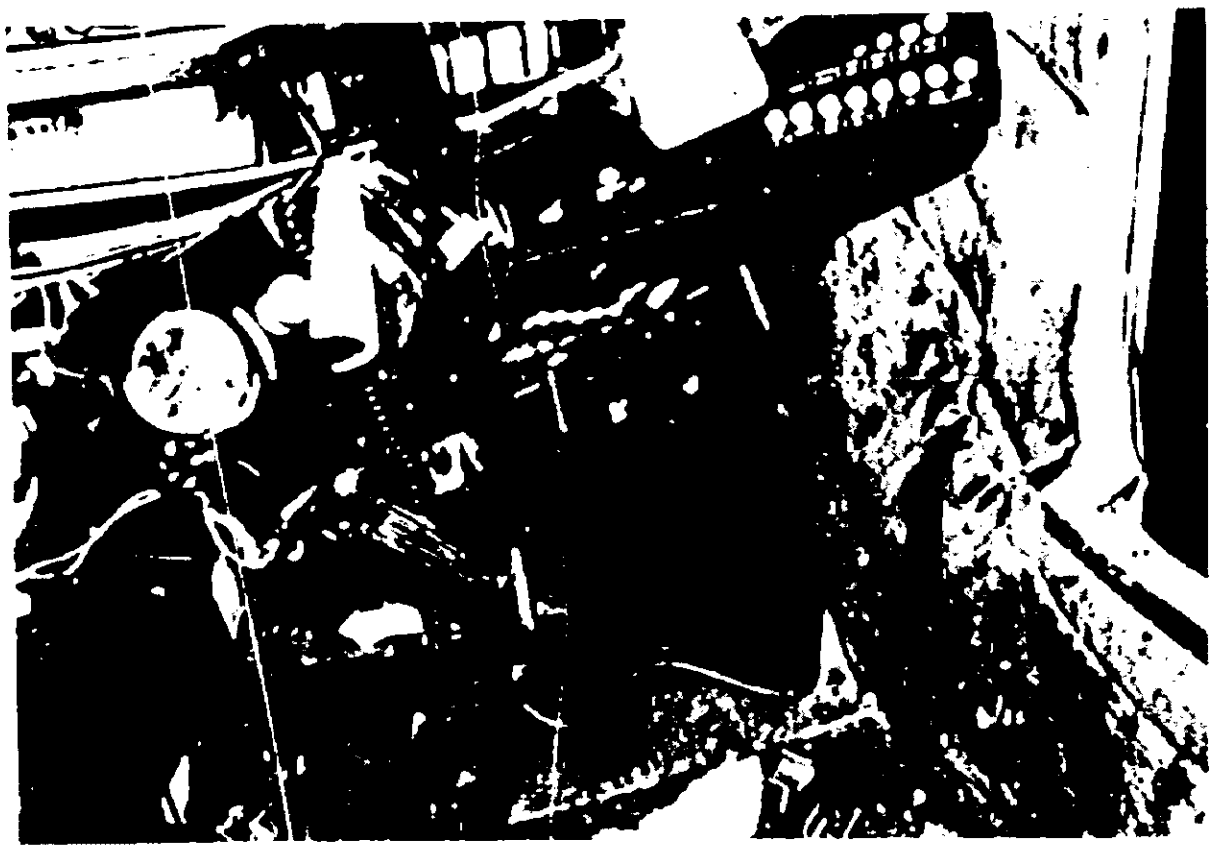
Accident No. 1 (photographs 1 through 4)

This accident, which resulted from fuel starvation, was totally survivable. During the emergency landing, the right wing struck a 25-foot-high tree. The airplane contacted the ground 102 feet later and the airplane slid 45 feet. There were three serious injuries and one minor injury. Shoulder harnesses were available for the front-seat occupants only, but the shoulder harnesses were not used. All seats remained attached to the floor structure.

The measured flight path angle was 14 degrees. A pilot statement indicated that the airplane was near a flaps-up, power-off stall. The impact angle was coded as 10 to 15 degrees, and the impact speed was coded as 45 to 60 knots.



Photographs 1 and 2.



Photographs 3 and 4.

Occupant 1.--The pilot's head had impacted the instrument panel, and he sustained facial and scalp lacerations, a possible basilar skull fracture, a knee laceration, and a fractured right thumb. The energy-absorbing seat in which he was seated had stroked about 1 inch. Since the cockpit area near the pilot's position was intact, it was assumed that the shoulder harness, had it been used, would have prevented the face and head injuries. Therefore, the injury data on the pilot was coded as "Serious to Minor" to reflect the shoulder harness benefits. The energy-absorbing seat benefit was coded as "Serious to Serious" since the energy-absorbing seat would not have prevented the head injuries. The fact that the stroked seat probably helped to protect the pilot from spinal injuries was disregarded.

Occupant 2.--The right-front seat occupant sustained multiple facial, head, and upper body injuries from impacting the instrument panel. These injuries included facial fractures and lacerations, cerebral concussion, fractured left clavicle, chest wall contusions, and probable pulmonary contusions. It was estimated that the use of a shoulder harness would have prevented the injuries; therefore, shoulder harness benefits were coded as "Serious to Minor."

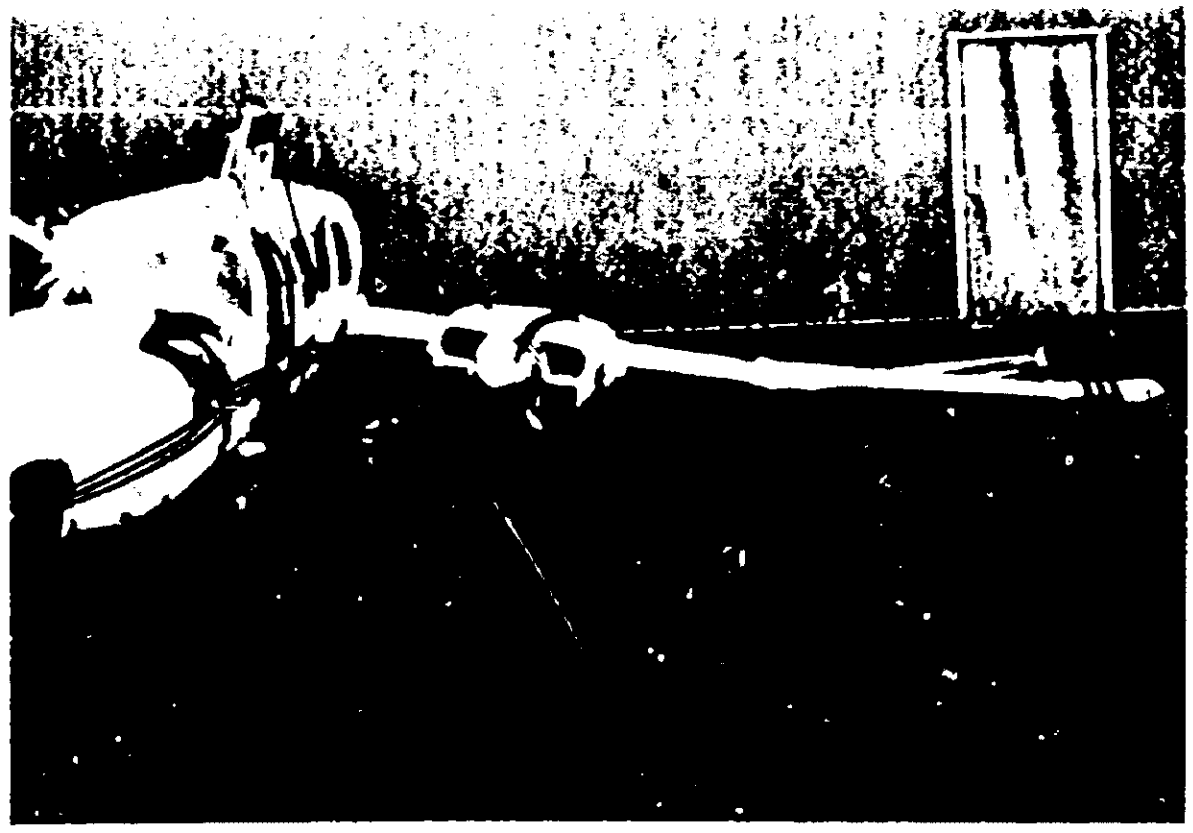
Occupant 3.--The right-rear seat occupant sustained a compressed fracture of the L5 vertebra. The rear seats were not of an energy-absorbing type, so the energy-absorbing seat benefit was coded as "Serious to Minor." The shoulder harness benefit was coded as "Serious to Serious" because it could not be determined whether shoulder harness use would have prevented the back injury, even though there was that potential as a result of better spinal positioning created by a shoulder harness.

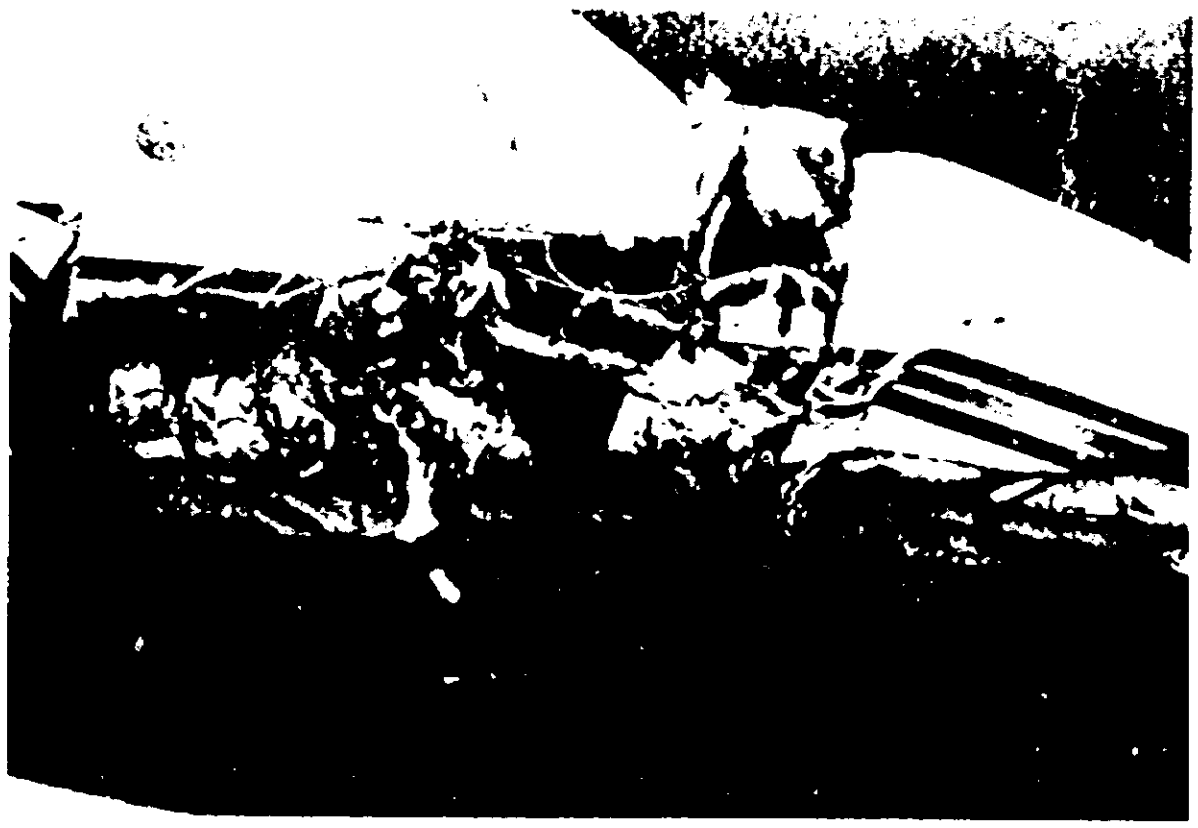
Occupant 4.--This occupant had minor injuries consisting of bruises and tenderness. Shoulder harness benefits and energy-absorbing seat benefits were both coded "Minor to Minor" since these minor injuries probably would not have been eliminated by a crashworthiness device.

Accident No. 2 (photographs 5 through 7)

During a night go-around, the airplane impacted gently rising terrain, damaging the propellers. With the loss of power, the airplane then descended down a shallow hill and impacted into level terrain. The airplane was flying at slightly above the flaps-up stall speed and in a right wing-down condition. The speed was estimated at 75 to 90 knots, and the impact angle, based on ground scar reconstruction, was estimated at 5 to 10 degrees down. The deceleration was more severe than that in accident No. 1 because the soft dirt allowed significant gouging. The pilot was injured seriously, although these injuries were considered preventable.

Occupant 1.--The pilot was not wearing the available shoulder harness, and he sustained significant head injuries. The cranial bone above the bridge of the nose was driven into the sinus cavities, the right cheekbone was fractured, the nose was fractured, the right ankle was fractured, and the left ankle was sprained. Back spasms were present due to minimal compression of the T12 vertebra (no fracture). The head impacted the instrument panel at the Kollsman knob of the altimeter and at the bug knob of the HSI. The knees impacted into the subpanel, and the seat pan was torn from downloading.





Photographs 5 and 6.

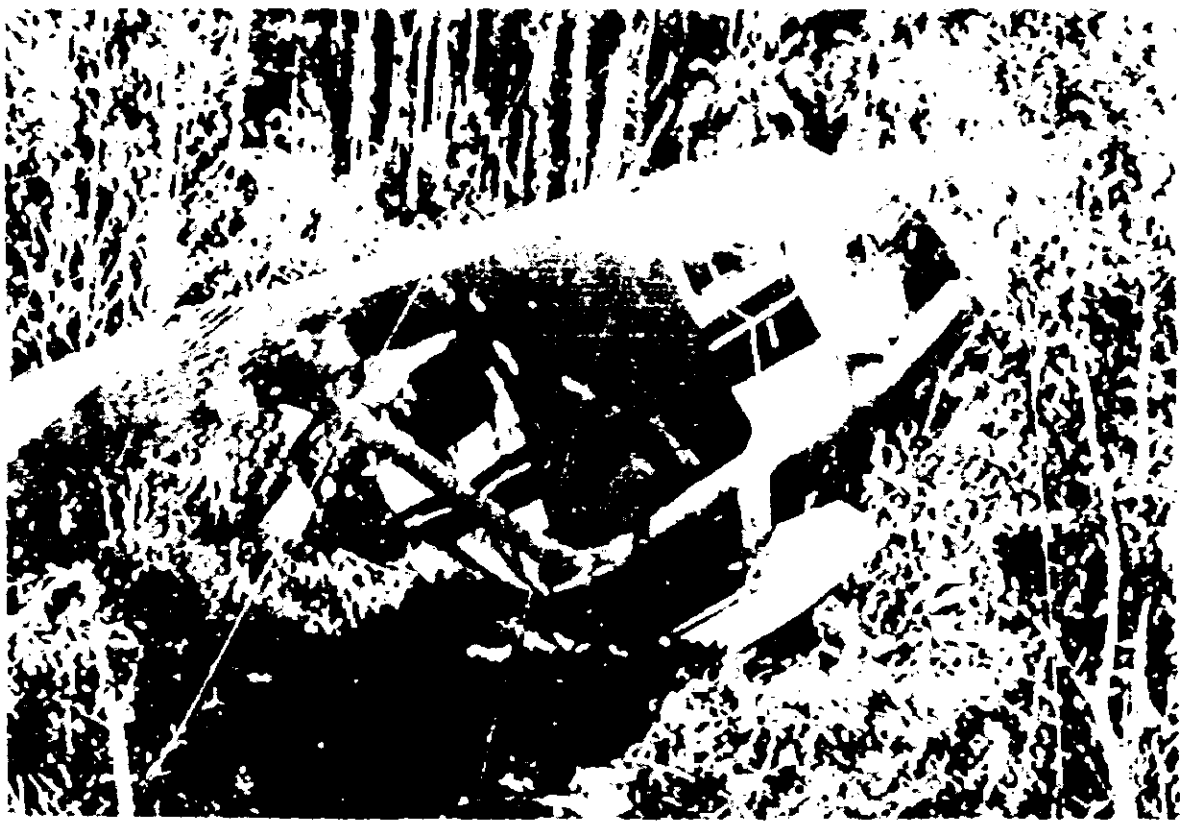
Photograph 7.

Since shoulder harness use would be expected to have prevented the head injuries, the shoulder harness benefit was coded as "Serious to Minor." Had an energy-absorbing seat been available, the minor back injuries possibly could have been avoided. The energy-absorbing seat benefit was coded as "Serious to Serious" since the seat alone would not have prevented the serious head injuries.

Accident No. 3 (photographs 8 through 11)

This accident occurred on a gusty day, and the pilot lost control of the airplane on approach to landing. The airplane made a hard right turn, cleared some trees, and then made a steep, right descending turn into the ground. Ground scar reconstruction indicated that the impact angle was near 35 degrees and the roll angle was near 90 degrees. (See figure 10.) The flaps were up, and the impact speed was estimated at 60 to 75 knots. Since the right wing was down at impact, there was substantial cabin deformation in the upper right front of the cockpit. The left cockpit area had only minor deformation. There was one fatality and two serious injuries.

Occupant 1.--The left-front seat occupant sustained fatal injuries by impacting the radio stack. These injuries consisted of multiple blunt trauma to the head and multiple fractures of the skull resulting in laceration and hemorrhage of the brain. Secondary injuries included diffused pulmonary hemorrhage. Nearly all of these injuries could have been prevented had the available shoulder harness been used. It is possible that serious injuries still might have occurred because of the aft movement of the floorboards and the instrument panel; however, it is more probable that the injury level would have been reduced to minor by the shoulder harness. Therefore, the shoulder harness benefit was coded "Fatal to Minor."



Photographs 8 and 9.

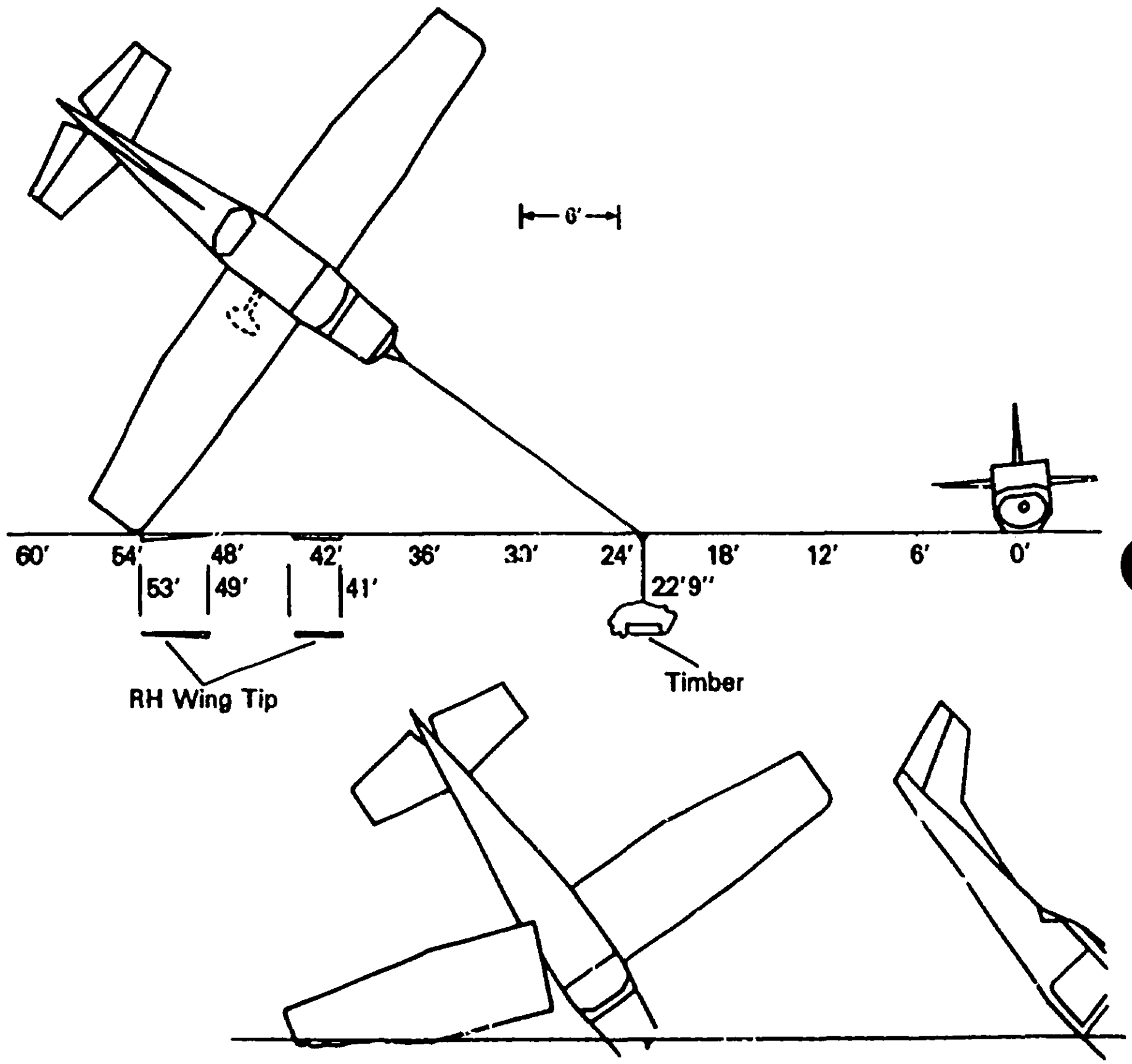


Figure 10.—Reconstruction of impact angle and attitude using groundscar information.

Occupant 2.--The right-front seat occupant sustained serious injuries. The injuries were more widespread than the left-front seat occupant because of the closer proximity to the focal point of the impact. This occupant sustained a mid-facial bone fracture, closed-head injury, multiple lacerated wounds of the face, cervical sprain, contusion of the chest, fracture of the transverse process of the L5 vertebra, feet fractures, and a hand fracture.

Although there was aft displacement of the instrument panel, the upper body injuries would have been less severe had the available shoulder harness been worn. The seat also came loose. Had it stayed in place and been of an energy-absorbing type, the back injuries would have been less serious, and possibly lesser loads would have been imposed on the feet. Therefore, the shoulder harness benefits and energy-absorbing benefits were coded "Serious to Minor."

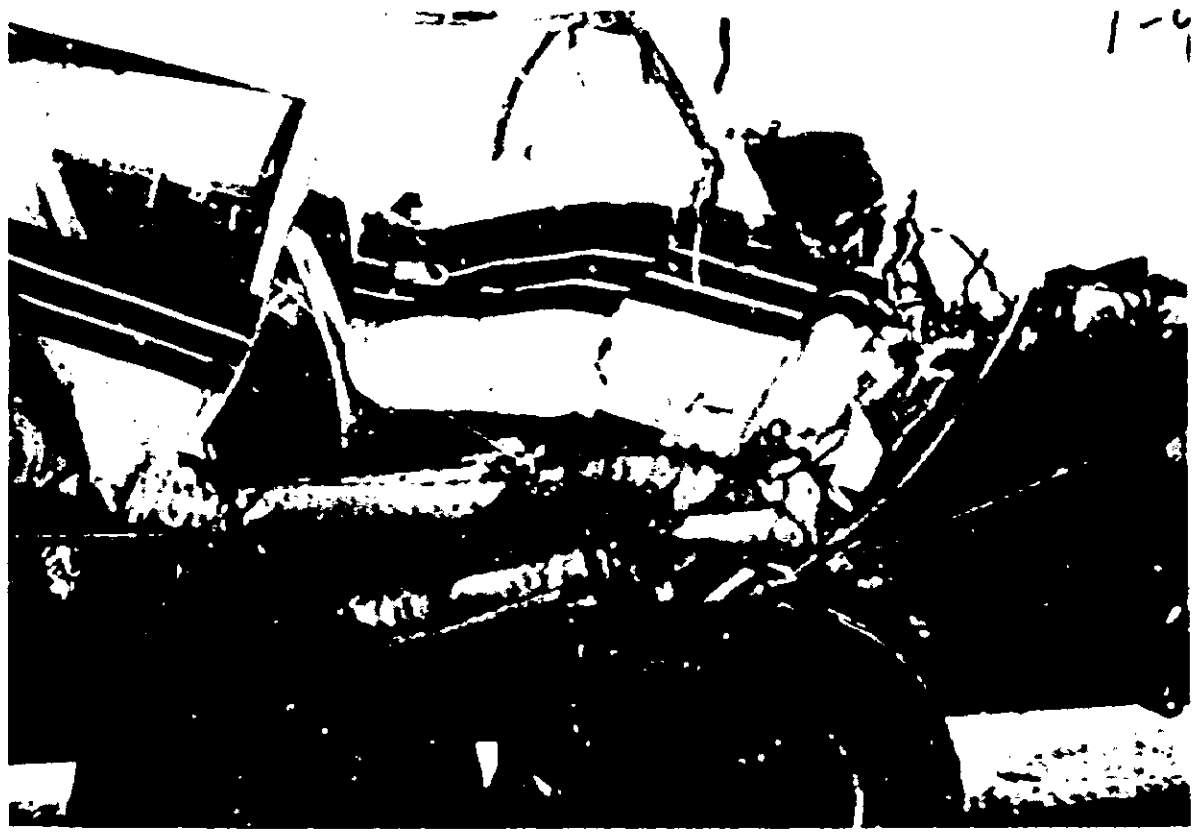
Occupant 3.--This occupant's lapbelt separated at the buckle when the adjusting cam cut through the webbing. Other areas of the belt also showed evidence of high loads. This occupant was ejected from the airplane and sustained serious injuries. His injuries were a perforated small bowel, a fractured clavicle and scapula, a fractured arm and leg, a head laceration, and a general concussion. Had he worn a shoulder harness, the lapbelt loads would have been better distributed, resulting in a lesser load to the lower abdomen. A shoulder harness also would have reduced the likelihood of the lapbelt separation and subsequent ejection. The shoulder harness would have resulted in a lesser injury level and, therefore, the shoulder harness benefit was coded "Serious to Minor."

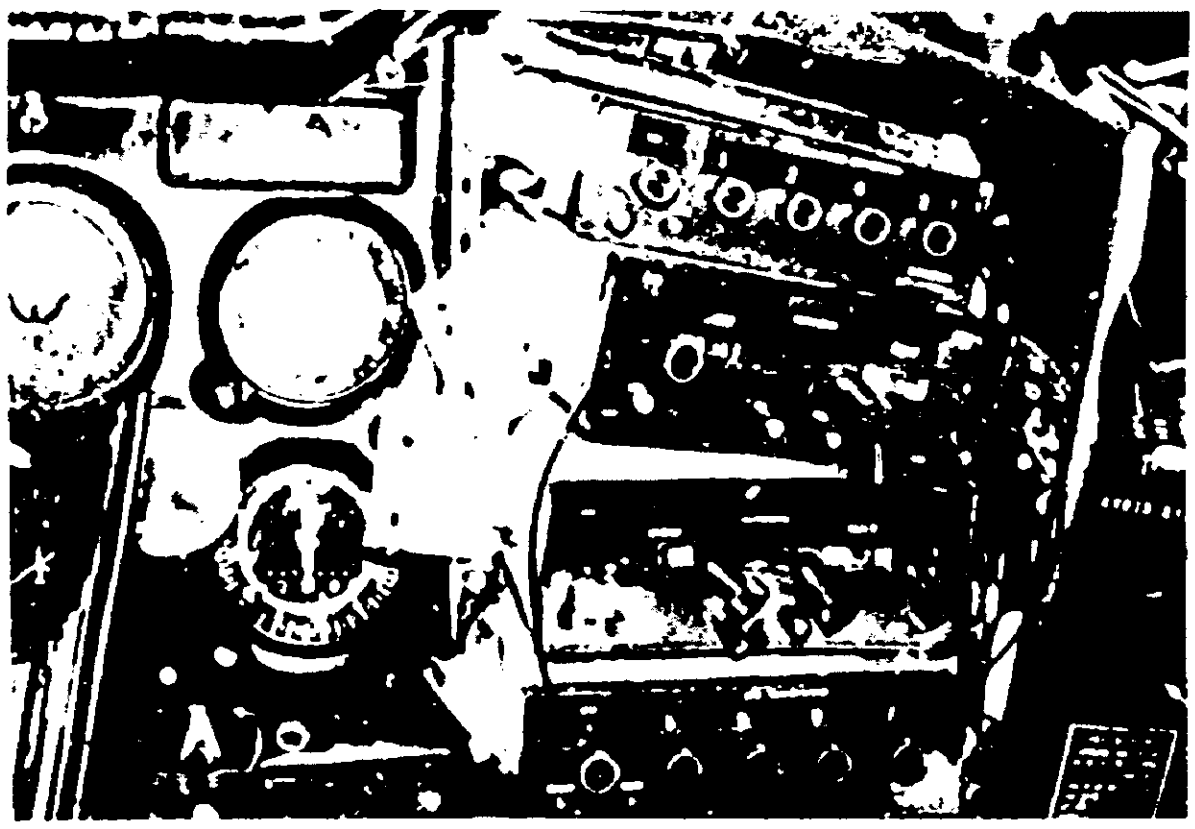
Accident No. 4 (photographs 12 through 15)

This accident was relatively severe for a survivable accident. The airplane cartwheeled and susequently stopped inverted. The pilot was killed, and the two passengers suffered significant head injuries. The attitude at principal impact was 28 to 30 degrees nose down with a 90-degree roll. The speed was estimated at slightly above stall or between 45 to 60 knots.

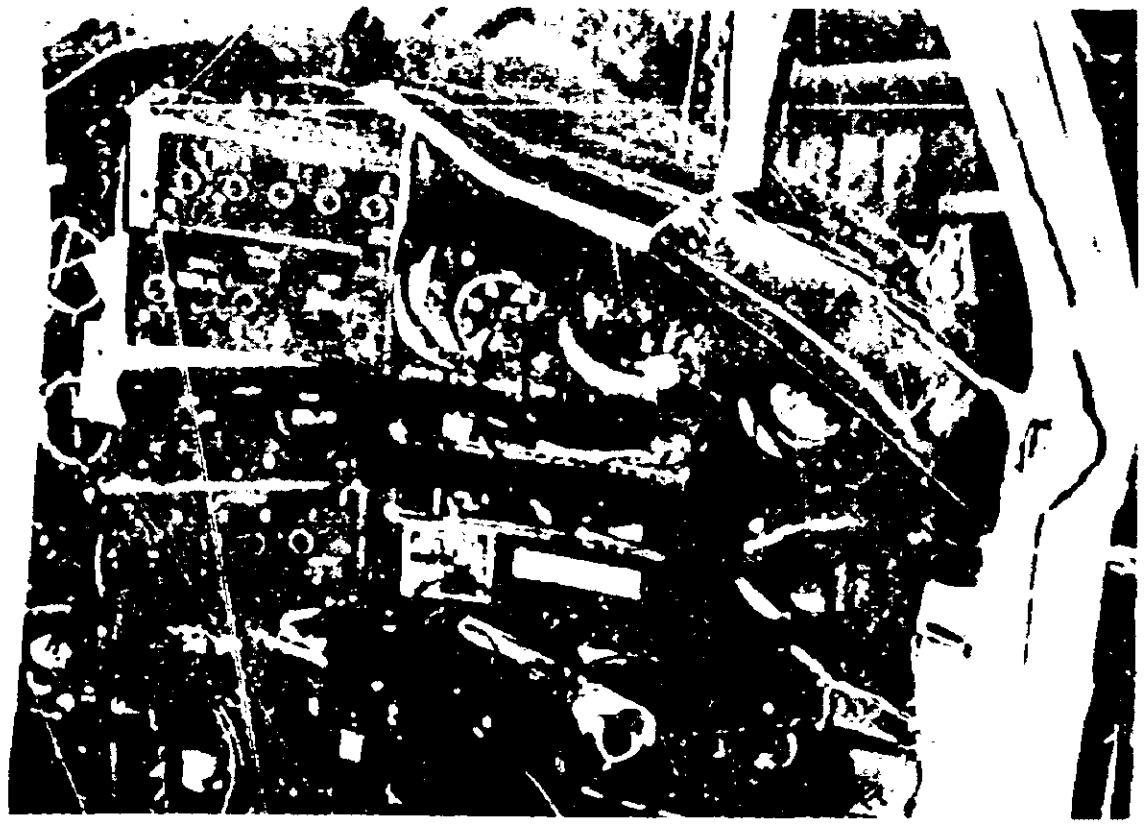
Occupant 1.--This occupant, the pilot of the airplane, sustained fatal injuries. The injuries consisted of fractures of the sternum extending into the chest cavity with severe hemorrhaging, fractures of the second, third, fourth and fifth left anterior ribs, and multiple brain contusions. These injuries resulted from impact into the control column and instrument panel. The instrument panel on the pilot's side moved aft far enough to hit the door post, reducing the livable volume. It is believed however, that the fatal injuries could have been prevented with the use of a shoulder harness even though the occupant still would have sustained serious upper body injuries. Therefore, the shoulder harness benefit was coded "Fatal to Serious." The stroked energy-absorbing seat probably prevented severe back injuries. The energy-absorbing seat benefit was coded "Fatal to Fatal" since such a seat would not have prevented the fatality.

Occupant 2.--This occupant was in the right-front seat near the crush line on the airplane and sustained serious injuries. Typically, the crush line can be regarded as the ground line, and if the crush line moves near the seat area, the occupant usually sustains very serious or fatal injuries. However, she did receive significant protection from the stroked energy-absorbing seat. Her injuries included a fractured sacrum, fractured hand, and facial laceration. The facial lacerations were not classified as serious, but they did present a danger since she was hanging upside down. A local farmer had to clear her mouth and throat of blood to prevent suffocation. The shoulder harness benefit was coded





Photographs 12 and 13.



Photographs 14 and 15.

"Serious to Minor." The energy-absorbing seat probably prevented very serious injuries but would not have prevented all of the serious injuries. The injury level would have been serious with or without an energy-absorbing seat. The energy-absorbing seat benefit was coded "Serious to Serious," but it was flagged so that the protection offered by the seat could be accounted for in this study.

Occupant 3.--The right-rear seat occupant also had serious injuries. She sustained a burst-type fracture and dislocation of the L2 vertebra. No neurological effects were noted. A shoulder harness could have benefited this occupant only by providing a better sitting position at impact and thus giving the back better protection. Since this is not a function of shoulder harnesses and only would offer limited injury protection, the shoulder harness benefit was coded "Serious to Serious." An energy-absorbing seat could have offered a great deal of protection. The energy-absorbing benefit was coded "Serious to Minor."

Accident No. 5 (photographs 16 through 18)

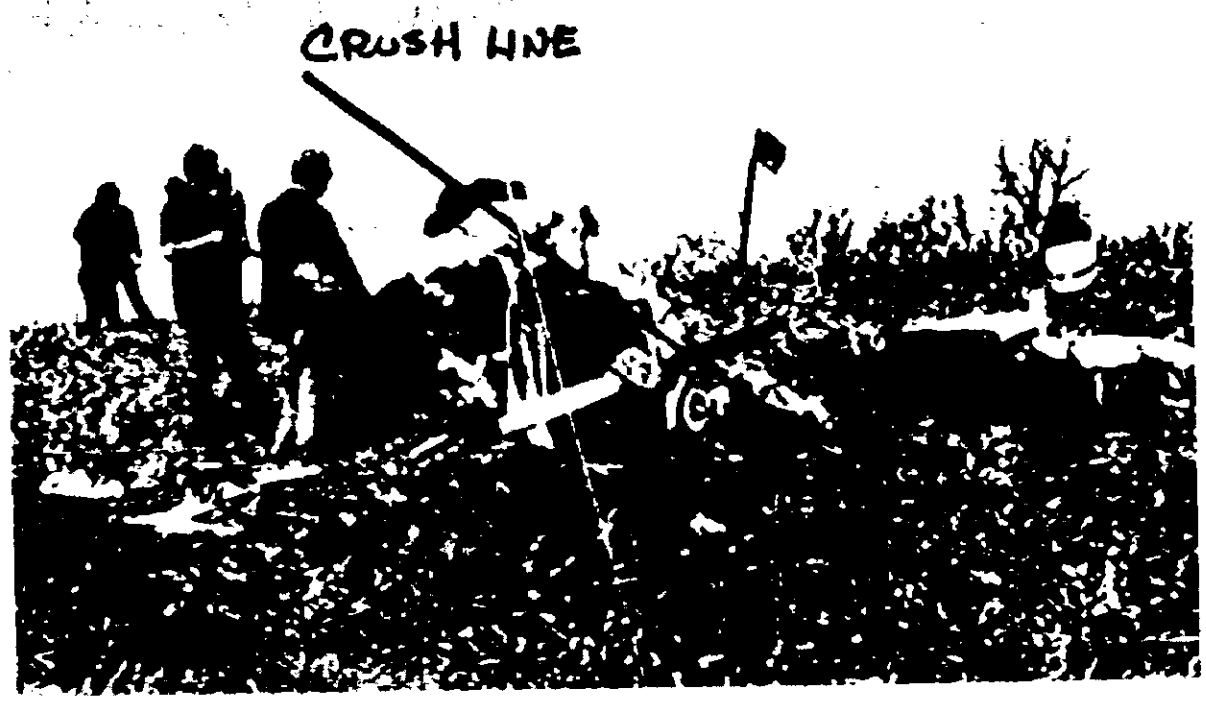
This accident was considered nonsurvivable even though the cabin remained relatively intact and two of the four occupants survived for several hours. The impact attitude of the airplane was the prime reason that the decelerative loads and secondary impact loads precluded survival.

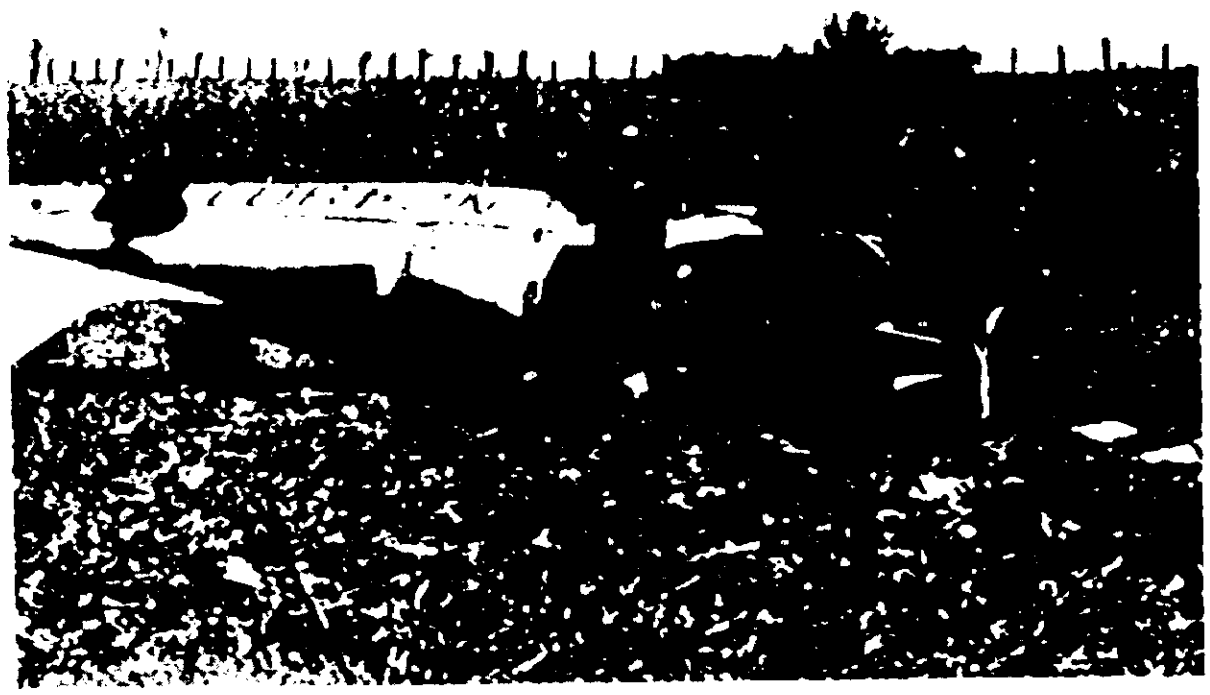
The airplane contacted trees causing a wing to separate and the fuselage to yaw. The airplane decended to the ground along a 39-degree flight path. The fuselage hit sideways with a nose-down attitude of about 25 degrees and a roll attitude of about 30 degrees. (See figure 11.) Since the predominant impact force would have driven the occupants to the left, neither shoulder harnesses nor energy-absorbing seats would have provided the lateral protection that was required for survival. All occupants were coded "Fatal to Fatal" for both shoulder harness and energy-absorbing seat benefits.

Occupant 1.—The pilot was very near the crush line and sustained more severe injuries than the other three passengers. He had a depressed fracture of the skull with profuse hemorrhage, complete cervical fracture, multiple pelvic fractures, ruptured aortic arch, and a ruptured blood vessel in the chest cavity. No head contact area could be identified in the airplane, but evidence of body contact could be seen on the sidewall next to the pilot's position. It was assumed therefore that the head contacted the ground through the pilot's side window during the impact.

Occupant 2.--The copilot also had severe upper body injury, but he did not receive extensive lower body injuries. He had a fractured cervical spine, with incomplete transection of the spinal cord, severe brain hemorrhage, fractured sternum and ribs (flailed chest), and a fractured leg. Again, no evidence of occupant contact was found on the instrument panel. Occupant movement was lateral (to the left) which precluded shoulder harness effectiveness.

Occupants 3 and 4.--The left-rear seat occupant had severe bleeding due to significant facial fractures and a flailed chest. The right-rear seat occupant survived briefly but died of a severe brain hemorrhage.





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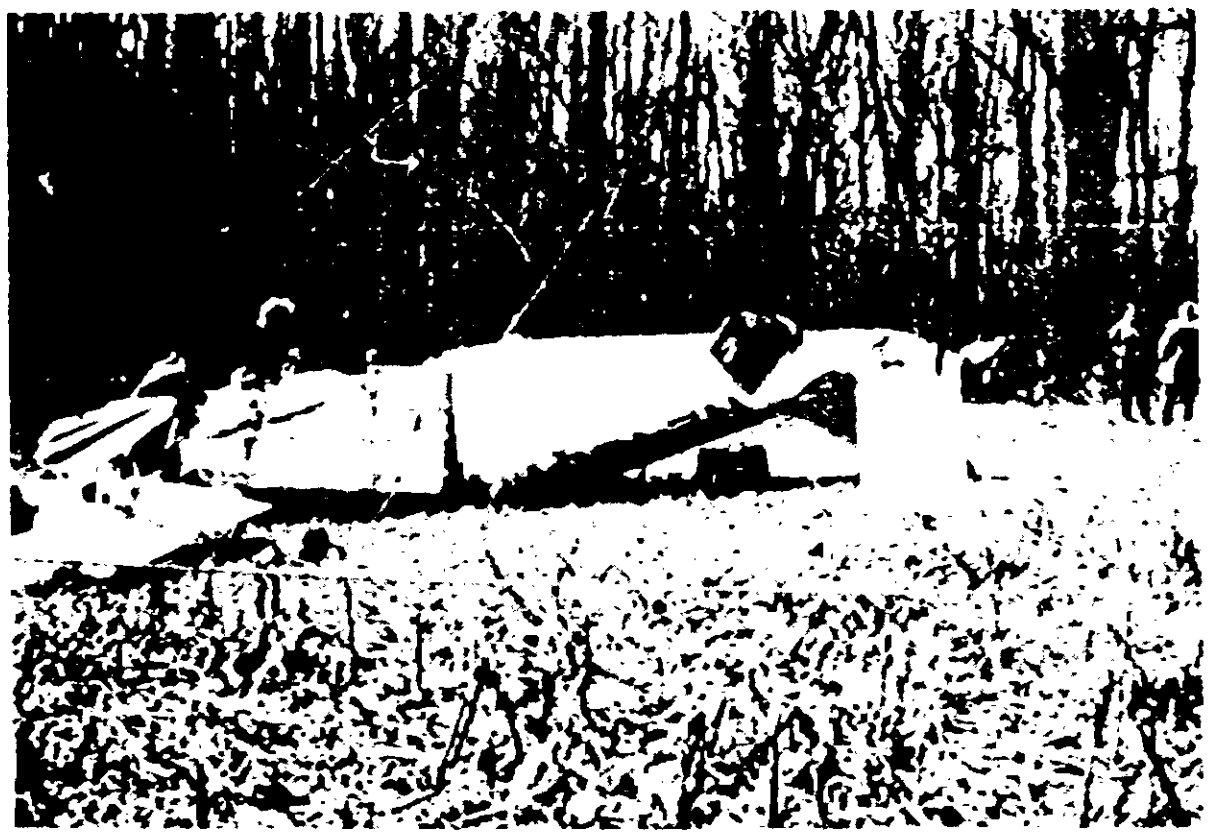

Photograph 18.

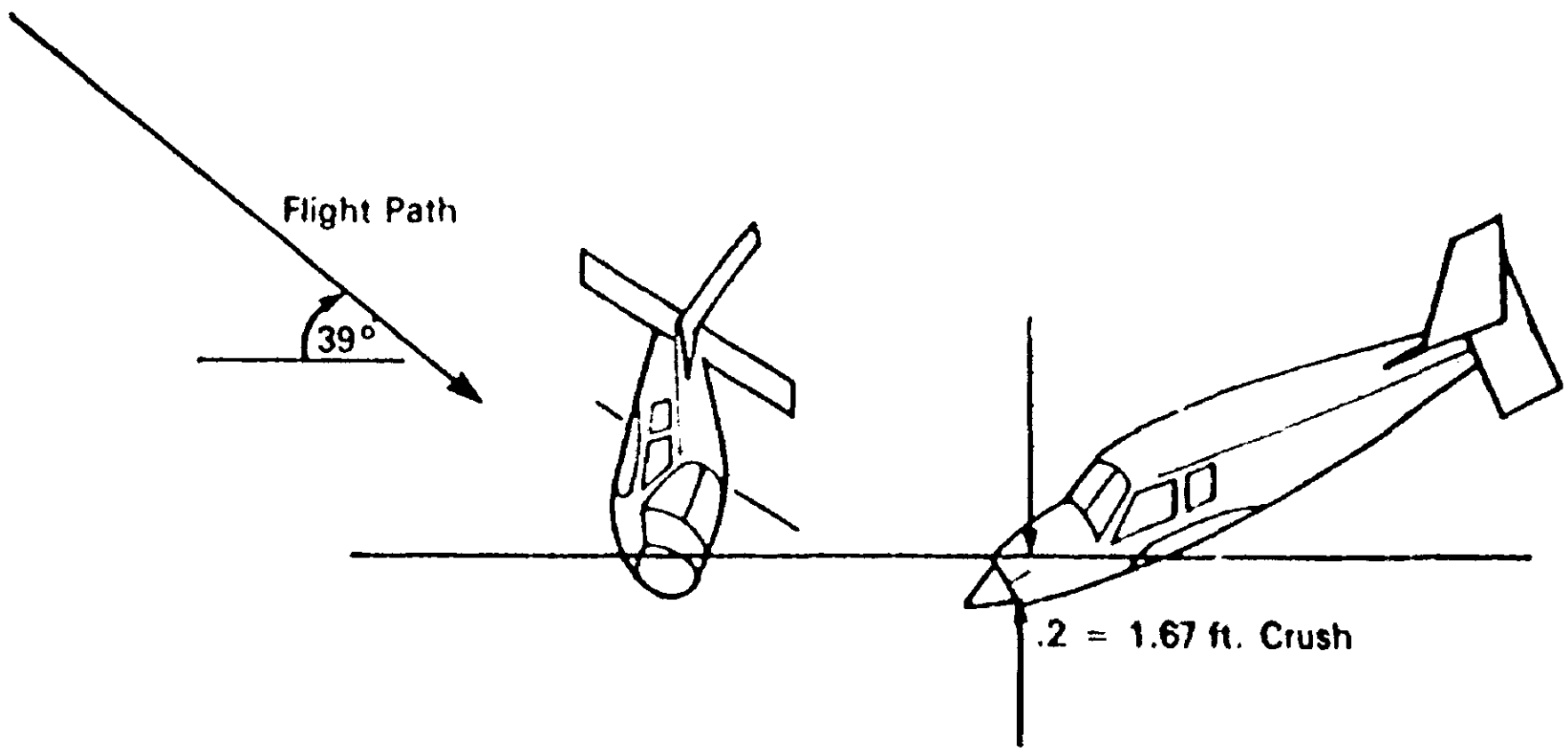

Figure 11.--Reconstruction of impact angle and attitude.