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# GENERAL AVIATION STRUCTURES DIRECTLY RESPONSIBLE FOR TRAUMA IN CRASH DECELERATIONS


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SPECIAL REPORT

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*Prepared for*

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**FEDERAL AVIATION ADMINISTRATION**
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**Washington, D.C. 20590**



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16. Abstract

An analytical study of general aviation accident injuries is presented. Needs for improvement of both the crash design of the interior of the cockpit and the structural integrity of the cockpit itself are clearly illustrated. Crash safety design in light aircraft has fallen so far .ehind that for the automobile that death rates per 100,000,000 passenger mi.es in light aircraft are at least seven times those for automotive transportation. The author concludes, after many detailed analyses in this study, that many p ent-day general aviation aircraft with their rigid instrument panels studde. with heavy instruments, protruding knobs and sharp edges, along with a lack of slow-return padding and very inadequate restraint equipment, are producing fatal or very serious injuries during low cabin crash decelerations with some as low as 3-4 "g". Again based on the author's calculations, it is not uncommon for light aircraft cabins to start to disintegrate and/or collapse on the occupants if the crash forces exceed 9 or 10 "g". And yet, some manufacturers have produced aircraft for aerial application that have cockpits that can withstand up to 40 "g". Engineering design changes can sharply reduce the death and injury rate in general aviation accidents.



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## AUTHOR'S COMMENT

All calculations of decelerative forces presented in this report are those of the author and he readily concedes that the determination of exact deceleration "g" forces experienced by various portions of the vehicle during different phases of its ground impact will be subject to debate and can only be determined accurately by crash testing of numerous instrumented aircraft. A knowledge of the exact decelerative forces in the cabin area would be most useful for evaluating cabin integrity, seat tie-down requirements, and effectiveness of restraint devices. Cabin decelerations need not be of great magnitude to produce injuries to the head and other portions of the body flailing about during seat belt restraint as long as this deceleration is of sufficient magnitude to overcome the strength of the human to brace against flailing (2½–3 "g"). Bodily injuries are more related to the velocity of the body before impact, its velocity during secondary impact with the structures inside the cabin, the yield characteristics of these structures, and the load distribution of the impact over body area contours. During a study to determine human facial tolerance to impact, the yield characteristics of 73 automotive dash panels were evaluated in terms of radius of curvature, "g" force and time parameters of the impact, maximum depth and area of yield, metal thickness, and head impact velocity. Head impact velocities were varied from 14 to 43.7 ft./sec. and impact forces varied from 40 to 230 "g". Occupants producing these deformations in the actual crash vehicles should have escaped without injury but instead many occupants received serious to fatal head injuries since the areas of head contact were small and concentrated the loading above human tolerance limits. Appropriate padding for load distribution over the contours of the head would have prevented most of these injuries. Since certain portions of the anterior head have less tolerance to impact decelerations than others, and since any portion of the face and/or forehead may be expected to contact the decelerative structure, the author believes that engineers should design structures such that pressure loads on the anterior head cannot exceed 100 lbs./sq. in. during head impact velocities of 50 ft./sec.

The author feels that these data (heretofore unpublished) may be most useful to general aviation design engineers for redesigning light aircraft instrument panels for better protection against head injury in future aircraft and are being presented in this report as an appendix.

The author has combined a knowledge of structure deformation from body impact, area of body contact, velocity of secondary impact injuries inflicted as related to established tolerances and strength of restraint webbings to work backwards in establishing estimated *cabin decelerations* in most of the crash cases presented in this report. These cabin decelerations, especially at seat belt attachments, are not average decelerations but plateaus of maximum "g" forces for a duration of 20 to 100 milliseconds.

# GENERAL AVIATION STRUCTURES DIRECTLY RESPONSIBLE FOR TRAUMA IN CRASH DECELERATIONS

## I. Introduction.

The title of this study may, at first, suggest to the reader that this is a duplication of many reports published in the past 25 years. The concept of protecting occupants in crash circumstances is not new. Statistics have been presented by many authors[1-18] showing that in sudden decelerations the unrestrained or partially restrained (seat belt) occupant flails about in a disintegrating cabin, striking various portions of the body against objects which penetrate or crush body structures during the "so-called" secondary impact. The literature is full of statistics[19-23] showing that most deaths (75–85%) and serious injuries in all transportation vehicle crashes are a result of head impact.

Speaking of statistics, it is well known that automotive deaths in the United States have risen to an alarming figure of something over 55,000 per year and that the number of serious injuries is more than ten times this figure.[24] The automotive death rate for each 100,000,000 passenger miles of travel is given as five. However, if only passenger automobiles and taxis are included (excluding pedestrians, motorcycles, bicycles, buses and trucks) this figure is reduced from 5 to 2.4. On the other hand, the number of fatalities in general aviation aircraft accidents is only about 1,100–1,200 per year and the number of serious injuries accompanying these deaths is only slightly over 50% of the number of fatalities or approximately 600.[25] This comparison of deaths and injuries in two transportation systems, one (automotive) in which the serious injury rate is 1000% greater than the death rate and the other (general aviation) in which serious injuries are only about 50% of the death rate certainly arouses one's curiosity and calls for some explanation. Flight velocities of general aviation aircraft are usually higher than automotive speeds. However, most general aviation aircraft land at speeds that are approximately the same as those commonly found on interstate freeways. The actual reasons for this peculiar inconsistency will be made apparent in the text of this study.

In 1967 the National Transportation Safety Board (NTSB) reported[25] 111,000 general aviation aircraft flew an estimated 21,000,000 hours. Assuming an average flying speed of 150 miles per hour (which is probably on the high side), this would represent 3.15 billion miles. The same report states 12,298 occupants were on board 6,115 aircraft involved in accidents, indicating the average occupancy for general aviation aircraft is *two.* Multiplying total miles flown by average occupancy gives 6.3 billion or 63(100,000,000) passenger miles. Based on 1,100 fatalities, the rate for 100 million passenger miles (17.5) is more than seven times that for automotive accidents. Again we ask, why?

The purpose of this study is to present a detailed analysis of aircraft structural components directly responsible for human trauma during sudden deceleration and, at the same time, by a similar study of automotive accidents compare advances in structural design for crash protection in the two modes of transportation in order to explain why automotive transportation is nearly seven times safer than general aviation aircraft today. It is hoped that this report may stimulate the manufacturers of general aviation aircraft to make design changes in future aircraft to utilize some of the crash safety design principles developed in recent years by the automotive industry as well as other structural changes that will be necessary to improve crashworthiness of small aircraft. Studies by DeHaven, Hasbrook, Patrick, Snyder, Swearingen, Stapp, Beeding, and others describing tolerances of the body to impact, body kinematics, effectiveness of restraint equipment, and injury statistics are well known.[26-53]

## II. Procedure.

Eight scientists of the Protection and Survival Laboratory received extensive training (National Aircraft Accident Investigation School) in accident investigation and were available on immediate notification, day or night, to proceed to the crash scene in a three-state area (Oklahoma, Texas and Arkansas) and conduct and document an intensive investigation to relate injury or death to structural impact and/or failure in effectiveness of restraint devices and determine escape and survival after ditching. The investigator made a thorough study at the crash site to determine angles of impact by trajectory and direction occupants were thrown. Force of impact was determined by measuring deceleration distances, gouge marks, and fuselage compression. Portions of the aircraft impacted by various parts of the human body could usually be determined from deformation of aircraft structure, presence of bits of hair, blood and/or tissue. Special note was made of the failure of safety equipment, seats, and cabin integrity. All information at the crash site was documented by detailed photography, notes, and diagrams. Survivors and witnesses were interviewed to establish altitude, attitude, and flight path of the aircraft just before impact. Photographs were also made of external injuries of survivors in hospitals and external and internal trauma of the fatally-injured during autopsy at the morgue. Complete medical records and autopsy reports were obtained in each case.

Three categories of aircraft crashes were usually not investigated: (a) very minor incidents—no injuries, (b) crashes in which the aircraft completely disintegrated (nonsurvivable), and (c) crashes where the fuselage was consumed by fire after the crash since deformation of structure from body impact and/or crash forces could not be identified.

Concurrently, a study is being made at CAMI to correlate injuries to structural deformation during body impacts in automobile accidents and to evaluate recent structural design changes resulting from automotive safety standards in terms of reduction of fatalities and injuries.

Seventy general aviation accidents have been investigated to date. While the original plan was to accumulate at least three times this quantity of data, analysis of these cases has shown so clearly the glaring lack of progress in engineering design for crash survival in general aviation aircraft that it was decided to present the results of these in order to make the data available to the aviation community.

On the other hand, the automotive industry is continually redesigning to make their product a safer vehicle for transportation and crash survival. A continued evaluation of their efforts is warranted.

## III. Results.

DeHaven,[54] in 1952, stated "Safe transportation of people in any type of vehicle must of necessity apply the practical principles which are used by every packaging engineer to protect goods in transit." There are four simply basic packaging principles:

A. The shipping container should not open up and spill its contents or collapse on its contents under reasonable or expected conditions of impact forces.

B. Articles contained in the packages should be held and immobilized inside the container to prevent movement and resultant damage against the inside of the package itself.

C. The means of immobilizing the contents inside the container must transmit forces to the strongest part of the contained articles.

D. The inside of the container must be designed to cushion and distribute impact forces over maximum surface area of the contents and have yield qualities to increase deceleration time in case it breaks loose from its restraint.

To evaluate the extent to which general aviation design engineers have succeeded to date in applying the basic packaging principles to the safe transportation of people in light aircraft, 27 accidents will be presented and evaluated in terms of these packaging principles. Each accident case presented includes a brief summary of the crash circumstances, some photographs of a *similar** or *identical* aircraft before impact,

*These photographs are intended to give the reader a general impression of the aircraft before it crashed. In some cases it was not possible to find the same year aircraft and even if the model and year are matched, the observant reader may note variations in control wheel and instrument panel design, even in the same year.

photographs of occupant injuries, and a table listing injuries of each occupant and the aircraft structure responsible for the injury.*

It was the intent of the author to select individual crashes to illustrate the degree that each of the four packaging principles is being utilized in present-day general aviation accidents, but since all four principles are directly involved in each impact, it was deemed necessary to discuss each accident from a standpoint of crash survival packaging.

The words survivable and nonsurvivable have been used freely for a number of years to describe aircraft accidents, but may be extremely misleading. Obviously, in accidents where the aircraft flies into the ground at a very high velocity, digging a huge crater in the earth and disintegrating into small pieces with a crash force calculated to be 198 "g" (Case 1—1966 Beech Baron 95C–55), or flies into a stone mountain at full cruise velocity (328 "g" calculated) (Case 2—1956 Cessna 310D), or impacts a large tree on the ground with sufficient force to allow the tree to penetrate to the front edge of the front seat (31 "g") (Case 3—1964 Piper Cherokee PA 28–235), they would be classed as nonsurvivable simply because a cabin structure cannot be designed with sufficient strength to withstand such impact forces and still be light enough to fly. Even if such a cabin structure were feasible, in Cases 1 and 2 the human body would not be capable of withstanding the restraint forces. In Case 3, the occupants could have tolerated the restraint forces but would probably have been fatally injured by the deep penetration of the tree into the cockpit.

In other, less severe accidents, one may look at the remains of the aircraft and say it was nonsurvivable simply because the cabin structure collapsed or disintegrated and, indeed, it was probably impossible to survive the accident. However, an analysis must be made to determine whether the crash forces alone were sufficient to cause a nonsurvivable accident, or whether they were of low magnitude and inadequate design of the shipping container allowed it to collapse upon its occupants and cause the fatalities.

In a normal landing (65 miles per hour with 600 feet stopping distance) the aircraft and its occupants experience a deceleration of about 1/4 "g" and the occupants have no difficulty maintaining their seated posture with or without restraint.

In Case Number 4 the pilot, flying a Piper Cherokee PA 28–140 (1968), hooked some steel telegraph wires and decelerated smoothly from 65 miles per hour to "0" in 55 feet. In this instance the aircraft fuselage and occupants experienced approximately 1.4 "g" deceleration. The aircraft cabin maintained its integrity and the pilot bumped his head only slightly and knocked off his glasses. Therefore, with only seat belt restraint, the upper torso can be expected to jackknife forward, allowing the head to strike the instrument panel when aircraft deceleration forces exceed 1.5 to 2.0 "g".

Swearingen [55] has adequately described the kinematics of the body and the head strike areas in numerous general aviation aircraft. Figure 1 shows head clearance area of the path taken by the top of the head (5th to 95 percentile), when the body jackknifes over a seat belt, superimposed on scale size drawings of 11 popular general aviation aircraft (A through K). The composites shown in "L" indicate clearly that all the instrument panels (vertical lines) and top of the control wheels (circles) lie directly in the path of the head. Figure 2 is another, more detailed composite of the same group of aircraft showing forward motion of the body (95th percentile) with seat belt restraint along with arcs swept out by the head, arms, and legs during the flailing motions that accompany crash deceleration. The acceleration forces in these tests on unbraced individuals were less than one "g" and yet the head impact velocity at the point of instrument panel impact exceeded 12 ft./sec.

Other investigators [56] have shown that with aircraft decelerations of 8 "g" with lap belt restraint, the head strike velocity can easily reach 50 ft./sec. or more. Also, in recent tests conducted by The Boeing Company at CAMI, a very accurate study was made to determine head strike velocity. The results confirmed those given in Reference 56. A deceleration of 8.5 "g" produced a head strike velocity of 53.9 ft./sec.

---

*Abbreviations used in injury-structure correlation tables:

| | | | |
|---|---|---|---|
| & | And | L. F. | Left Front |
| C | Cervical Vertebra | L. R. | Left Rear |
| (F) | Fatality | Mult. | Multiple |
| Hem. | Hemorrhage | R. F. | Right Front |
| L | Lumbar Vertebra | R. R. | Right Rear |
| (L) | Left | (R) | Right |
| Lac. | Laceration | (S) | Survivor |
| Lac's. | Lacerations | T | Thoracic Vertebra |

**1966 BEECH BARON**

BEECH BARON 95-C-55, a 1966 model aircraft with pilot and one passenger (R. F.), flew into the ground at approximately a 50° angle in a right-hand bank during bad weather. Both occupants were wearing seat belts but aircraft disintegrated, digging a hole in the ground 38 feet long, 12 feet wide, and 4 feet deep. Pilot seat belt held, but seat failed and body in the seat was found in a tree 190 feet from impact point. The passenger's seat belt buckle failed and his body was found 450 feet from impact.

ACCIDENT INVESTIGATED BY:
GALE BRADEN AND TERRY WALLACE
CAMI

# CASE 1-1

A. Crater formed by aircraft impact 38' long, 12' wide, & 4' deep.

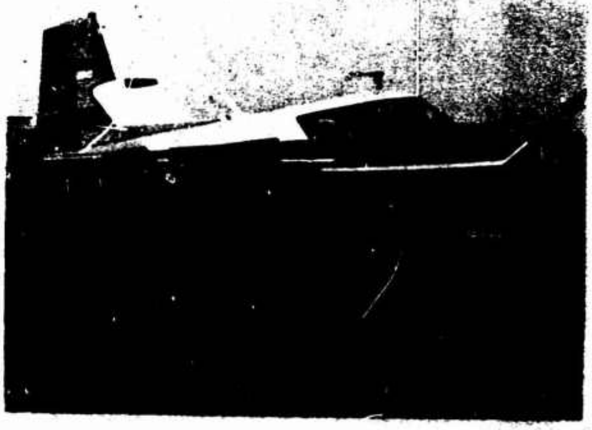
B. Broken & distorted remains of pilot control column.

C. Part of copilot's seat showing failure of tongue half of seat belt buckle.

D. Portion of instrument panel, broken, deformed & covered with tissue.

| INJURIES | STRUCTURES IMPACTED |
|---|---|
| Both bodies were badly crushed (F). | Aircraft disintegration. |

## CASE 1-2




**1956 CESSNA 310**

**CESSNA 310, a 1956 model aircraft with pilot and one passenger (R. F.), flew into the side of a solid rock mountain at full cruise velocity during a snowstorm. The aircraft disintegrated.**

**ACCIDENT INVESTIGATED BY:**
**EDDIE D. LANGSTON AND JACK BLETHROW**
**CAMI**

# CASE 2-1

A. Remains of aircraft after impact with a stone mountain. Man indicating impact point.

B. Bodies were thrown into crevice in the rocks.

C. Remains of passenger in right front seat.

D. Remains of pilot. Note that only his hands are not injured. They probably trailed behind the body as it was ejected from the a/c.

| INJURIES | STRUCTURES IMPACTED |
|---|---|
| Both bodies were badly crushed (F). | |

# CASE 2-2

**1967 PIPER CHEROKEE 180**

PIPER CHEROKEE PA-28-235, a 1964 model aircraft with pilot only, flying at night, was in a very gradual descent (9°). Aircraft clipped the top of some small trees and crashed into the base of a large tree two feet in diameter. The large tree trunk penetrated the aircraft at the root of the (R) wing, cut through the middle of the instrument panel and cabin, and ended up between the two front seats. The pilot was thrown forward and to the (R), impacting the tree and ending up with his legs and arms on the left side of the tree and his head and shoulders on the (R) side.

ACCIDENT INVESTIGATED BY:
GALE BRADEN AND TERRY WALLACE
CAMI

# CASE 3-1

A. Overall view of aircraft impact with tree.

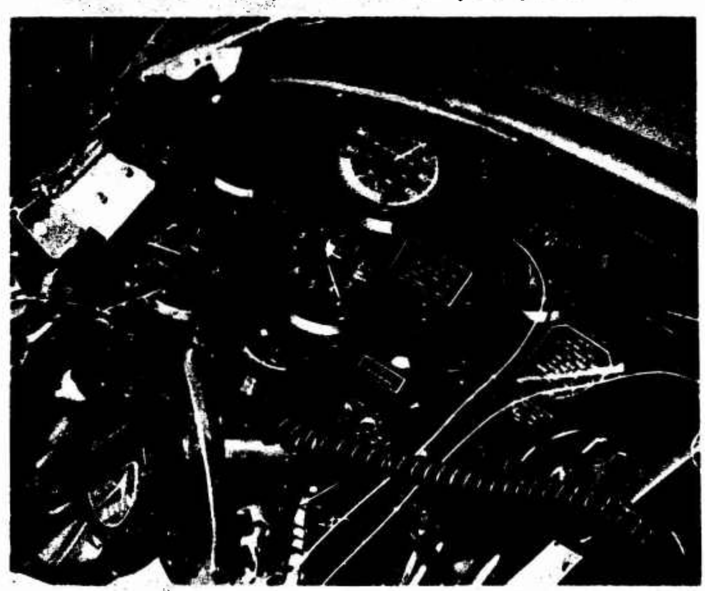
B. Close-up showing relative size of tree & depth of its penetration into the aircraft.

C. Inside the cabin, the tree is almost touching the front edge of the pilot's seat. An outline of a head indicates head impact area on the tree.

## CASE 3-2

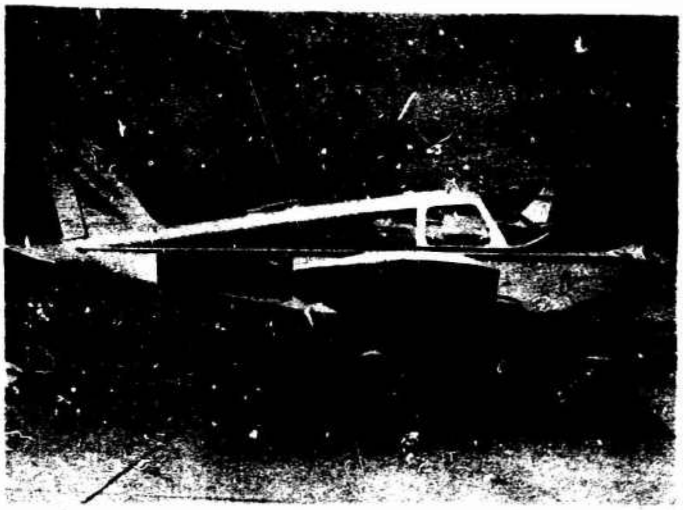
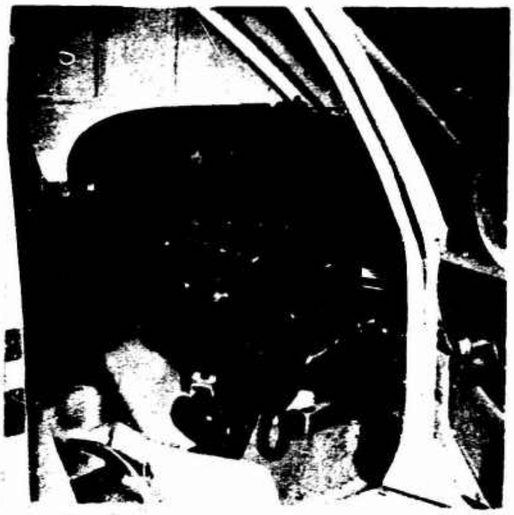
E. Right half of instrument panel sheared off by tree penetration.

D. Left half of the instrument panel shows no signs of body impact. Note broken pieces of plastic windshield in the cockpit.



| INJURIES | STRUCTURES IMPACTED |
|---|---|
| Pilot: (F) Head - Head & trunk crushed. | Tree |

## CASE 3-3

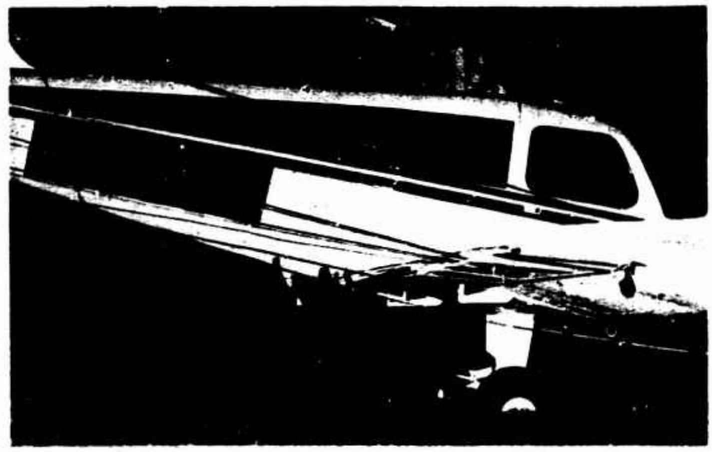
**1968 PIPER CHEROKEE 140**

**PIPER CHEROKEE PA-28-140, a 1968 model aircraft with pilot only, had taken off and climbed to 150 feet when it experienced power failure, lost altitude, and struck several strands of 1/8-inch steel telegraph wires. The aircraft traveled another 25 feet and the left wing struck a lower wooden telephone pole, turning the fuselage 90° before it reached the ground. Five strands of the steel wire were hooked around the propeller and stretched taut without breaking. These wires served as an arresting gear allowing the aircraft to decelerate with very little "g" force. Seat belt was in use and held. No shoulder harness was installed.**

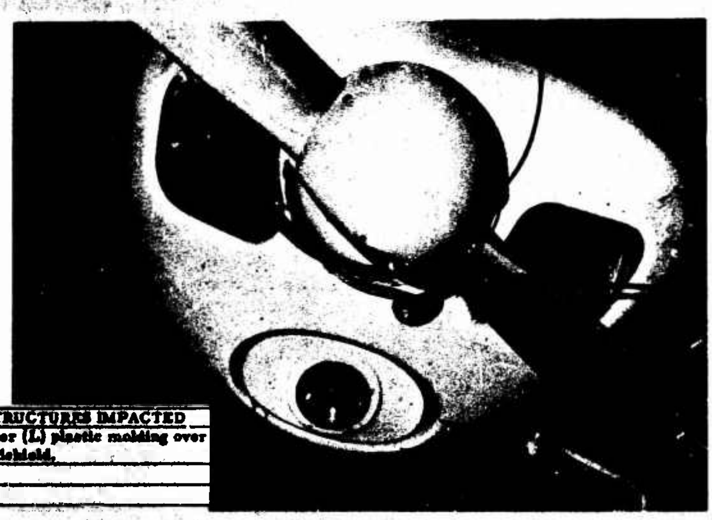
**ACCIDENT INVESTIGATED BY:**
**TERRY WALLACE**
**CAMI**

# CASE 4-1

A. Aircraft after left wing impacted telephone pole.



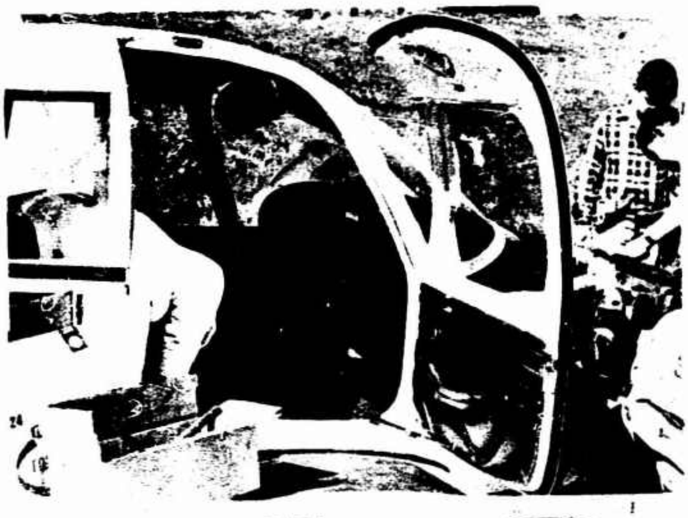
B. Five strands of steel telegraph wires stretched taut along sides of the fuselage.



C. Front view showing wires hooked on propeller.

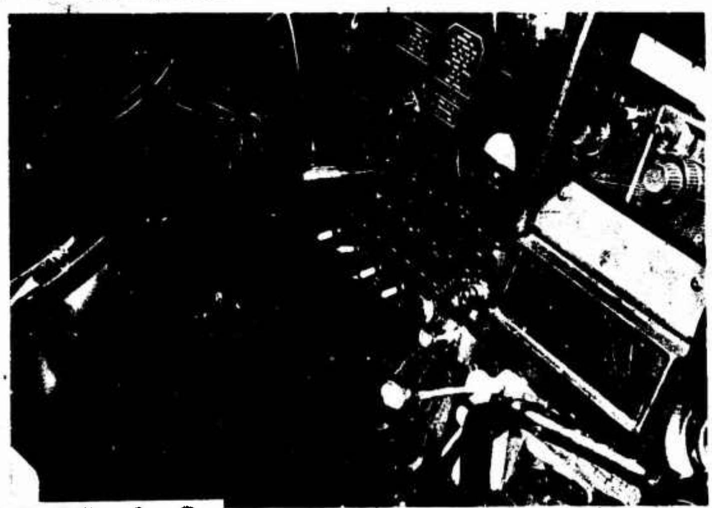
| INJURIES | | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (S) | Head - Slight bump on forehead knocked his glasses off. | Upper (L) plastic molding over windshield. |
| | Trunk - None. | |
| | Extremities - None. | |

# CASE 4-2



D. General view of cabin interior.

E. Upper left instrument panel. No damage from head impact.



F. Lower left instrument panel. No damage from knee impact.

**CASE 4-3**

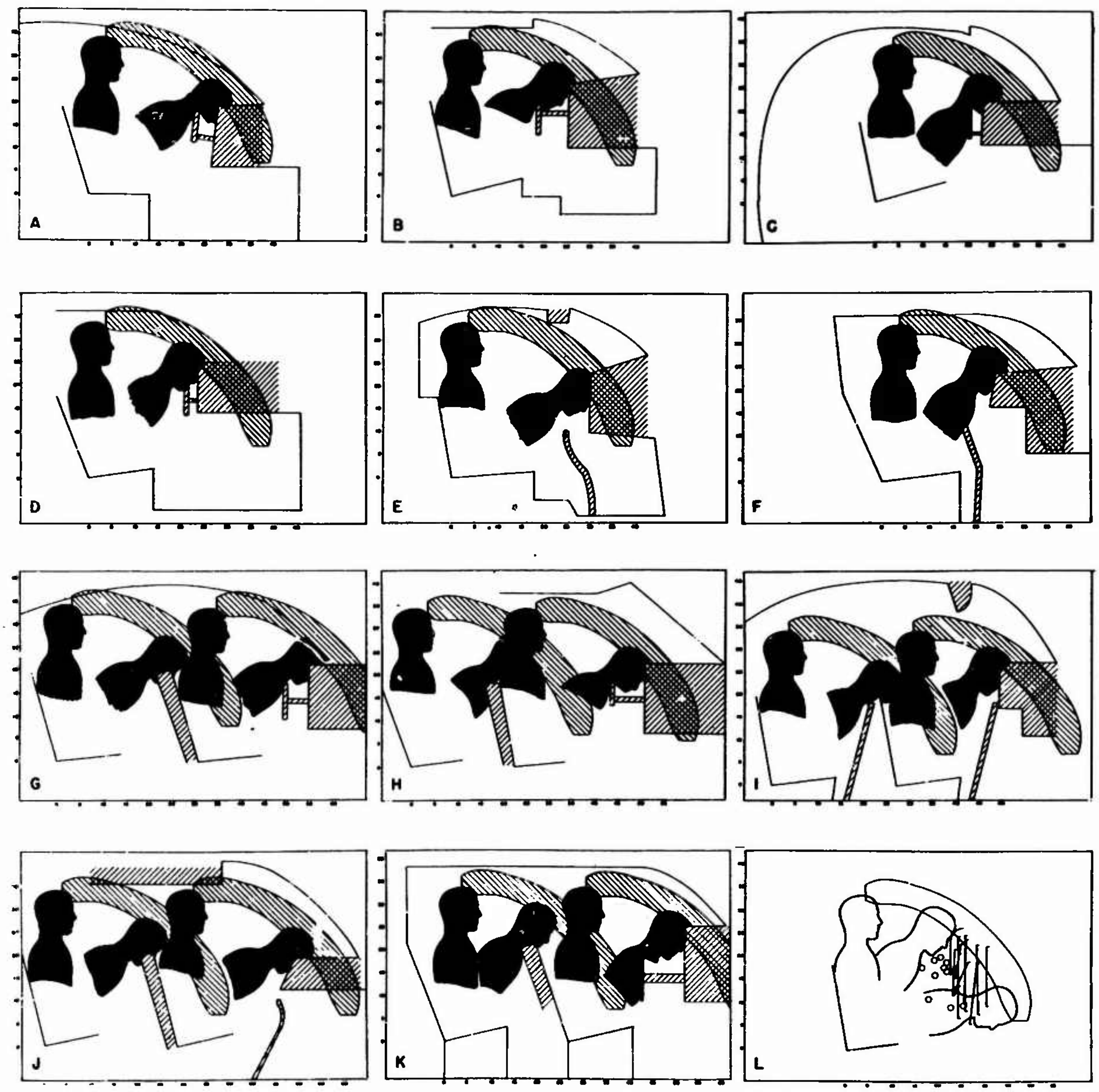



**Figure 1. Minimum head clearance as related to 11 popular personal type aircraft.**

In Case Number 5 a Piper Comanche PA 24–250 (1962) skidded 305 feet on muddy ground before coming to rest. Assuming a flight velocity of 65 miles per hour just before initial contact with the ground, one can calculate an average deceleration of less than ½ "g". However, since the pilot received a 5-inch laceration across the top of both eyebrows from striking the top edge of the instrument panel, we can safely state that at one point the deceleration slightly exceeded

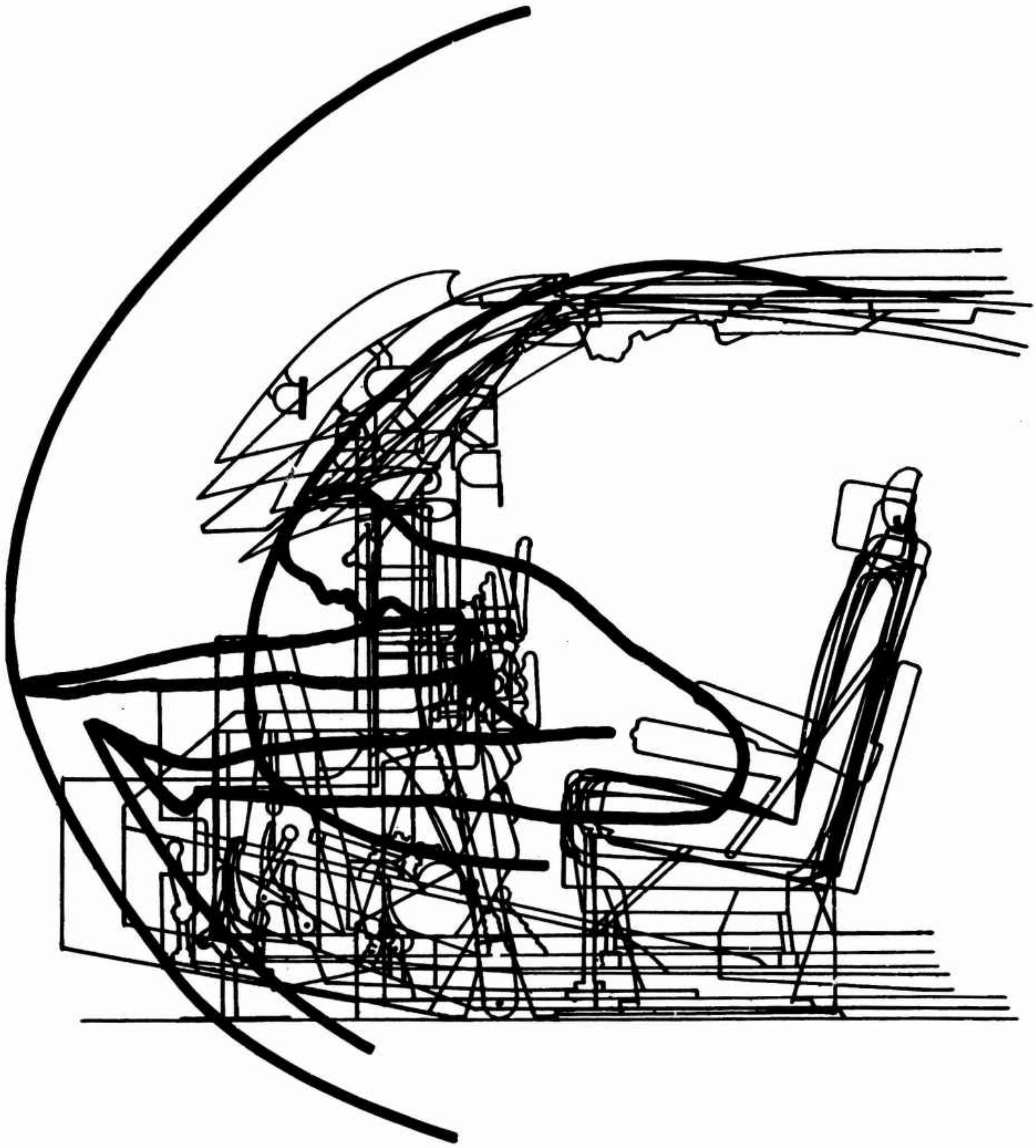


FIGURE 2. Area of forward flailing (95th percentile) with seat belt restraint, superimposed on scale drawings of 11 general aviation aircraft.

2.5 "g" (reference Case 4), probably during initial impact where the aircraft was changing direction. More severe facial injuries were probably not sustained since the pilot's head hit a relatively flat arc of the instrument panel (Case 5 C), and since a significant portion of the forward force of the head and trunk was dissipated when the chest struck the control yoke fracturing several ribs as well as the horns on the yoke.

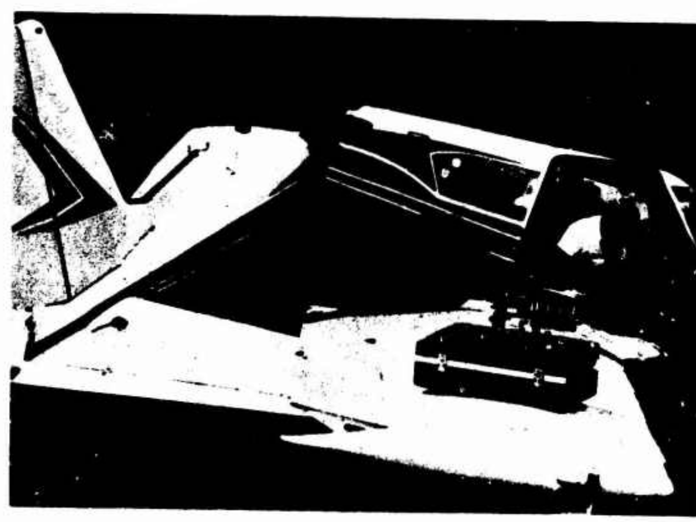
1963 PIPER COMANCHE

PIPER COMANCHE PA-24-250, a 1962 model aircraft with pilot and three passengers (R. F., L. R., R. R.), encountered bad weather and struck muddy ground in a flat attitude and skidded 305 feet over a small hill. All occupants were wearing seat belts and they held. No shoulder harnesses were in the aircraft.

ACCIDENT INVESTIGATED BY:
GALE BRADEN AND EDDIE LANGSTON
CAMI

# CASE 5-1

A. Path taken by aircraft during 305-foot deceleration.



B. Final attitude of aircraft. Tail section separated at the rear of the cabin & turned 90°.

# CASE 5-2

C. Left half of instrument panel showing head impact and broken control wheels.

D. Pilot with 5-inch laceration from contact with upper instrument panel.

E. Pilot leg fracture from impact with lower instrument panel shown above.

F. Lower left instrument panel. Heavy radio fractured right leg of copilot shown below.

| | INJURIES | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (S) | Head - Large transverse lac. across both eyebrows & above nose. | Top edge of instrument panel. |
| | Trunk - Fx. ribs lower (L) chest. | Control wheel. |
| | Extremities - Fx. (R) talus. | Pedal area. |
| R. F.: (S) | Head - "V" shaped lac. (L) eyebrow. Lac. nose, (R) upper eyelid & (R) brow. | Upper instrument panel. |
| | Trunk - None. | |
| | Extremities - Lac. (L) knee. | Lower instrument panel. |
| L. R.: (S) | Head - None. | |
| | Trunk - None. | |
| | Extremities - Fx. (R) ankle. | Wedged under front seat. |
| R. R.: (S) | Head - Fx. nose. | Back of front seat. |
| | Trunk - Chest pains (no Fx.). | Back of front seat. |
| | Extremities - Sprained ankles (R) & (L). | Under front seat. |

# CASE 5-3

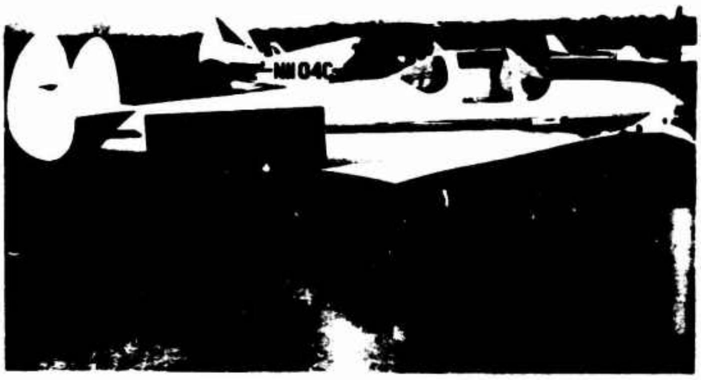
In Case Number 6, photographs are shown of the right front passenger with crushing fractures of the nose and right maxillary sinus along with severe lacerations of the nose and frontal sinus area (Case 6 K & L) received when he jackknifed over his seat belt and impacted the top edge of the instrument panel at the point indicated by the head outline (Case 6F). Since this Ercoupe 415–C (1946) skidded 114 feet before coming to rest, an average deceleration of slightly over one "g" can be calculated, assuming an impact velocity of 95 ft./sec. However, as discussed earlier, one can brace against a one "g" impact and it must be assumed that since he hit the ground at about a 30° angle, the deceleration forces were somewhat higher than one "g" during a few milliseconds time span. Again, as in Case 5, the chest contacted the control wheel and evidently the occupant was able to hang onto the rim with sufficient strength to deform the wheel toward the instrument panel (Case 6 G), probably reducing the head impact velocity to a point that barely prevented the fatal head injuries. It is impossible to calculate the exact velocity of head impact, but based upon the author's studies of tolerances of the human face to crash impact (to be discussed later), the author estimates that the head impact velocity could not have been more than 15 ft./sec. in this case. Since the stopping distance of the head was about one inch (¼ inch dent in panel +¾ inch crushing of facial bones), the deceleration of the head may be calculated to be 42 "g". The human face cannot tolerate this magnitude of deceleration force on two square inches of area (see tolerances of face discussed later). We begin to appreciate the head injuries which may occur at cabin decelerations as low as three "g" when the impact force must be absorbed on small areas of the head.

Case Number 7 describes a later model (1966) Cessna 150F that crashed with a calculated average deceleration of 6.93 "g". The pilot's seat belt held and his upper torso was thrown slightly to the right, allowing his face to impact the upper center instrument panel. Crash sled testing in this laboratory indicates that the seat belt restrained occupant will impact the instrument panel with a head velocity of nearly 40 ft./sec. during a 7 "g" deceleration of the aircraft. Fortunately for this pilot, he impacted his chest on a control wheel designed to fit the contour of the rib cage bending the control column to the right and down with only a slight contusion of the chest and right shoulder (Case 7 F) and slowing his head velocity to a point (estimated 18 ft./sec.) that he survived with very severe facial injuries. Especially worthy of note at this point is the needless deep laceration (8 inches long) across the chin and right cheek inflicted when his face slid down and engaged the thin cover plate over the radio (Case 7 E). Teeth marks in the same figure indicate that his upper teeth and hard palate were destroyed when he impacted the top edge of the instrument panel just above the key insert.

In Case Number 8 a 1959 Piper Comanche PA 24–250 wiped its landing gear off by striking an earthen embankment around a farm pond and slipped over the embankment into the pond. The deceleration was again determined to be in the 5 to 6 "g" range. The pilot and copilot were thrown forward, impacting their heads at the two points clearly indicated on the instrument panel (Case 8 E), causing severe, but survivable, facial lacerations. Post-mortem examination revealed that the two front seat occupants were rendered unconscious and drowned when the plane sank. An autopsy was not performed on the rear seat passenger, but since rear seat occupants usually receive less severe injuries it is very probable that he also drowned.

Crash Case Number 9 was almost identical to the previous case described, the difference being that this Piper PA 22–135 (1959) aircraft did not end up in the water and all five occupants survived. Total ground contact stopping distance was 84 feet after contact with the fence and it is doubtful if the maximum deceleration force exceeded 5 "g". Head impact depressions of the two front seat occupants were clearly visible in Case 9 C and D. There were no trunk or leg injuries and the three children in the rear seat received only bruises.

In evaluating Crash Cases 4 through 9 (all of which must be classed as minor) in terms of the four principles of packaging presented earlier, we can conclude that general aviation aircraft pretty well meet the first principle (container or cabin integrity) as long as the crash impact does not exceed 6 or 7 "g". However, the other rules for safe packaging have been almost completely ignored, the exception being that means are provided for restraining the long, flexible, fragile contents only at their central points—




**1946 ERCOUPE**

ERCOUPE 415-C, a 1946 model aircraft with pilot and one passenger (R. F.), circled low over a farm house, reduced power to talk to someone on the ground, and crashed at a 30° angle on a hard pasture land, skidding 114 feet before coming to a stop. The impact force threw both occupants forward and slightly to the left. Seat belts (attached to the fuselage) were in use and held. There were no shoulder harnesses in the aircraft.

(Note: Aircraft does not have rudder pedal.)

ACCIDENT INVESTIGATED BY:
GALE BRADEN
CAMI

# CASE 6-1

**A. Distant view of resting aircraft & part of its 114-foot skid mark.**

**B.**

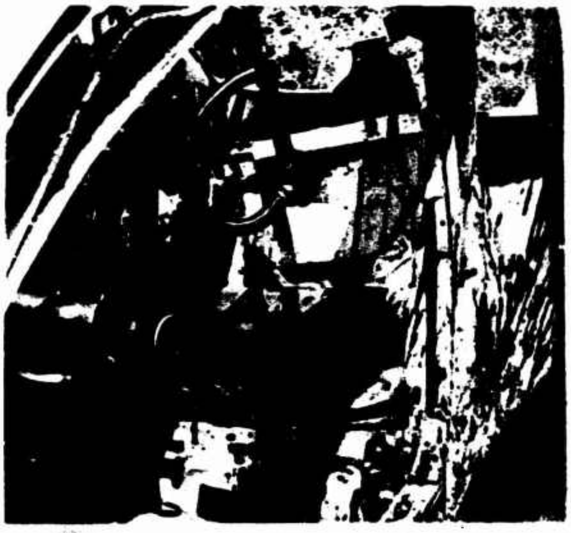
**C.**

D.

**CASE 6-2**

**B C D**

**Close-up views of the exterior of the aircraft. The cabin maintained its integrity. The plastic windshield disintegrated & some outward buckling of the sides of the cockpit may be noted.**



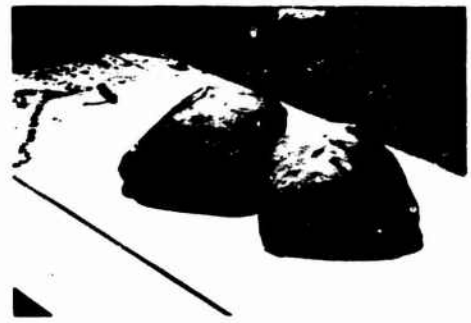
E. Internal view of cockpit. Note control wheel rims bent forward.

F. Head outline & dent in upper right instrument panel indicate head impact of copilot.

G. Area of body impact of pilot.

H. Note broken plexiglass windshield.

# CASE 6-3



J. Seat cushions.

I. Seat construction consists of aluminum buckets for cushions shown in J.

K & L Side & frontal views of facial injuries suffered by copilot when his head hit the top corner of the instrument panel (Figure F).

| INJURIES | | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (S) | Head - Lac's. scalp & forehead. | Windshield. |
| | Trunk -None. | |
| | Extremities - Lac's. both wrists, open Fx. (R) radius & ulna, closed Fx. (R) hand. Lateral ligament tear (L) ankle. | Instrument panel, after hands tore free of control wheel. Left cockpit wall. |
| R. F.: (S) | Head - Crushing Fx's. nose & (R) maxillary sinus. Severe lac's. nose & (R) frontal sinus area. | Top edge of instrument panel. |
| | Trunk - None. | |
| | Extremities - None. | |

# CASE 6-4

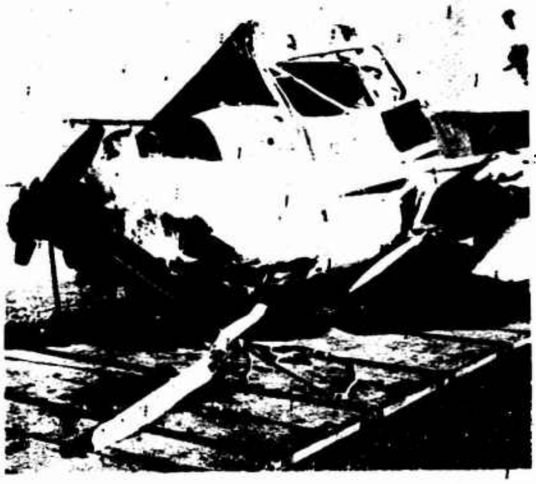
 

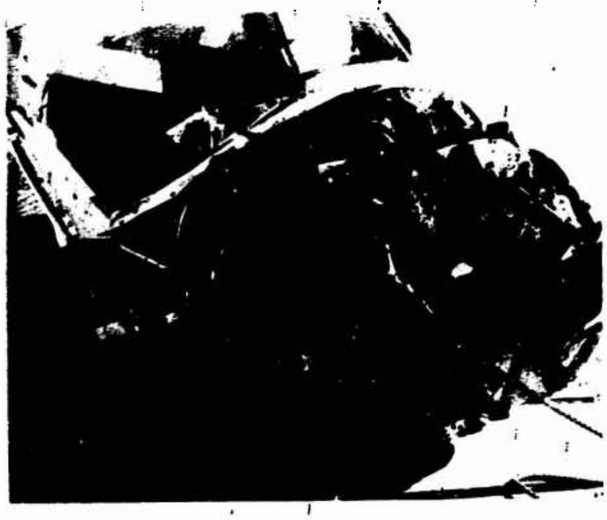
**1966 CESSNA 150**

CESSNA 150 F, a 1966 model aircraft with pilot only, was observed circling a farm house. Aircraft pulled up - stalled - crashed at a steep angle, left wing first. Engine was pushed to the right. Seat belt was in use. No shoulder harness was in the aircraft. Pilot's head and trunk were thrown slightly to the right.

ACCIDENT INVESTIGATED BY:
DON ROWLAN AND TERRY WALLACE
CAMI

# CASE 7-1



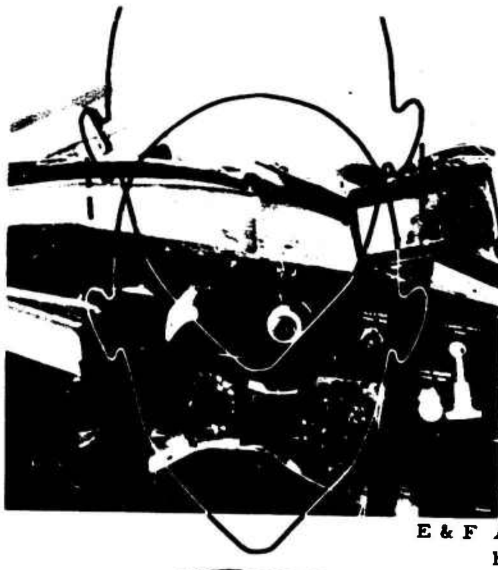


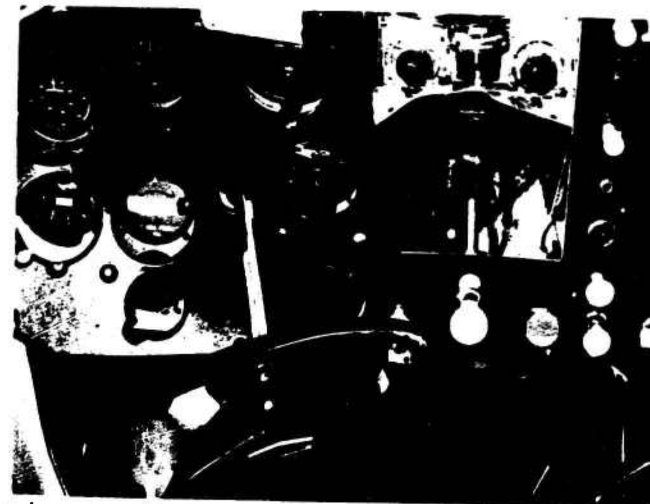
A & B Slight damage to the motor & cabin are indicative of a minor crash impact.

| | | INJURIES | STRUCTURES IMPACTED |
|---|---|---|---|
| Pilot: (S) | Head - | Evulsed Lac. over (R) eye, both eyes swollen shut; all upper teeth & soft palate destroyed. | Upper center instrument panel. |
| | | Deep Lac. 8" long across chin & cheek. | Radio cover plate. |
| | Trunk - | 6" contusion mid-line of chest & (R) shoulder. | Control wheel. |
| | | Seat belt marks on abdomen & pelvis. | Seat belt. |
| | Extremities - | Arms & legs, minor abrasions & bruises. | Instrument panel. |

C & D Minor abrasions in the pelvic area are proof that this pilot was wearing a seat belt.

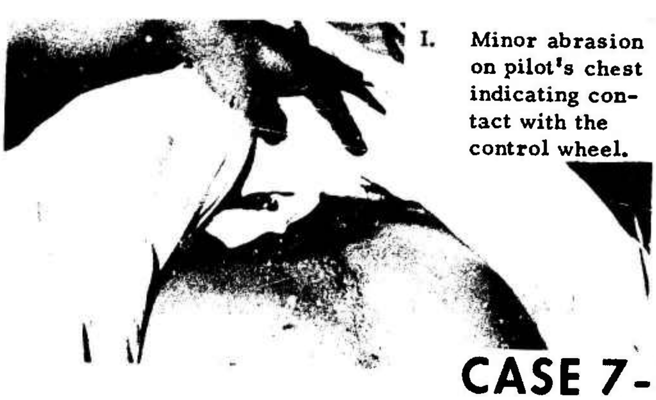
CASE 7-2



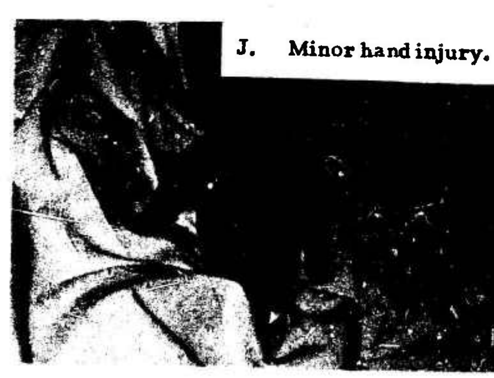


E & F Area in center of instrument panel where pilot's head struck. Note teeth enamel above key insert and sharp edge of radio cover plate.

G & H Artist sketch & actual photograph of severe facial injuries inflicted.



I. Minor abrasion on pilot's chest indicating contact with the control wheel.



J. Minor hand injury.

# CASE 7-3

**1959 PIPER COMANCHE**

PIPER COMANCHE PA-24-250, a 1959 model aircraft with pilot and two passengers (R. F. and ?R.), failed to clear a fence on takeoff, struck the fence with its landing gear, and traveled 420 feet before making ground contact. The gear and nose struck on the earthen dam of a farm pond. The aircraft then bounced over the dam and sank in the pond about 20 feet from the bank, after floating for two or three minutes. The aircraft was equipped with seat belts, but only the R. F. was in use and it held. No shoulder harnesses were installed. Occupants were thrown forward and to the left.

ACCIDENT INVESTIGATED BY:
GALE BRADEN
CAMI

# CASE 8-1

A. Blacktop landing strip with 4' fence across the end. Landing gear of aircraft hooked fence on take-off.

B. After traveling 420 feet in the air, aircraft impacted this dirt embankment, tore off its gear, and slid over into the pond.

C. View of the aircraft as it was pulled out of the pond. Note cabin is entirely intact.

# CASE 8-2

D. General appearance of cabin interior.

E. Head outlines indicate dented areas at top edge of the instrument panel produced by head impacts of two front seat occupants - all were knocked unconscious & drowned.

| | | INJURIES | STRUCTURES IMPACTED |
|---|---|---|---|
| Pilot: (F) | Head | - Irregular V-shaped lac. to bone (L) front parietal scalp 4 cm. & 7 cm. Lac. (L) side of neck 2 cm. | Upper (L) instrument panel. Knocked unconscious & drowned. |
| | Trunk | - None. | |
| | Extremities | - None. | |
| R. F.: (F) | Head | - 4 cm. lac. (L) lateral inferior mandible. 2 cm. lac. (L) lateral inferior mandible. | Top center of instrument panel. Knocked unconscious & drowned. |
| | Trunk | - None. | |
| | Extremities | - None. | |
| ?R: (F) | Injuries unknown - drowned. | | |

# CASE 8-3

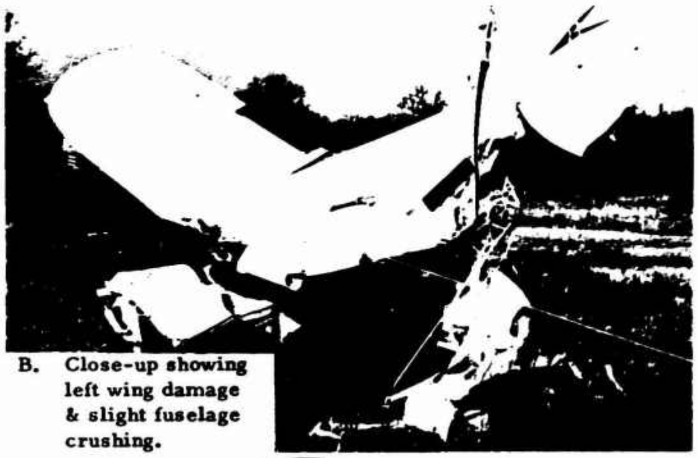
 

**1953 PIPER PA-22**

**PIPER PA-22, a 1953 model aircraft with pilot and four passengers (R. F., L. R., C. R., and R. R.) (three children in the rear seat) had taken off and was about two miles from the airport. The motor started missing and the pilot had started to return to the airport when the motor stopped and he attempted to land in a field. The (L) wing tip and landing gear (L) struck the top strand of a four-foot high fence. The aircraft traveled 21 feet and struck the ground, skidded 36 feet, left the ground for 30 feet, impacted again and skidded an additional 48 feet. The aircraft came to rest on the (L) wing and nose. Seat belts were in use and held. No shoulder harnesses were installed. Occupants were thrown to the (L) and forward.**

ACCIDENT INVESTIGATED BY:
BILL REED AND LEE LOWREY
CAMI

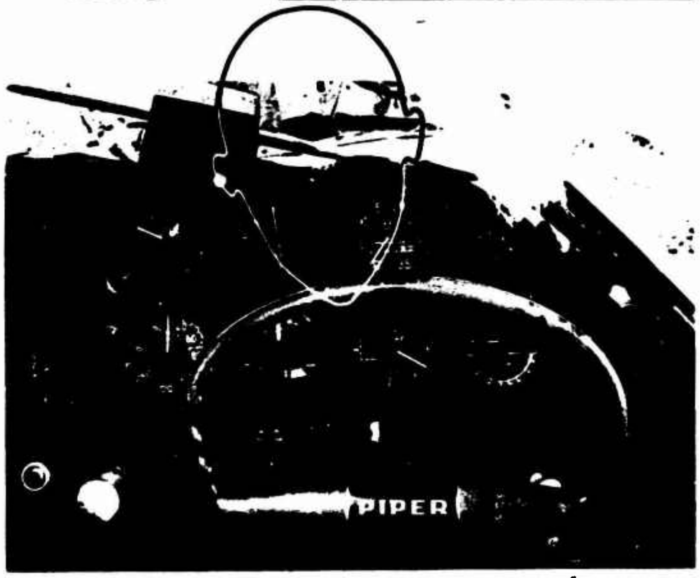
# CASE 9-1



B. Close-up showing left wing damage & slight fuselage crushing.

A. Side view of aircraft after impact.

C. Area of pilot's head impact.




D. Dent at the top edge of instrument panel caused by copilot's head impact.

| | INJURIES | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (S) | Head - Cerebral concussion. Lac's face & mouth. Cut & bruised chin. Lac. behind (L) ear. | (L) "A" post & vent window. |
| | Trunk - None. | |
| | Extremities - None. | |
| R. F.: (S) | Head - Mult. small lac's. face, nose & scalp. | Top of instrument panel (center) |
| | Trunk - None. | |
| | Extremities - None. | |
| L. R., C. R., & R. R.: (S) | Minor bruises. | |

# CASE 9-2

the lap belts applied around the pelvic structure. The lap belt, if worn and if it does not fail, restrains only the pelvic area and allows the rest of the body to continue in motion until stopped by impacting some portion of the container. In a number of cases in this study it was noted that even the lap belt is an ineffective restraint because of faulty installation. In numerous aircraft the lap belt goes across the thighs and straight down to the floor (Figures 3 and 4) instead of across the iliac crest and then back at a 45° angle to the floor.

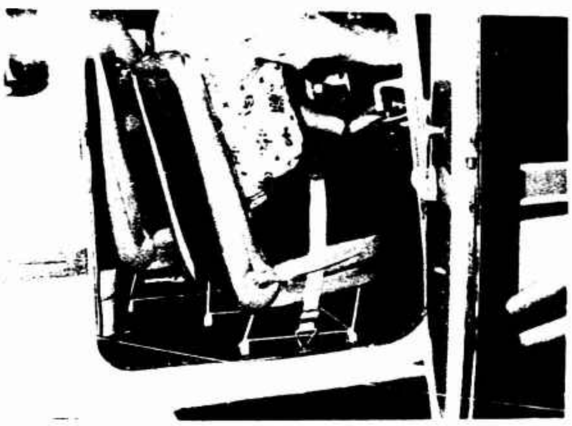


FIGURE 3. Subject wearing seat belt in 1968 Cessna 150.

During deceleration the occupant is free to move forward until the belt is at nearly a 45° angle with the floor before the belt offers any restraint. By this time he is sliding off the front edge of the seat (Figure 5) and the forward motion added to belt stretch allows him to penetrate the firewall.

In general aviation aircraft design, engineers have completely ignored the fourth rule of safe packaging (inside of container must be designed to cushion and distribute impact forces over maximum surface area and yield to increase deceleration time). The head, trunk, arms and legs flailed against a conglomeration of rigid edges, angles, points, and knobs causing numerous injuries at body impact velocities of 15 ft./sec. and less in the five very minor accidents just presented. In contrast, the rewards of the safety improvements of the interiors of late automotive vehicles are clearly demonstrated in six automotive crashes shown in Figures 6 through 11. Occupants were subjected to "g" forces ranging from 3 to 12 with minor or no injuries even

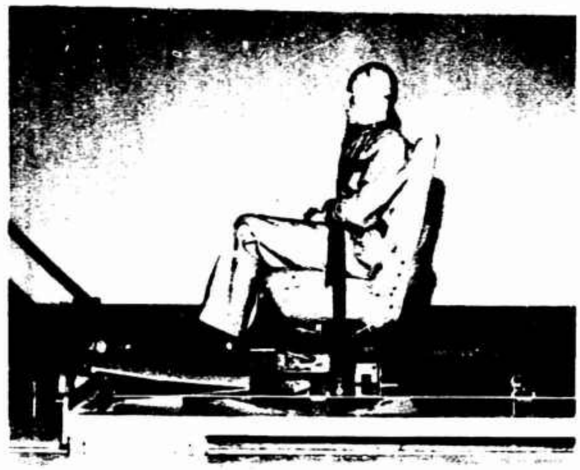


FIGURE 4. Dummy with seat belt attached straight down over thighs before crash test.

FIGURE 5. Position of dummy after crash test. Extreme forward motion is allowed by improper seat belt installation.

though none of them were wearing seat belts. Each automotive crash case presents on a single page the angle of impact, object impacted, direction of motion, number of occupants, presence and use of seat belts, direction occupants were thrown, structures impacted by the body, and body injuries.

Before presenting crash cases of a little more severity than these, it might be well to discuss some of what is known of human body tolerances to impact. The author has presented extensive data in a previous study [57] defining human tolerances of the frontal portion of the head (face and forehead) to impact. He has shown

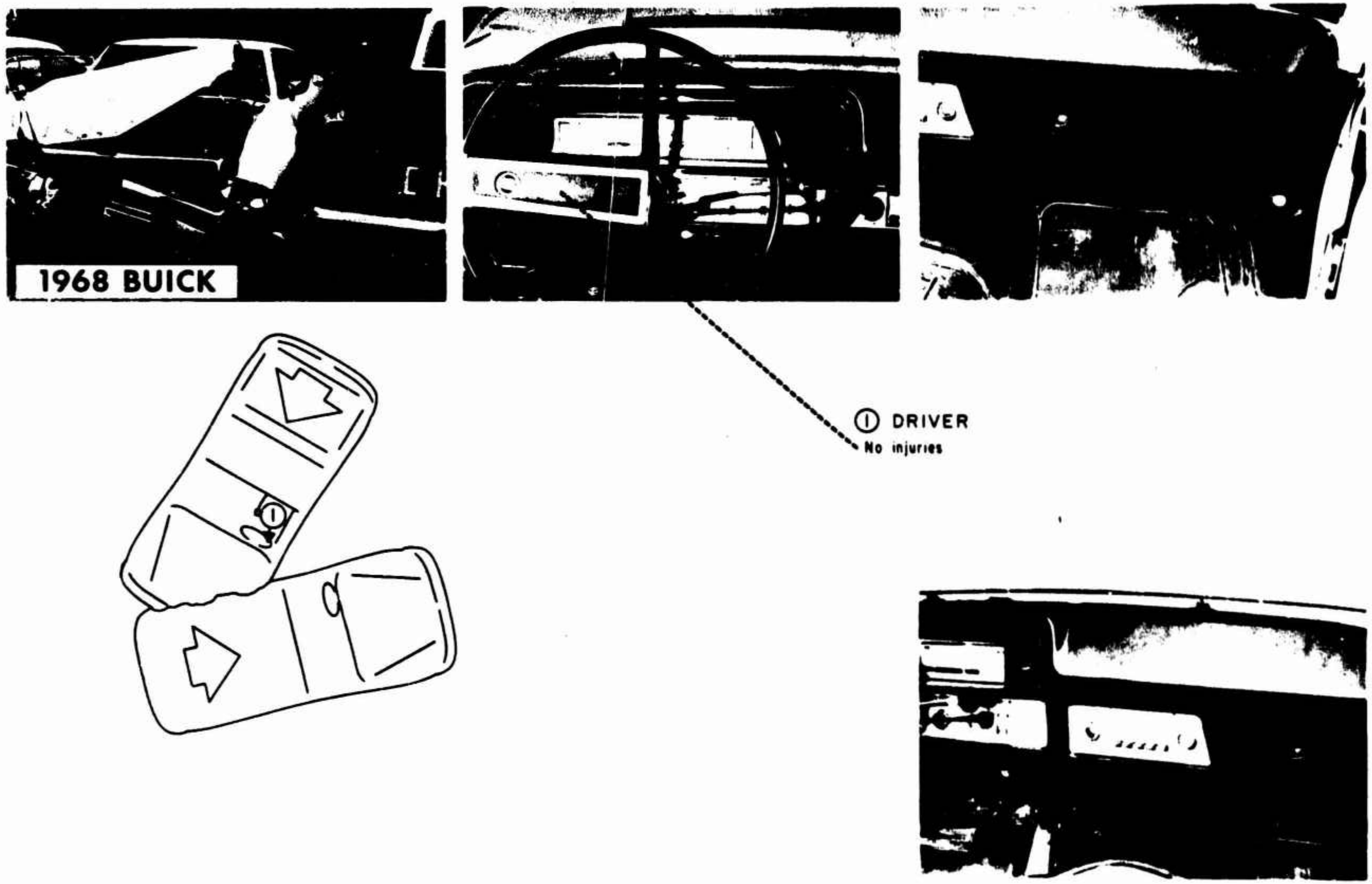



FIGURE 6. Automotive accident of a calculated 3 "g" impact force.

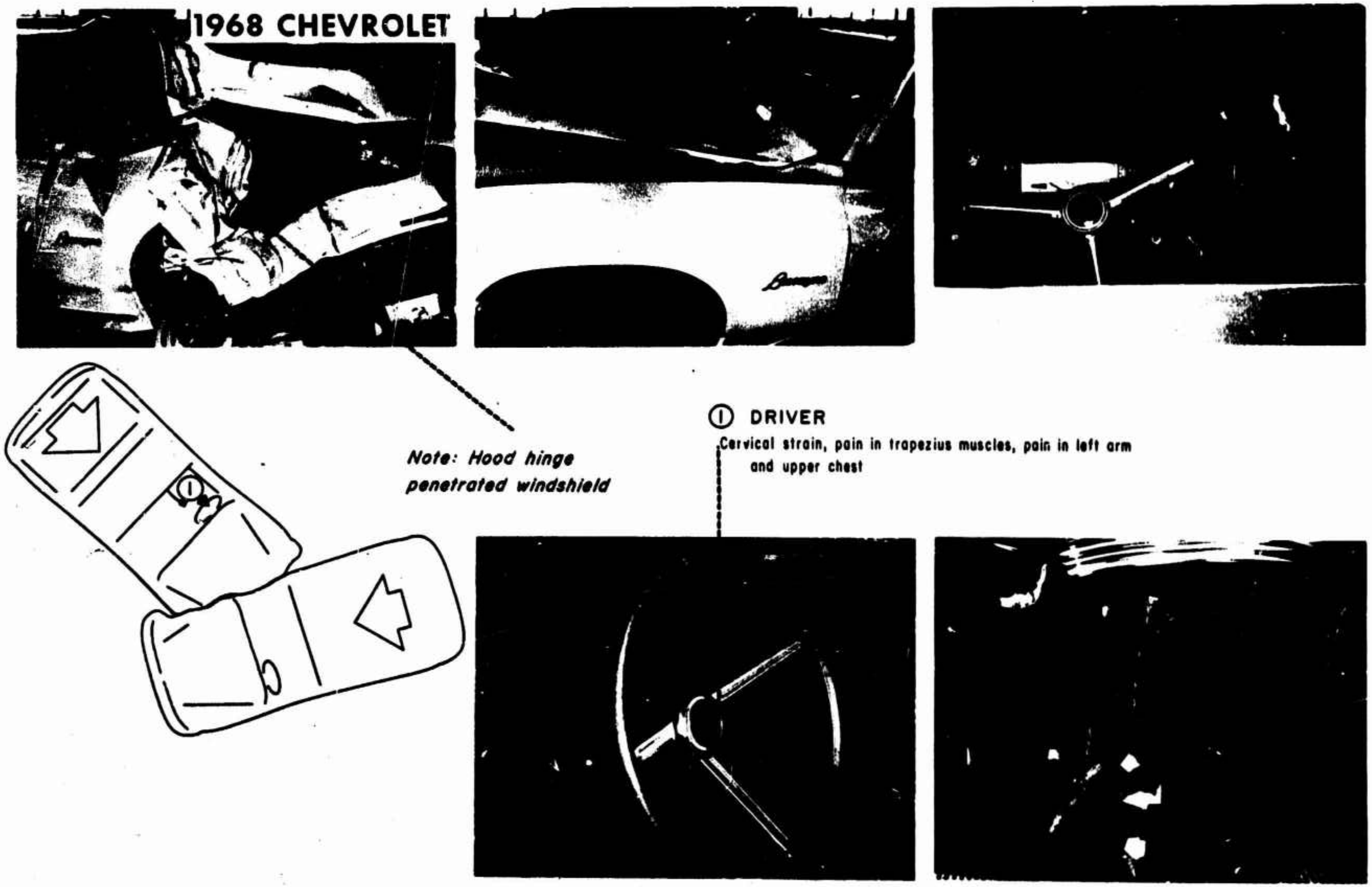



FIGURE 7. Automobile accident in which driver was subject to 7 "g" forward deceleration.

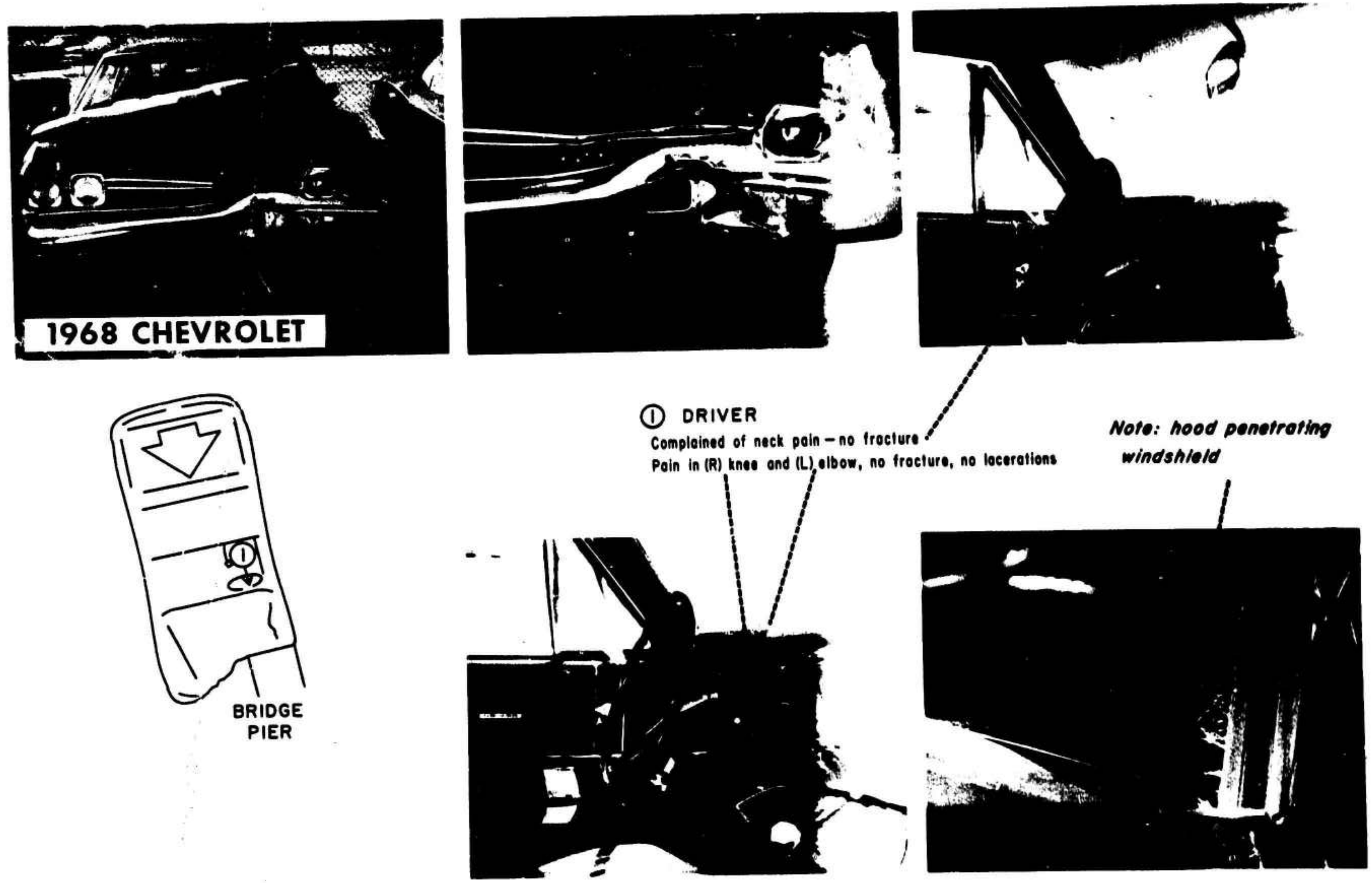



Figure 8. Automobile accident that subjected driver to 9 "g" deceleration.

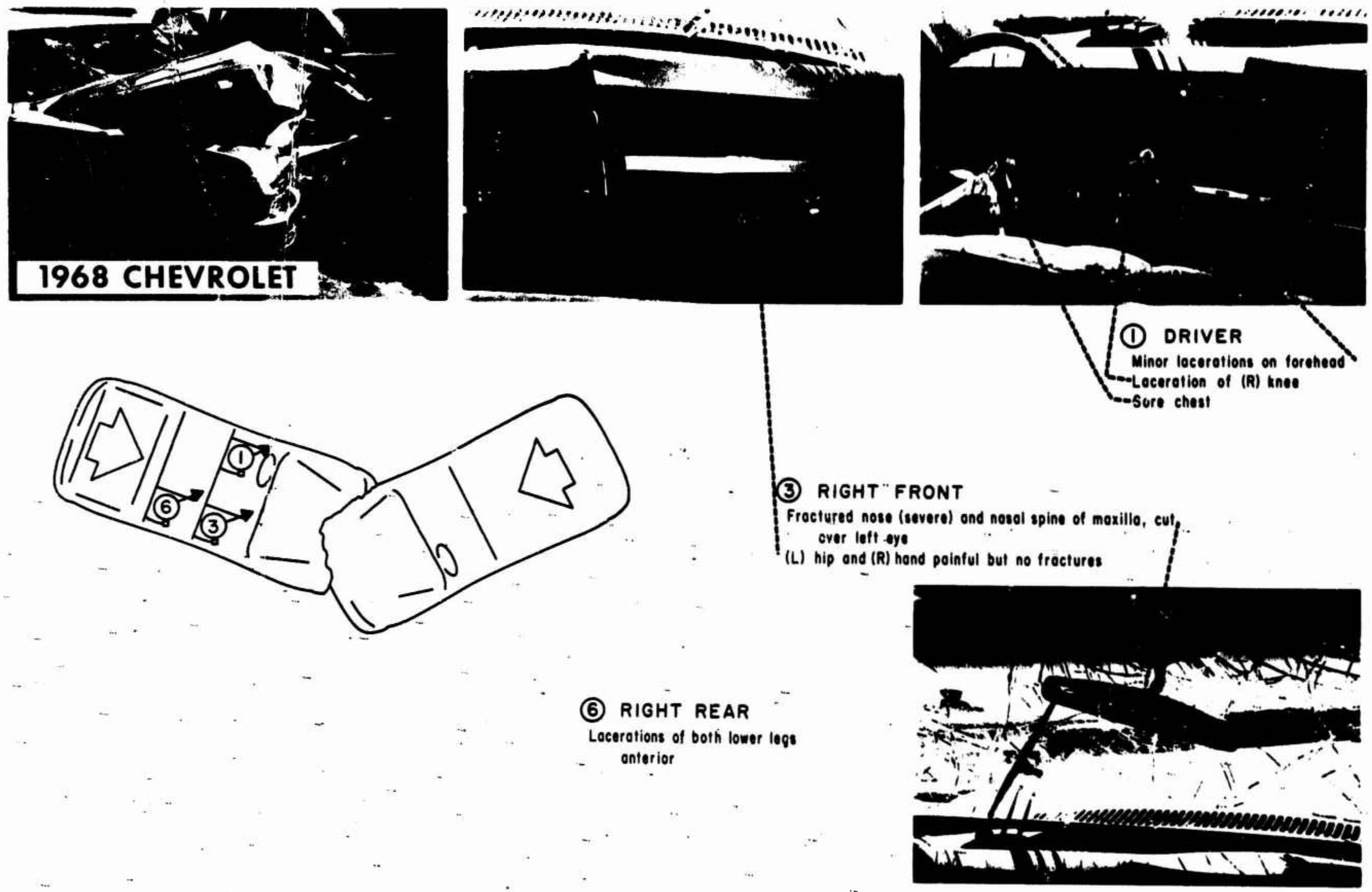



FIGURE 9. Effects on occupants in a 10.5 "g" automotive crash.

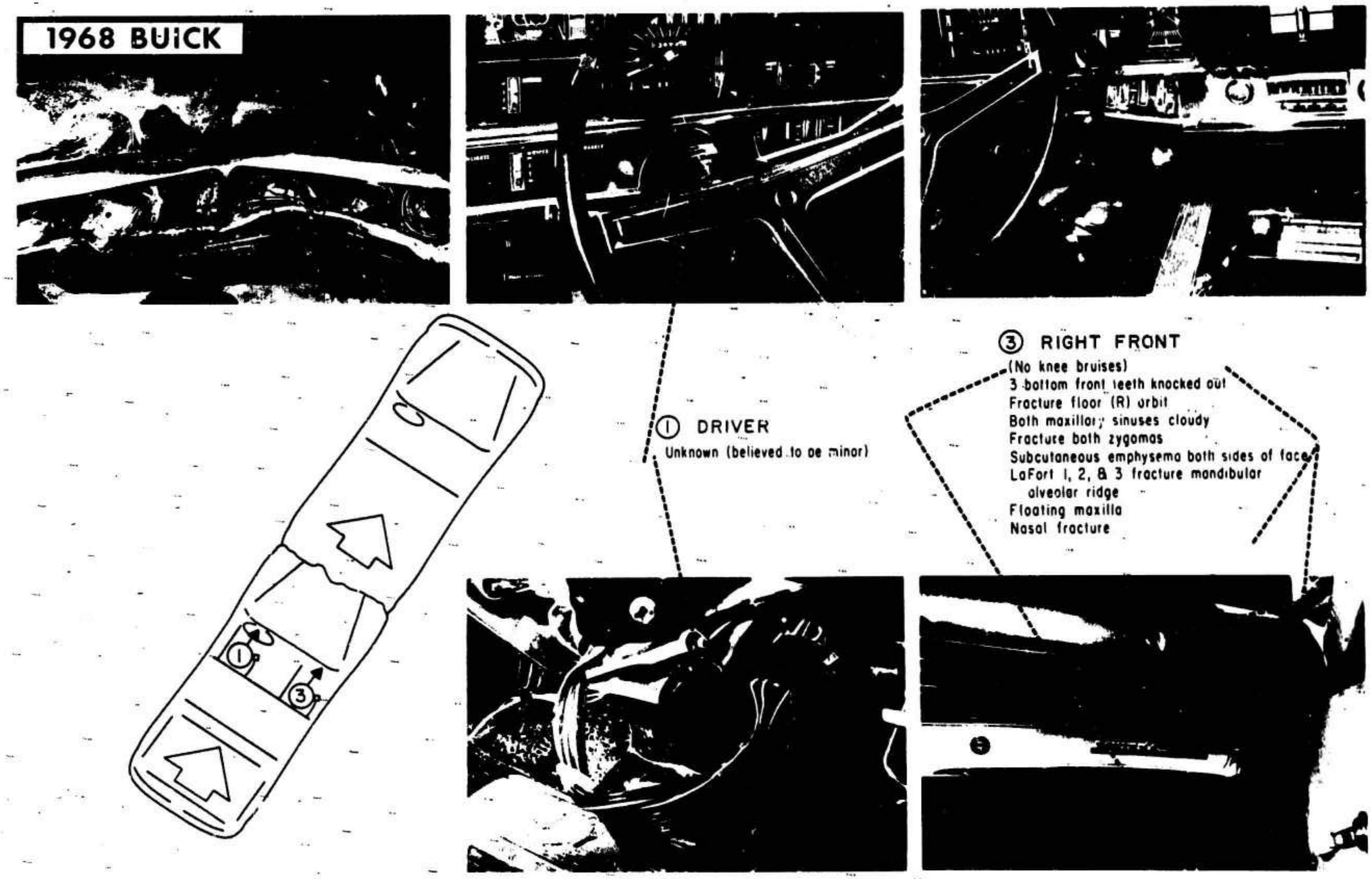



FIGURE 10. Driver impact against right door and dash in a 12 "g" intersection crash.

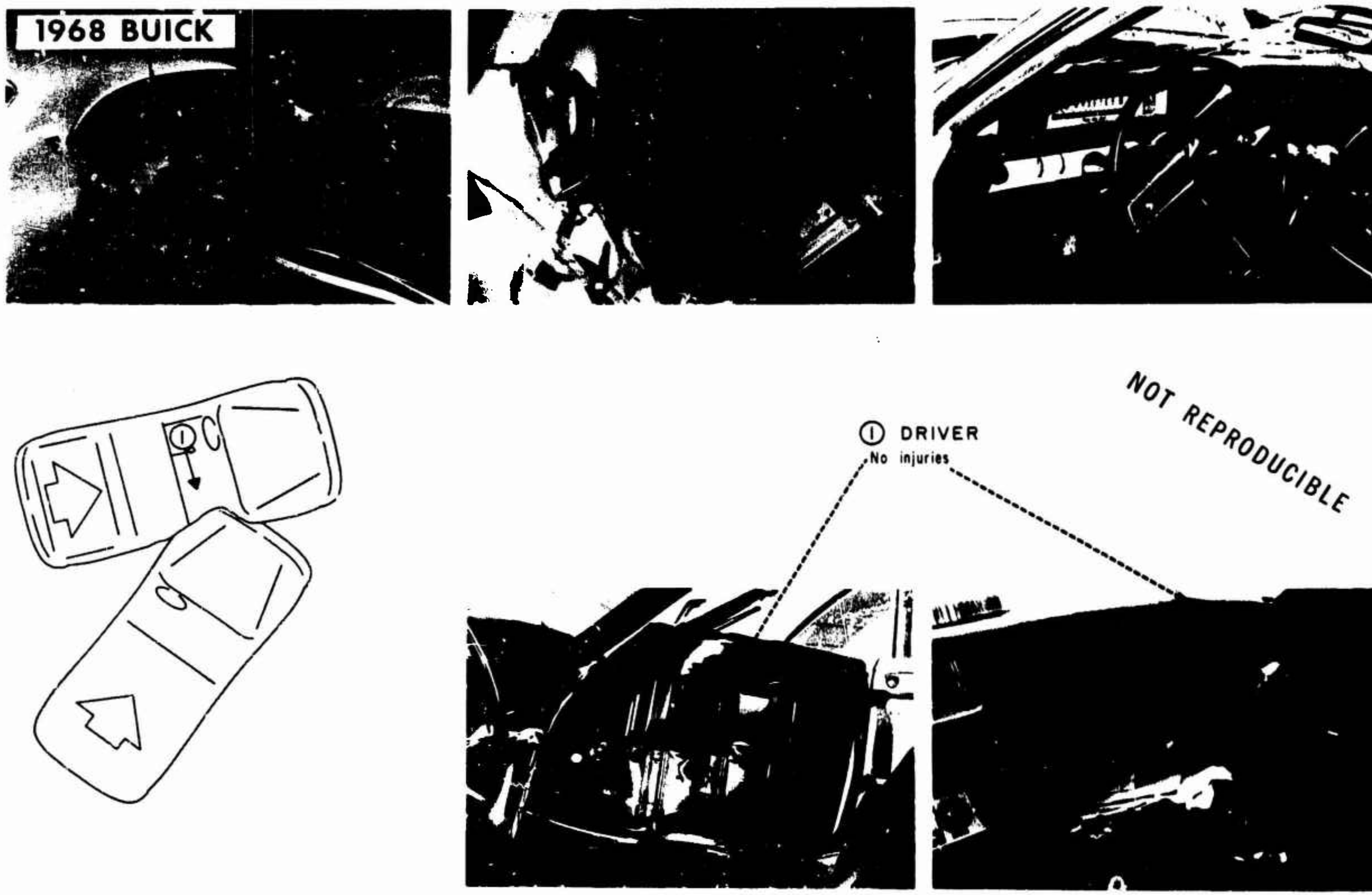



FIGURE 11. Automobile collision of 12 "g" magnitude in forward direction.

that a single square inch of the forehead is capable of withstanding an 80 "g" impact without fracture—*PROVIDED* the force is evenly distributed over the contour of the area impacted. If this area of contact is increased to 3 square inches, the frontal skull of most adults can withstand 200 "g" without fracture. Other portions of the face explored include the zygomas, nasal area, maxilla, and mandible and tolerance limits are shown in Figure 12.

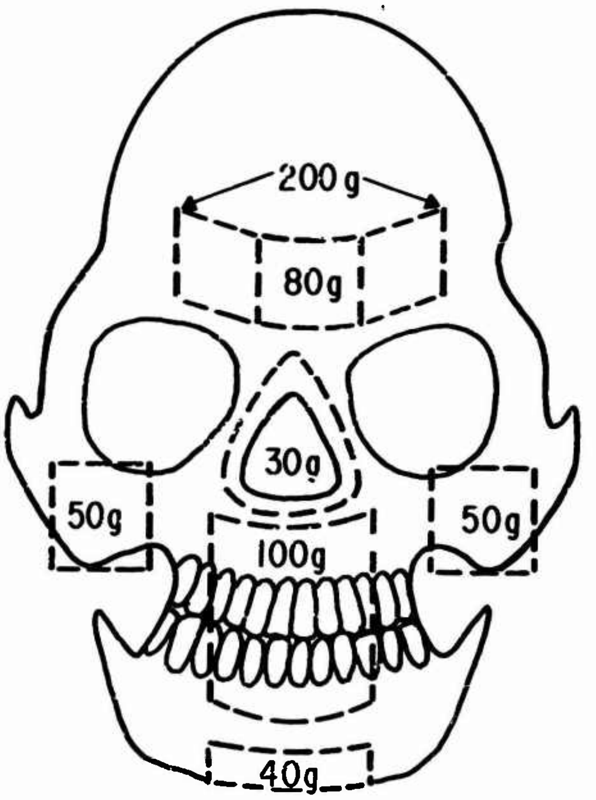



FIGURE 12. Tolerances of the human head to crash impact.

He then became curious as to whether or not these impact tolerance areas were additive. A rigid cast was made for one cadaver head to provide even distribution of force over the entire frontal face and forehead. Impact tests exceeding 300 "g" produced no signs of soft tissue laceration or bone fractures. Every tooth and even the thin turbinate bones of the nose remained undamaged (Figure 13).

This study shows conclusively that it is possible through engineering design of the inside of the container to completely eliminate lacerations and fractures of the head and face during head impact of extremely high forces (over 300 "g").

A separate study by the author [58] shows that this can be accomplished utilizing a fairly firm, slow-return padding material to distribute impact forces evenly over the contour of body structures being impacted along with a ductile backing structure that will yield and extend the deceleration time. In addition, there is evidence in the literature [59, 60] that brain injury and even concussion may be prevented with head impacts up to 300 "g", *provided* skull deformation is prevented through the use of force distribution. The principle itself is not new as even the Knights of King Arthur's Round Table wore suits of armour to distribute the blow of their opponents' sword edge and prevent body penetration by distributing the load. For the same reason we have invented bullet-proof vests, football helmets, and even shoes. Since this simple principle has been known for such a long time, it is difficult for one to understand why manufacturers of people-shipping containers have neglected the use of it. Lack of protective design has been the direct cause of over 300,000 deaths and better than 20,000,000 serious head injuries in transportation vehicles over the past ten years. The automotive manufacturers in the past two or three years have begun using a dash panel of ribbon steel covered with slow-return padding (Figures 14 and 15) that is proving effective in preventing head injuries.

Forty other different materials and combinations of materials for instrument panel design have been evaluated recently to determine their ability to absorb occupant energy.[61]

Continuing our crash case analysis, in Case Number 10, a 1959 Cessna 182 B nosed over into a lake from a height of 18 feet after hooking its vertical stabilizer on a telephone wire. The two occupants jackknifed forward over their seat belts and the pilot's head struck the top edge of the ⅛ inch thick aluminum plate which covers the front of the instrument panel (Case 10 C). A knife-like penetration wound (Case 10 D) through the bridge of his nose and both eyes back into the brain caused almost instant death and was his only injury. The impact force is not known but must, of necessity, have been relatively low as attested to by the lack of leg injuries and the fact that the seats and seat belts did not fail. It was unfortunate for the pilot that this knife-like edge contacted the bridge of his nose and eye areas—probably the weakest

FIGURE 13. Full-face (maximum area) crash test exceed 300 "g" deceleration.

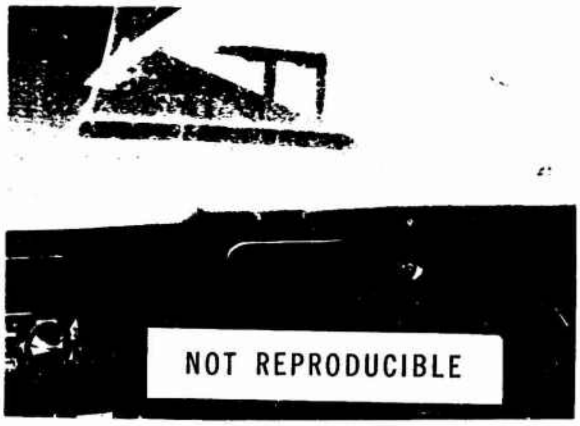



FIGURE 14. An example of a padded dash panel in a late-model automobile.

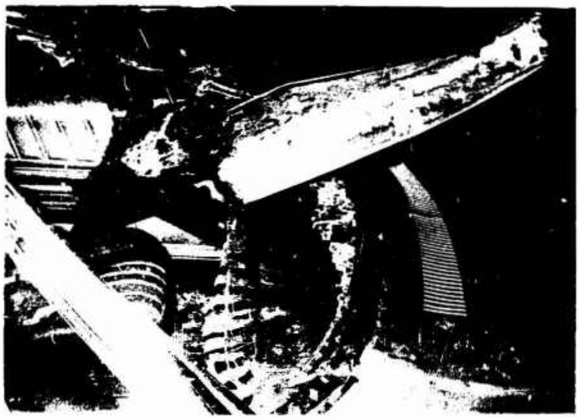


FIGURE 15. Steel ribbon design of dash structure under padding has good yield characteristics.

part of the face, but even if it had contacted the frontal skull (the strongest structure of the anterior head), it would have produced a fatal skull penetration with a head impact velocity as low as 5 ft./sec. (3+mi/hr.). In the above discussion of facial tolerances it was stated that a one-square-inch area of the forehead could withstand an 80 "g" impact. In this case the 1/8 inch sheet metal could not have made contact with more than a two-inch strip of the flattened portion of the forehead or a total area of contact of ¼ square-inch. Skull fractures can be expected with slightly over 20 "g" impact forces on a ¼ square-inch area and since the sheet metal impacted by the head deformed only ½ inch, a head velocity impact of 5 ft./sec. stopping in ½ inch would produce a rate of change of velocity of 600 ft./sec.$^2$, or nearly 20 "g". This discussion only serves to illustrate the fragility of the human head and face when impacted against small rigid objects even at very low velocities. Since head impact velocities of 40 to 50 ft./sec. are commonplace in even moderate crashes, the present high rate of deaths from head injury should be expected. In Case 10 A and B the aircraft appears to have sustained extensive damage during impact—the entire front cabin and engine missing—but most of this destruction can be attributed to recovery operations. The fact that the top of the instrument panel was within striking distance of the head bears out the theory that the cabin was intact when it entered the water.

Three "extreme" and seven "minor" accidents have been discussed thus far. The next four cases are of crashes of a little more severity and will be classed as "moderate". Moderate here is applied to crashes of the 8, 9 and 10 "g" deceleration range and the terminology selected on a basis of a study of automobile crashes of comparable intensity. An automobile traveling 60 miles per hour and striking a movable object such as another vehicle at an intersection and pushing it 15 feet would produce decelerative forces on the occupants of about 9 "g". Numerous accident cases involving late model automobiles in which occupants were tossed about with crash forces of 19 to 42 "g" are in our files and the occupants received minor or no injuries (Figures 16 through 26).

Case Number 11 shows a 1965 Mooney M-20-E aircraft after it crashed in muddy soil with a calculated impact force of 8 "g". A number of factors in this aircraft should be noted and discussed. For the first time we are beginning to see signs of failure of the shipping container (cabin) itself. As a single-engine aircraft crashes at an angle, the aircraft forward of the cabin may be crushed or deflected upward, downward, or to the side. Obviously, any crushing of the forward structure is beneficial as it reduces the deceleration forces ultimately transmitted to the cabin and its occupants as long as the cabin area itself is not compromised by penetration of structure. In this case there is evidence (Case 11 A and B) that the engine was forced up during some stage of the deceleration (probably as the aircraft flipped over) until it was at right angles to the axis of the aircraft and pushed the instrument panel back toward the front seat occupants. It should be noted, however, that there is no apparent structural failure with separation at the ends of the instrument panel. It is also worthy of note that the Mooney Corporation has installed a thin layer of padding on the top of the instrument panel (Case 11 C) in this aircraft and they are to be congratulated as it probably saved this pilot from fatal head injuries. On the other hand, the significant contribution of the padding to safety was partly nullified when the heavy compass was mounted on top of the instrument panel. A severe cerebral concussion was caused by this instrument when the pilot impacted it with his head (Case 11 D). In the same figure it is obvious that the pilot received his severe scalp lacerations on the broken plexiglass windshield and a fractured mandible with the loss of several teeth on the right horn of the control wheel which his body had bent up into the facial impact area. These plexiglass windshields have caused numerous severe lacerations, some fatal, as will be seen in other cases presented later in this report. Late-model automobiles are equipped with thin, strong, laminated glass windshields which have greatly reduced the head penetration and severe laceration problems. The control wheel in this aircraft is poorly designed from the standpoint of crash injury prevention. The horns frequently break off and sometimes penetrate the chest. Mounting a heavy protruding instrument with a reset knob protruding even further in the center of the control wheel significantly increases the chance of serious to fatal chest injuries. Beech redesigned their control wheel to fit the chest contour and eliminated the horns and protrusions 20 years ago. Cessna later developed a similar, well-designed control wheel (refer to Case 7). It should be noted, however, that both of these companies have gone back to the horned control wheel in some of their latest aircraft. The heavy radio with protruding knobs in the center of the instrument panel and the row of extended heavy aircraft controls (power, mixture, pro-

**1958 CESSNA 182**

CESSNA 182 B, a 1959 model aircraft with pilot and one passenger (R. F. ), was flying over a lake (approximately 18 feet from the water), flew under a telephone wire and hooked the vertical stabilizer on it, nosing over into the water. Both occupants were wearing seat belts and both belts held. No shoulder harnesses were in the aircraft. Pilot and passenger were thrown straight forward. Impact forces are not known but must, of necessity, have been very low, impacting water from only 18 feet.

ACCIDENT INVESTIGATED BY:
JIM SIMPSON AND DON ROWLAN
CAMI

# CASE 10-1

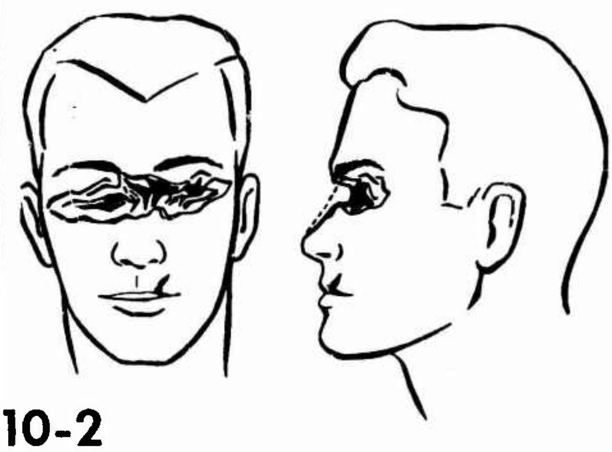
A. Side shot of wreckage retrieved from the lake.

B. Front view of wreckage showing seats & seat belts still in place.

| | | INJURIES | STRUCTURES IMPACTED |
|---|---|---|---|
| Pilot: (F) | Head - | Fatal, crushing, knife-like blow through both eyes & bridge of nose into the brain. Small cut on (L) upper lip. | Top left edge of instrument panel. |
| | Trunk - | None. | |
| | Extremities - | None. | |
| R. F.: (F) | Head - | 4.5 cm. Lac. of forehead just above eyes. Nasal bridge extensively Fx. | Top edge of instrument panel. |
| | Trunk - | Aspiration of water & mud. | Unconscious & drowned. |
| | Extremities - | Compound comminuted Fx's. (R) fibula & tibia & (L) femur | Lower edge of instrument panel. |

D. Fatal & only injury of pilot, inflicted by impact shown in C.

C. Left half of instrument panel retrieved from lake showing head outline of head impact of the pilot against the top edge of the 1/8"-thick aluminum instrument panel.



# CASE 10-2

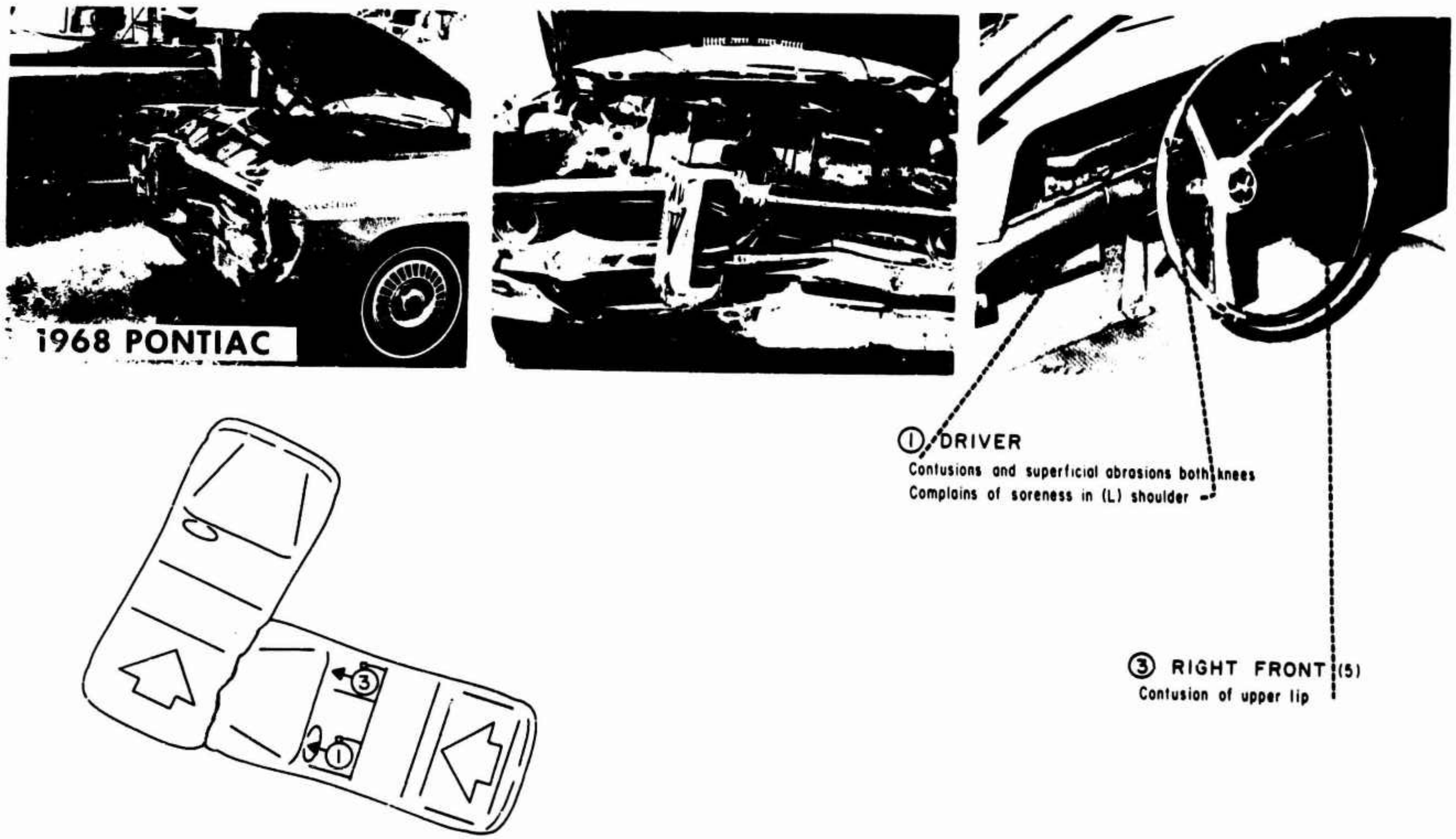



Figure 16. Automobile accident—calculated 19 "g".

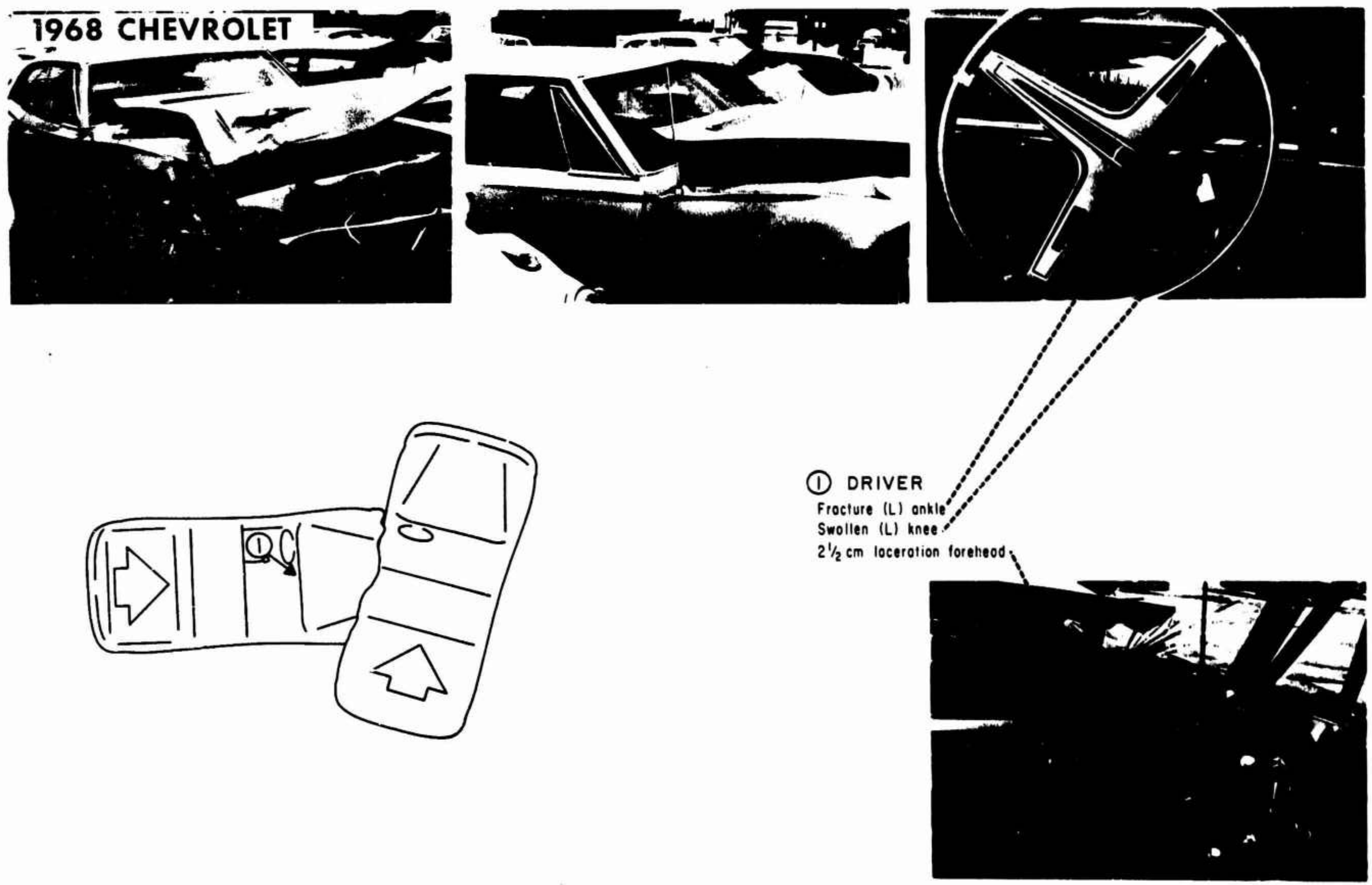



FIGURE 17. 19 "g" impact.

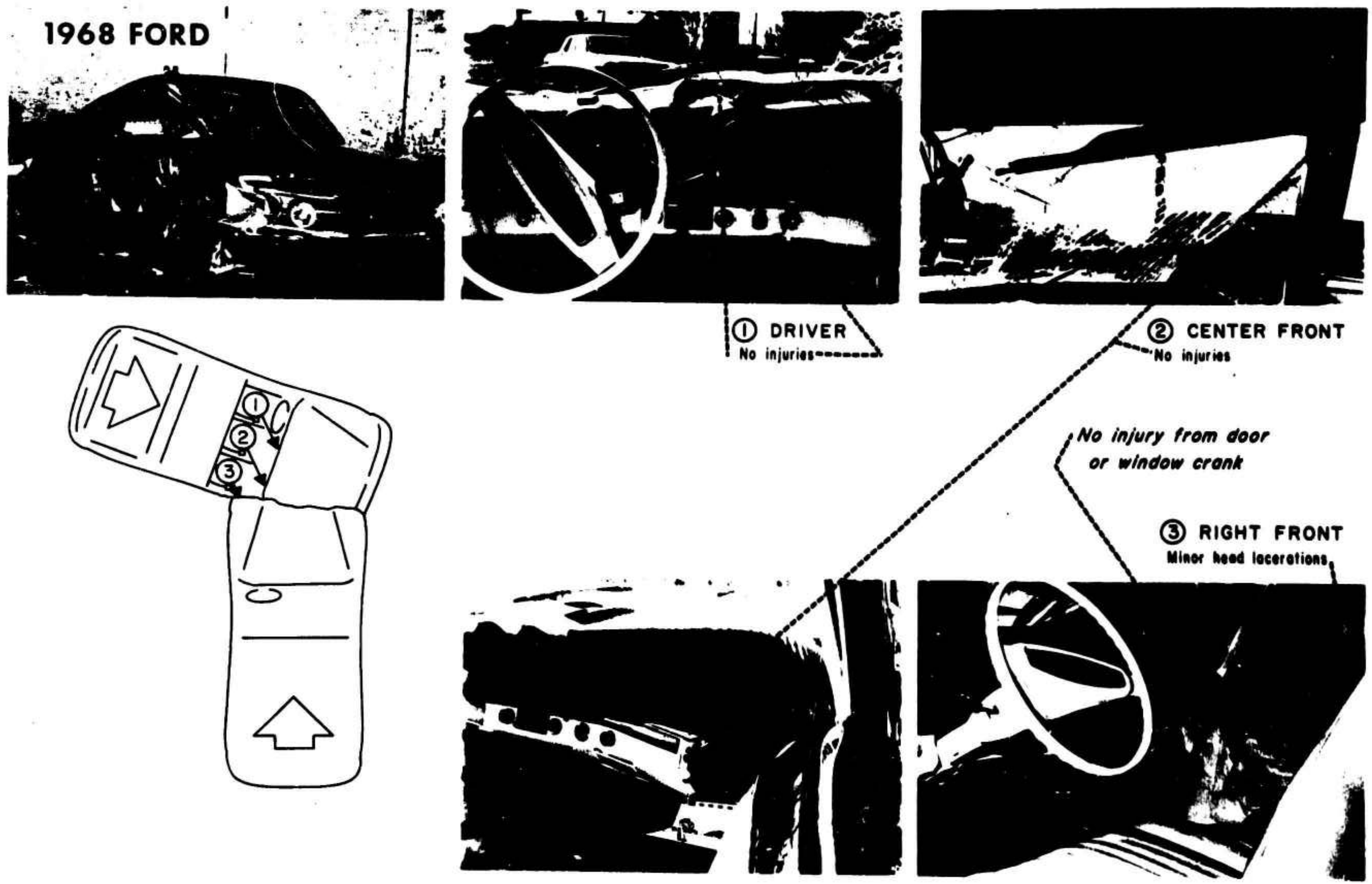



FIGURE 18. 20 "g".

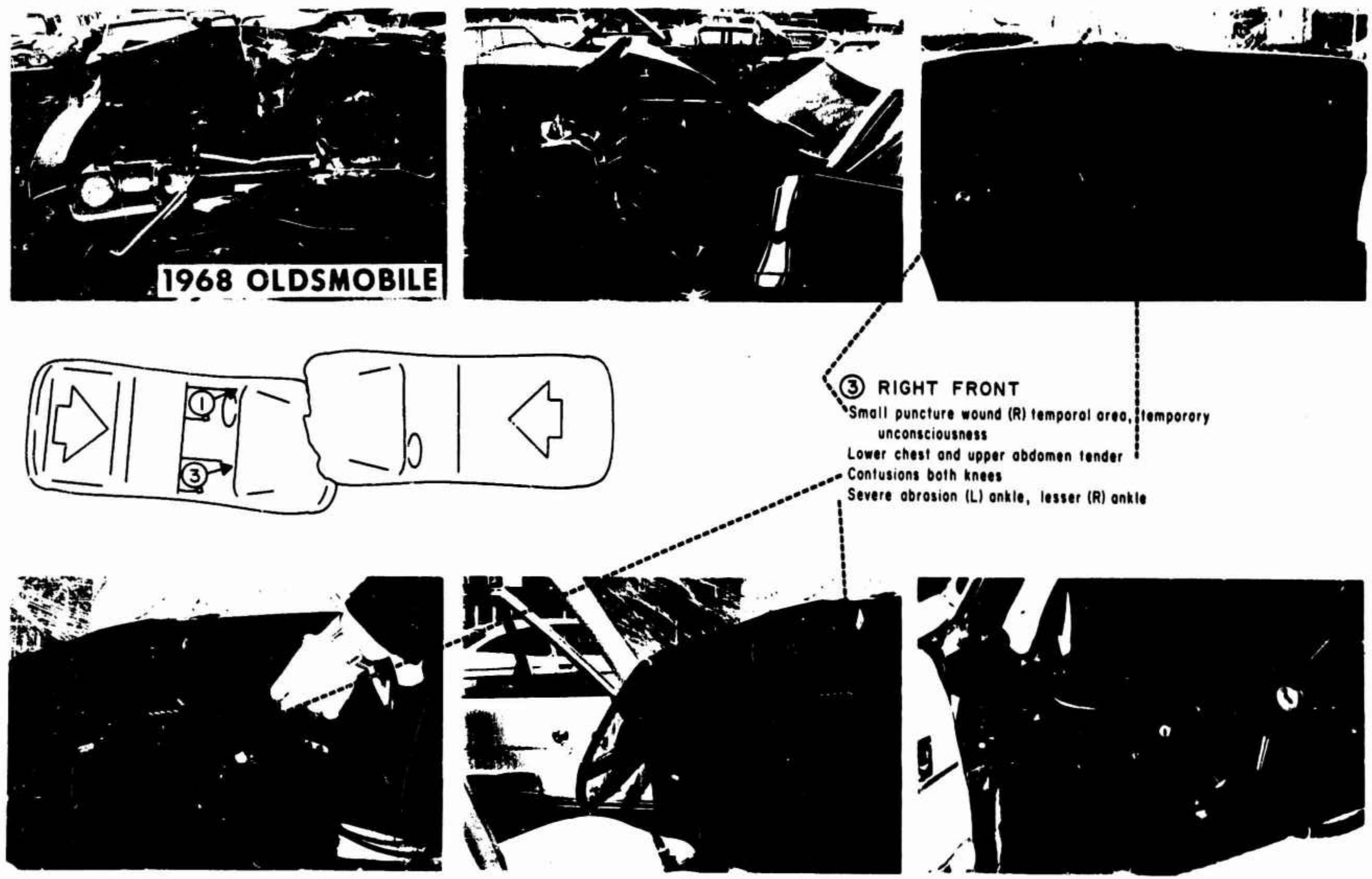



FIGURE 19. Deceleration =22 "g".

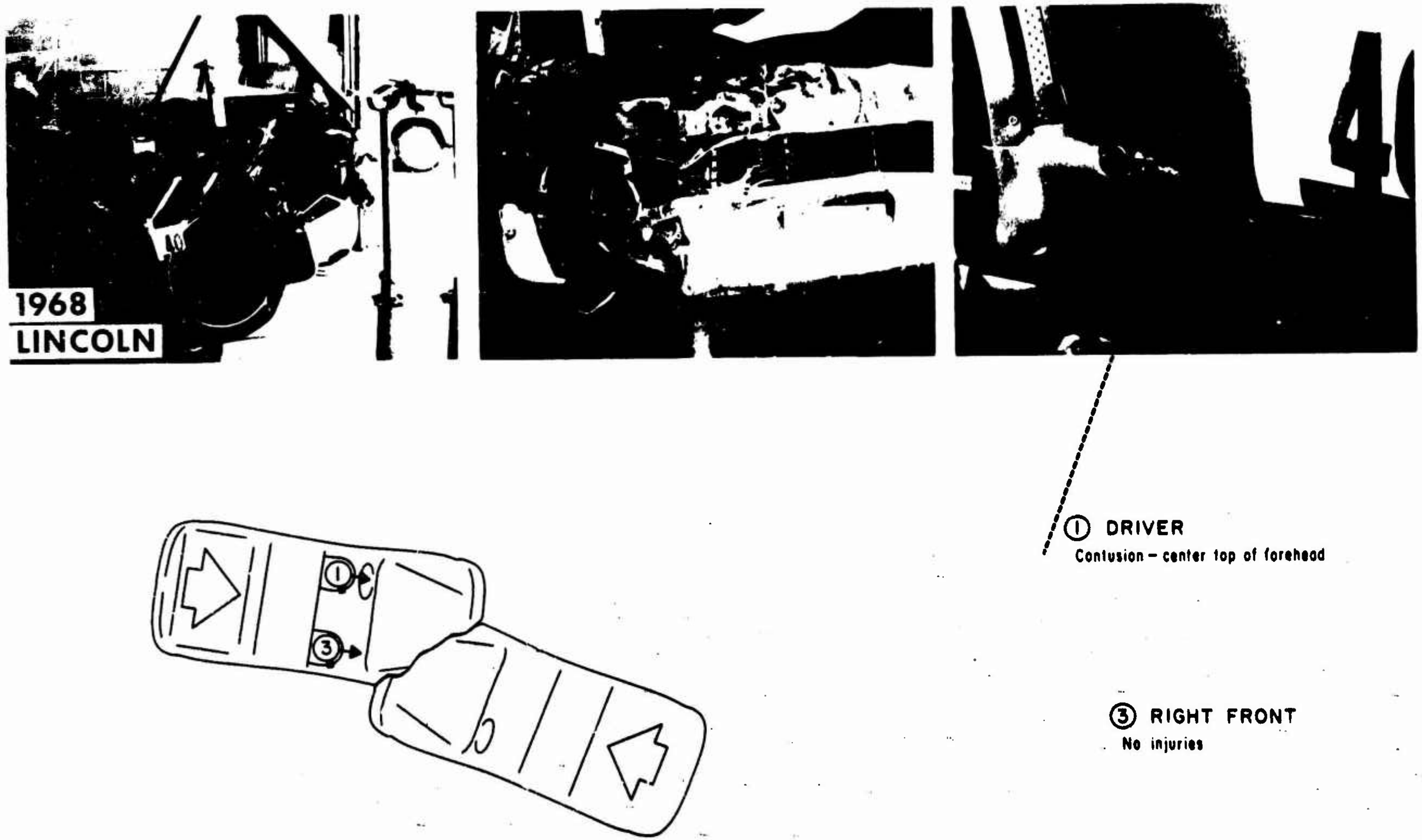



FIGURE 20. Deceleration =28 "g".

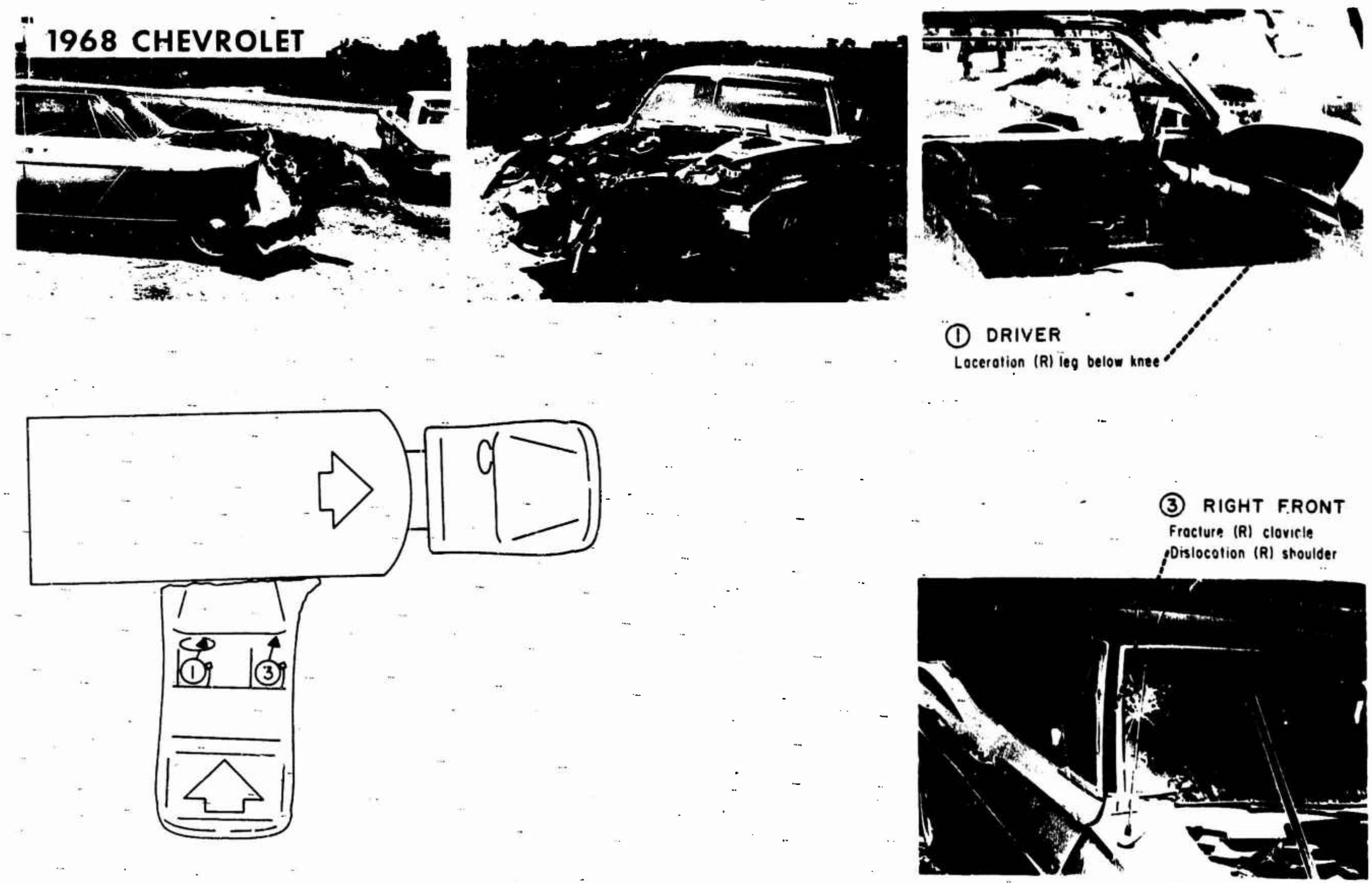



FIGURE 21. Deceleration =23 "g".

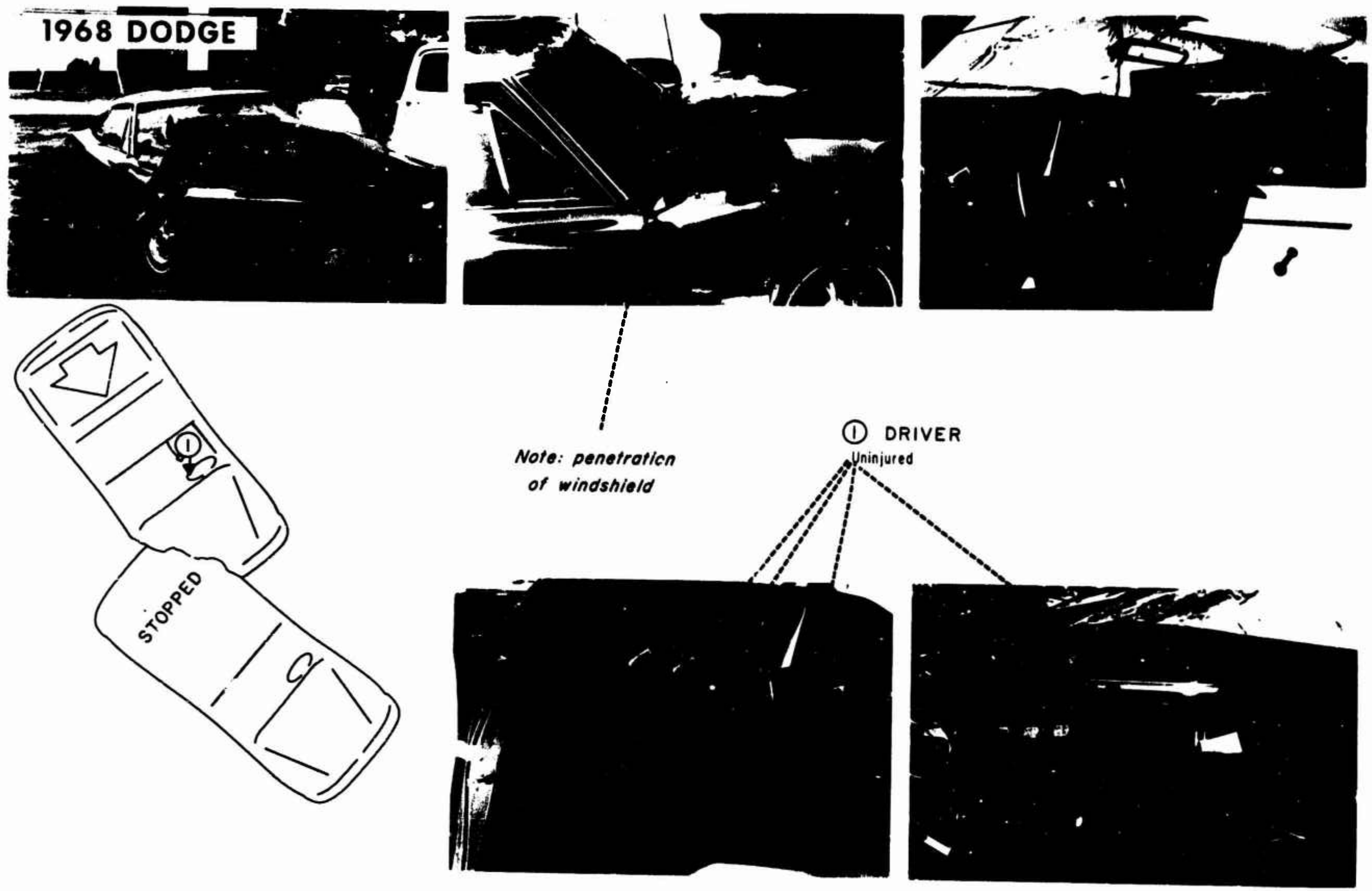



FIGURE 22. Deceleration =24 "g".

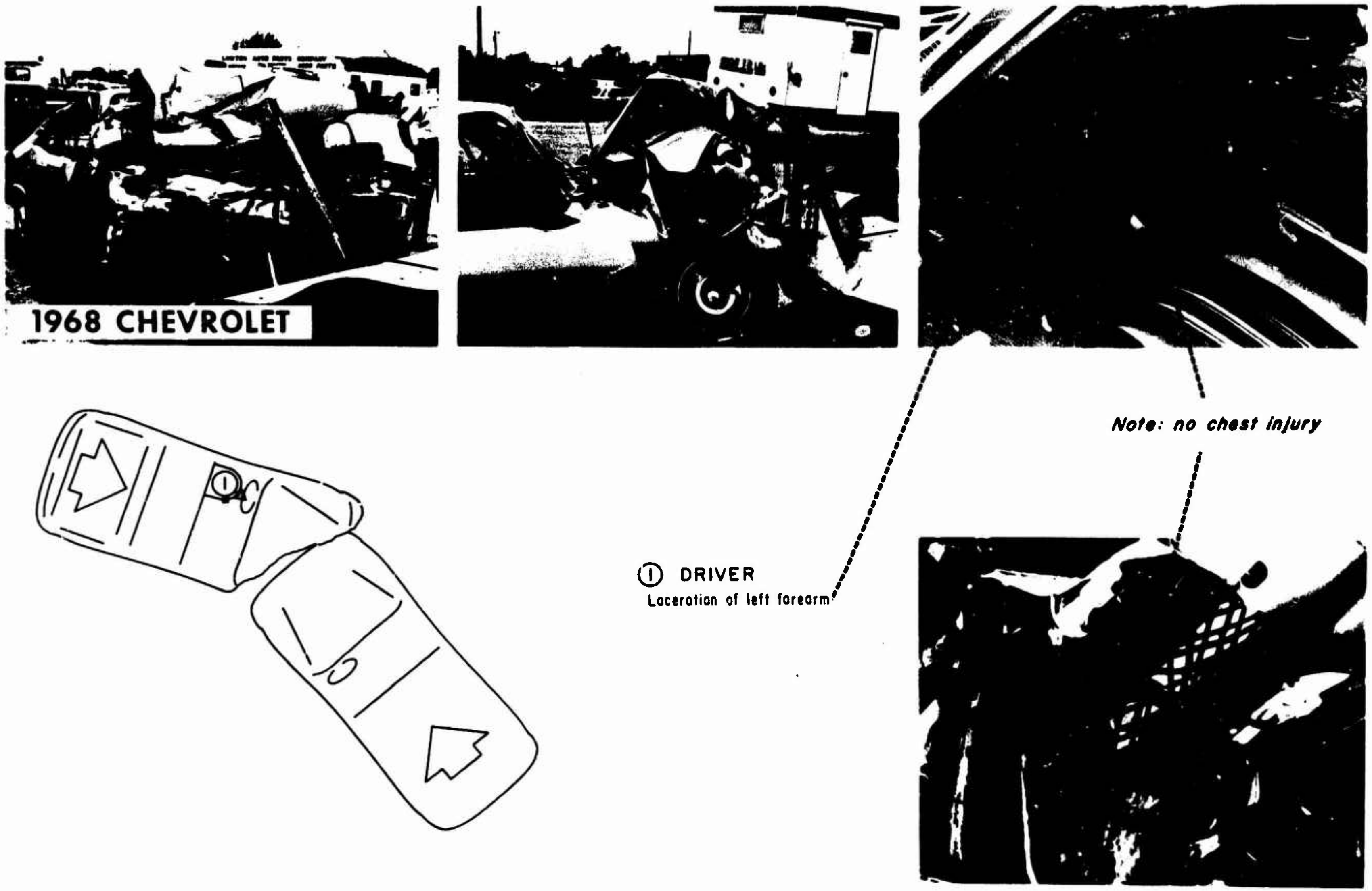



Figure 23. Deceleration =26 "g".

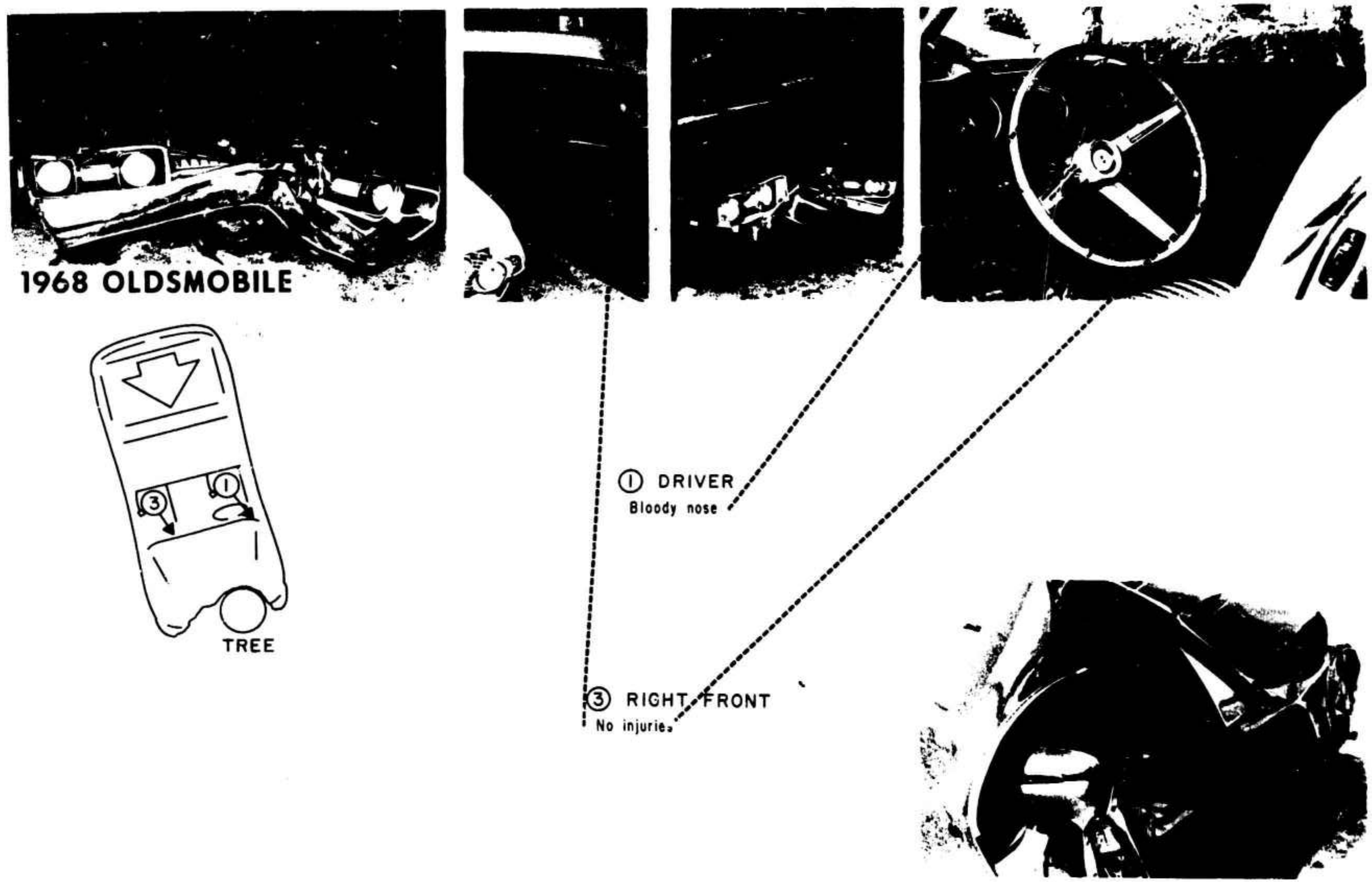



FIGURE 24. Deceleration =26 "g".

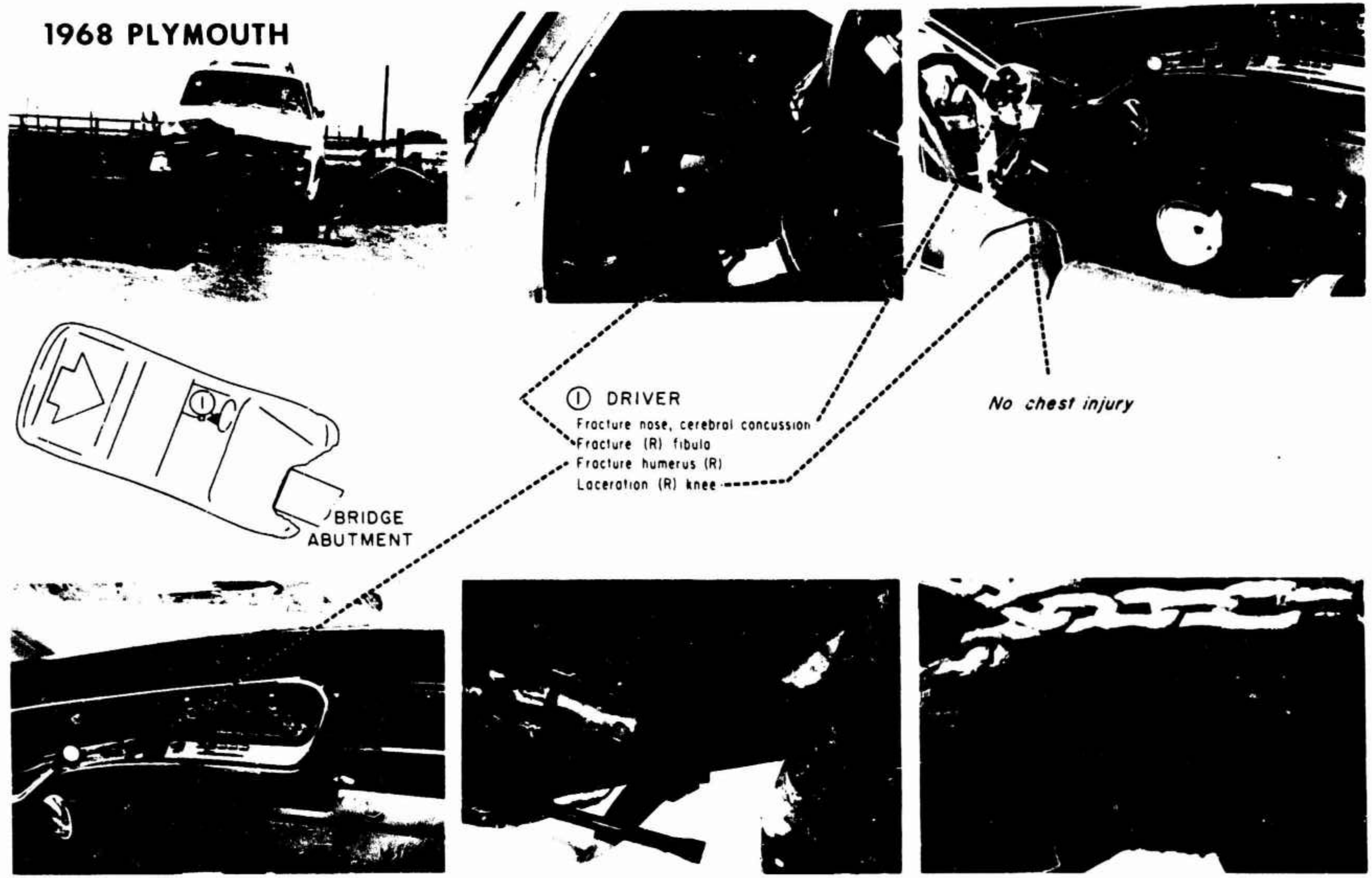



FIGURE 25. Deceleration =38 "g".

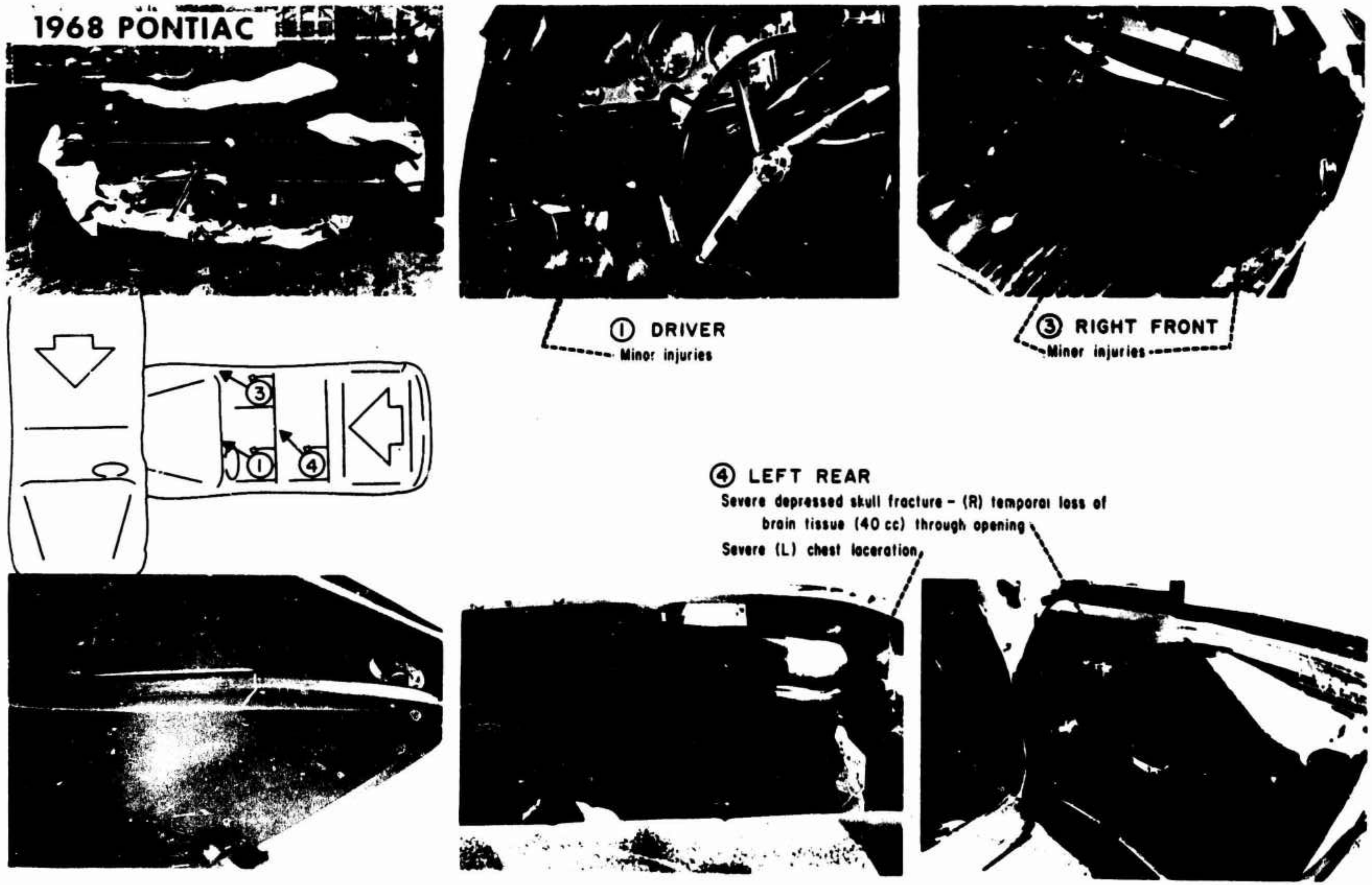



FIGURE 26. Deceleration =42 "g".

peller controls, etc.) on the lower left instrument panel (Case 11 E and G) were directly responsible for a fractured arm, fractured pelvis, and dislocated hip and knee in this accident. The author feels that the manufacturers of general aviation aircraft could significantly reduce leg and pelvic injuries by copying the design trends of the automobile manufacturers (Figure 27).

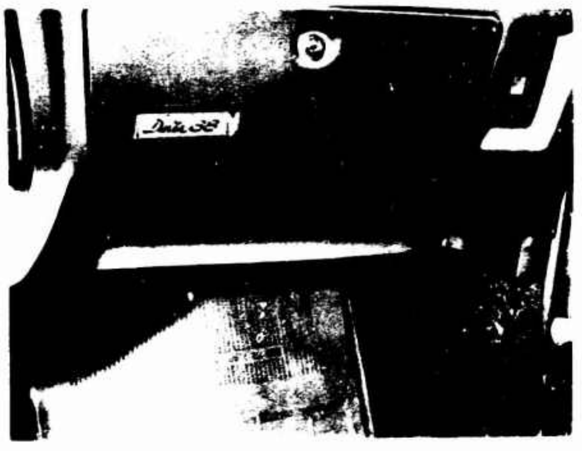
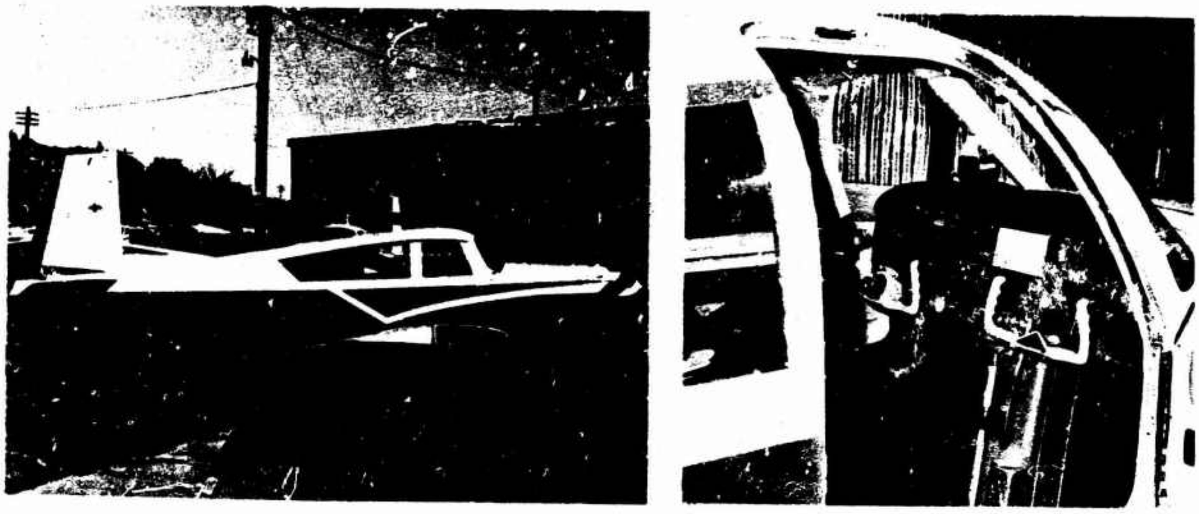


FIGURE 27. Knee impact area in late-model automobile.

In Case Number 12 there has been a complete separation of the cabin structure at both ends of the instrument panel (Case 12 B and C) as a result of the impact. Since this 1955 Piper Tripacer PA 22–150 has doors on both sides, the only structure preventing the engine and instrument panel from being pushed back into the faces of the front seat occupants is the "A" post on each side of the windshield. The inboard half of each seat belt was attached to the seat while the outboard half was attached to the fuselage. Attaching lap belts to seats loads the seat tie-down attachments unnecessarily, often causing them to fail and the package contents are no longer even partially restrained. Seat attachments in this case did fail (Case 12 I, J. K and L), allowing the two front seat occupants to smash their faces into the formidable structure of the upper instrument panel and their knees and legs into the prong-studded lower panel (Case 12 D). Facial injuries were more severe in this case than in Case 11, partially because there was no padding on the instrument panel and partially because the crash impact force was slightly greater as attested to by the significant increase in lower leg injuries. The bare survival of these two occupants could probably be attributed to well-designed control wheels for chest impact without injury. Note in Case 12 F and G these control wheels are smashed flat against the instrument panel and probably slowed the upper bodies just enough to prevent fatal crushing head injuries. Federal Aviation Regulations (FAR) Part 23 requires that all general aviation aircraft have a tie-down strength to withstand a forward static loading of 9 "g". Since this seat did fail at its attachment, one might assume the crash forces involved in this case exceeded 9 "g". However, a recent research report published by the National Aviation Facilities Experimental Center (NAFEC)[62] shows the unreliability of predicting dynamic strength from static testing and the author believes that the maximum crash force in this case was well below 9 "g" as measured dynamically. A cabin deceleration of 8.5 "g" would have produced head strike velocities in excess of 50 ft./sec. and the head injuries from impacting this instrument panel would have been fatal to both occupants.

The total weight of the radio equipment in this aircraft was approximately 30 pounds. Radio equipment incorporating miniaturization technology is available today. By substitution of this new equipment, communication weight could be greatly reduced and the pounds saved utilized to strengthen the forward areas of the cabin as Beech Aircraft Corporation did so successfully nearly 20 years ago.

Again referring to FAR Part 23, vertical tie-down strength for seats is required to meet a 3 "g" static pull force. In Case Number 13 a 1955 Piper Tripacer PA 22–150 ran off the end of a runway into some loose soil, collapsed the nose gear, and skidded 75 feet almost to a stop when it flipped over onto its back (Case 13 A and B). Deceleration of the cabin was less than 1.4 "g" as evidenced by the fact that the pilot was not thrown forward with sufficient force to bump his head (refer to Case 4). The pilot found himself hanging uninjured, upside down in his seat belt, but when he released his seat belt, he and the seat fell down to the top of the cabin and the pilot bumped his head as he fell (Case 13 C). Note in Case 13 E that the inboard half of his seat belt was attached to the center of the seat. It is difficult for the author to understand how a seat meeting the FAR requirements of 9 "g" forward and 3 "g" upward based on the weight



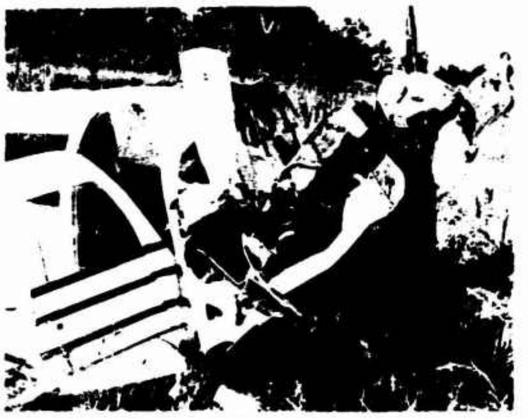
**1965 MOONEY MARK 21**

MOONEY M-20-E, a 1965 model aircraft, had taken off at night with pilot, an automobile accident patient on a stretcher (R. F.), and a nurse in the rear seat. At about 200 feet altitude the motor faltered; the aircraft cut through the tops of some small trees, crashed (R) wing first in muddy ground, and flipped over onto its back. Pilot was wearing his seat belt and it held. Stretcher patient (R. F.) was not strapped down and the nurse in the rear seat was not wearing her seat belt. No shoulder harnesses were in the aircraft. All occupants were thrown forward and slightly to the (R).

ACCIDENT INVESTIGATED BY:
LEE LOWREY, EDDIE LANGSTON,
AND
JACK BLETHROW
CAMI

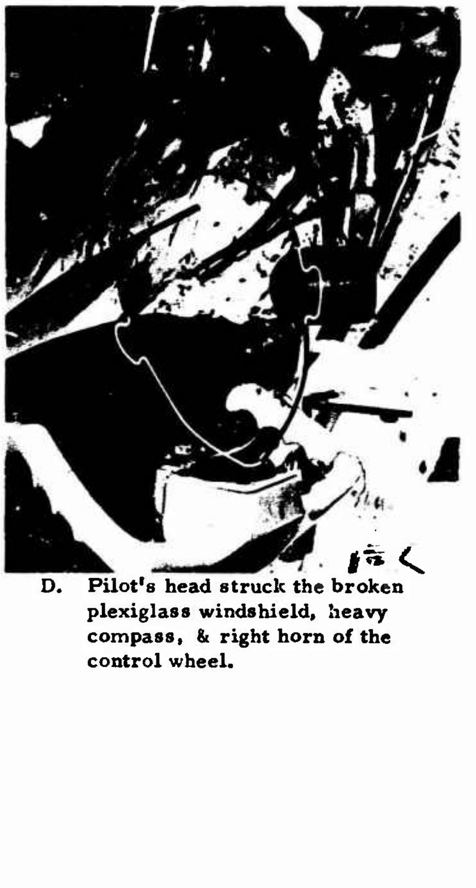
# CASE 11-1

A. General appearance of wreckage.



B. Motor forced upward, pushing instrument panel inward.

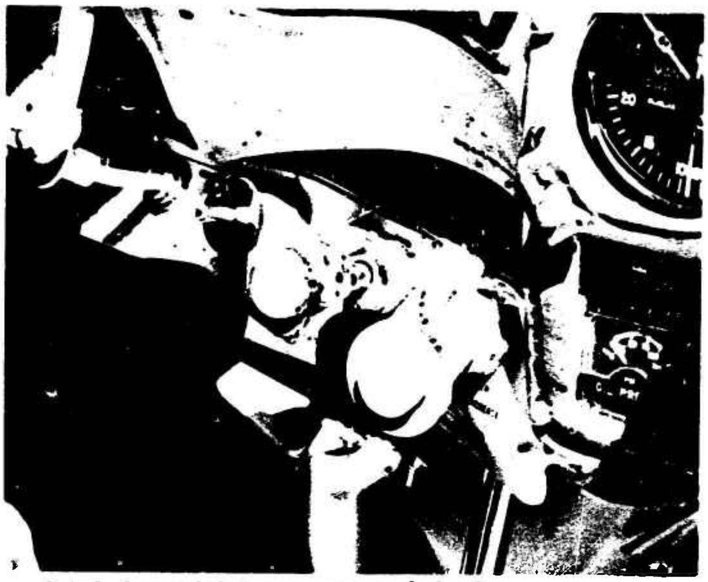
C. The left control column has been bent upward by chest impact of the pilot until the control horns rest against the light padding.



D. Pilot's head struck the broken plexiglass windshield, heavy compass, & right horn of the control wheel.

| INJURIES | STRUCTURES IMPACTED |
|---|---|
| Pilot: (S) Head - Cerebral concussion. | Padded dash to (R) of control column. |
| Fx. mandible (R) & chipped teeth. | (R) horn of control wheel. |
| Severe lac's. of the scalp. | Windshield (broken) |
| Trunk - Contusions of chest | Control wheel hub |
| Fx. (L) pelvis (acetabular) posterior | Lower instrument panel (L). |
| Extremities - Lac's. & compnuod Fx's. (R) forearm. | Center of instrument panel. |
| Dislocations (L) hip & (L) knee. | Lower instrument panel (L). |
| Bimalleolar Fx. (L) ankle. | P dal area. |
| R. F.: (F) Thought to be dead before impact. | |
| C. R.: (S) Fx. cranium, brain concussion. Other injuries unknown. | Probably hit bottom of stretcher |

# CASE 11-2

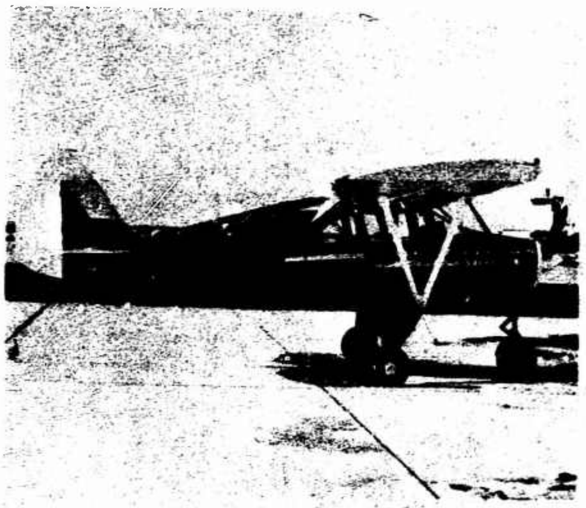


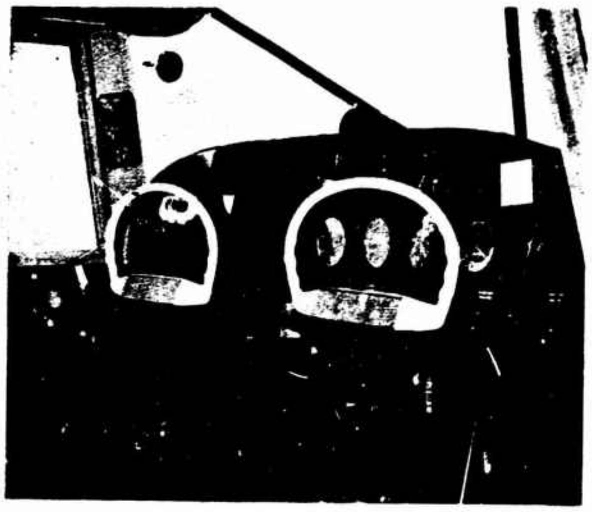
E & G Lower left instrument panel showing knobs bent and broken by pilot's legs.

F. Damage to right half of instrument panel from unrestrained stretcher.

H. Pelvic & lower leg injuries.

## CASE 11-3



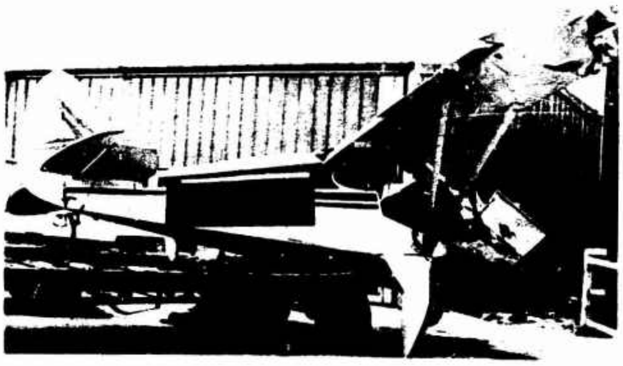


**1955 PIPER TRIPACER**

PIPER TRIPACER PA-22-150, a 1955 model aircraft with pilot and one passenger (R. F.), was landing at an airport after a commercial jet had taken off. Aircraft was caught in the wake turbulence and crashed on the runway, (L) wing hitting first. Both occupants were wearing seat belts which were attached inboard to the seat and outboard to the fuselage. Seats tore loose. No shoulder harnesses were in the aircraft.

ACCIDENT INVESTIGATED BY:
GALE BRADEN AND TERRY WALLACE
CAMI

# CASE 12-1

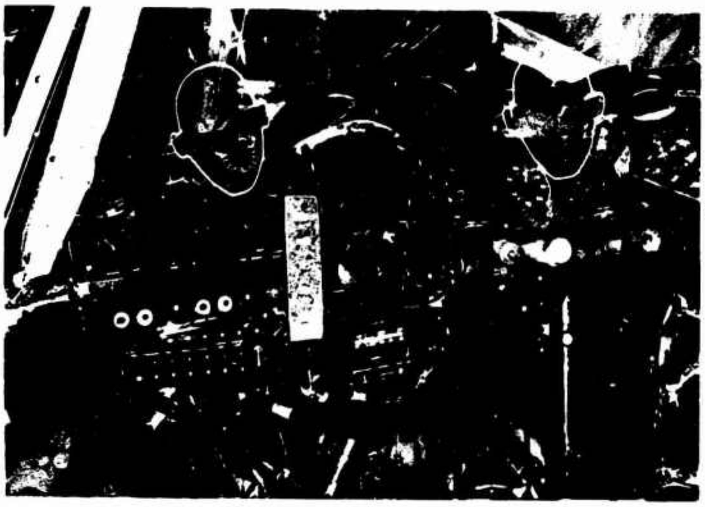


A. Aircraft from right side after removal from crash site. Note that most of the aircraft appears to be undamaged.

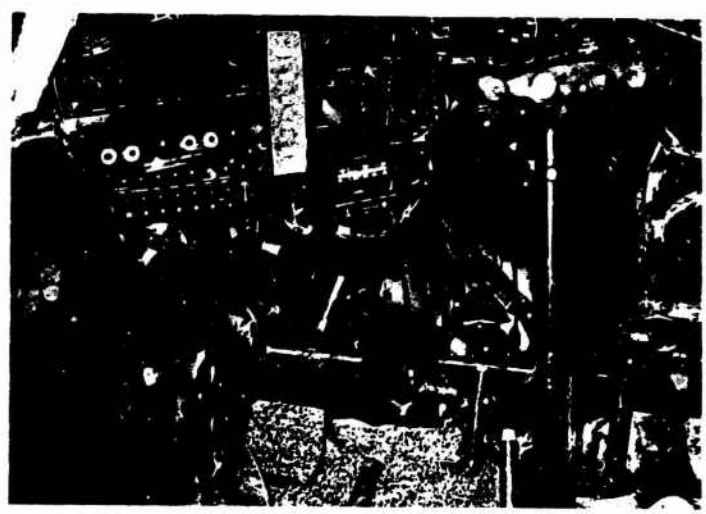
B. View from left side of aircraft showing that only the structure between the rear door & motor protected the pilot from being crushed.

C. Close-up of right side of aircraft shows complete failure of right "A" post. (Only structure resisting backward displacement of motor & instrument panel on that side).

# CASE 12-2

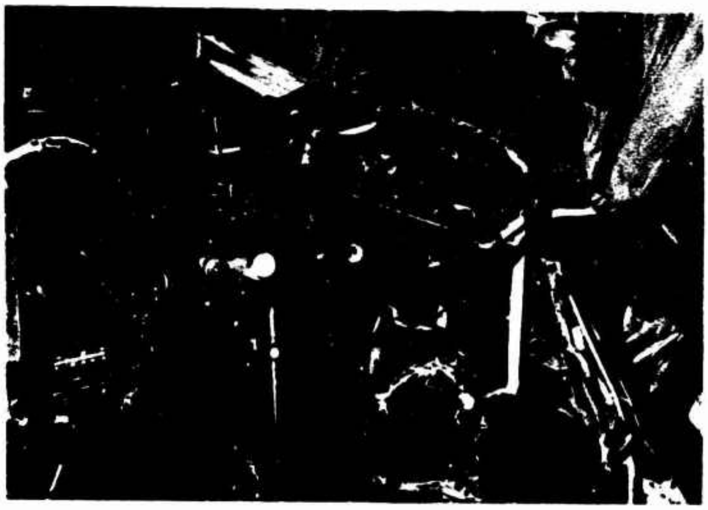


D. Head outlines indicate instrument panel depression areas produced by head impacts of the two front seat occupants. Note control wheel crushed into instrument panel.

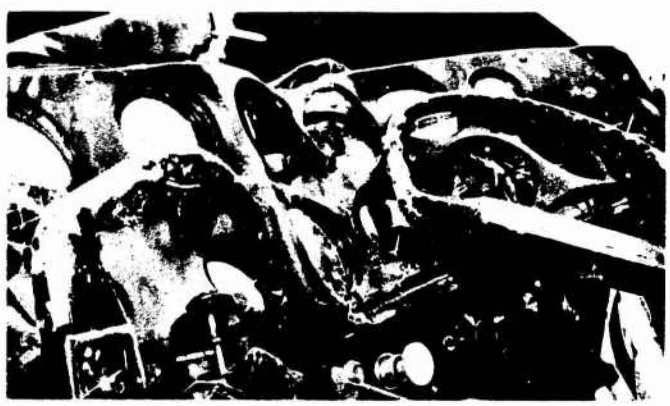


E. Lower left instrument panel conglomerate, responsible for numerous leg and ankle fractures & lacerations.

## CASE 12-3



F. Right half of instrument panel.



G. Close-up of copilot's head imprint.

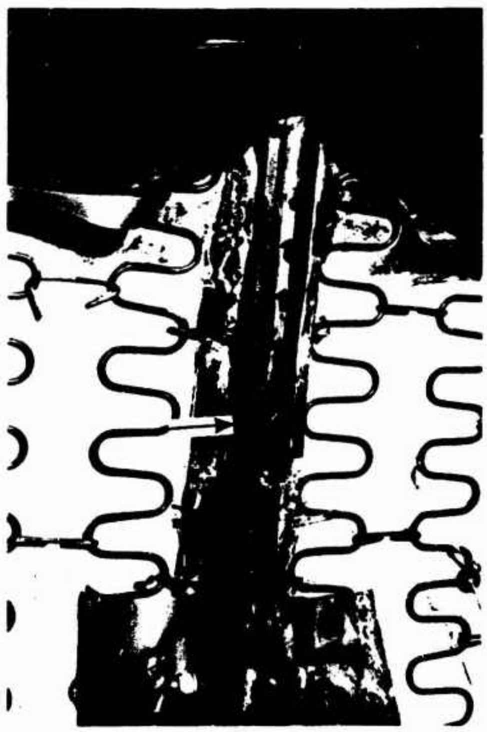
H. Close-up of heavy radio structure on copilot's side causing four lower limb fractures.

CASE 12-4

I. Inboard halves of seat belts were attached to the seat in this aircraft, transferring heavy belt loads to fragile seat tie-down structure.

J. End attachments of seat to side of cabin failed.

K. Adjustment pin & center tie-down flanges. Notice that the thin tie-down flanges are spread open, allowing the seat to leave the track.



L. Tie-down & adjustment structure on bottom of seat. The thin metal on either side of the adjustment holes bent & allowed seat to tear loose.

| INJURIES | STRUCTURES IMPACTED |
|---|---|
| Pilot: (S) Head - Acute subdural hematoma (R). Severe lac. lip (R). Front teeth knocked out. Lac. (R) forehead. | Top edge of instrument panel in upper (R) corner of radio. |
| Trunk - None. | |
| Extremities - Comminuted Fx's. tibia & fibula (R) & (L). Avulsed Fx. (R) ankle. Lac's. & Fx. (R) forearm. | Lower instrument panel & pedal area. Control wheel. |
| R. F.: (S) Head - Face swollen round, abrasions. Deep lac. on chin. Concussion lasting 3 weeks. Fx's. nose, (R) maxilla, (R) zygoma, (R) infraorbital ridge. | Instrument panel. |
| Trunk - None. | |
| Extremities - Compound Fx's. ulna & radius (R) & (L). Fx's. (R) talus, (R) tibia, (L) fibula, (R) patella. | Lower instrument panel. |

# CASE 12-5

of two occupants and the weight of the seat could fail with only one occupant in such a minor deceleration. It is possible, since this aircraft was nearly 15 years old, that deterioration of the seat attachments may have been a factor. However, since general aviation aircraft keep on flying until they disintegrate in a crash, seat tie-down attachments should be designed for long usage. If the restraint system fails under these minor conditions, certainly it is of little or no benefit in even a hard landing, let alone a minor crash.

In Case 14 a young male pilot crashed in a 1946 Piper J-3C-65 at the edge of a blacktop road and slid 26 feet before coming to rest. The pilot jackknifed over his seat belt and buried his face in the soft aluminum instrument panel making a rounded dent between 4 and 5 inches deep (Case 14 C). This rounded soft surface depressed in a manner similar to the light aluminum semi-cylinder at the top edge of a Piper Pawnee instrument panel (to be discussed later in Cases 23 and 24). The head dent also closely approximates the head strike imprint in the Pawnee panel made by impacting an instrumented dummy head at a velocity of 30 ft./sec. (Figure 36). If the pilot's head struck at even 40 ft./sec., it would indicate that the major crash impact force did not exceed 7 to 8 "g". The almost complete lack of injuries to the trunk* and appendages (Case 14 E, F and G) tend to bear out these conclusions. The pilot would have survived if the top seam of the fuel tank had not formed a narrow protruding ridge as the head forced the instrument panel downward. The high concentrated loading on this narrow structure was sufficient to cause a fatal skull fracture. The pilot also received a severe fracture of his right ankle (Case 14 G) inflicted by the diagonal tubular brace located directly above the ankles when the feet are located on the pedals.

A second 1946 Piper J-3C-65 crash with two occupants aboard the aircraft is shown in Case 15. Many similarities between this accident and the one presented as Case 14 may be worthy of notice. Comparing Case 14 B and Case 15 A, it will be noted that both cabins maintained their integrity to a fair degree. In Case 15 C we see a head print in the instrument panel almost identical to the one seen in Case 14 C. The top seam of the fuel tank has formed a sharp edge (see arrow) against which the front seat occupant hit and fractured his skull. One significant difference is the fact that the heavy compass near the center of the panel remained in place in Case 15 and caused severe crushing injuries of the lower face (see injury table) while in Case 14 it broke loose from its mounting before or during head impact and the occupant suffered only a fractured mandible.

The rear seat lap belt failed at its attachments allowing the occupant of this seat to be thrown forward over and on top of the front seat occupant. His body weight may have added to the force of head impact of the front seat occupant. The fatal head injuries of the rear seat occupant were inflicted by the broken windshield and rigid edge for attachment of the windshield (Case 15 E). Failure of the rear seat belt attachments cannot be taken as indicative of severe crash forces since the ends of the seat belt are fastened by $\frac{3}{32}$ inch wire loops to a $\frac{3}{4}$ inch floating tube running through the canvas seat bottom. Ends of this tube are in turn fastened to the fuselage by similar wire fasteners. Failure of these latter attachments allowed the seat belt attachments to slip off the end of the tube. As in Case 14, the front seat occupant received a severe fractured ankle, almost severed (Case 15 G) from the tubular cross brace (Case 15 F) in the lower cockpit.

Referring to data showing tolerances of the human head to crash impact (presented earlier in this report), the author is of the opinion that the extensive head injuries received by the front seat occupant when his head struck two small rigid areas could have occurred progressively at a head impact velocity not exceeding 40 ft./sec. Lack of severe facial tissue disfigurement (Case 15 D) and the absence of abdominal injuries from the seat belt tend to confirm this estimate. For these reasons, the author estimates that the major crash forces in this accident did not exceed 8 or 9 "g".

In all cases discussed thus far, with the exception of the first three (nonsurvivabe), all occupants should have survived without any injury whatsoever, providing they had been wearing shoulder harness restraint and properly anchored lap belts. All 11 of these accidents involved crash impact forces of 10 "g" or less. Armstrong[63] reports human voluntary tolerance

*Sutures in Case 14 E are from embalming procedure.

**1955 PIPER TRIPACER**

PIPER TRIPACER PA-22, a 1955 model aircraft with pilot only, had just taken off when the windshield fogged over. The pilot tried to set the aircraft back down on the runway. The aircraft rolled off the end of the runway, hit a dirt embankment and collapsed the nose gear. The aircraft skidded 75 feet on its nose and flipped over. The seat belt was in use and held. No shoulder harness was in the aircraft. The forces were not sufficient to cause head impact with the instrument panel. The seat tore out and fell when the pilot released his seat belt.

ACCIDENT INVESTIGATED BY:
DON ROWLAN AND EDDIE LANGSTON
CAMI

# CASE 13-1

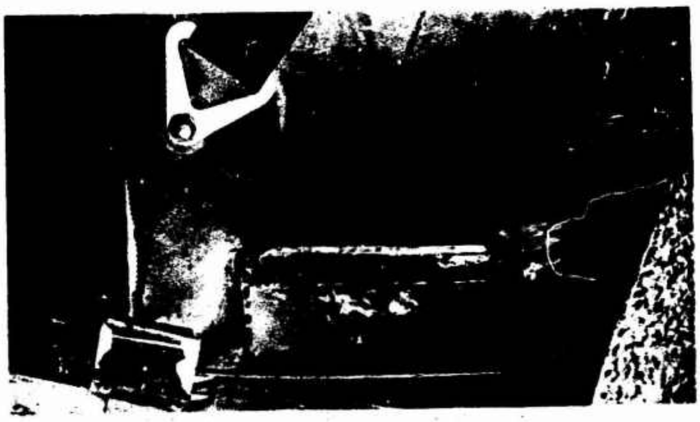
A & B Two views of aircraft that simply flipped over onto its back without damage.

C & D Views of instrument panel and control wheels show no signs of damage & indicate deceleration forces were not of sufficient magnitude to cause pilot to be thrown forward. However note seat has torn free & is lying in the top of the aircraft.

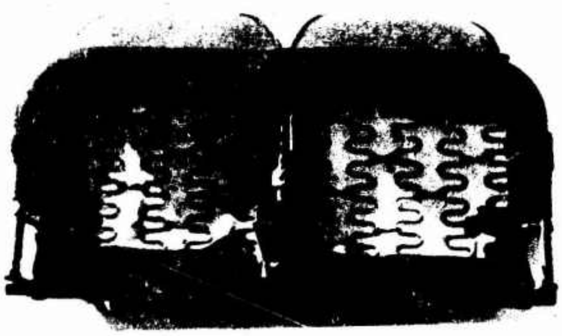
| | | INJURIES | STRUCTURES IMPACTED |
|---|---|---|---|
| Pilot: (S) | Head - | Not injured in crash but bumped head severely when he released his seat belt in inverted position & fell on his head. | Radio. |
| | Trunk - | None. | |
| | Extremities - | None. | |

# CASE 13-2

E. Seats failed in this minor incident (1) because seat belts were attached to the seat.

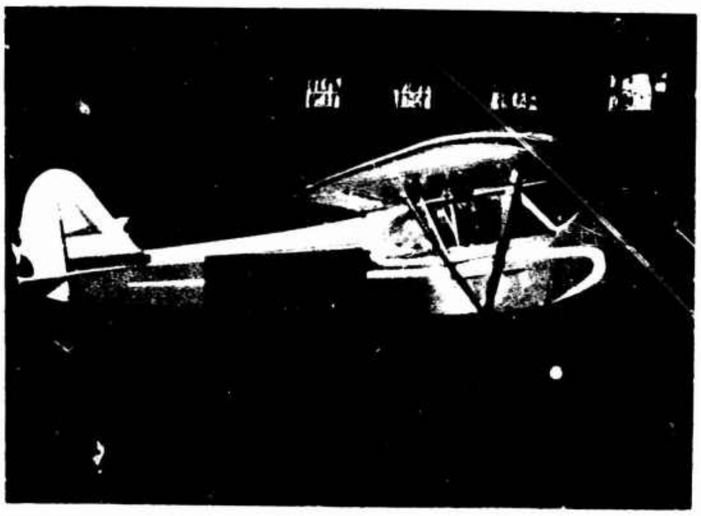


F. (2) wall track for end of seat allows seat to slip out.



G. and (3) center seat tie-down structure is inadequate.

## CASE 13-3

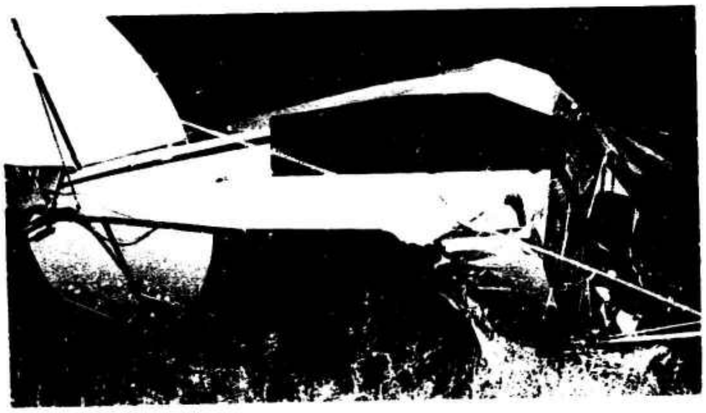


**1946 PIPER J-3**

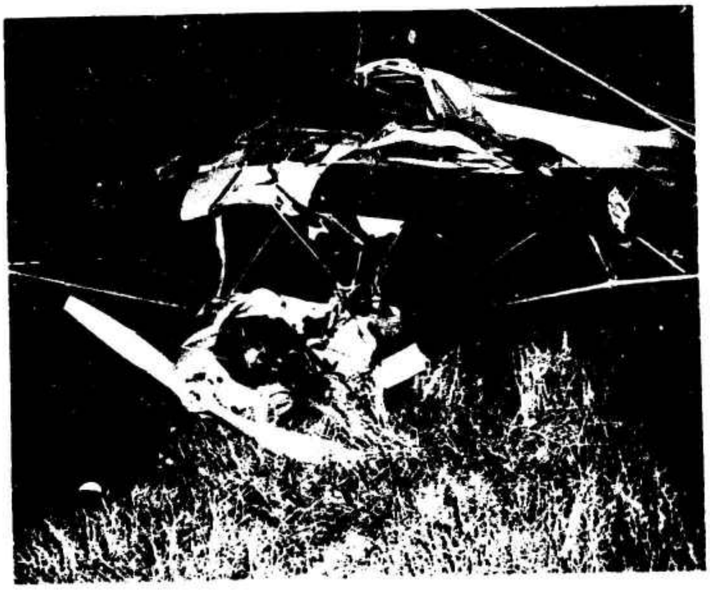
PIPER J-3C-65, a 1946 model aircraft with only the pilot flying from the front seat, made a touch-and-go landing, pulled up sharply, made quick left turn, nosed down and crashed on a highway. Pilot was wearing his seat belt and it held. No shoulder harness was in the aircraft. Major impact force threw the pilot forward and slightly to the left.

ACCIDENT INVESTIGATED BY:
EDDIE LANGSTON AND LEE LOWREY
CAMI

# CASE 14-1



A. Rear view of aircraft wreckage.



B. Front view showing tubular framework of this aircraft prevented cabin collapse.

**CASE 14-2**

C. Impression in the top center of the instrument panel that caused fatal head injuries.

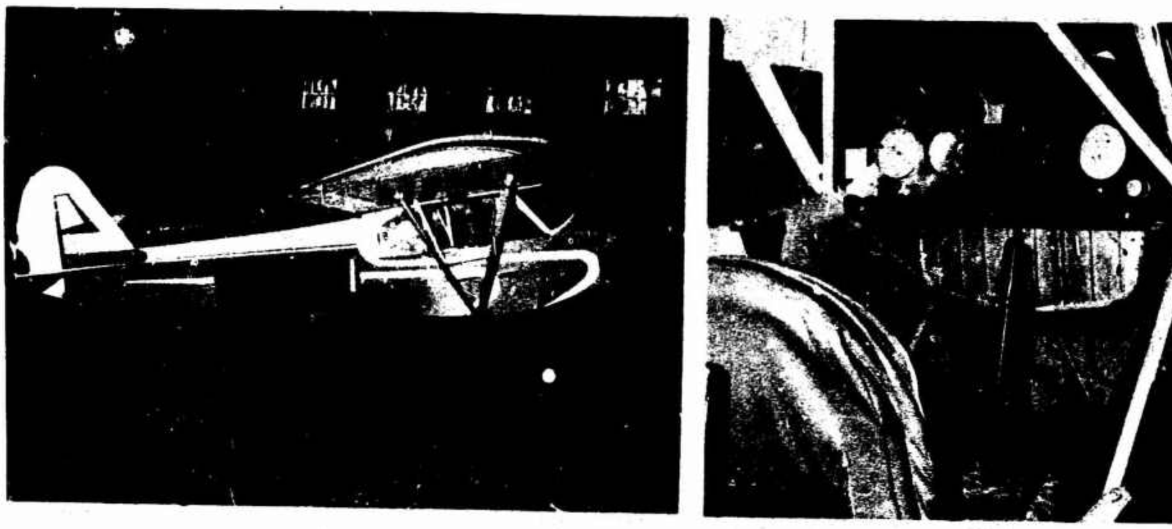
| | INJURIES | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (F) | Head - Small lac. over (R) eye. Lac. of chin & Fx. mandible. Front teeth broken off. Bleeding from both ears. | Upper left instrument panel. |
| | Trunk - None. | |
| | Extremities - Fx. (R) ankle. | Diagonal tubular frame structure directly over ankle. |

D. Artist sketch of facial injuries.

# CASE 14-3

E, F & G Body pictures to show complete lack of body injuries with the exception of a broken ankle.

# CASE 14-4



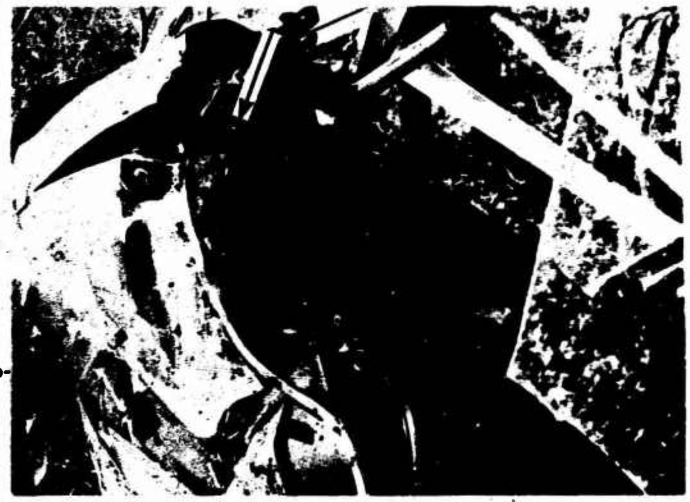
**1946 PIPER J-3**

PIPER J-C3-65, a 1946 model aircraft with pilot (rear) and one passenger (front), was flying low over the land hunting coyotes. Aircraft pulled up suddenly and crashed in a near vertical position. Both occupants were wearing seat belts. Front seat belt held, but rear seat belt failed at the attachment point, allowing the pilot to be thrown on top of and over the front seat passenger. No shoulder harnesses were in the aircraft.

ACCIDENT INVESTIGATED BY:
BILL REED AND LEE LOWREY
CAMI

# CASE 15-1

A. Photograph of wreckage from side showing cabin space not compromised.



B. Close-up of instrument panel. Note edge of heavy compass protruding & top seam of gasoline tank pressed into instrument panel cover forming a rigid knife-life edge.

| INJURIES | STRUCTURES IMPACTED |
|---|---|
| Pilot: (F) Head - 4 deep lac's. (R) jaw, (R) neck, under (R) chin. | Windshield. |
| Fx. mandible (R) teeth driven back. | Top of instrument panel just aft of windshield junction. |
| Fx. base of skull. | |
| Trunk - Fx. rib 7 (R). Lac's. liver & spleen. Lac's. pleura & lungs. | Probably back of front seat. |
| Extremities - Fx's. both ankles. | Jammed under front seat. |
| Fx. (R) arm & (L) hip. | Unknown. |
| Front: (F) Head - Extensive Fx's. maxilla, mandible, nasal bones, & orbital bones. Massive skull Fx's. Linear lac. forshead. Lac. bridge of nose & chin. | Instrument panel. |
| Trunk - None. | |
| Extremities - Fx. lower (L) leg. | Diagonal tubular frame structers in front of leg. |

# CASE 15-2

C. Head outline shows area on instrument panel where front seat occupant impacted his face.

D. Photograph & artist sketches of head injuries of front seat passenger.

E. Pilot (rear seat) head injuries. Note lacerations from broken windshield.

## CASE 15-3

F. Lower instrument panel showing tubular cross brace that passes over the ankle.

G. Typical ankle fracture from cross brace.

# CASE 15-4

to decelerations wearing the single shoulder strap—seat belt combination to be 17 "g"; however, actual tolerance is probably nearly 30 "g". Stapp[64] has established the upper limits of human tolerance to forward impact while wearing a double shoulder harness and seat belt to be about 40 "g". Snyder[65] reconfirmed these data with experimental crash testing using baboons as subjects. Leveau[66] first invented and patented the shoulder harness concept in 1903, and yet nearly 70 years later, it is difficult to understand why today, this principle of restraint is rarely found in use in any type of transportation vehicle. Only in the past two years has shoulder harness restraint equipment become mandatory in automotive vehicles, but very few people are utilizing them. Beech Aircraft Corporation installed a double harness—seat belt combination in all of their aircraft in the early 1950's, but some of their customers wanted them removed. Cessna[67] has had nut plates for easy attachment of shoulder harnesess in most of their general aviation aircraft since 1950 and has offered the shoulder harness as optional equipment. The Beech harness installation was thoroughly tested with a 200-pound dummy and found to effectively restrain the occupant up to 25 "g". These facts have not been publicized and very few pilots know this equipment is available. Other aircraft companies[68] are now putting in shoulder harness attachment points, primarily because they are required by some of their overseas customers. Those interested in retrofitting current aircraft (not equipped with attachment points) with shoulder harness should refer to Young's[69] report and FAA Advisory Circular[70] showing how attachments may be made simply. Many needless deaths and serious injuries have occurred simply because the contents of the packages were not properly restrained.

Case Number 16 describes the crash impact of a 1969 Mooney Executive aircraft. Judging from increase in severity of facial and appendage injuries (Case 16 I, J, P, Q and R) and the fact that the shipping container (cabin) has failed to a greater degree and spilled part of its contents (Case 16 B and D), one would have to conclude that the impact forces were somewhat greater than in the previously-described cases. If the major deceleration forces of the cabin had been as great as 15 "g", the head impacts of the two occupants against the instrument panel would have exceeded a velocity of 100 ft./sec. (70 mi./hr.). Since the depth of the head imprints measured less than 6 inches, the average deceleration of these two heads was in the order of 10,000 ft./sec.$^2$, or over 300 "g" which approaches the tolerance limits of the human face and head with the load distributed evenly over the facial contours. In this case, the impact loads were concentrated by irregular structures and the crushing injuries inflicted would be expected. Also note that both seat belts and seat attachments did not fail. The author concludes that the crash forces in this case were less than 15 "g" and, since the rear cabin structure is intact, it is likely these two men could have survived this crash had they been wearing shoulder harnesses. Special attention should be called to the head impact areas outlined in Case 16 H. Note that these two depressions are down on the face of the instrument panel, the right one being lower than the left, and not on top as would have been expected, indicating that the instrument panel was moving or had moved away from the front seat occupants before they made their head strikes. In other words, the cabin structure had failed and most of the failure occurred on the right side of the cabin, allowing the right end structure of the instrument panel to fail (Case 16 B). The left side of the cabin of this aircraft does not have a door (Case 16 A) and for that reason has more structural strength. This weakness of cabin structure around the door area has been observed throughout this crash investigation study with the exception of aircraft manufactured by Beech Aircraft Corporation who, through the use of light channel, greatly increased the strength of the Beech aircraft cabins in the early 1950's. Attention was called to the poor design of the control wheel of this aircraft in Case 11. Here we see it again—the protruding clock in the center of the wheel has left its mark and the horns have broken off (Case 16 K and L).

In Case Number 17, a 1952 Piper Tripacer PA-22 with four occupants crashed at a shallow angle (about 15°) on a blacktop road and skidded 159 feet before coming to rest. One's first impression, after viewing the wreckage (Case 17 B and C), would be that this accident should be in the nonsurvivable class. However, since three of the four occupants did survive, two with minor injuries, it must be assumed that only

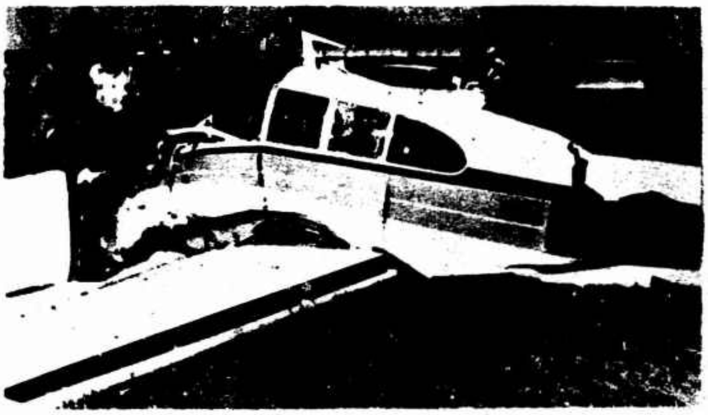
 

**1969 MOONEY EXECUTIVE**

MOONEY EXECUTIVE 21, a 1969 model aircraft with pilot and one passenger (R. F.), was observed going into a right spin after engine failure. The aircraft crashed (R) wing low in a grassy pasture (hard ground). As the (R) wing hit the ground the right side of the cabin was torn open and both occupants were thrown forward and to the right into the instrument panel. Seat belts were in use and held. No shoulder harnesses were in the aircraft.

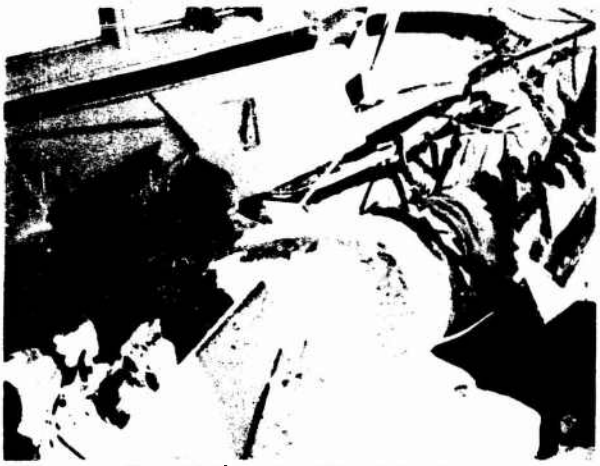
ACCIDENT INVESTIGATED BY:
DON ROWLAN
CAMI

# CASE 16-1



A. Left side of aircraft after impact.

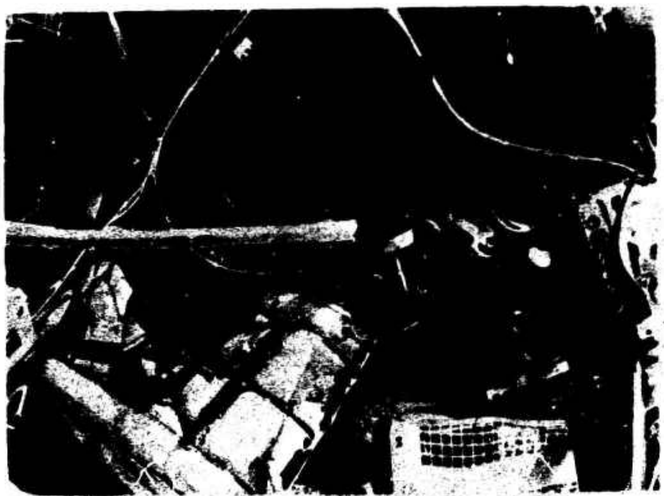
B. Right view shows cabin structure failed & opened up.



C. Pilot's body still retained by seat belt.

D. Copilot's body partly ejected through opening.

# CASE 16-2



F Seat belts are attached to the seats.

E. General appearance of cabin interior.

G. Seat track pulled loose from floor.

CASE 16-3

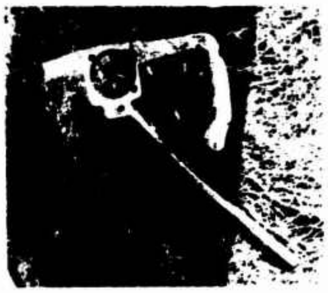
H. Structures impacted by heads of front seat occupants.

I. Crushing injuries of pilot's head.

J. Copilot head injuries.

| | INJURIES | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (F) | Head - Mult. & extensive facial & skull Fx's. | Instrument panel. |
| | Trunk - Fx's. pelvis mult., separation of membranous urethra & rectum. Tears in mesentery & small bowel, with treumatic separation of small bowel. Lac's. liver & spleen; Fx's. of ribs & destruction of interventricular system of heart. | Control wheel, radio, seat belt, seat structure (below). |
| | Extremities - Fx's. humerus (R), (L) thumb, 5th finger on (R) hand, both ankles. Mult. severe lac's. & abresions. | Instrument panel & pedal area. |
| R. F.: (F) | Head - Fx's. facial bones, mandible, basal skull Fx. with subdural hemorrhage. | Instrument panel. |
| | Trunk - Lac's. of heart & aorta. Fx's. of ribs, mult. Flail chest. | Control wheel & radio. |
| | Extremities - Fx. (R) humerus, (R&L) legs & ankles, bilateral. | Lower instrument panel & pedal area. |

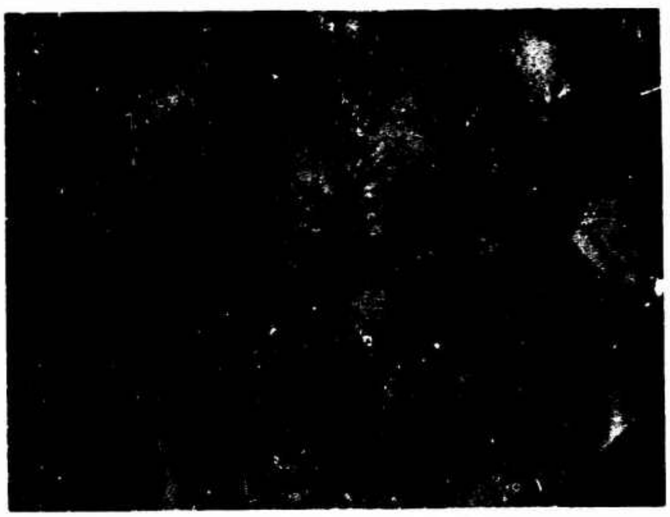
# CASE 16-4



K. Broken control wheel with center-mounted altimeter & reset knob.

L. Chest injury inflicted by altimeter & reset knob shown in K.

M. Tubular control column broken off.



N. Chest injuries from control wheel horns & broken column.

O. Shoulder injury inflicted by circular instrument.

# CASE 16-5

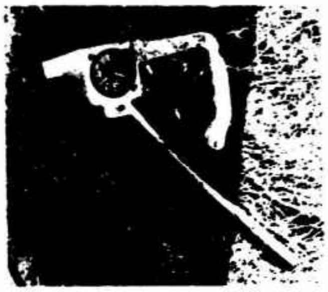
H. Structures impacted by heads of front seat occupants.

I. Crushing injuries of pilot's head.

J. Copilot head injuries.

| | INJURIES | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (F) | Head - Mult. & extensive facial & skull Fx's. | Instrument panel. |
| | Trunk - Fx's. pelvis mult., separation of membranous urethra & rectum. Tears in mesentery & small bowel, with traumatic separation of small bowel. Lac's. liver & spleen; Fx's. of ribs & destruction of interventricular system of heart. | Control wheel, radio, seat belt, seat structure (below). |
| | Extremities - Fx's. humerus (R), (L) thumb, 5th finger on (R) hand, both ankles. Mult. severe lac's. & abrasions. | Instrument panel & pedal area. |
| R. F.: (F) | Head - Fx's. facial bones, mandible, basal skull Fx. with subdural hemorrhage. | Instrument panel. |
| | Trunk - Lac's. of heart & aorta. Fx's. of ribs, mult. Flail chest. | Control wheel & radio. |
| | Extremities - Fx. (R) humerus, (R&L) legs & ankles, bilateral. | Lower instrument panel & pedal area. |

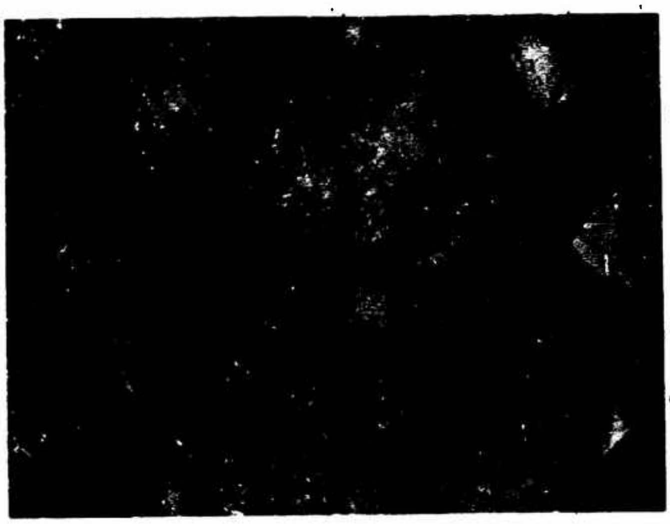
# CASE 16-4



K. Broken control wheel with center-mounted altimeter & reset knob.

L. Chest injury inflicted by altimeter & reset knob shown in K.

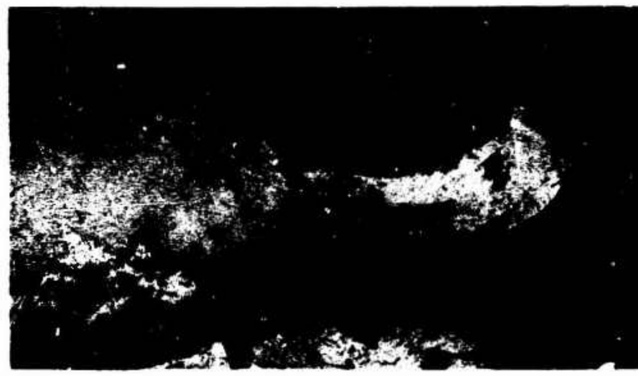
M. Tubular control column broken off.



N. Chest injuries from control wheel horns & broken column.

O. Shoulder injury inflicted by circular instrument.

# CASE 16-5



P, Q & R Severe lacerations & fractures inflicted when arms & legs flailed into broken structures.

## CASE 16-6

a small portion of the deceleration occurred during the initial impact with the blacktop road while the rest was gradual during the 159-foot slide. Since three seat belts held and only one, the pilot's, failed in the seat structure (Case 17 E), it is plausible to conclude that the tubular failure of the pilot's seat may have resulted from the extensive fuselage break-up and not from the initial impact force per se. However, since his restraint did fail, he was thrown forward, striking his head on the instrument panel (Case 17 D) with sufficient force to cause multiple lacerations and brain hemorrhages and as his chest struck the control wheel the small diameter control column folded over to form a spear (Case 17 E) that penetrated the vital thoracic organs and caused his death. On the other hand, a woman, seated in the right front seat, was restrained by a lap belt that did not fail. She received no facial injuries, only a fractured left radius and there is no head imprint on the right side of the instrument panel. It is obvious that she threw her left arm up in front of her face and by so doing kept her head from impacting the lethal construction of the instrument panel. Since her leg injuries were relatively minor, it is doubtful if the major impact force of this crash exceeded 10 "g".

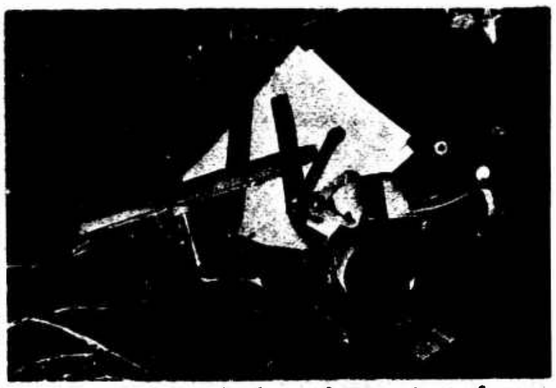
While the aircraft crash discussed as Number 18 is an older aircraft (1940 Aeronca Chief), it serves to show numerous design parameters contributing to the high death and injury rate. Many of these design "mistakes" are still present in late model general aviation aircraft; namely, lack of cabin integrity (Case 18 A), instrument panels with knife edges, heavy instruments and protruding knobs that destroy the face and head even at low impact forces (Case 18 B), a control wheel and column lacking in load distribution qualities and/or of a construction that allows the outer rim to break away, leaving a small area for concentrated loads that can penetrate the chest or cause fatal injuries without pentration. In this instance the rim not only broke away and the hub penetrated the chest (Case 18 F), but the wire spoke design opened like an umbrella within the chest making removal from the body most difficult. In spite of the severe destruction of the fuselage and the multiple facial injuries, this crash was well within limits of human survival—probably not more than 12–15 "g".

The engineering changes for crash safety made by Beech Aircraft Corporation in 1953 in the Bonanza;[71] namely, reinforced channel sections surrounding the cabin, a heavy keel forward of the cabin, a safety-type control wheel, instrument panel mounted on shearable shock mounts, strong seat tie-down to basic structure and the installation of shoulder harness (Figure 28) are in direct contrast to all the safety features lacking in most other general aviation aircraft.

The degree to which these improvements are paying off is well illustrated in Case Number 19. This 1954 Bonanza E–35 (with two front-seat occupants) impacted two large trees (12-inch diameter) at a velocity of 100 miles per hour. The impact force was sufficient to uproot the trees (Case 19 B) and the fuselage continued on to impact vertically on its nose. Note that even though the initial crash force was sufficient to tear off the wings, engine and rear fuselage, the cabin is still intact (Case 19 A and C). Since the impact point with the trees was 12 feet above the ground and the aircraft decelerated in an arc of a 1/4 circle as it pushed the trees over, it is possible to calculate an average deceleration from 150 ft./sec. to zero in 18 to 20 feet to be approximately 19 "g". It may be assumed that the decelerations during initial impact with the trees and the final impact with the ground would have been somewhat greater than the average—perhaps 20–25 "g". In spite of the high deceleration forces, both occupants received only minor injuries (see injury table), compared to those presented in this report thus far of occupants of crashes of much lower magnitude. Injuries would probably have been prevented altogether in this accident had the occupants been wearing their shoulder harnesses more securely. The author feels that this crash again illustrates that *Crash Safety Can Be Engineered.*

To illustrate the significance of recent crash safety design in automotive vehicles as contrasted to the lack of it in general aviation aircraft, a single automobile accident will be presented at this time. An 18-year-old male driving a 1969 Mercury two-door on a freeway at night claimed he fell asleep and his car ran off the road. The path of his car and a general view of the crash site are shown in Figure 29.

The automobile actually flew through the air a distance as measured on the horizontal of 117 feet. During its flight it cleared a cable hang-

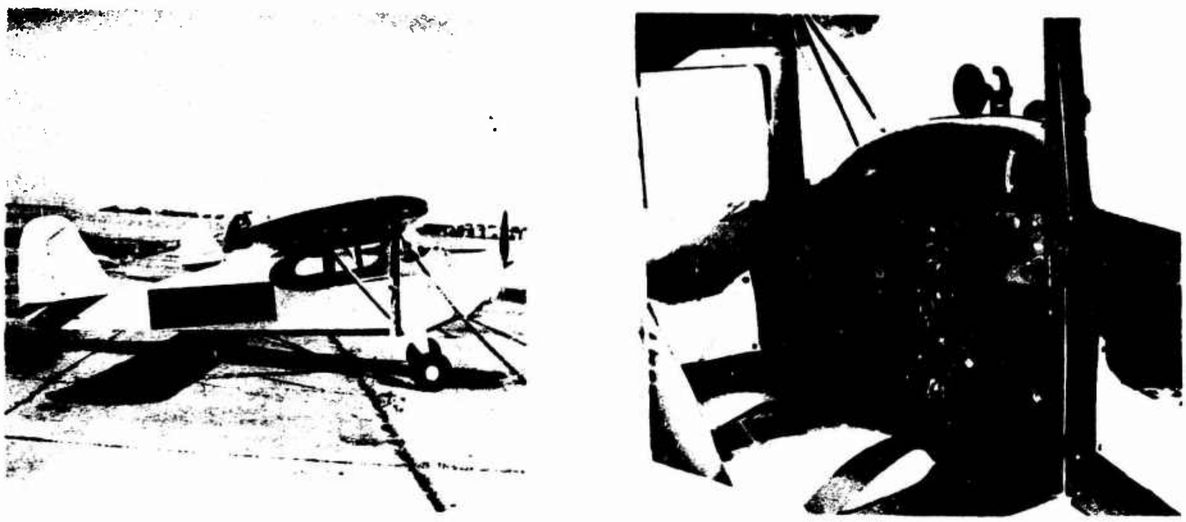


**D.** **The pilot received fatal head injuries when his face impacted the area outlined on the instrument panel. Also note the absence of the pilot's control column & wheel.**

**E.** **Pilot received massive puncture of all major body viscera when control column bent to form a spear after seat belt attachment failed.**

| | | INJURIES | STRUCTURES IMPACTED |
|---|---|---|---|
| Pilot: (F) | Head - | Mult. Lac's. & contusions, contusions & hem. of (R) temporal lobe of brain. | Upper left instrument panel. |
| | Trunk- | Fx. ribs 1 through 10 with massive puncture of all major body viscera. | Control wheel & control column when it bent double to form a spear. |
| | Extremities - | Mult. Lac's & contusions. Fx. (R) ankle. | Tubes & torn metal under dash. |
| R. F.: (S) | Head - | Mild facial contusions, Fx. (L) radius. | Probably had (L) arm in front of face, hit upper center of instrument panel. |
| | Trunk- | Fx. T6. | (R) control wheel. |
| | Extremities - | Fx. (L) os calcis. | Structure under dash. |
| L. R.: (S) | Head - | Compound basilar skull Fx. Brain contusion. Compound Fx. maxilla. Blowout Fx. floor (R) orbit. Compound Fx. nose. Lac. through (R) upper lip. | Unknown. Probably (L) door post structure and/or pilot's seat back. |
| | Trunk - | None. | |
| | Extremities - | Fx. (R) wrist. Dislocation (R) thumb. | Unknown. |
| R. R.: (S) | Head - | Mult. contusions face (mild). | |
| | Trunk - | Contusion (L) chest, Fx. L1, Separation (R) pelvis opening of pubis. | Unknown. |
| | Extremities - | Sprained (L) ankle. | |

## CASE 17-3



**1947 AERONCA CHIEF**

AERONCA CHIEF, a 1940 model aircraft with pilot only, was buzzing friends on the ground. Aircraft pulled up into a stall and crashed into ground in a very steep angle. Seat belt was in use and held. No shoulder harness was in the aircraft. The pilot was thrown forward and slightly to the (R).

ACCIDENT INVESTIGATED BY:
DON ROWLAN AND LEE LOWREY
CAMI

# CASE 18-1

A. Close-up of aircraft wreckage looking into the cockpit area.

B. Head outlines on instrument panel indicate areas impacted by the pilot's head.

C. Artist sketch of severe lacerations & facial crushing resulting from impact with the instrument panel.


D. Close-up of heavy instruments struck by pilot's head.

## CASE 18-2

**1952 PIPER TRIPACER**

PIPER TRIPACER PA-221-35, a 1952 model aircraft with pilot and three passengers (R. F., L. R., R. R.), took off and climbed to an approximate altitude of 400 feet, stalled and crashed on a blacktop road left wing first at a shallow angle and skidded 159 feet down the road. Pilot and all three passengers were wearing seat belts. Pilot's seat belt failed at the attachments; the other three held. No shoulder harnesses were in the aircraft. All four occupants were thrown forward and to the left.

ACCIDENT INVESTIGATED BY:
TERRY WALLACE AND GALE BRADEN
CAMI

# CASE 17-1

a small portion of the deceleration occurred during the initial impact with the blacktop road while the rest was gradual during the 159-foot slide. Since three seat belts held and only one, the pilot's, failed in the seat structure (Case 17 E), it is plausible to conclude that the tubular failure of the pilot's seat may have resulted from the extensive fuselage break-up and not from the initial impact force per se. However, since his restraint did fail, he was thrown forward, striking his head on the instrument panel (Case 17 D) with sufficient force to cause multiple lacerations and brain hemorrhages and as his chest struck the control wheel the small diameter control column folded over to form a spear (Case 17 E) that penetrated the vital thoracic organs and caused his death. On the other hand, a woman, seated in the right front seat, was restrained by a lap belt that did not fail. She received no facial injuries, only a fractured left radius and there is no head imprint on the right side of the instrument panel. It is obvious that she threw her left arm up in front of her face and by so doing kept her head from impacting the lethal construction of the instrument panel. Since her leg injuries were relatively minor, it is doubtful if the major impact force of this crash exceeded 10 "g".

While the aircraft crash discussed as Number 18 is an older aircraft (1940 Aeronca Chief), it serves to show numerous design parameters contributing to the high death and injury rate. Many of these design "mistakes" are still present in late model general aviation aircraft; namely, lack of cabin integrity (Case 18 A), instrument panels with knife edges, heavy instruments and protruding knobs that destroy the face and head even at low impact forces (Case 18 B), a control wheel and column lacking in load distribution qualities and/or of a construction that allows the outer rim to break away, leaving a small area for concentrated loads that can penetrate the chest or cause fatal injuries without pentration. In this instance the rim not only broke away and the hub penetrated the chest (Case 18 F), but the wire spoke design opened like an umbrella within the chest making removal from the body most difficult. In spite of the severe destruction of the fuselage and the multiple facial injuries, this crash was well within limits of human survival—probably not more than 12–15 "g".

The engineering changes for crash safety made by Beech Aircraft Corporation in 1953 in the Bonanza;[71] namely, reinforced channel sections surrounding the cabin, a heavy keel forward of the cabin, a safety-type control wheel, instrument panel mounted on shearable shock mounts, strong seat tie-down to basic structure and the installation of shoulder harness (Figure 28) are in direct contrast to all the safety features lacking in most other general aviation aircraft.

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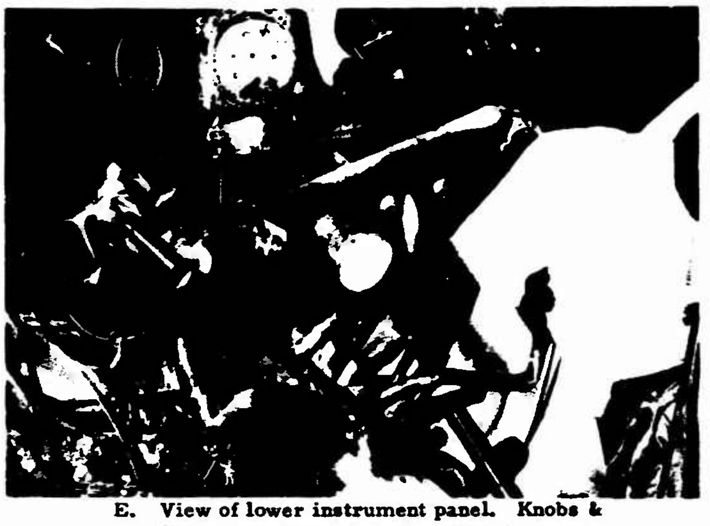
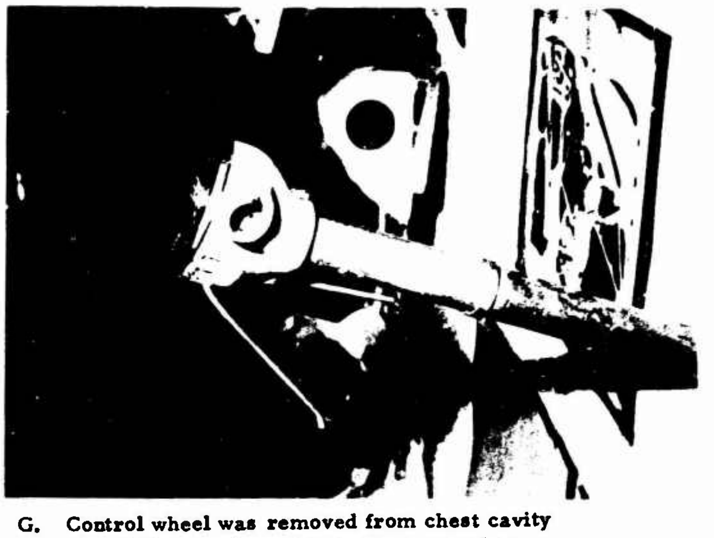


E. View of lower instrument panel. Knobs & sharp-edged metal produced leg injuries shown in J. Note pilot's control column has been sawed off.

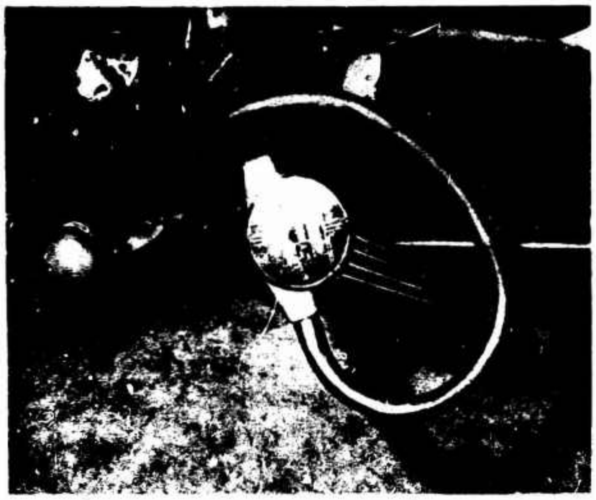
F. Poor design of control wheel allowed chest penetration.



G. Control wheel was removed from chest cavity with difficulty since wire spokes opened up like an unbrella.

## CASE 18-3

**H. Puncture wounds in the right shoulder from hub & spokes of right control wheel.**



**I. Copilot's control wheel.**

| | INJURIES | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (F) Head | Crushed facial bones below suborbital ridge. Mult. basal skull Fx's. Brain Hem's. | Upper center instrument panel. |
| | Severe & mult. facial lac's. | Upper & lower center instrument panel. |
| Trunk | Penetrating wound (L) chest, (L) lung, heart, diaphragm, liver & spleen. Mult. rib. fx's. | (L) control wheel rim broke off, hub & spokes penetrated chest like a harpoon. Removed at autopsy. |
| Extremities | Small puncture (R) upper anterior shoulder surrounded by 3 smaller punctures. | (R) control wheel & spokes. |
| | Mangled lower extremities with mult. fx's. | Lower instrument panel. |

**J. Lower leg injuries.**

# CASE 18-4

These special features are indexed to correspond to the recommendations outlined in the attached article, "Crash Safety Can Be Engineered".

A. The BEECHCRAFT Bonanza's long nose section provides gradual impact deceleration.

B. The BEECHCRAFT Bonanza's wing design provides crash shock absorption in addition to its rugged design which has been tested to over 8.4 G's which is 47 percent above government required safety margins.

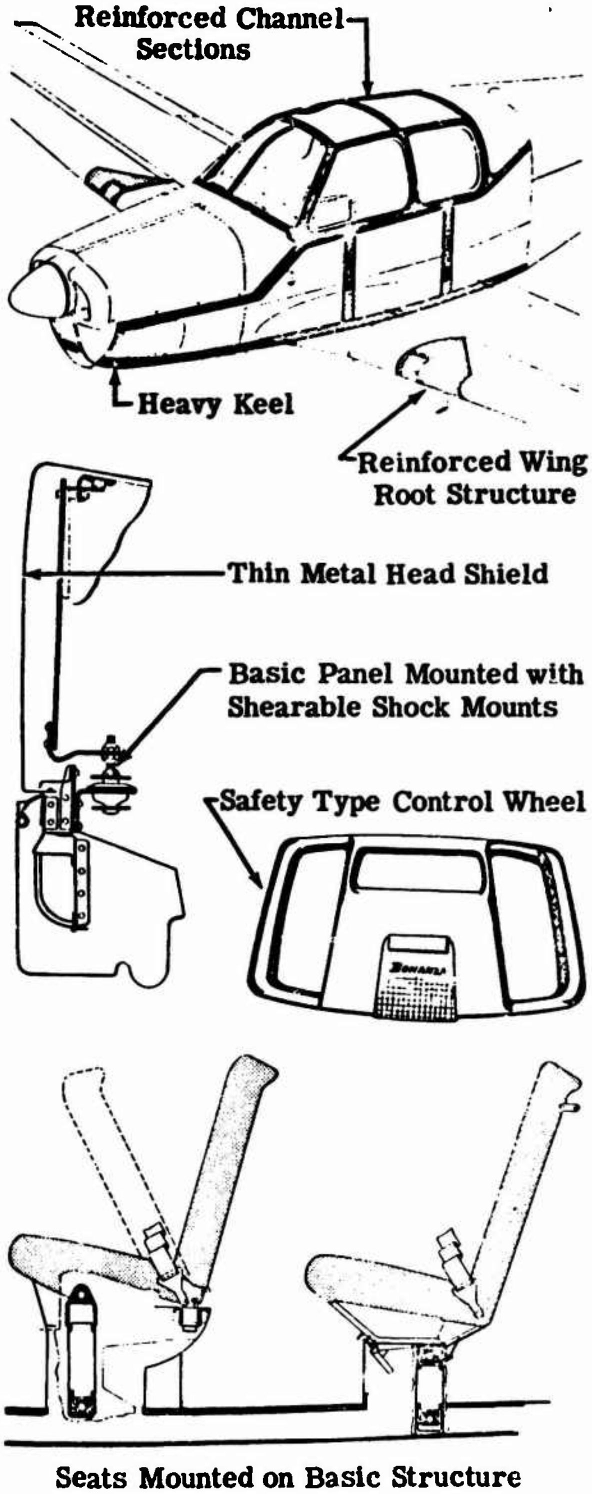
C. The Bonanza's fuselage has reinforced keel section providing occupant protection against crashes and lessening crash damage.

D. The Bonanza's reinforced cockpit provides a strong crash-resistant passenger compartment or structurally-reinforced capsule for maximum occupant protection.

E. The Bonanza instrument panel is installed with shearable shock mounts on basic instrument panel with a thin gauge soft metal head shield to lessen the possibilities of passenger injuries in event of crash landing.

F. The new Bonanza is equipped with body supporting safety-type control wheel to reduce chest and lung injuries in event of crash landing.

G. The Bonanza seats and safety belts are securely mounted to the basic spar truss with the front seat backs hinged to swing forward out of head range of occupants in the rear seat to provide a maximum of passenger protection.




These features which have been outlined above are some of the results of years of private research and testing to enable us to build safer and more practical airplanes.

FIGURE 28. Safety release bulletin—Beech Aircraft Corporation.

**1955 BEECH BONANZA**

BEECH BONANZA E-35, a 1954 model aircraft with pilot and one passenger (R. F. ), was on approach for a landing in poor weather. The aircraft clipped the tops of some small trees and then struck (at 100 m. p. h. ) two larger trees, one with each wing, dislodged the trees, and slid to the ground tail-first. The aircraft was equipped with shoulder harnesses and seat belts. The pilot was wearing only his seat belt, while the passenger was utilizing both harness and belt. The pilot was thrown through the windshield; the passenger remained in the aircraft. All restraint equipment, attachments, and seat tie-downs held. The pilot slipped out of his belt. The aircraft cabin remained intact!

ACCIDENT INVESTIGATED BY:
ERNEST MC FADDEN AND JIM SIMPSON
CAMI

# CASE 19-1

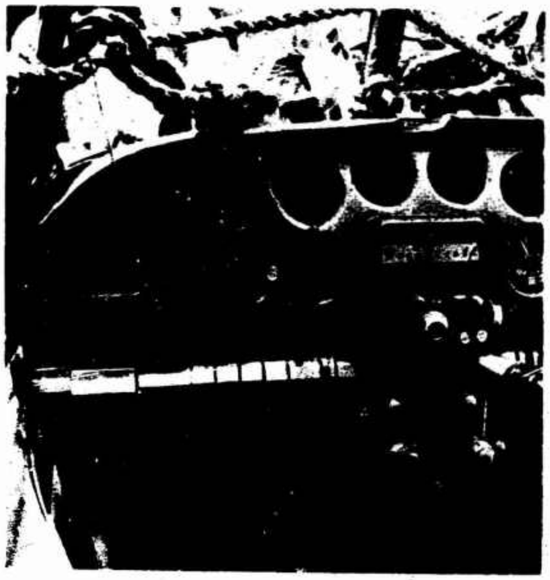
**A. Wreckage of Beech Bonanza. Note that the tail, wings, & motor are torn away, but the cabin is intact.**

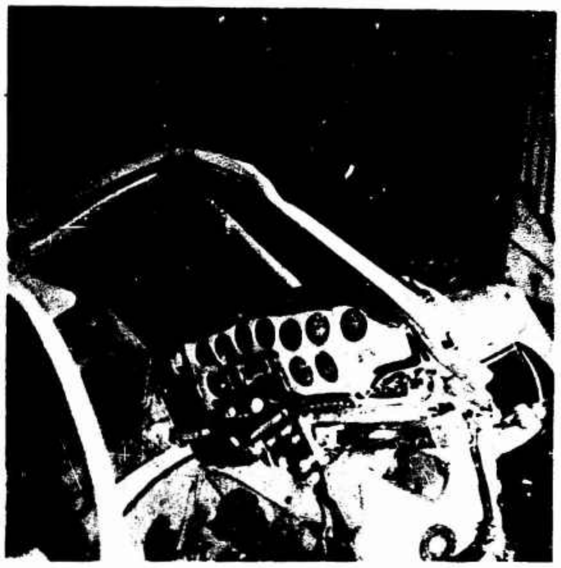
**B. Two large trees uprooted by aircraft impact.**

**C. Close-up showing cabin integrity.**

| | INJURIES | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (S) | Head - Contusions & abrasions, small lac's. | Windshield. |
| | Trunk - Fx. (L) ribs 7, 9, 10, 11. Fx. dorsal vertebra #5. | Control wheel. |
| | Extremities - None. | |
| R. F.: (S) | Head - Lac. scalp. | Broken windshield entered cabin. |
| | Trunk - Fx. (L) rib #8 with lung contusions. | Control column post. |
| | Extremities - Sprain (R) ankle. | Pedals. |

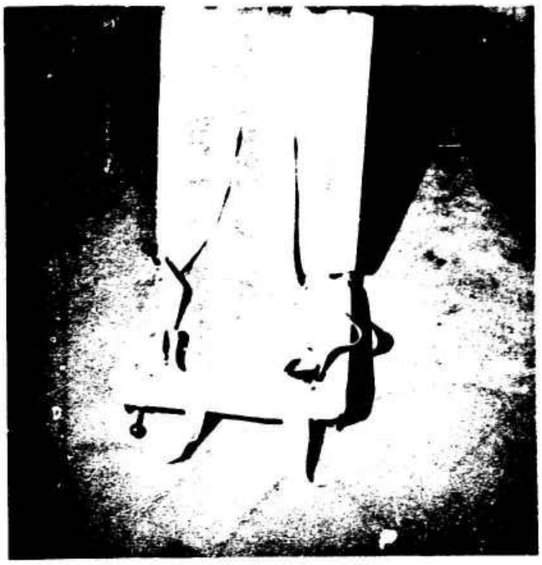
# CASE 19-2





D, E & F Views of instrument panel & cabin interior.

**CASE 19-3**



G & H Continuous shoulder harness--seat belt combination installed in the Beech Bonanza.

# CASE 19-4

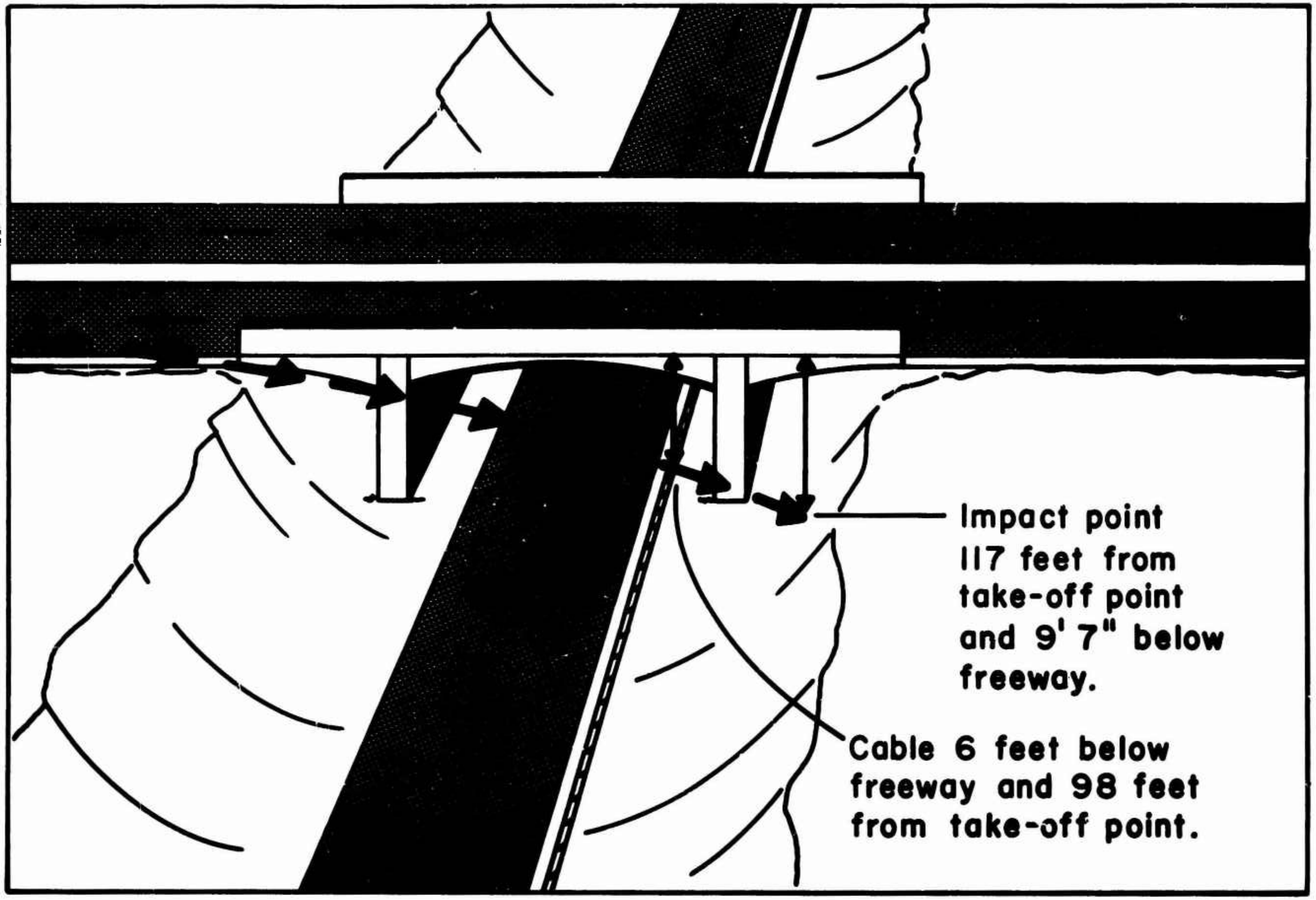



FIGURE 29. Trajectory of an automobile traveling at high velocity after it ran off the freeway.

ing 6 feet below the bridge and about 98 feet from the take-off point. Acceleration due to gravity caused a drop of only 9 feet, 7 inches, during its 117-foot flight. In this instance, one can easily calculate with accuracy that the flight velocity of this vehicle must have been slightly over 100 miles per hour. Crushing of the front of the vehicle was approximately 5 feet (Figure 30) and the depression in the hard earth embank-

FIGURE 30. Side view of vehicle showing crushing of front end during deceleration.

ment measured 8 to 12 inches. Hence, it can be calculated that the average deceleration of the car was in excess of 50 "g". Even with these very severe impact forces, the shipping container maintained its integrity and the heavy motor was pushed back under the floor board and not into the cabin. While it is doubtful if light aircraft cabins can be designed to withstand "g" forces of this magnitude, their interior certainly could be modified to incorporate some of

FIGURE 32. Left knee impact.

the succesful design principles for crash survival illustrated in this accident. Although both shoulder harness and seat belt restraint were available in this automobile, the driver was not utilizing either. As a result, his body slid forward in the seated position until his knees embedded themselves in the lower dash (Figures 31 and 32), a smooth, rounded, ductile metal without knobs or rigid edges. His chest contacted the large diameter steering wheel contoured to fit the body and distribute the load over a large chest area (Figure 33). The chest impact was of sufficient force to crush the collapsible control column mechanism to its maximum distance (8″) (Figure 34). At the same time his head was impacting the padded sunvisor and pushed it through the windshield (Figure 35). The only injuries suffered by the operator of this automobile were a laceration of the face and a small puncture wound on the upper left arm, both resulting from contact with the broken windshield.

FIGURE 31. Right knee impact area.

FIGURE 33. Large diameter contoured steering wheel.

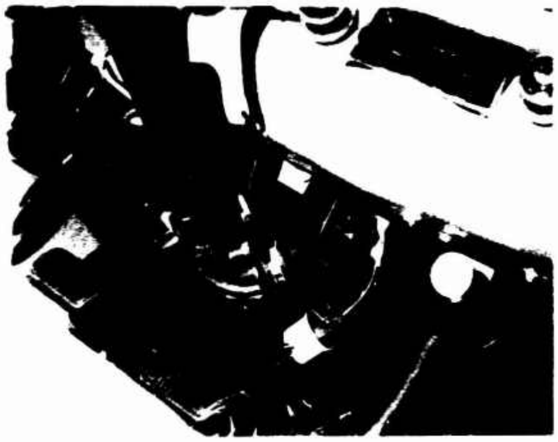


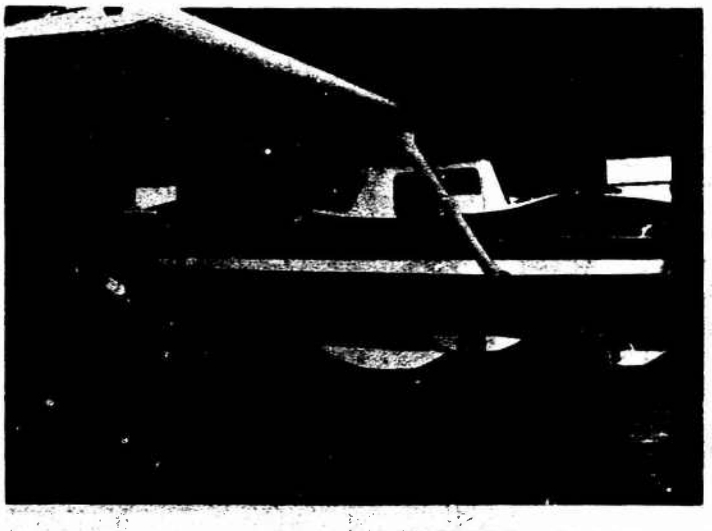
FIGURE 34. Collapsible control column compressed by chest.

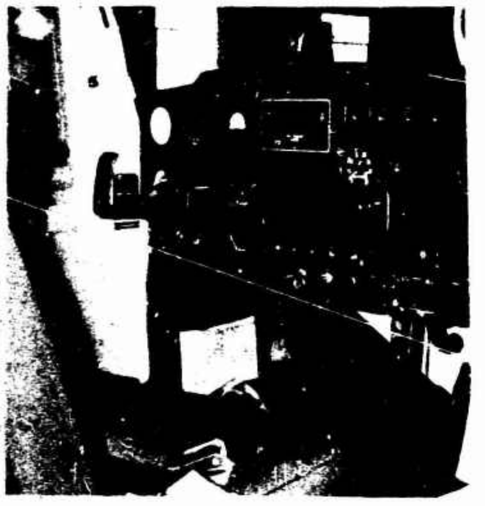
FIGURE 35. Padded sunvisor pushed through the windshield by head impact.

The fact that crash safety engineering is sorely lacking in the forward cabin in most current general aviation aircraft is further illustrated by three unusual crash cases presented here. In Case 20 a 1968 Cessna 150–H crashed upside down and the heads of both occupants dragged along the ground, thereby staying away from the lethal instrument panel. Injuries were limited to lacerations of the scalp and abrasions of the face. The deceleration distance for this aircraft as its nose rooted under a large flat rock could not have been more than 4 feet. Assuming a flight velocity before impact of 50 miles per hour, we can calculate a rather impressive 18 to 19 "g" deceleration. The pilot of Case 7 (an identical aircraft) received severe facial injuries when he crashed with an impact of ⅓ this "g" force. Since his aircraft crashed right side up, his head was thrown into the instrument panel. If these two men had crashed into the same rock in an upright position. they would certainly have sustained fatal head injuries.

In two other accidents, occupants were prevented from hitting the instrument panel since one crashed sideways into a telephone pole (Case 21) (1949 Swift GC–1B), and the other hooked one wing root on a tree (Case Number 22) (1961 Piper Colt PA 22–108). In both cases the upper torsos of the occupants were thrown to the side and thereby avoided striking the instrument panel with a much better chance of avoiding serious injury.

Aircraft manufacturers have incorporated some excellent crash safety features in some of their aerial applicator planes. The Piper Pawnee has a steel tubular framework around the cockpit, is equipped with double shoulder harness and seat belt, all anchored to strong fuselage structure, and has a lightweight semicylinder of aluminum (4-inch radius) at the top edge of the instrument panel. In addition, in the knee and lower leg impact area, protruding knobs, sharp edges, and heavy equipment have been reduced and the crushable fiberglass hopper lined with lightweight perforated aluminum helps to attenuate knee impact. In Case 23 a young pre-medical student (while flying a 1960 Piper Pawnee PA–25) crashed from a stall at 140 feet altitude into hard soil at a 45° angle. The actual "g" force is not known, but he impacted hard enough to break both his double strap harness and a 3-inch seat belt. In Case Number 24, the pilot of another Pawnee PA 25–235 (1964) crashed with sufficient force to break his double strap shoulder harness, but his seat belt held. In laboratory testing of 2-inch wide double shoulder harness restraint, the breaking point was found to be over 35 "g" and since both pilots still had sufficient body momentum left to impact their heads at velocities of over 30 ft./sec. on the instrument panel protected by the aluminum roll, the author estimates that these two aircraft crashed with impact forces of at least 40 "g". It is amazing that even with these crash forces the shipping container (aircraft cockpit) retained its integrity and did not collapse on its occupant. Tests were conducted in this laboratory to evaluate the energy attenuating characteristics of the aluminum roll for head impact protection. The results of the test impacts with an instrumented dummy head at 15 and 30 ft./sec., along with





**1968 CESSNA 150**

CESSNA 150 H, a 1968 model aircraft with pilot and one passenger (R. F. ), became inverted at night, clipped some small trees and crashed inverted. Aircraft motor plowed under a large flat rock (the only one in the field). Top metal structure of the cabin was ground away. Since pilot and passenger were hanging upside down in their seat belts, their heads dragged the ground. No shoulder harnesses were in the aircraft. Major deceleration forces were straight forward.

ACCIDENT INVESTIGATED BY:
GALE BRADEN AND DON ROWLAN
CAMI

# CASE 20-1

A. Tree tops clipped by inverted aircraft just before it crashed.

B. Forward motion of the aircraft was stopped when motor plowed under a large flat rock.

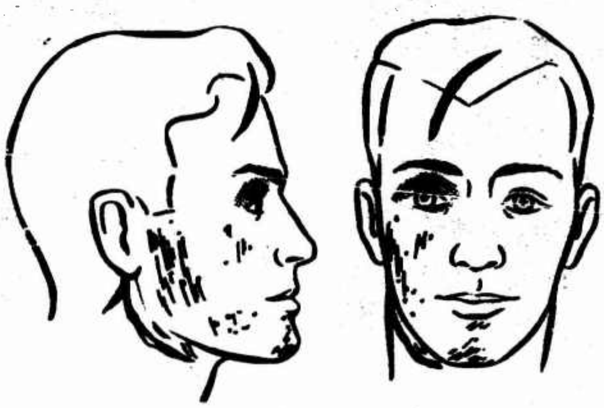
| INJURIES | | | STRUCTURES IMPACTED |
|---|---|---|---|
| Pilot: (S) | Head - | Severe Lac. (Y-shaped) forehead & scalp. Moderate concussion. Lac. lower lip (R). Lac. (R) face. Numerous facial abrasions. | Torn metal - cabin roof & ground. |
| | Trunk - | Pelvic abrasions. | Seat belt. |
| | Extremities - | Lac. (R) forearm. Lac. (L) knee. Fx. (L) hand. | Lower instrument panel. |
| R. F.: (S) | Head - | Lac's. anterior scalp & behind (R) ear. Abrasions. Moderately severe concussion. | Cabin roof & ground. |
| | Trunk - | Pelvic abrasions. | Seat belt. |
| | Extremities - | Lac. (R) elbow & (L) hand. | Instrument panel. |

C & D Abrasion marks on the iliac crests offer positive proof of seat belt use.

# CASE 20-2

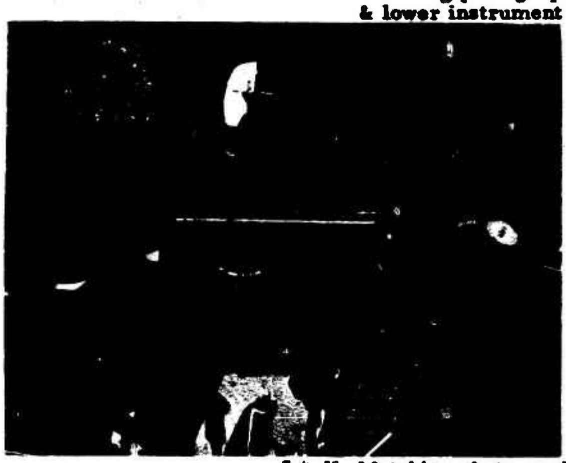
F. Head outlines of head positions in inverted aircraft.

E & G Artist sketches of lacerations & abrasions of 2 occupants heads from dragging along the ground & contact with torn metal from top of cabin.



## CASE 20-3

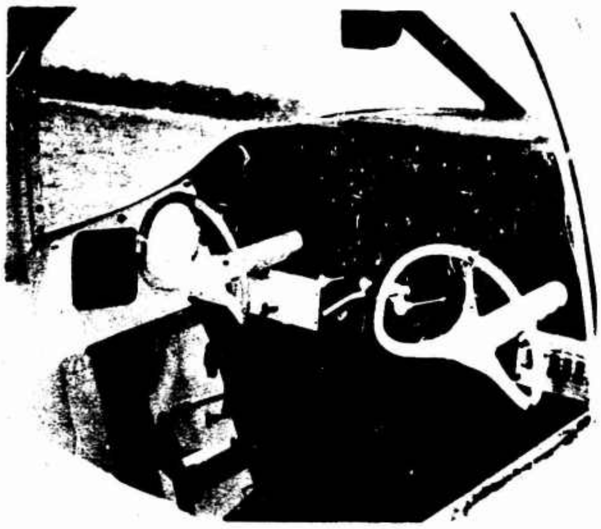
H & I  Matching photographs of knee abrasions of copilot & lower instrument panel push buttons.



J & K  Matching photographs of pilot's knees & lower left instrument panel.

L. Head impact with upper instrument panel was prevented since both occupants heads dragged along the ground.

**CASE 20-4**

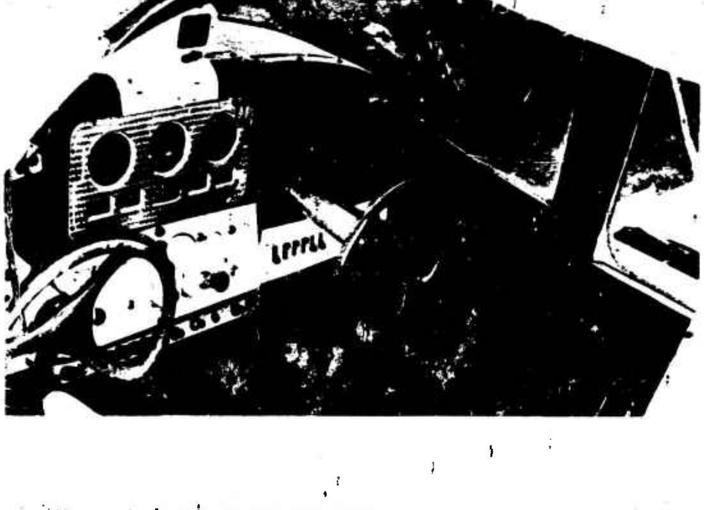
**1946 TEMCO SWIFT**

TEMCO SWIFT GC-1B, a 1949 model aircraft with pilot and one passenger (R. F.), struck some telephone wires between two poles, breaking one of the poles and sliding down the wires to impact the second pole with its (L) wing. As the second pole broke, the aircraft rotated through the air and impacted a third pole with the (R) side of the fuselage, wrapping around it and sliding down to the ground. Both occupants were wearing seat belts and they held. No shoulder harnesses were in the aircraft. The principal impact force threw the occupants to the side. They did not impact the instrument panel.

ACCIDENT INVESTIGATED BY:
DON ROWLAN AND EDDIE LANGSTON
CAMI

# CASE 21-1

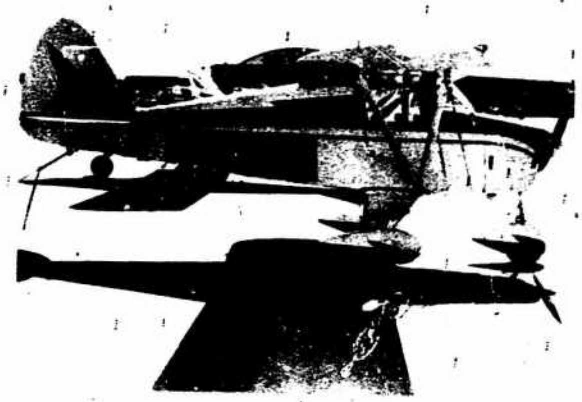
A. Telephone pole is completely buried in fuselage after side impact by aircraft.



B. Since both occupants were thrown to the side, the instrument panel is unmarked.

| INJURIES | | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (S) | Head - Small lac's. (L) forehead & scalp. | Side of cockpit (?). |
| | Trunk - None. | |
| | Extremities - Contusion (L) shoulder. | Side of cockpit (?). |
| R. F.: (S) | Head - Lac. (minor) (L) ear & (L) forehead. | Side of cockpit (?). |
| | Trunk - None. | |
| | Extremities - None. | |

# CASE 21-2



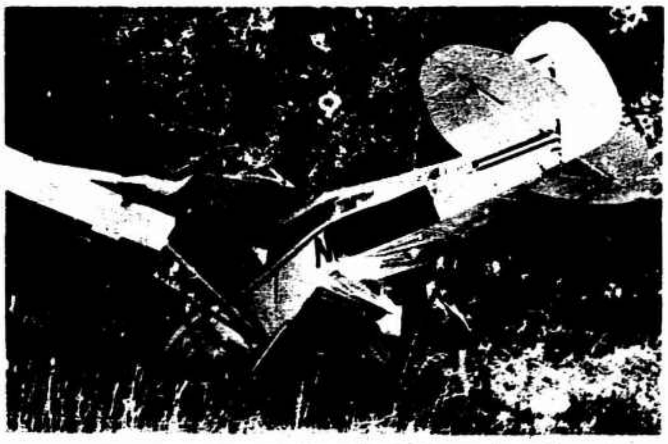
**1961 PIPER COLT**

PIPER COLT PA-22-108, a 1961 model aircraft with pilot and one passenger (R. F.), was flying at an altitude of 5,000 feet when the pilot cut the engine to practice some power-off maneuvers. At about 2,500 feet, he tried to restart the motor but could not and crashed while trying to return to his private air field. At impact the right wing of the aircraft struck a 10-inch diameter tree which tore it from the aircraft and opened the right side of the cockpit next to the passenger. Pilot and passenger were thrown to the right toward the opening. Seat belts (fuselage attached) were in use and held, but the seats came loose from their fittings. No shoulder harnesses were in the aircraft.

ACCIDENT INVESTIGATED BY:
TERRY WALLACE
CAMI

# CASE 22-1

A. Distant view of crash site. Tracks in wheat field were made by rescue personnel as aircraft did not touch the ground before striking the tree.



B. Rear view of aircraft after tree impact & 90° change of direction.

C. Right side of aircraft. Note bark missing from tree & snagged control cable abouc 5 feet above the ground.

D. Front of aircraft showing complete separation of motor & instrument panel.

| INJURIES | | | STRUCTURES IMPACTED |
|---|---|---|---|
| Pilot: (S) | Head | - Slight lac. on bridge of nose. | Unknown. |
| | | Occipital bematome & moderate concussion. | Unknown. |
| | Trunk | - None. | |
| | Extremities | - None. | |
| R. F.: (S) | Head | - Slight lac. (R) center forehead. | Unknown. |
| | Trunk | - Severe contusion of (R) abdomen & (R) iliac crest. | Seat belt. |
| | | Fx. (R) iliac crest. | Seat belt. |
| | Extremities | - Slight lac's. (R) forearm. | Torn metal (R) side of cabin. |
| | | Fx. (R) tibia & fibula. | Lower (R) door frame. |

# CASE 22-2

E. Copilot received only minor nose injury as he was thrown sideways away from the instrument panel.

F. Seat belt abrasion on copilot.

G. Copilot fractured tibia & fibula of right leg.

H. Pilot with minor laceration of forehead.

I. Right leg of pilot with minor injuries.

J. Minor lacerations of pilot's right elbow.

CASE 22-3

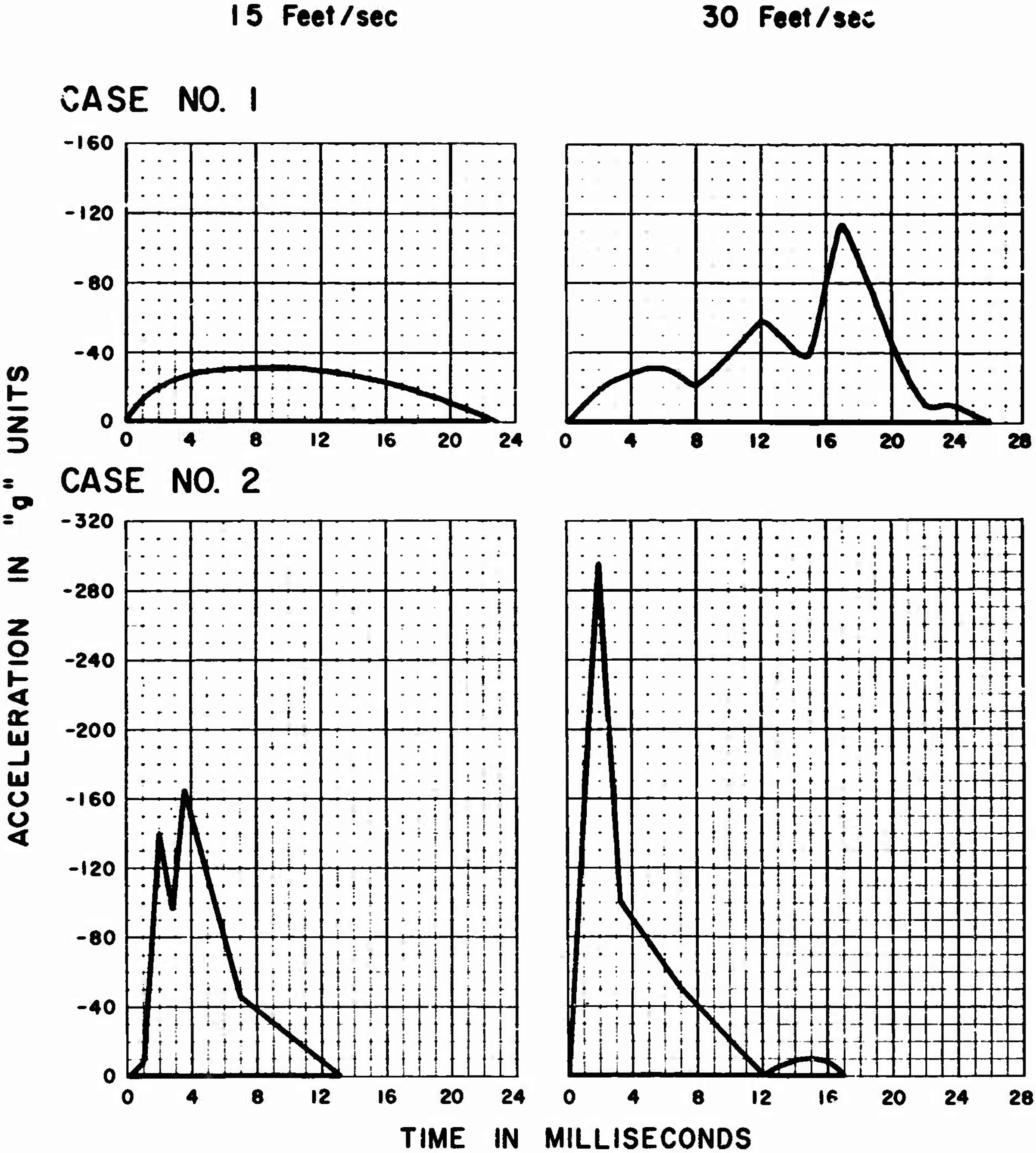


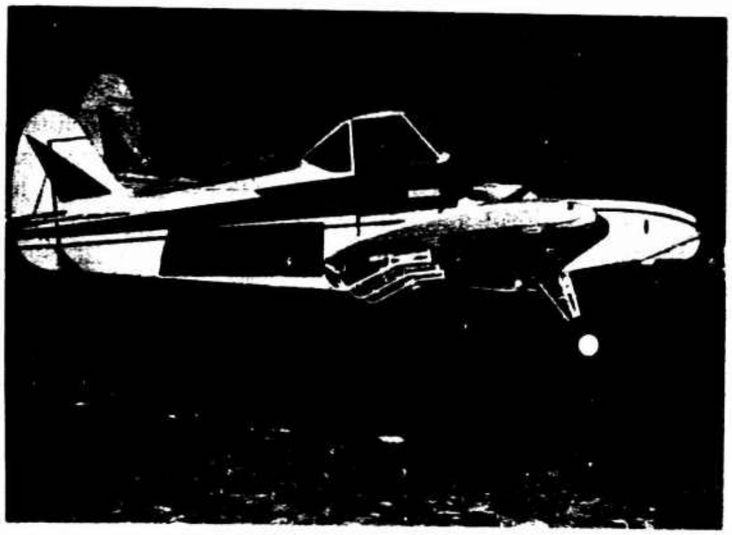

FIGURE 36. Comparison of test results of head impact tests against the Piper Pawnee aluminum ½ cylinder (Case 1), and one of the common rigid instrument panels in general aviation aircraft (Case 2).

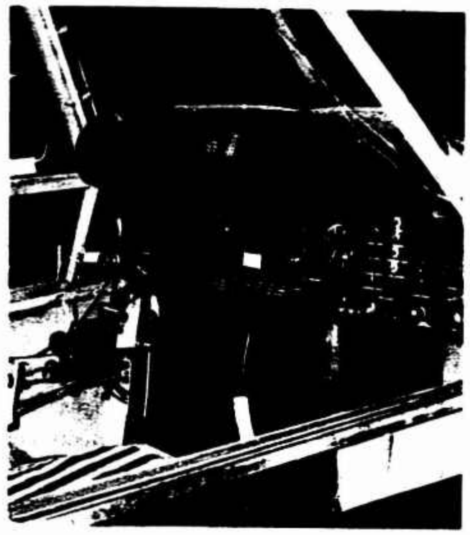
similar data for impacts against a rigid instrument panel in common use in general aviation aircraft, are presented in Figure 36. Note that not only does the aluminum roll reduce the peak "g" force at 15 ft./sec. from 160 to 30 "g", but also extends the time for deceleration from 12 milliseconds to nearly 24, while at 30 ft./sec. impact velocity it reduces the force of head impact from 300 "g" to 110 "g" with a doubling of the deceleration time. Decreased impact forces and extended duration times are most important for preventing head injuries, but of even more significance was the distribution of the load over a greater surface area. As the light aluminum roll was impacted by the face, it deformed to roughly fit the contours of the head (Case 23 F and Case 24 E and F) and in the laboratory tests increased the head contact area from less than one square inch for the common rigid instrument panel to better than 16 square inches on the deformed aluminum roll. The importance of these three factors for head protection cannot be overemphasized and is further illustrated by these two pilots escaping with only minor lacerations (Case 23 G and Case 24 H). Even better protection could be afforded by covering the aluminum roll with a one-inch layer of slow-return padding to prevent facial lacerations from torn metal and to obtain a more even distribution of pressure loads.

This report would not be complete without pointing out still another area where general aviation aircraft design engineers could improve crash survivability with a minimum of effort. It has been noted throughout this study that protection of aircraft occupants from vertical impact has been virtually ignored. Three cases (25, 26 and 27) will serve to illustrate the need for improvements in this area. Human tolerances to vertical impact in the seated position have been established by the author,[72] by vertical ejection seat research,[73] and by Snyder studies of fall cases.[74, 75] Also, numerous energy attenuating methods and devices have been developed[76, 77, 78, 79] to reduce vertical loads on the spine during crash deceleration.

In Case 25 (a 1940 Piper Cub J-3C-65) numerous serious vertebral fractures resulted from vertical impact forces on a seat constructed of a cushion placed on top of a sheet of canvas laced to the sides of the seat structure. This flimsy structure gave way readily, allowing the buttocks of the front seat occupant to impact the heavy tubular structure under the center of the seat (Case 25 D). The forces involved in the crash of the 1964 Beech Musketeer A-23 presented as Case 26 were not all vertical as indicated by the pilot's receiving a brain concussion when his head hit the unpadded "A" post (Case 26 E) and the copilot's receiving a similar head injury from impact with the compass (Case 26 F) mounted on top of the instrument panel. However, the vertical component was significant as attested by the engine breaking straight down (Case 26 B and C) and the buckling of the legs of the front seats (Case 26 H and I). The fact that the legs did buckle to a degree probably prevented more serious back injuries of these two occupants. Fractures of L1 for both front seat occupants would have been avoided in this case if only one or two additional inches of vertical attenuation had been provided. It is interesting that the single occupant of the rear seat escaped without vertebral injury or even a back sprain. The rear seat cushion (3-inch-thick foam) is not mounted on a rigid seat pan and rigid legs as is the case with the front seats, but instead lies on top of lightweight aluminum stringers perforated with 5½-inch diameter holes. The attenuation offered by this type of construction, offering up to 9 inches of crush distance, was sufficient in this case to prevent vertebral fractures.

This need for attention to design for attenuation of vertical loads in aircraft with horizontal take-off as well as for those with vertical take-off and landing characteristics is dramatically shown in Case Number 27. Case 27, A through I, shows six young men sitting in an aircraft (a 1967 Cherokee 6 PA-32) with seat belts still fastened and with no visible injuries such that they appear to be sleeping. However, they all died from severe and massive internal injuries (see injury chart). After hooking its vertical stabilizer on some power lines and nosing up to some degree, this aircraft pancaked to the ground without any forward motion. The tall wheat all around the aircraft was completely undisturbed and one blade of the propeller was sticking vertically in the ground without any evidence of soil disturbance either fore or aft. The magnitude of the vertical deceleration force imposed on the bodies in this case is difficult to calculate, but assuming the aircraft started its vertical descent from a height of 100 feet along with a measured vertical crush distance of 4 inches for the seats and approximately 4 inches for the fuselage, one can calculate an average deceleration of 150 "g". However, since the tubing forming the seat legs was of small diameter, it is apparent that the seats crushed to the floor with much less force and the occupants experienced a vertical deceleration peak force much greater than 150 "g" for a brief period of time. Snyder[80] describes one case of man that was subjected to over 4,000 "g" in the seated position for a period of .0023 seconds and could have survived if his internal injuries could have been diagnosed





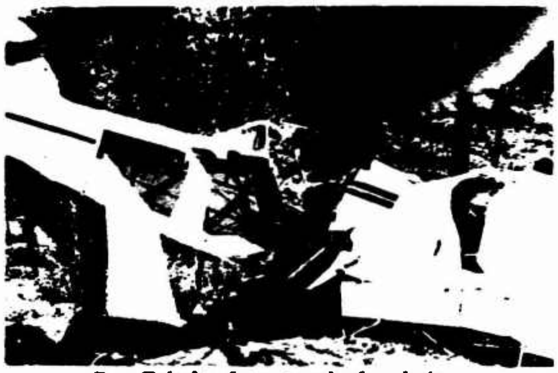
**1961 PIPER PAWNEE**

PIPER PAWNEE PA25, a 1960 model aircraft with pilot only, engaged in aerial application of insecticide, pulled up and stalled at about 140 feet in the air, nosed over, and impacted hard soil at approximately a 45° angle. The pilot was wearing helmet, shoulder harness, and a 3-inch seat belt. Helmet penetrated windshield and was torn off. Seat belt and shoulder harness broke in webbing. Pilot was thrown straight forward.

ACCIDENT INVESTIGATED BY:
JOHN SWEARINGEN AND JIM SIMPSON
CAMI

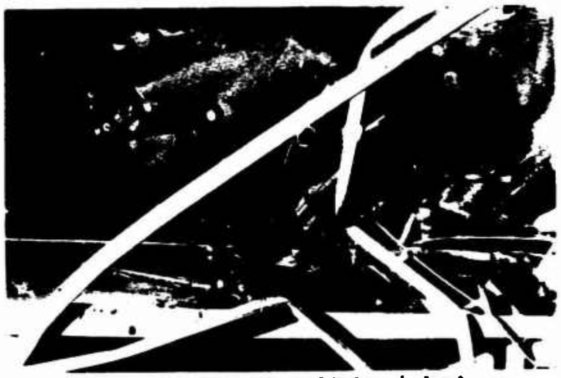
# CASE 23-1

A. Small earthen depression from Pawnee impact.



B. Tubular framework of cockpit maintained its integrity.

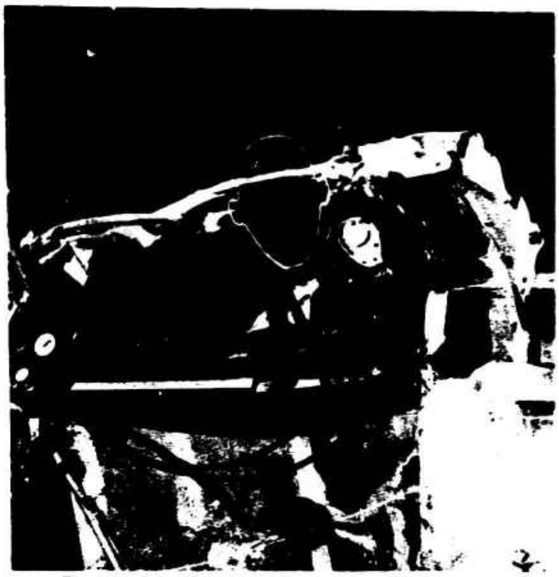
C. Crash design causes motor to fold under the aircraft.



D. Seat attachments held since belts & harness were attached to fuselage.

E. Shoulder harness & 3" seat belt broke.

CASE 23-2



F. Head outline indicates area of head impact on light aluminum cylinder.

G. Pilot with minor bruises & facial lacerations 4 days after crash.

H. Bruise on right shoulder from contact with microphone.

# CASE 23-3

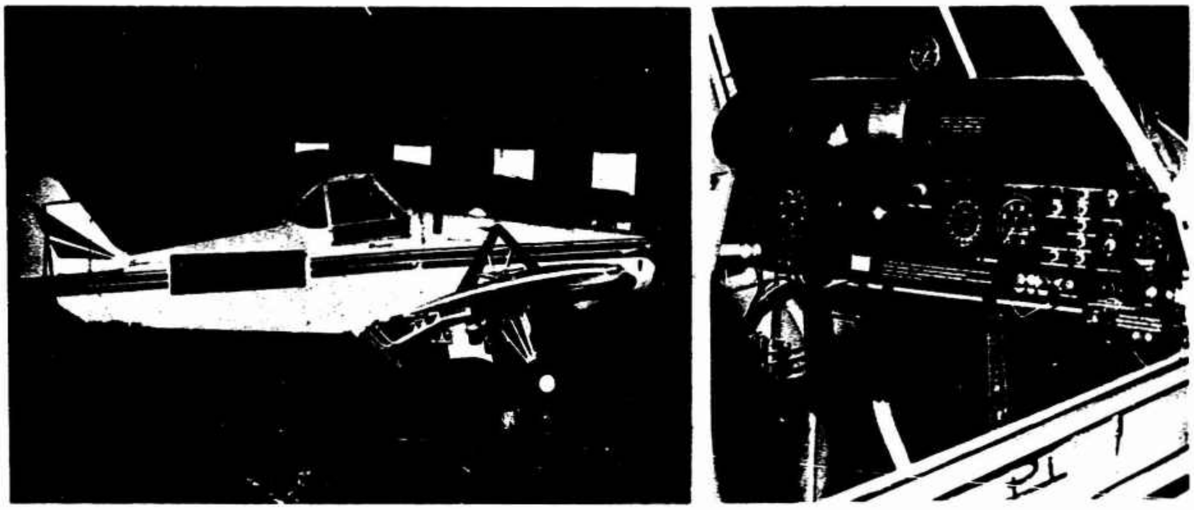
I. Knees penetrated fiberglass hopper without serious injury. Left ankle was fractured in pedal area.

J. Perforated aluminum hopper liner served as good decelerator for knees.

K. Minor lower leg injuries.

| INJURIES | | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (S) | Head - Depressed Fx. (R) frontal sinus. slight concussion. Minor facial lac's. | Junction of windshield with instrument panel. Light semi-cylinder of aluminum at top of instrument panel. |
| | Trunk - None. | |
| | Extremities - Bruise on (R) shoulder & under (L) upper arm. | Light semi-cylinder of aluminum |
| | Small lac's. (L) hand. | Windshield. |
| | Small lac's. (R) anterior leg. | Knees penetrated fiberglass hopper |
| | Fx. (L) ankle. | Pedal. |

# CASE 23-4

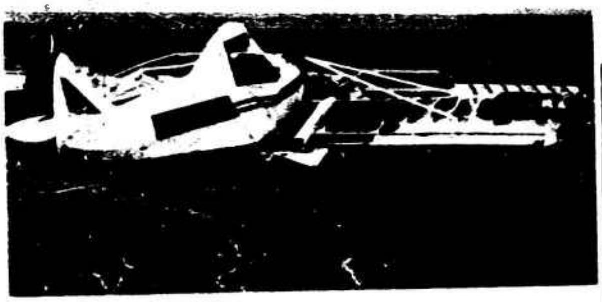


**1966 PIPER PAWNEE**

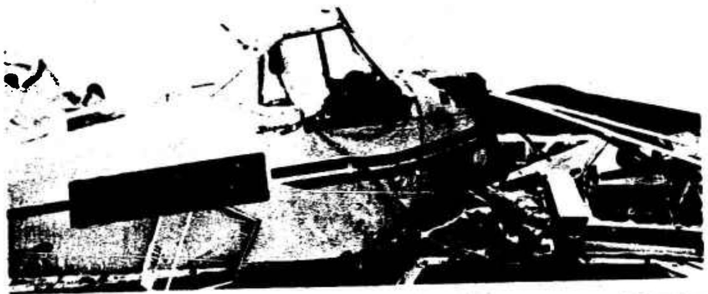
PIPER PAWNEE PA-25-235, a 1964 model aerial applicator with pilot only, had sprayed one-half of a field when the pilot made his pull-up on a west pass and caught some high wires with the left wing. The aircraft crashed 15 feet from the wires at about a 30° angle. The seat belt and shoulder harness were in use. The belt held but the harness failed. The pilot was thrown forward and to the left.

ACCIDENT INVESTIGATED BY:
GALE BRADEN AND EDDIE LANGSTON
CAMI

# CASE 24-1

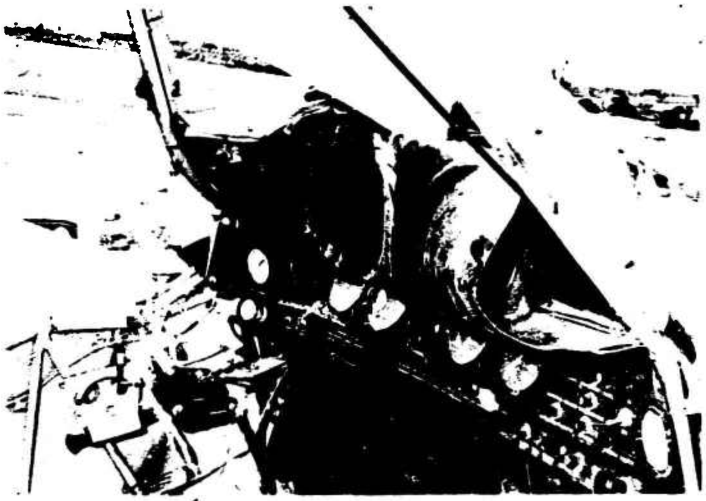


A, B & C Various views of aircraft showing how tubular construction around the cabin prevents its collapse on the pilot even in severe crash impacts.



D. Sides of Pawnee cockpit are designed to buckle outward away from the pilot.

## CASE 24-2



E. Side view of light aluminum cylinder at the top of the instrument panel designed to reduce head injuries.

F. Outline showing area of pilot's head impact on aluminum cylinder. Note chin slipped down & contacted reset knob on altimeter.

G. Shoulder harness failed in webbing but seat & seat belt held.

# CASE 24-3

H. Slight chin laceration was only head injury.

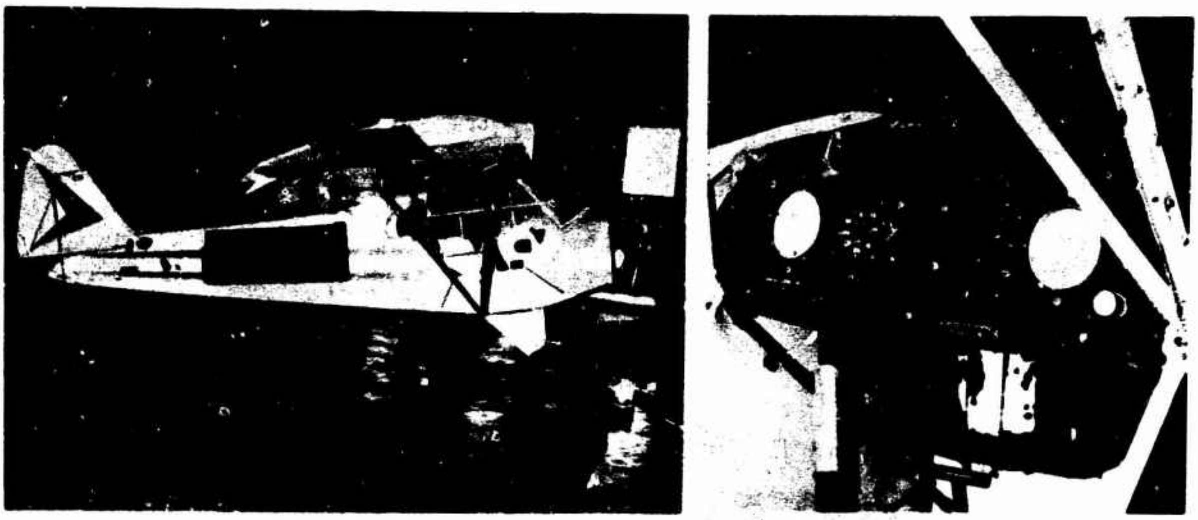
I. No chest injuries.

J. Minor laceration of left hand.

K. Practically no leg injuries.

| INJURIES | | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (S) | Head - Slight abrasion above (L) eye. Minor lac. chin | Light cylinder of aluminum, above instruments. Altimeter reset knob. |
| | Trunk - None. | |
| | Extremities - Lac. between index & 2nd finger. | Windshield. |
| NOTE: | Pilot was spraying with DiSyston & received extensive exposure & severe reaction to it when hopper ruptured & sprayed it over his body. | |

# CASE 24-4



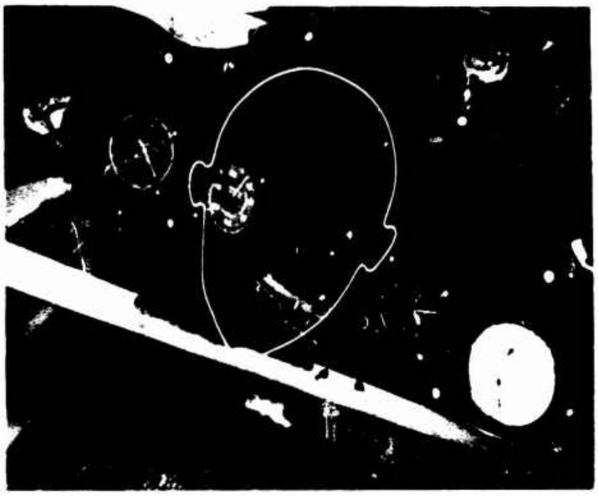
# 1940 PIPER CUB

PIPER CUB J-3C-65, a 1940 model aircraft with pilot (rear) and one passenger (front), was flying over farm land looking at stock. Aircraft pulled up in a (R) turn and (R) wing struck the top wires of a high tension line. Aircraft fell into some lower wires where it hung a few seconds, arresting all forward motion and fell 80 feet to impact the ground in a flat attitude. Vertical impact velocity was approximately 70 feet/second. Both occupants were wearing seat belts and they held. No shoulder harnesses were in the aircraft. Occupants were thrown forward only slightly, the major force on the bodies being from head to seat.

ACCIDENT INVESTIGATED BY:
BILL REED AND DON ROWLAN
CAMI

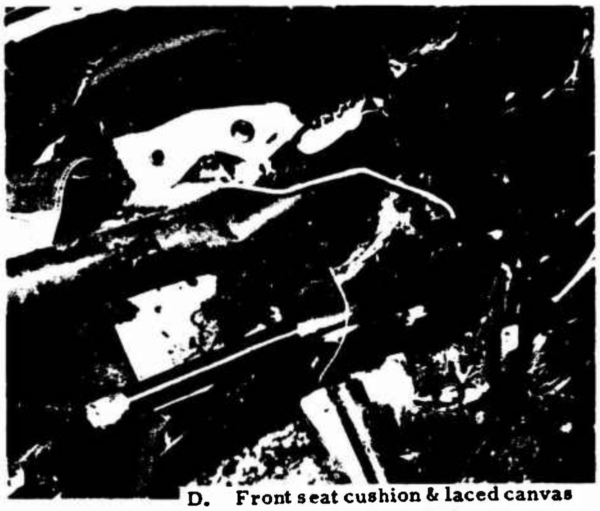
# CASE 25-1

A. Upward bending of landing gear indicates heavy vertical crash forces.



B. Outline indicating area of head impact.

C. Upward buckling of floor structure further indicates vertical forces.



D. Front seat cushion & laced canvas removed to show tubular structure under seat that was responsible for vertebral fractures.

| INJURIES | STRUCTURES IMPACTED |
|---|---|
| Front: (S) Head - Contusions & hematoma (R) parietal area. | Instrument panel. |
| Trunk - Fx. ribs 1, 2, 5 (L). Fx's. T5, T12, L1 & L2. | Instrument panel. Tubular connection between control sticks under canvas seat bottom. |
| Extremities - Fx. both ankles. | Diagonal tubular frame structure directly above ankles. |
| Pilot: (S) Head - (R) eye black, small lac's. (R) zygoma area & (R) side of lip. | Back of front seat. |
| Trunk - Fx. L1 & L2. | Heavy tubular structure under canvas seat bottom. |
| Extremities - None. | |

# CASE 25-2

**1966 BEECH MUSKETEER**

BEECH MUSKETEER A-23, a 1964 model aircraft with pilot and two passengers (R. F. and R. R.), was on a night approach to a runway when the (R) fuel tank ran out of fuel at about 300 feet altitude. An attempt was made to switch to the (L) tank, but the selector was turned past the (L) tank position to "off." The aircraft crashed with (L) wing down and very little forward motion. A heavy vertical impact was encountered. All seat belts were in use and held. No shoulder harnesses were in the aircraft. Occupants were thrown forward, to the left, and down.

ACCIDENT INVESTIGATED BY:
BILL REED AND LEE LOWREY
CAMI

# CASE 26-1

A. General view of crash site.

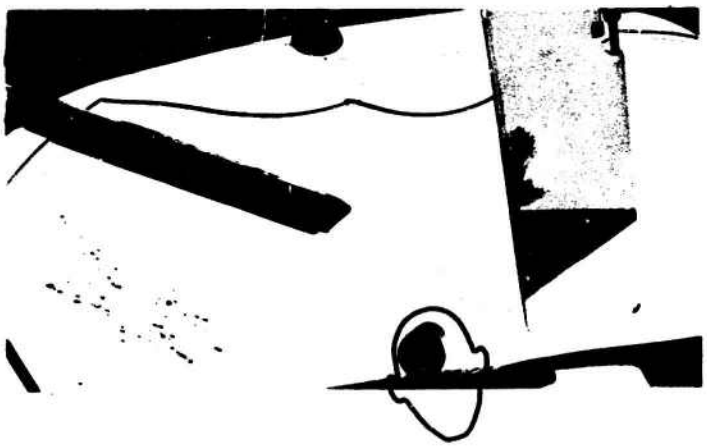
B & C Short 6-foot gouge mark under the aircraft, upward bending of the landing gear, & downward bending of motor all indicate that the aircraft crashed nearly flat with heavy vertical loads.

| | INJURIES | STRUCTURES IMPACTED |
|---|---|---|
| Pilot: (S) | Head - Brain concussion. Lac. scalp. | (L) "A" post. |
| | Trunk - Fx. L1, bruises. | Rigid seat bottom—no attenuation. |
| | Extremities - None. | |
| R. F.: (S) | Head - Brain concussion. Lac. scalp. | Compass & top edge of instrument panel. |
| | Trunk - Fx. L1. | Rigid seat bottom—no attenuation. |
| | Extremities - None. | |
| R. R.: (S) | Head - None. | |
| | Trunk - None (no vertebral Fx's. | Seat pan of rear seat yielded - light aluminum. |
| | Extremities - Fx. humerus (R) & (L). | Broken between body & upper seat back. |

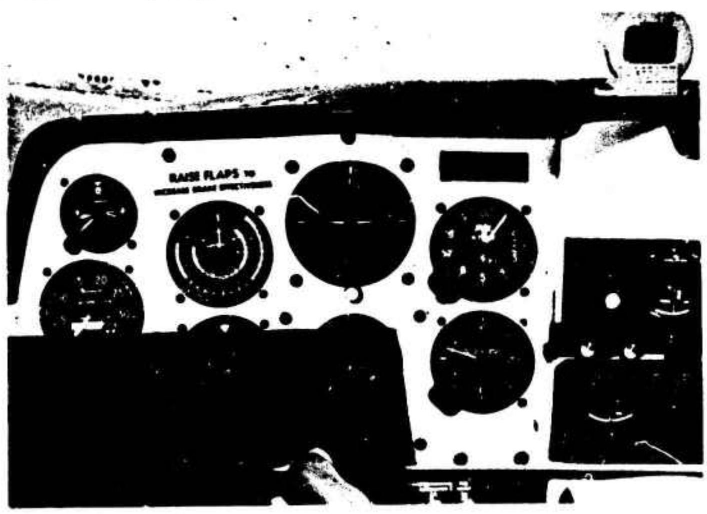
# CASE 26-2

E. Pilot was thrown slightly to the left & his head hit the rigid "A" post.

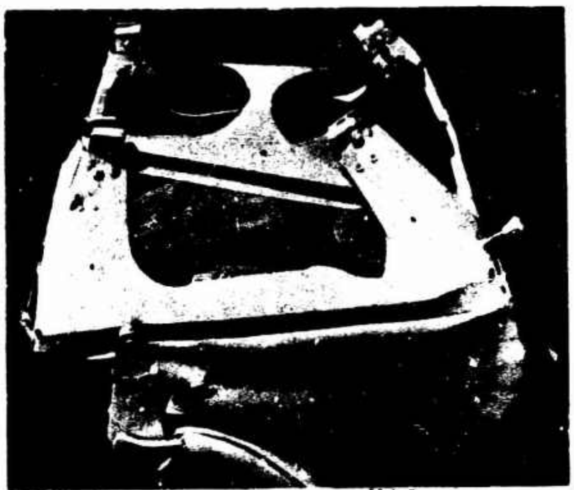
D. Cabin interior.



F & G Copilot's head struck compass & top center edge of instrument panel.



## CASE 26-3



H & I Heavy seat legs buckled from vertical forces. Vertebral fractures could have been prevented by attenuation in seats.

J. Outboard belts fuselage-attached.

K. Inboard belts attached to floor.

L. Rear seat with four inches of light aluminum structures beneath it saved rear passenger from spinal injuries.

# CASE 26-4

**1968 PIPER CHEROKEE "6"**

PIPER CHEROKEE 6 PA-32-300, with pilot and five adult passengers (R. F., C. L., C. R., R. L., R. R.) ran out of fuel at night and attempted an emergency landing. Unfortunately, the pilot could not see a power line on which he hooked the vertical stabilizer, causing loss of landing lights and making the aircraft nose up into the air. The aircraft then pancaked to the ground without any forward motion. Seat belts were in use and held. No shoulder harnesses were in the aircraft.

ACCIDENT INVESTIGATED BY:
LEE LOWREY
CAMI

# CASE 27-1

A. Aircraft crashed flat in a tall wheat field. Note wheat all around aircraft is undisturbed.

B. Motor is bent downward, landing gear pushed up into wings, instrument panel completely undamaged & rear passenger appears to be sitting flat on the ground.

| | | INJURIES | STRUCTURES IMPACTED |
|---|---|---|---|
| Pilot: (F) | Head | Extensive Fx. skull (calvarium & base) with severe brain hemorrhages. Compression Fx's. of cervical vertebrae. | All injuries from vertical impact force against seats, floor & underlying structures. Instrument panel & control wheel were undamaged. |
| | Trunk | Fxs. both clavicles; (R) anterior ribs 1, 2, 3, 4 & 5; (R) post ribs 1, 2, 3, 4, 5, 6, 7 & 8; (L) anterior ribs 1, 2, 3 & 4. Fx. sternum & pelvis (symphysis). Rupture & hemorrhages pulmonary arteries, lungs, kidneys, bladder, vena cava. | Same as above. |
| | Extremities | Fx. (R) femur, (R) & (L) tibia & fibula. | Same as above. |
| R. F.: (F) | Head & Neck | Cerebral congestion without Fx. | Same as above. |
| | Trunk | Rupture & hemorrhages lower lungs, adrenals, kidneys; Fx. both ilium (posterior) with anterior displacement. | Same as above. |
| | Extremities | Fx. (R) upper femur with anterior displacement. | Same as above. |
| Center & Rear Passengers: (F) | | No autopsy performed. However, with the total absence of external injuries, it must be assumed that death resulted from similar internal injuries (cerebral hemorrhage, lung rupture, hemorrhage, etc. | |

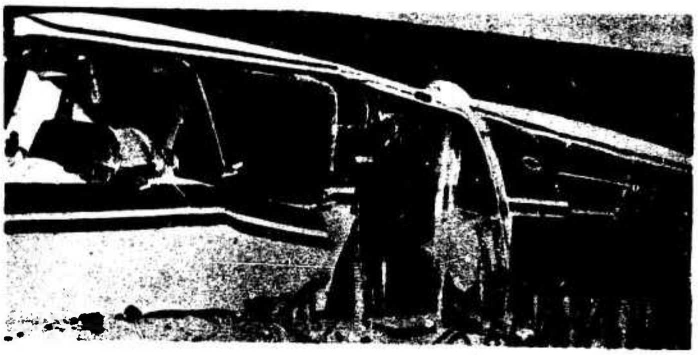
# CASE 27-2

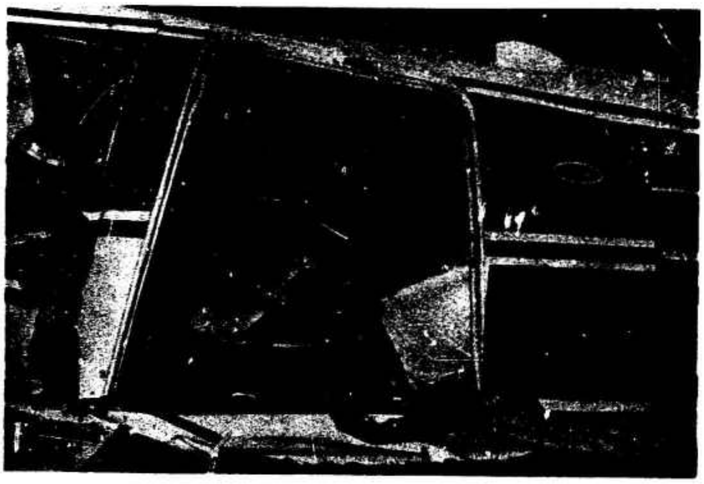
C & D Front seat occupants appear to be uninjured & asleep.

# CASE 27-3

**E & F Views of right front & center seat occupants.**

## CASE 27-4





G, H & I All occupants have seat belts fastened, appear to be sitting on the ground, & died from severe internal injuries produced by vertical forces.

CASE 27-5

and repaired in time. The author[72] has experienced vertical decelerations of up to 95 "g" for .0075 seconds with internal injuries corrected by surgery. In the same study, all subjects tolerated 220 "g" for .0065 seconds without injury or pain when the test seat was equipped with 4 inches of crushable foam under the seat pan. Judging from the massive internal injuries of the occupants in the crash case being presented here as compared to those for the fall case presented by Snyder, the peak vertical force generated when the seats bottomed out must have been in the range of 5,000 to 6,000 "g". The significant point to be made here is that the seats must not be of a frail design that allows them to crush, using up valuable deceleration distance while dissipating very little of the impact force and then bottom out against rigid structure and producing very high, intolerable "g" forces. Numerous simple methods for gradual vertical deceleration have been devised and are in use on Army helicopters. Use of energy attenuators in the design of the seats of this aircraft would have allowed the six occupants of this aircraft to survive without injury.

## IV. Conclusions.

An evaluation of the crashworthiness of current general aviation aircraft has been presented in terms of simple packaging and shipping principles. It is concluded that in most instances these well-known principles have been so grossly ignored that serious and fatal injuries have occurred in anything more severe than a hard landing. Many pilots have remarked that "light aircraft are made for flying and not for crashing" and the selected accidents presented in detail in this report prove their statement to be sadly true. In fact, of all vehicles designed for human transportation, the so-called general aviation aircraft offer the least protection from, and chances of survival in, crash decelerations. Beech Aircraft Corporation has made a sincere effort to build a cabin structure that approaches a sensible shipping container. Other companies have manufactured special purpose aircraft (Piper Pawnee, Cessna Ag Wagon, Grumman Ag Cat and the Helio-Courier) with cabin structures that can withstand 40 "g" impacts without collapsing. Most of the small general aviation aircraft built for passenger transportation are so fragile that they will open up and spill their contents or collapse inwardly in crash decelerations exceeding about 10 "g".

Thirteen of the aircraft described in this report (Cases 4–15 inclusive and 17) sustained crash forces of 10 "g" or less (calculated). These aircraft all crashed in a forward direction and the cabins remained intact to the extent that the author is of the opinion that all occupants would have survived without injury had they been properly restrained with shoulder harnesses and seat belts. Of the 31 occupants, 10 received fatal injuries, and of those that survived, 8 received severe injuries, 8 moderate injuries, and 5 minor or no injuries. Lack of protective design in the instrument panel in these 13 accidents was the direct cause of 5 severe and 2 moderate brain injuries, 30 facial fractures, 11 severe and 10 moderate facial lacerations, 33 fractured bones in arms and legs, and 9 joint dislocations. Poor control wheel design resulted in 7 severe trunk injuries. Further evidence of the lethal construction of the instrument panel is presented in Cases 20, 21 and 22. In Case 20, the aircraft crashed inverted and in Cases 21 and 22 they crashed sideways in such a manner that the occupants did not impact the instrument panel and survived with minor injuries even though the crash forces were considerably greater than those in similar fatal accidents in which occupants were thrown into the instrument panel.

Minor or no injuries occurred in "crashes" of one and two "g" decelerations. Severe but nonfatal injuries were common in 3 to 5 "g" accidents. Fatalities and very severe injuries occurred in crash decelerations of 6 to 10 "g". At 10 "g" and above, most present general aviation aircraft disintegrate to the extent that the value of restraint equipment for crash survival is doubtful. Inasmuch as the Bonanza appears to have about a 25 "g" cockpit and the Piper Pawnee one that can withstand impact forces up to 40 "g", the manufacturers of general aviation aircraft should be encouraged to strengthen cockpit design in all future aircraft models.

Almost 100% of the occupants of the 70 light aircraft accidents investigated to date were wearing seat belts, indicating that people are aware of the need for restraint equipment and are willing to wear it in this type of transportation. However, in most cases, the seat belts and seats themselves are inadequately attached to the cabin structure and fail or are ineffective even in moderate decelerations.

Even if all seat belts were ideally installed, they would restrain only the pelvis and still would allow the head, trunk, and appendages to continue to flail forward into structures that are so lethal that even minor velocity body impacts are sufficient to rip, tear, and crush body structures. Plexiglass windshields, unpadded "A" posts, rigidly-mounted compasses above the instrument panel, weak control columns that break off to form spears, lethal control wheels, instrument panels loaded with heavy instruments, sharp edges, and protruding knobs, heavy exposed pedal structures, and the lack of slow-return padding, all combine to make the area forward of the front seat occupants extremely unsafe for body impact. The statistics presented at the beginning of this report prove that this environment is so lethal to body impact that your chances of being killed are twice that of receiving serious injury.

The use of properly-designed and installed shoulder harnesses would help prevent impact of the head and upper torso with these structures, but experience has shown that shoulder harnesses have not received the acceptance of the general public. The automatically inflatable air bag looks very promising for use in body restraint and may offer a solution in future general aviation aircraft.

Nothing new in the way of principles or statistics has been presented in this report, but the author hopes that by presenting actual cases revealing structures responsible for specific injuries and showing the extreme severity of these injuries even in minor decelerations, that some action may be stimulated to reduce this needless loss of human life and suffering.

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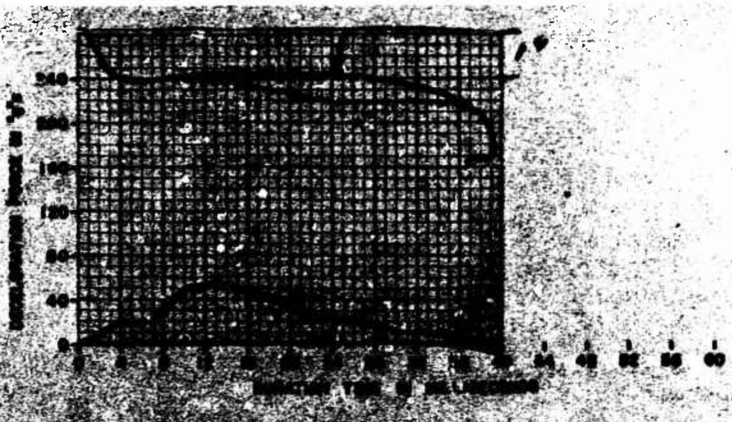
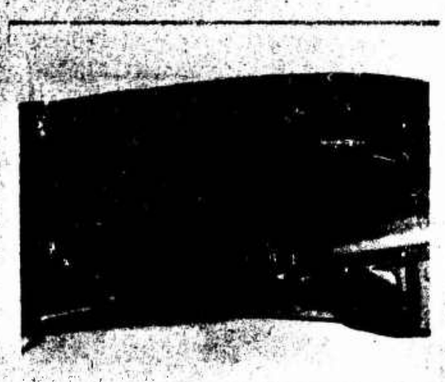
# APPENDIX



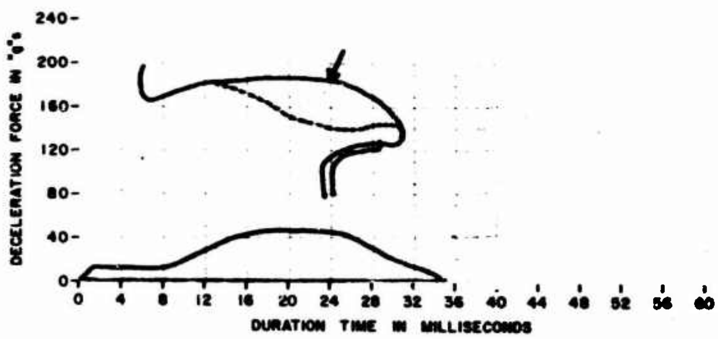
| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 14.0 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . | .034 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . . | 11.5 |
| PADDED . . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 5/8 |
| AREA (SQ. INCHES) . . . . . . . | 25.6 |
| YEAR AND MAKE OF CAR . . . . . | 64 CHEV |

SHAPE AND AREA OF DEPRESSION

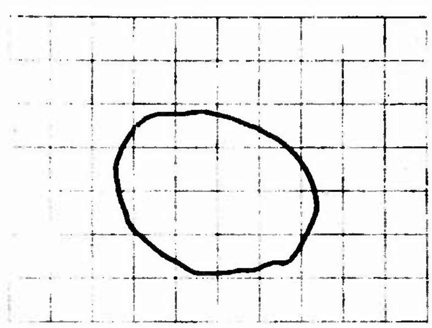
BEFORE IMPACT



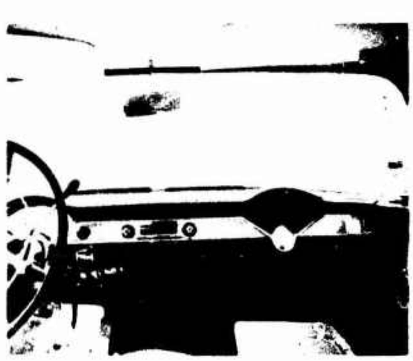
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 14.0 |
| METAL THICKNESS (INCHES) | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | $4\frac{1}{4}$ |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1 |
| AREA (SQ. INCHES) | 13.9 |
| YEAR AND MAKE OF CAR | 56 CHEV |

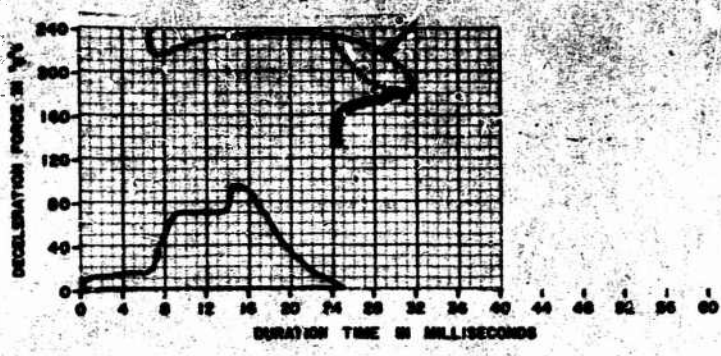


SHAPE AND AREA OF DEPRESSION

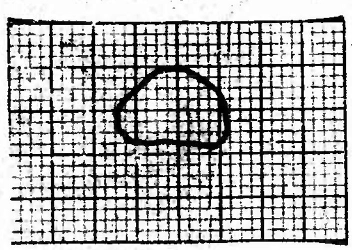


BEFORE IMPACT

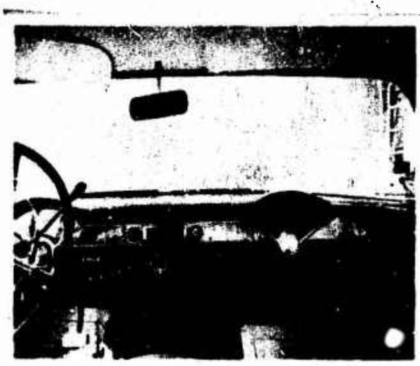
AFTER IMPACT



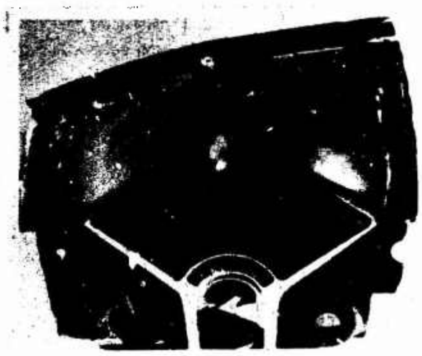

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 14.0 |
| METAL THICKNESS (INCHES) | .030 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 2 1/4 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 3/4 |
| AREA (SQ. INCHES) | 3.7 |
| YEAR AND MAKE OF CAR | 56 CHEV |



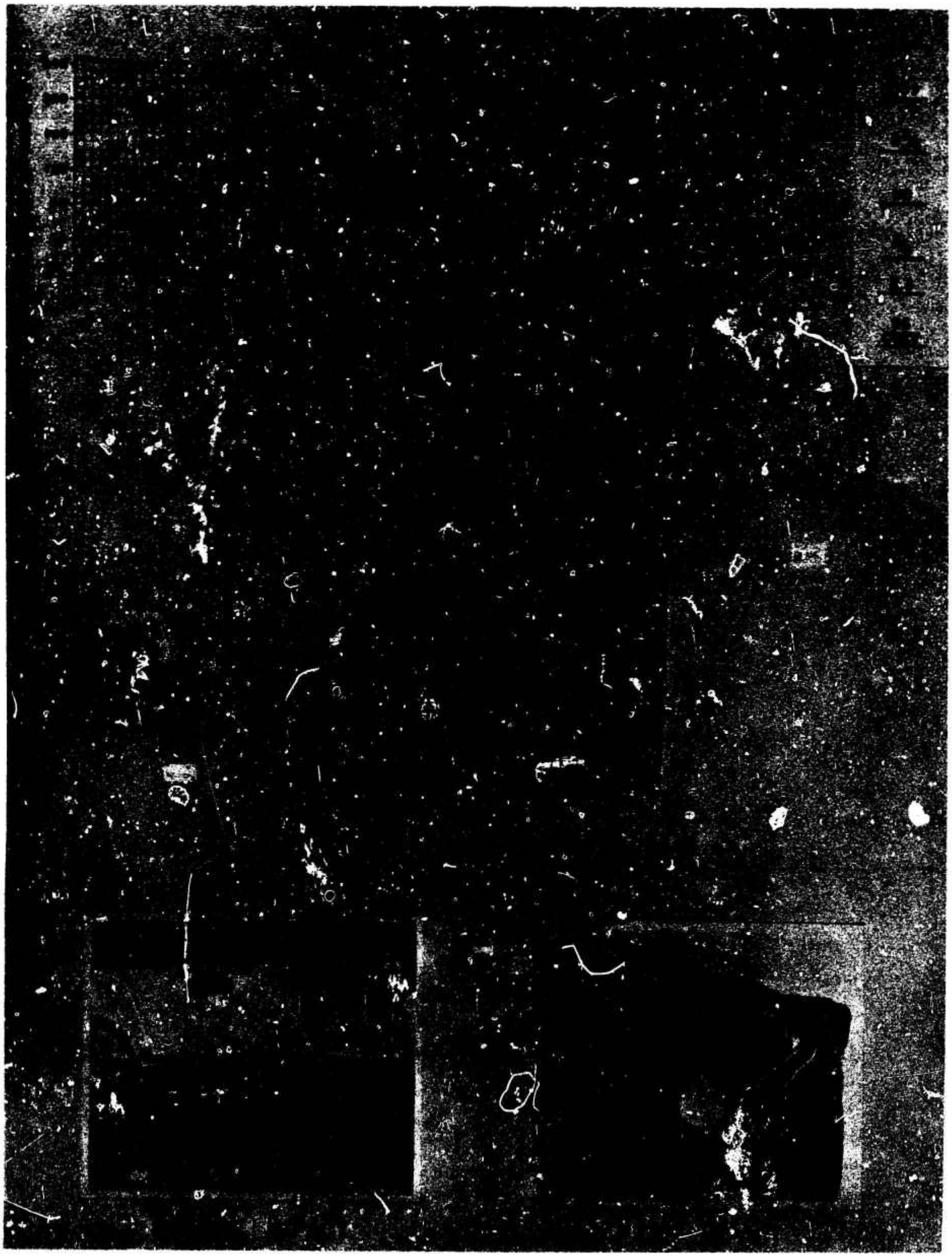
SHAPE AND AREA OF DEPRESSION



BEFORE IMPACT



AFTER IMPACT

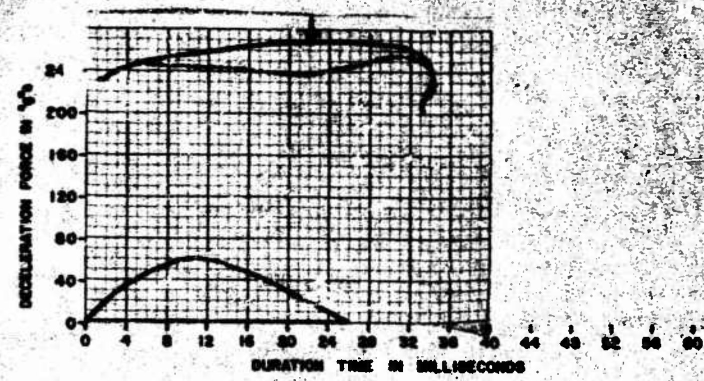


| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 15.67 |
| METAL THICKNESS (INCHES) | .042 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 3/4 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 3/4 |
| AREA (SQ. INCHES) | 10.6 |
| YEAR AND MAKE OF CAR | 55 PONTIAC |

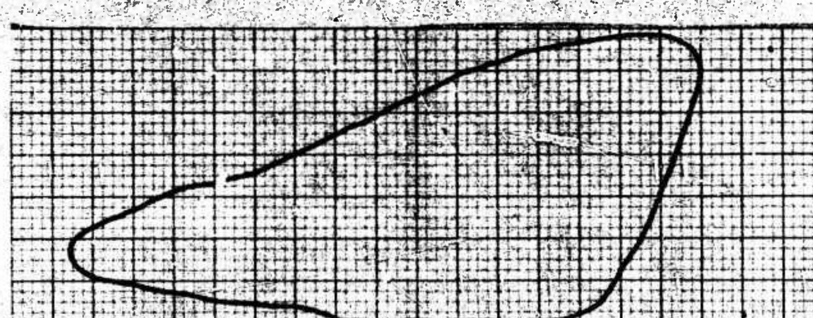
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

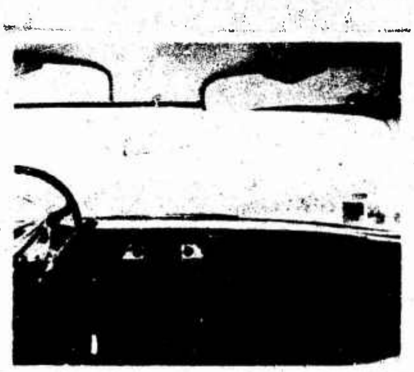
AFTER IMPACT



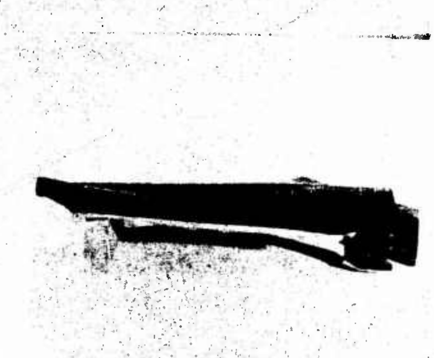

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 15.97 |
| METAL THICKNESS (INCHES) | .042 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 13 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 3/4 |
| AREA (SQ. INCHES) | 64.8 |
| YEAR AND MAKE OF CAR | 55 PONTIAC |



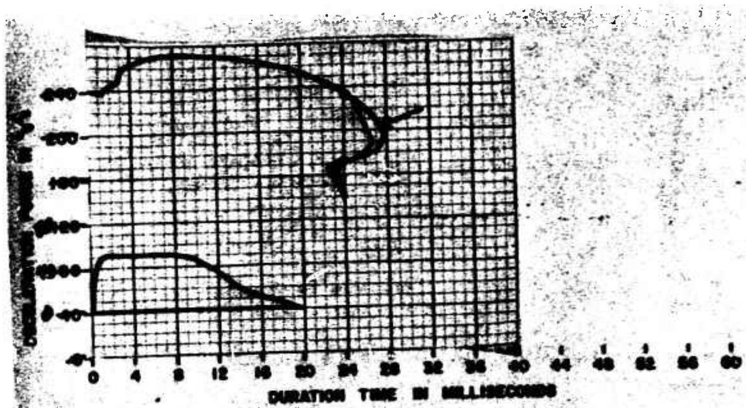
SHAPE AND AREA OF DEPRESSION



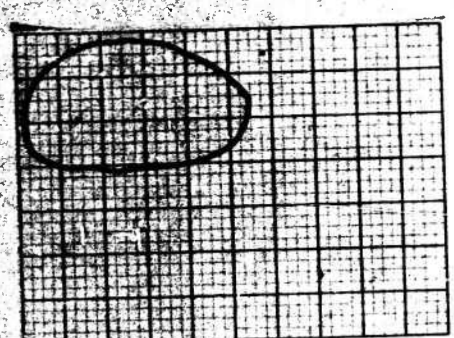
BEFORE IMPACT



AFTER IMPACT



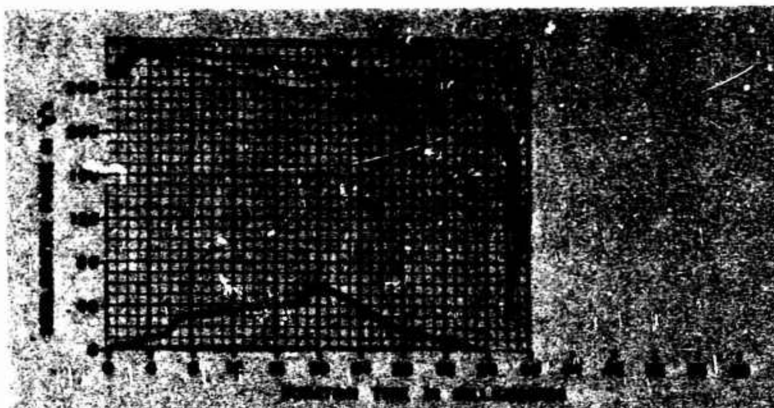

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . | 16.6 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . . | ½ |
| PADDED . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | ⅜ |
| AREA (SQ. INCHES) . . . . . . . | 12.4 |
| YEAR AND MAKE OF CAR . . . . . | 55 BUICK |



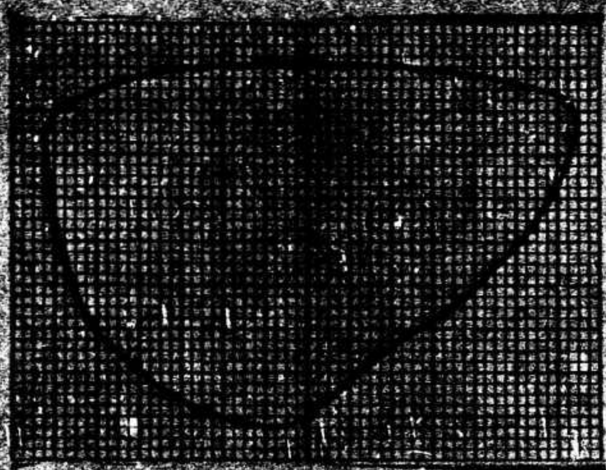
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

AFTER IMPACT

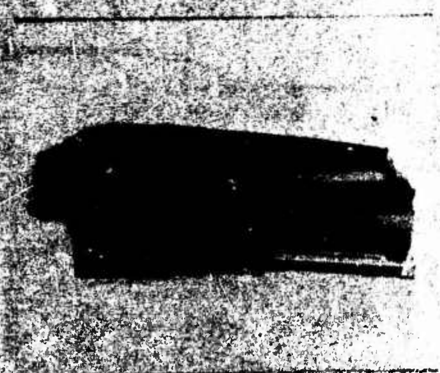


| | |
|---|---|
| [illegible] | 17.8 |
| [illegible] | .044 |
| [illegible] | 16 1/2 |
| [illegible] | 80 |
| [illegible] | 3/4 |
| AREA (SQ. INCHES) | 72.0 |
| YEAR AND MAKE OF CAR | 57 PLYM |

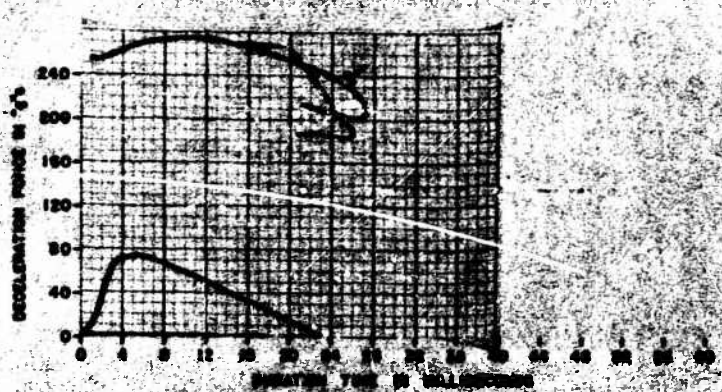


SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

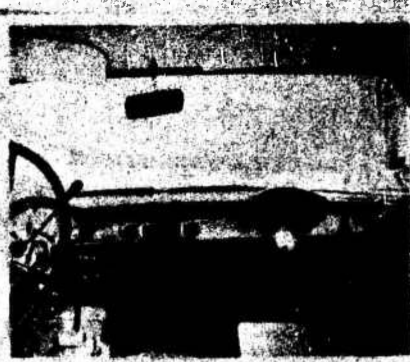


AFTER IMPACT



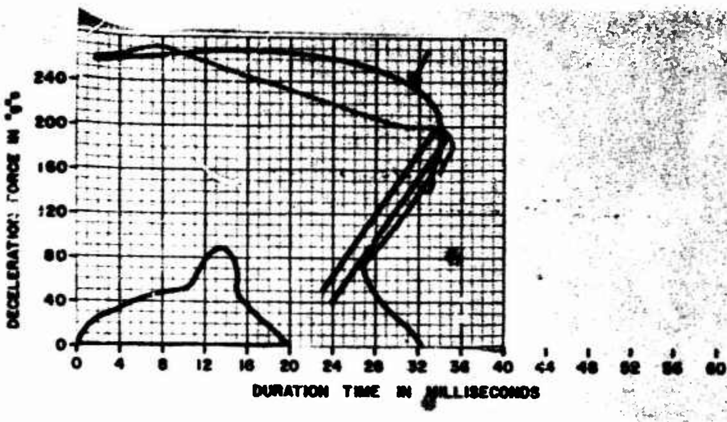

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 17.8 |
| METAL THICKNESS (INCHES) | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 3 3/8 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 3/4 |
| AREA (SQ. INCHES) | 6.5 |
| YEAR AND MAKE OF CAR | 56 CHEV |

SHAPE AND AREA OF DEPRESSION

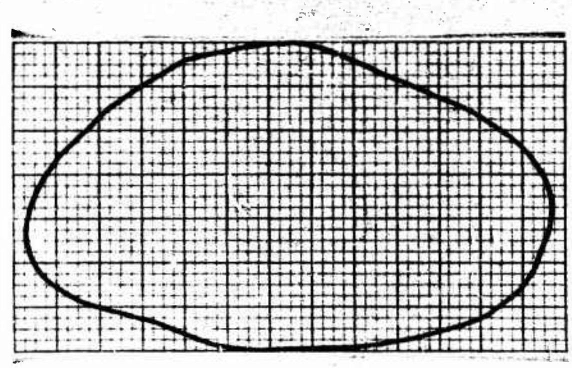


BEFORE IMPACT

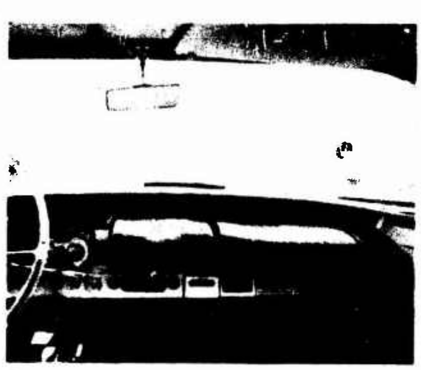
AFTER IMPACT



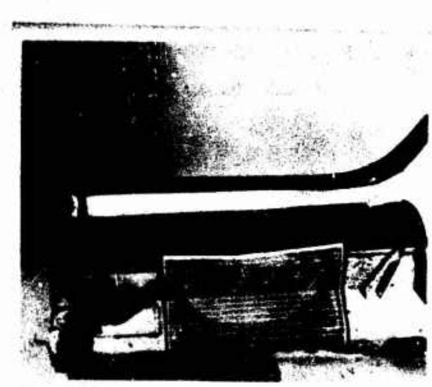

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 19.0 |
| METAL THICKNESS (INCHES) | .036 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 2 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1 |
| AREA (SQ. INCHES) | 63.5 |
| YEAR AND MAKE OF CAR | 57 MERC |



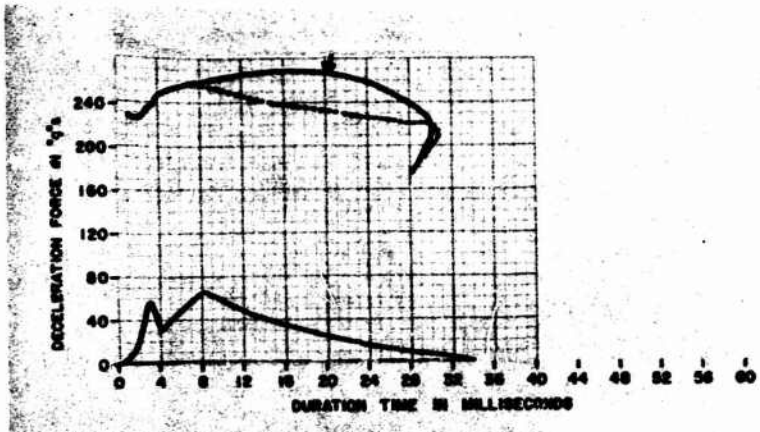
SHAPE AND AREA OF DEPRESSION



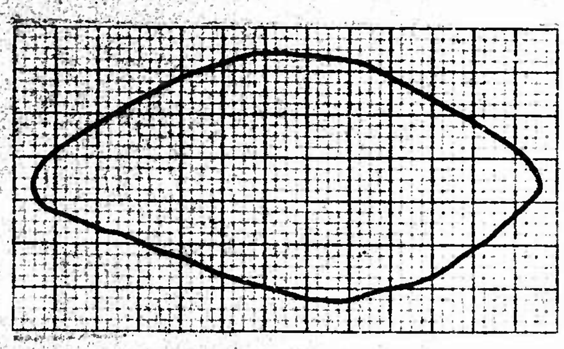
BEFORE IMPACT



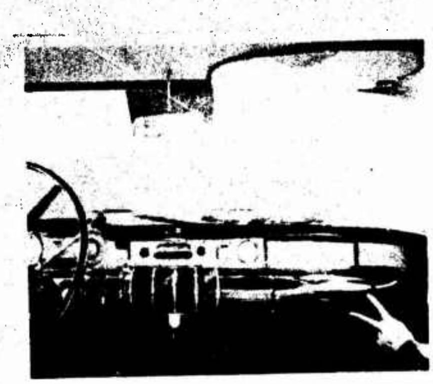
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 18.0 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . | .043 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . . | 4½ |
| PADDED . . . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 7/8 |
| AREA (SQ. INCHES) . . . . . . . | 45.1 |
| YEAR AND MAKE OF CAR . . . . . | 55 BUICK |

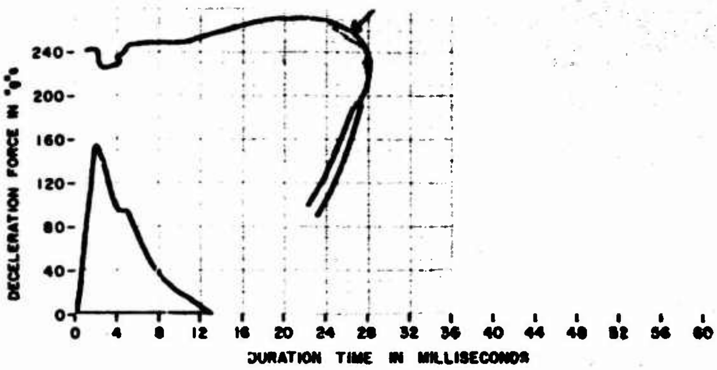


SHAPE AND AREA OF DEPRESSION

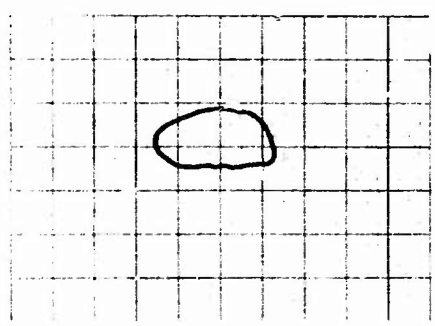


BEFORE IMPACT

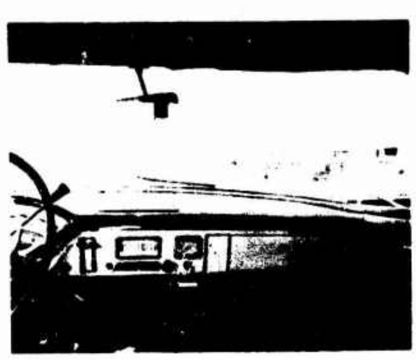
AFTER IMPACT



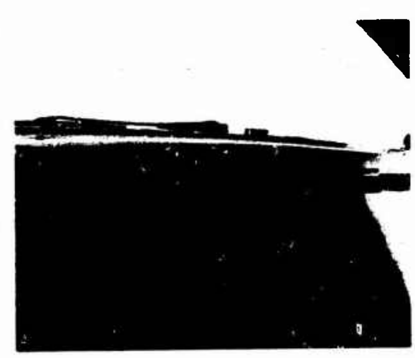

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . | 18.0 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . | .041 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES). . . . . | 1 |
| PADDED. . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 3/16 |
| AREA (SQ. INCHES) . . . . . . . | 2.9 |
| YEAR AND MAKE OF CAR . . . . . | 56 MERC |



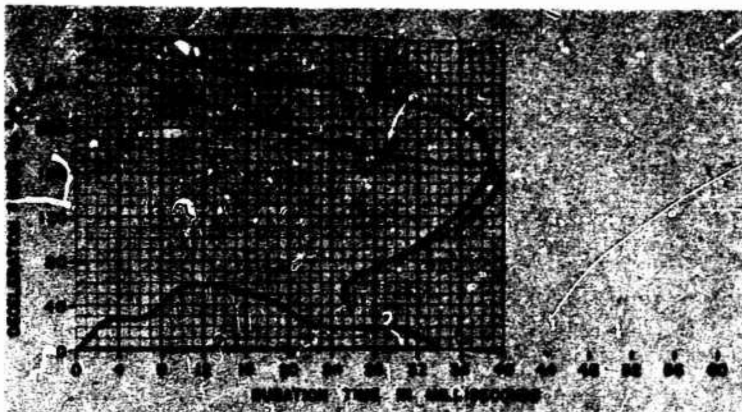
SHAPE AND AREA OF DEPRESSION



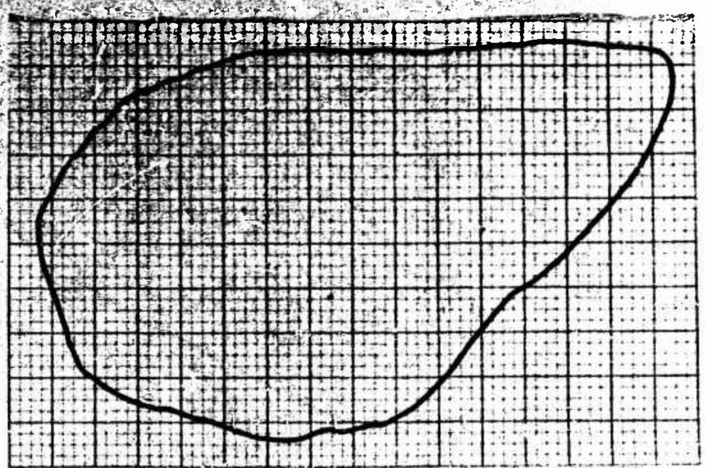
BEFORE IMPACT



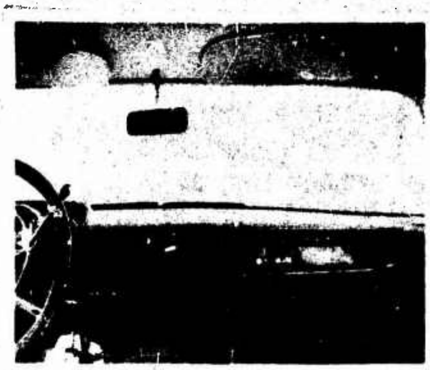
AFTER IMPACT



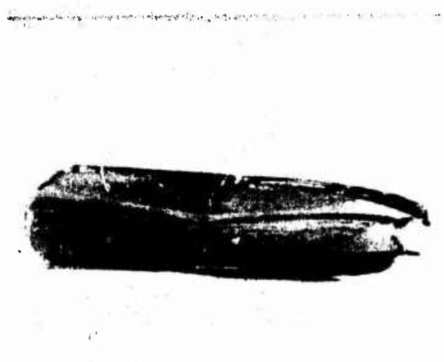
| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 18.0 |
| METAL THICKNESS (INCHES) | .046 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 14¾ |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1¼ |
| AREA (SQ. INCHES) | 92.6 |
| YEAR AND MAKE OF CAR | 57 CHEV |



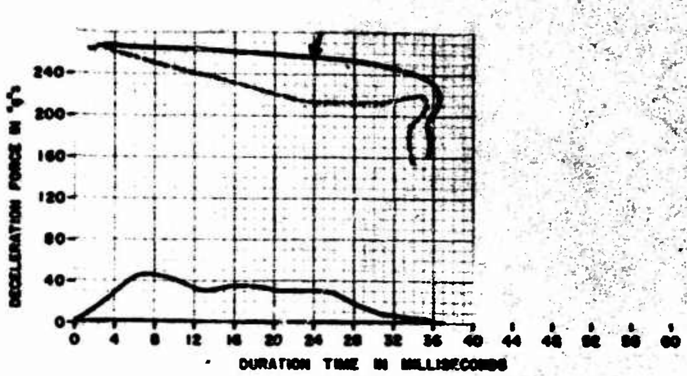
SHAPE AND AREA OF DEPRESSION



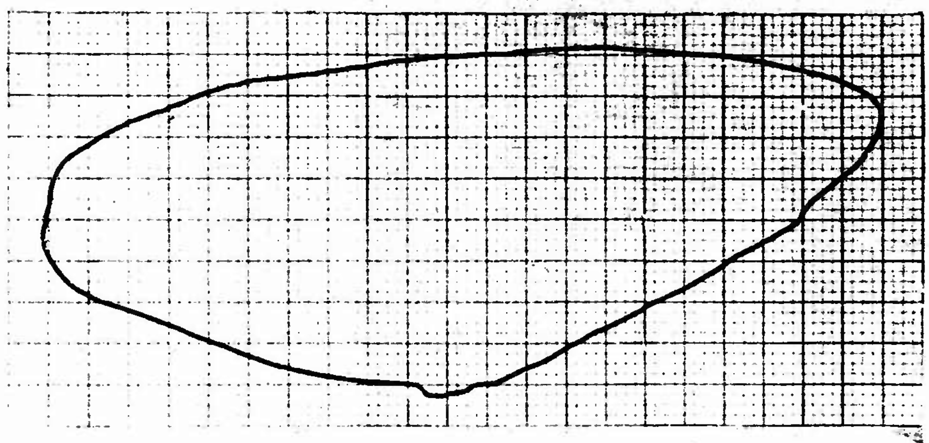
BEFORE IMPACT



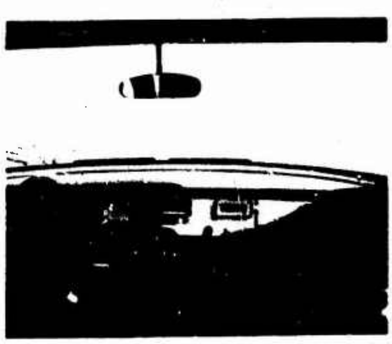
AFTER IMPACT



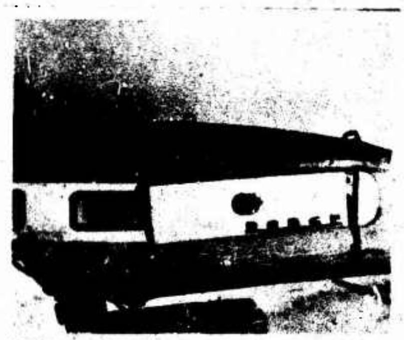

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 19.1 |
| METAL THICKNESS (INCHES) | .043 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 16 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1 |
| AREA (SQ. INCHES) | 122.7 |
| YEAR AND MAKE OF CAR | 54 DODGE |



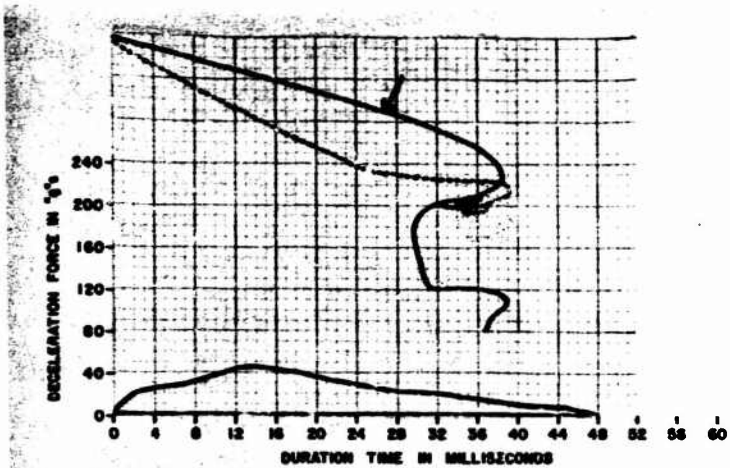
SHAPE AND AREA OF DEPRESSION



BEFORE IMPACT



AFTER IMPACT

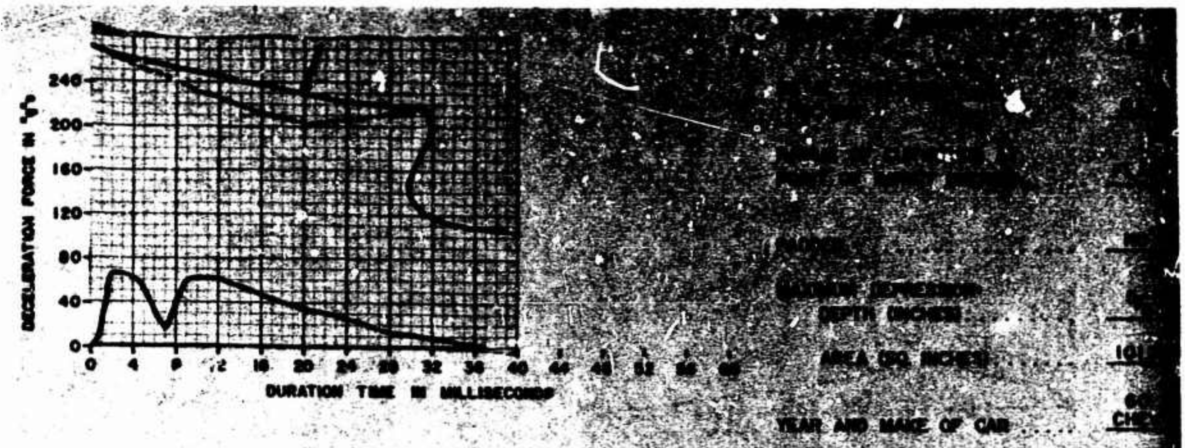


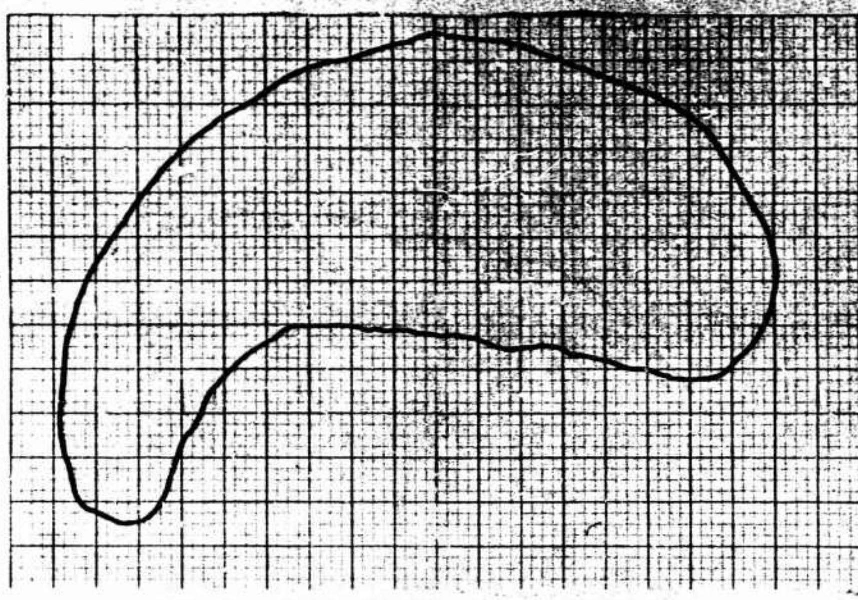

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 18.1 |
| METAL THICKNESS (INCHES) | .038 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 19 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | $1\frac{1}{2}$ |
| AREA (SQ. INCHES) | 101.8 |
| YEAR AND MAKE OF CAR | 59 PONTIAC |

SHAPE AND AREA OF DEPRESSION

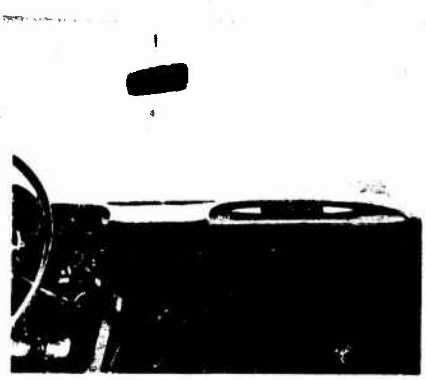
BEFORE IMPACT

AFTER IMPACT

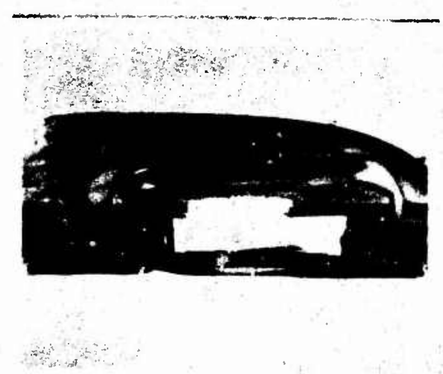


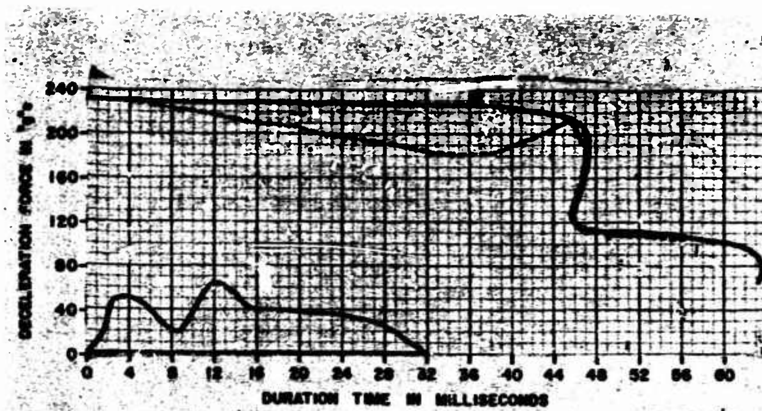
SHAPE AND AREA OF DEPRESSION



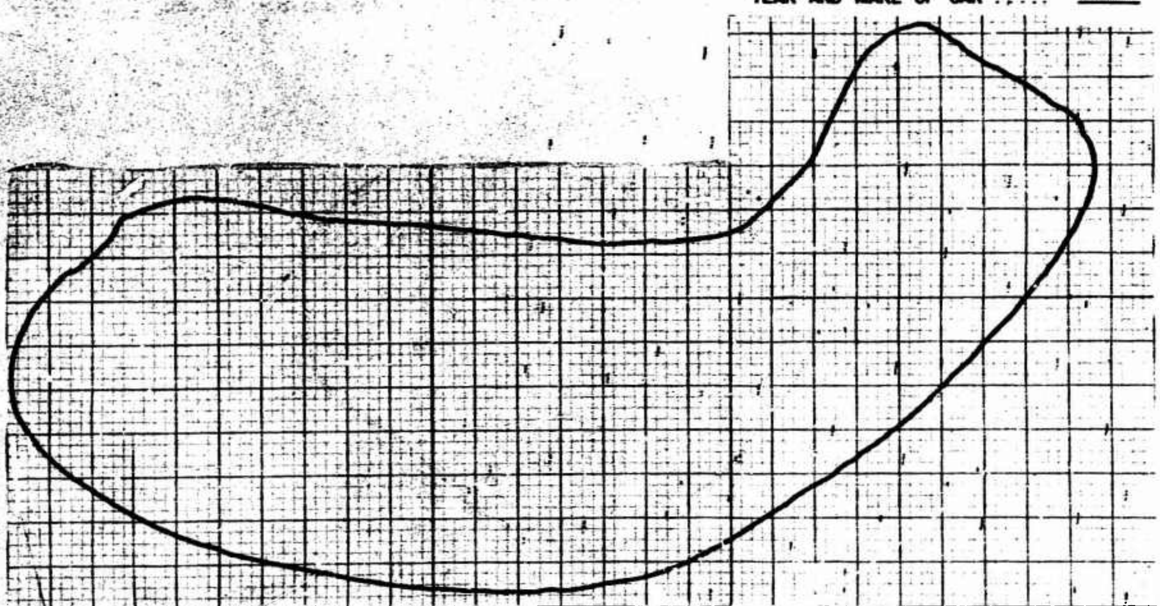
BEFORE IMPACT



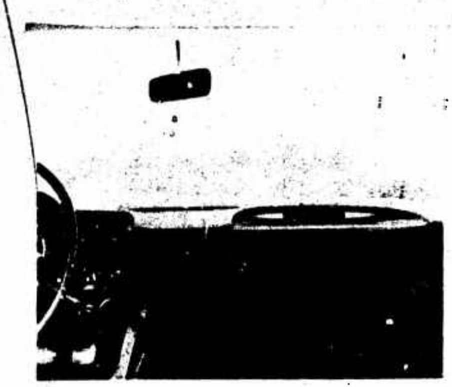
AFTER IMPACT



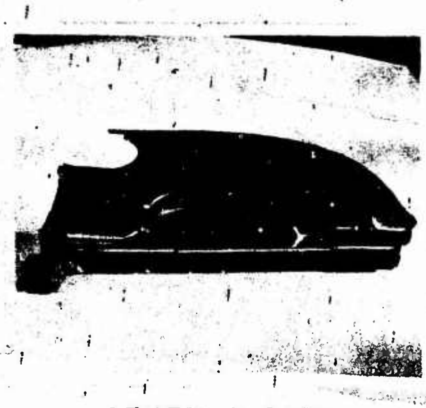

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . | 18.5 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . | .040 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . | 8 |
| PADDED . . . . . . . . . . . . . . . . | NO. |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . | 1 1/8 |
| AREA (SQ. INCHES) . . . . . . . | 182.7 |
| YEAR AND MAKE OF CAR . . . . . | 60 CHEV |



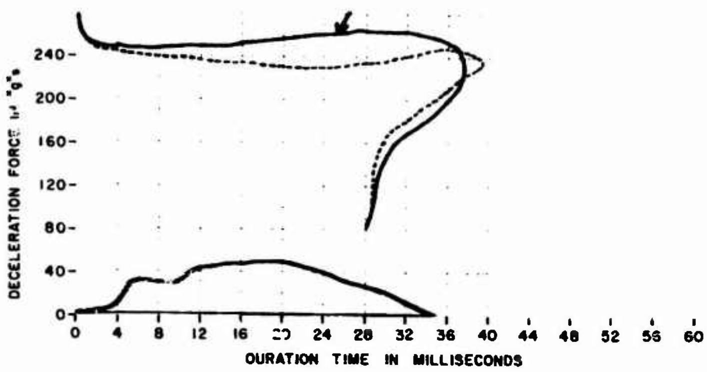
SHAPE AND AREA OF DEPRESSION



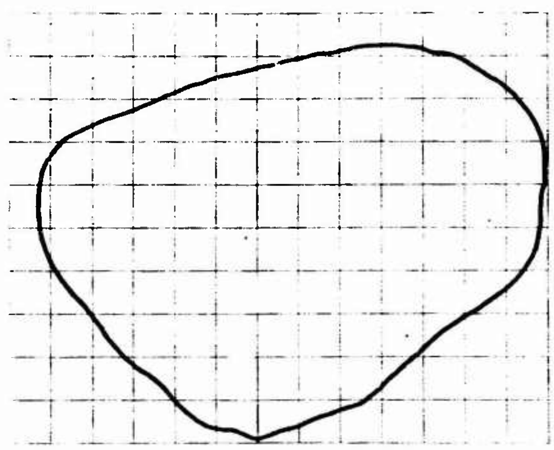
BEFORE IMPACT



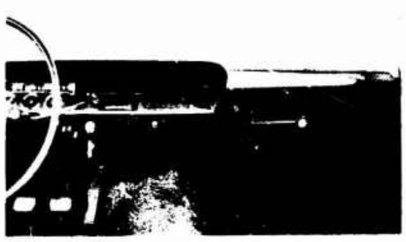
AFTER IMPACT



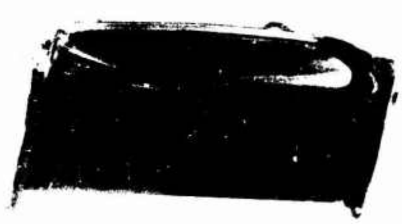

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 19.0 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . | .037 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . . | 8 |
| PADDED . . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 3/4 |
| AREA (SQ. INCHES) . . . . . . . | 81.3 |
| YEAR AND MAKE OF CAR . . . . . | 61 CHEV |



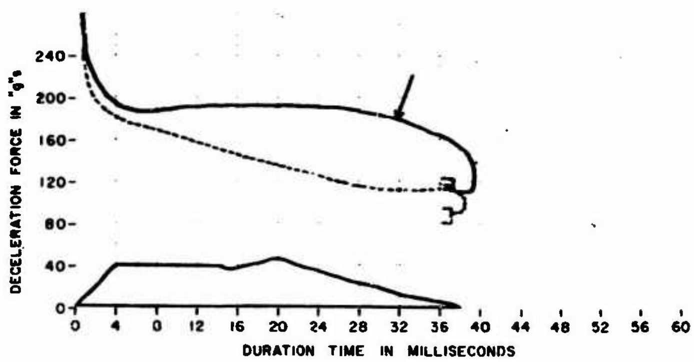
SHAPE AND AREA OF DEPRESSION



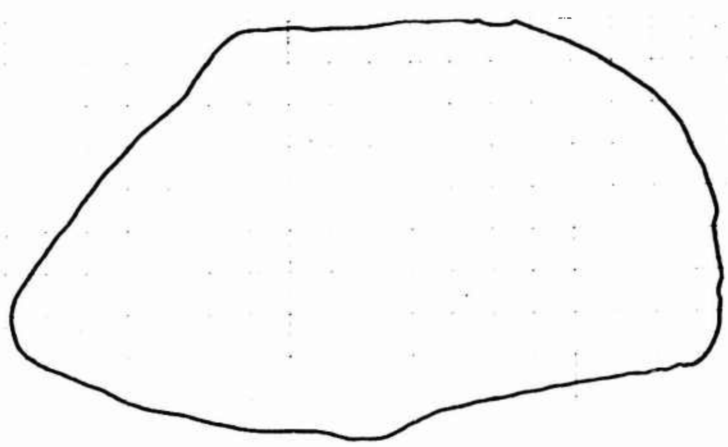
BEFORE IMPACT



AFTER IMPACT

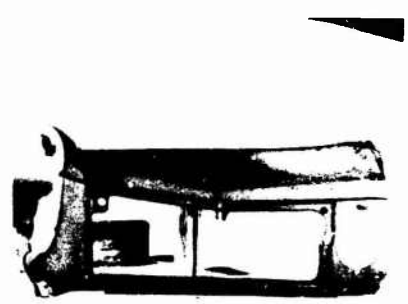



| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . | 22.4 |
| METAL THICKNESS (INCHES) . . . . | .037 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . | $5\frac{1}{4}$ |
| PADDED . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . | $1\frac{3}{4}$ |
| AREA (SQ. INCHES) . . . . | 131.5 |
| YEAR AND MAKE OF CAR . . . . | 64 CHEV |

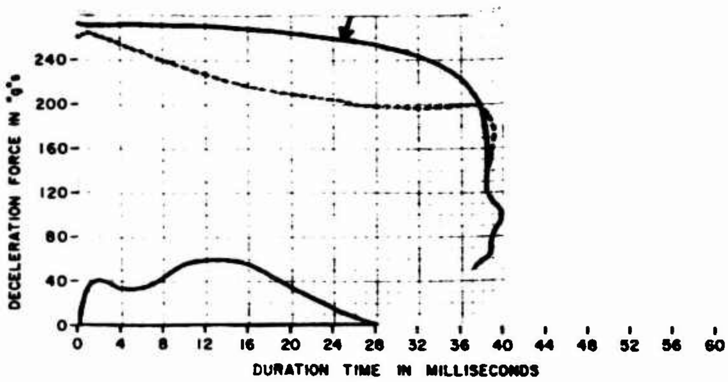


SHAPE AND AREA OF DEPRESSION

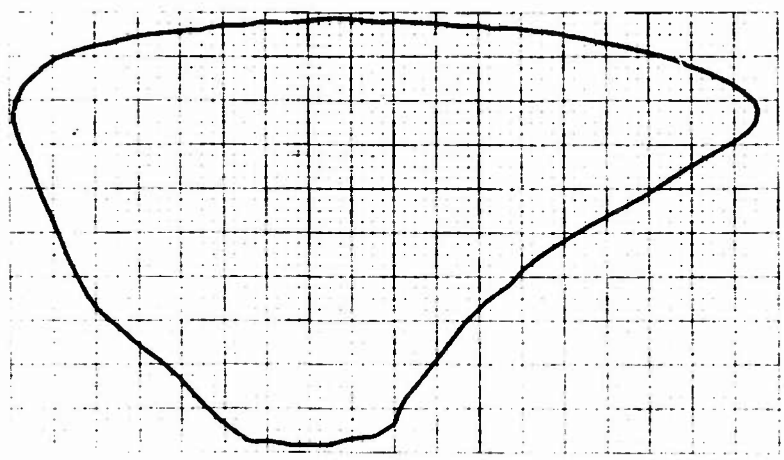
BEFORE IMPACT



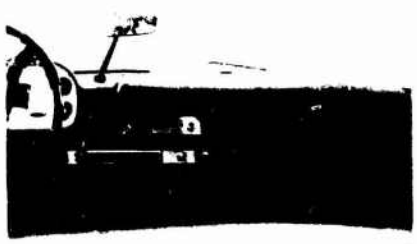
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 23.4 |
| METAL THICKNESS (INCHES) | .044 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 12 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1 3/8 |
| AREA (SQ. INCHES) | 110.0 |
| YEAR AND MAKE OF CAR | 57 PLYM |

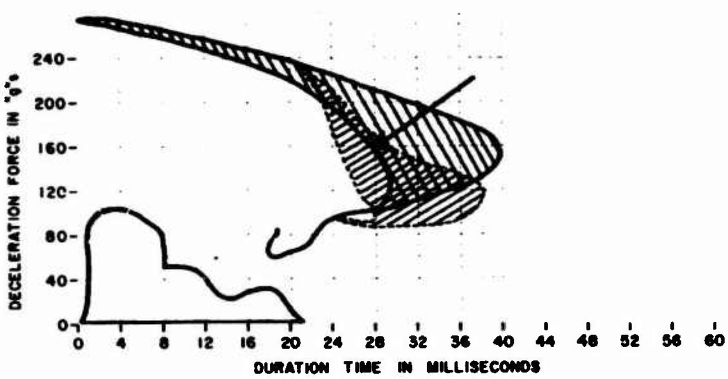


SHAPE AND AREA OF DEPRESSION

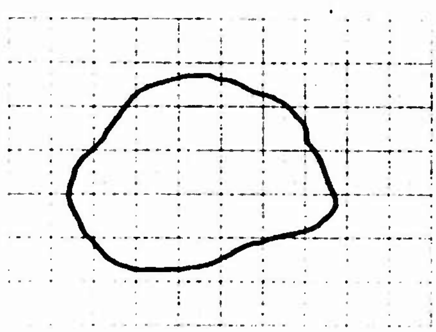


BEFORE IMPACT

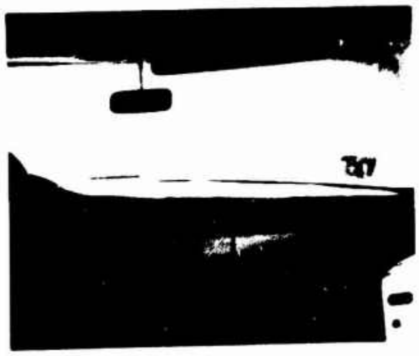
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 24.1 |
| METAL THICKNESS (INCHES) | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 2 |
| PADDED | YES |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 3/4 |
| AREA (SQ. INCHES) | 19.4 |
| YEAR AND MAKE OF CAR | 57 FORD |

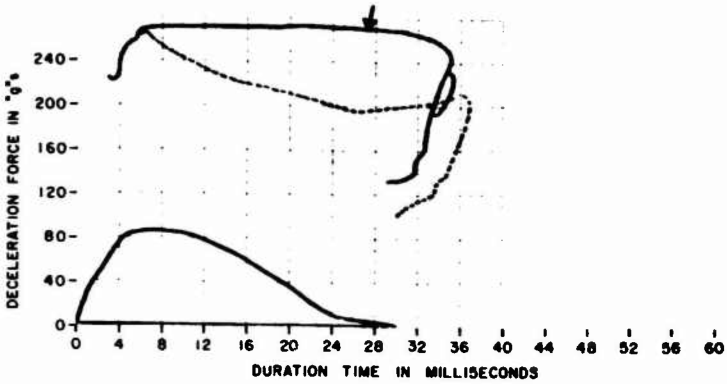


SHAPE AND AREA OF DEPRESSION

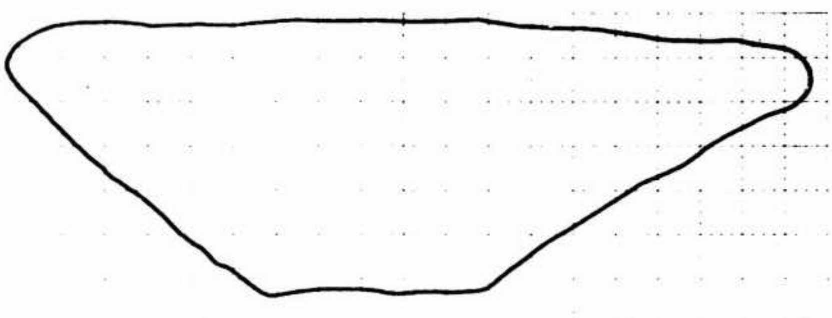


BEFORE IMPACT

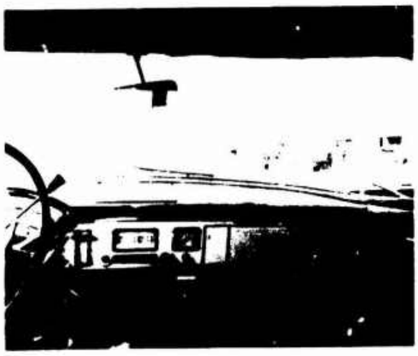
AFTER IMPACT



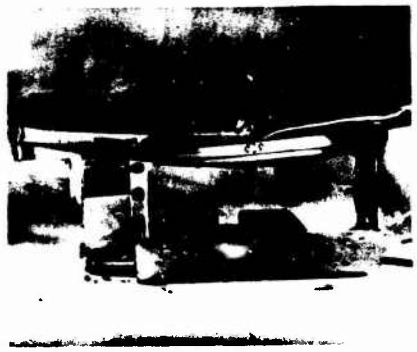

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 24.3 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . | .045 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES). . . . . | 10 1/2 |
| PADDED. . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . . | 1 7/8 |
| AREA (SQ. INCHES) . . . . . . . | 79.9 |
| YEAR AND MAKE OF CAR . . . . . | 55 MERC |



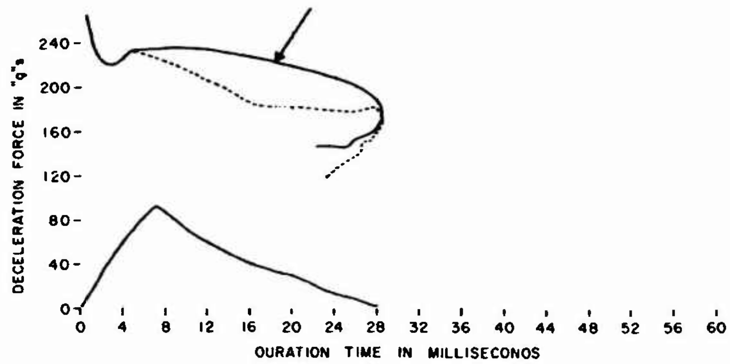
SHAPE AND AREA OF DEPRESSION



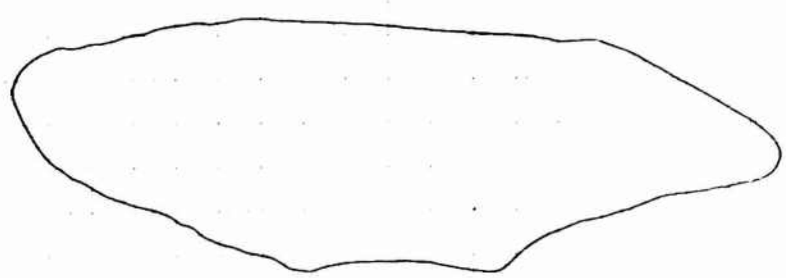
BEFORE IMPACT



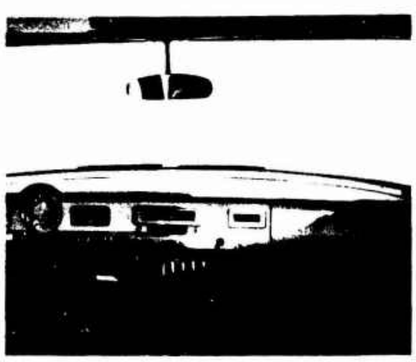
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 24.4 |
| METAL THICKNESS (INCHES) | 039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 13 |
| PADDED | NO |
| MAXIMUM DEPRESSION DEPTH (INCHES) | 1 1/8 |
| AREA (SQ INCHES) | 73.0 |
| YEAR AND MAKE OF CAR | 54 DODGE |

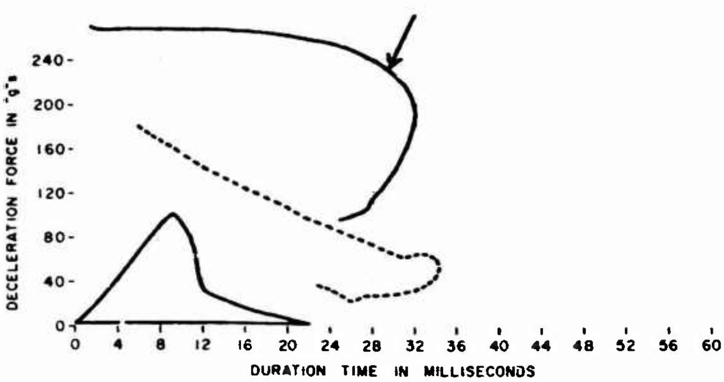


SHAPE AND AREA OF DEPRESSION

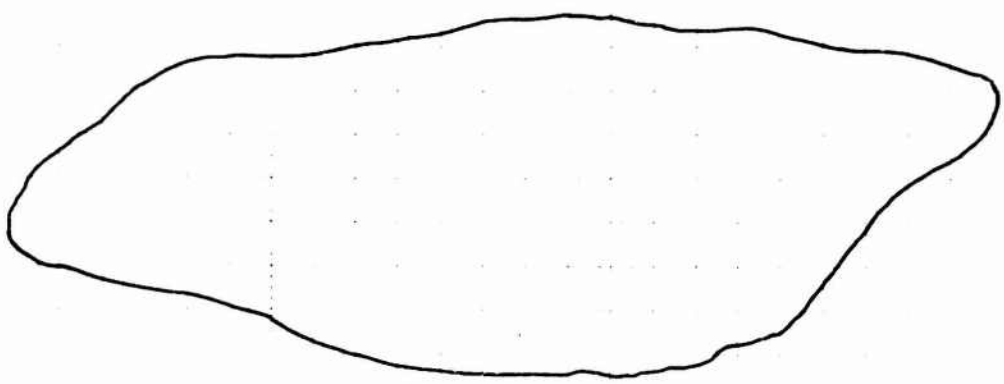


BEFORE IMPACT

AFTER IMPACT

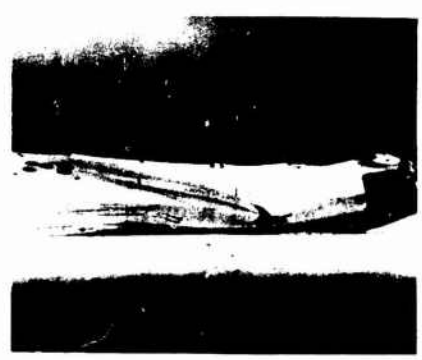



| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 24.5 |
| METAL THICKNESS (INCHES) | .038 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 2 1/2 |
| PAODEO. | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 2 1/2 |
| AREA (SQ. INCHES) | 2470 |
| YEAR AND MAKE OF CAR | 59 FORD |

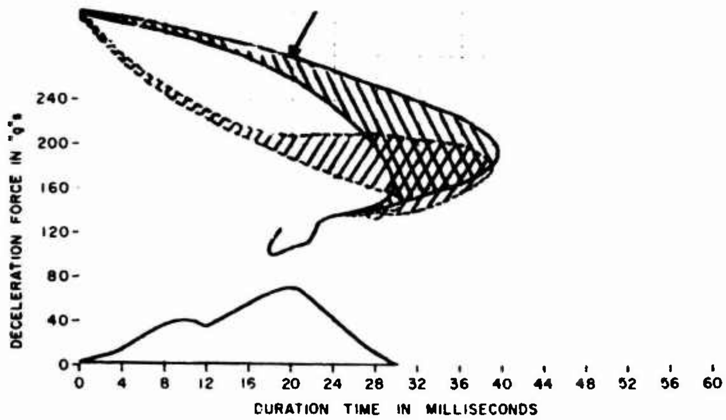


SHAPE AND AREA OF DEPRESSION

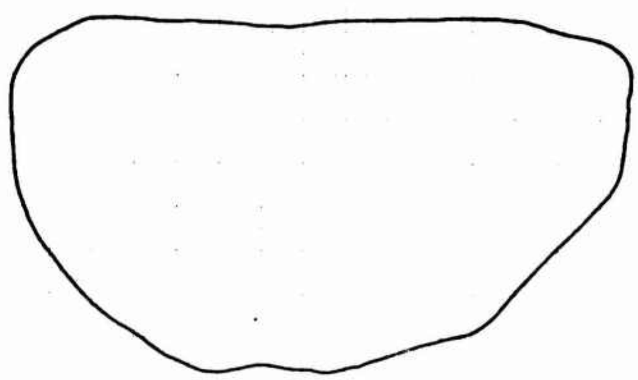
BEFORE IMPACT



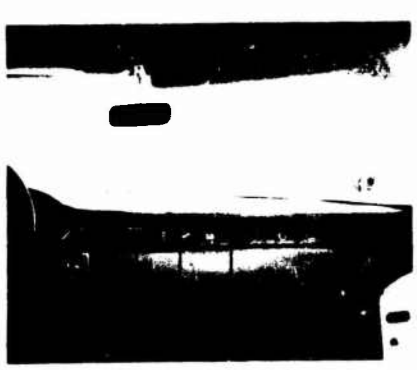
AFTER IMPACT



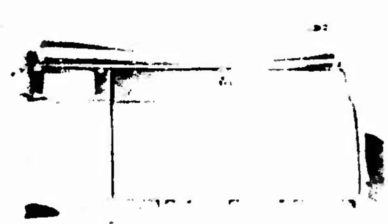

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 246 |
| METAL THICKNESS (INCHES) | 039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 9 |
| PADDED | YES |
| MAXIMUM DEPRESSION DEPTH (INCHES) | $1^3/_4$ |
| AREA (SQ INCHES) | 950 |
| YEAR AND MAKE OF CAR | 57 FORD |



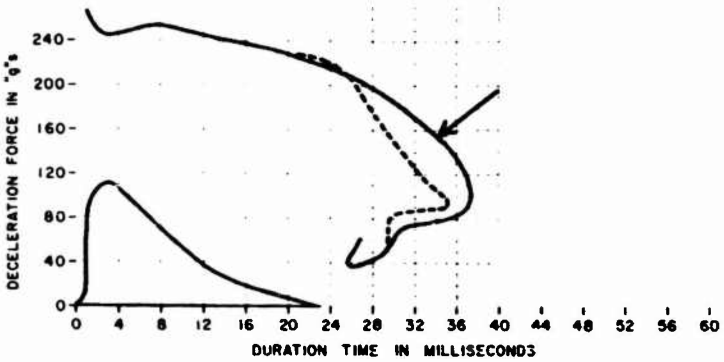
SHAPE AND AREA OF DEPRESSION



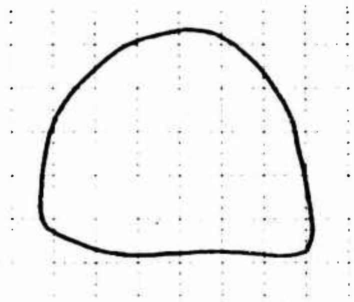
BEFORE IMPACT



AFTER IMPACT

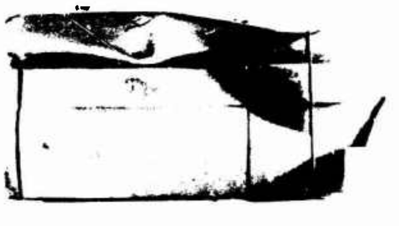



| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 24.6 |
| METAL THICKNESS (INCHES) | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | $4\frac{3}{4}$ |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | $\frac{7}{8}$ |
| AREA (SQ. INCHES) | 26.7 |
| YEAR AND MAKE OF CAR | 57 FORD |

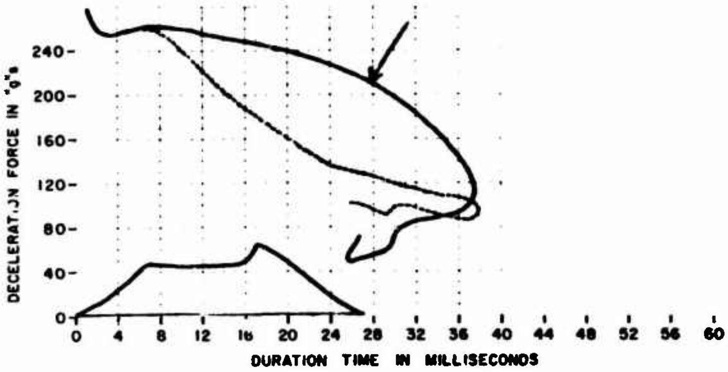


SHAPE AND AREA OF DEPRESSION

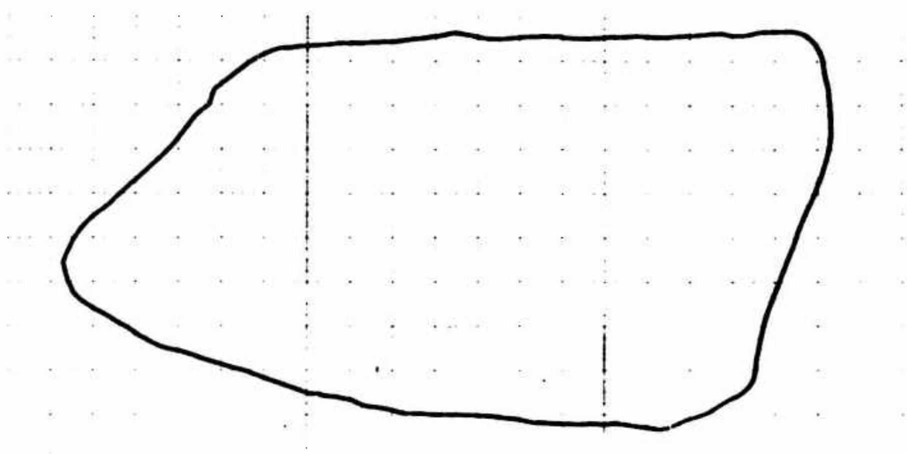
BEFORE IMPACT



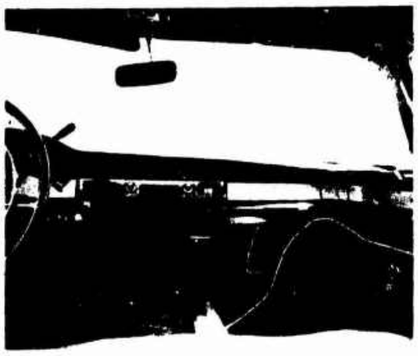
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 24.7 |
| METAL THICKNESS (INCHES) | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 8 3/8 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 2 1/8 |
| AREA (SQ. INCHES) | 126.4 |
| YEAR AND MAKE OF CAR | 57 FORD |

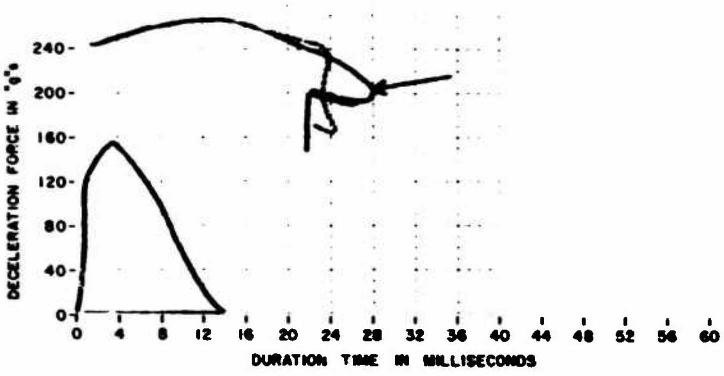


SHAPE AND AREA OF DEPRESSION



BEFORE IMPACT

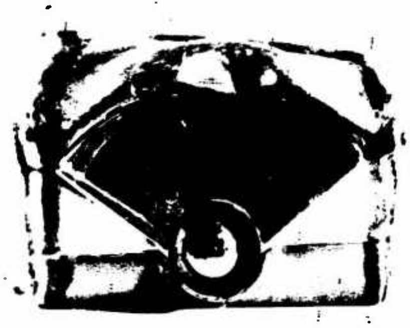
AFTER IMPACT



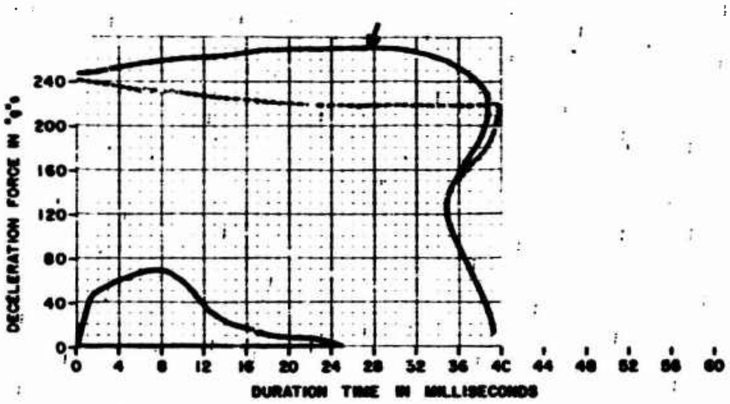

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 25.0 |
| METAL THICKNESS (INCHES) | .042 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 1/8 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1 1/8 |
| AREA (SQ. INCHES) | 6.0 |
| YEAR AND MAKE OF CAR | 55 CHEV |

SHAPE AND AREA OF DEPRESSION

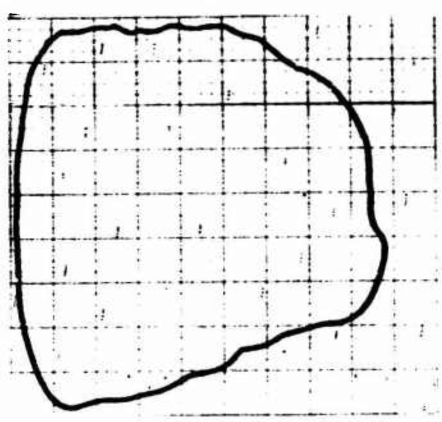
BEFORE IMPACT



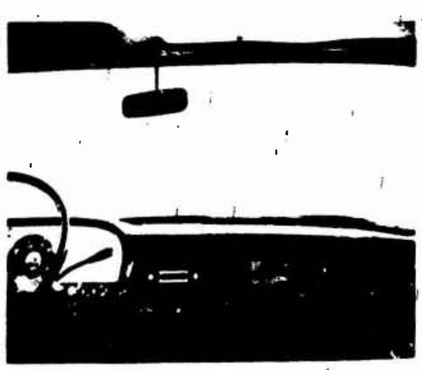
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 25.2 |
| METAL THICKNESS (INCHES) | .037 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 10¾ |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1¼ |
| AREA (SQ. INCHES) | 28.7 |
| YEAR AND MAKE OF CAR | 61 FORD P/U |

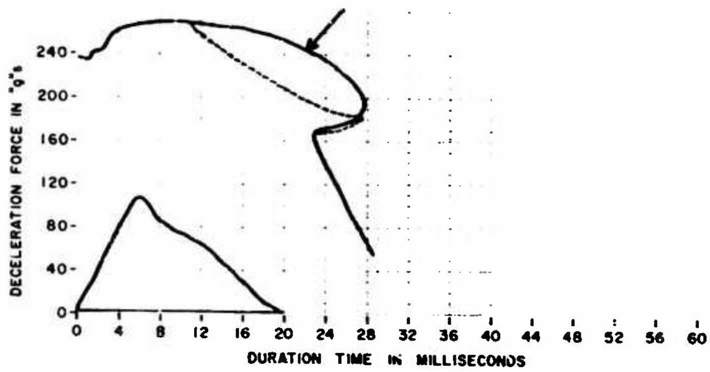


SHAPE AND AREA OF DEPRESSION

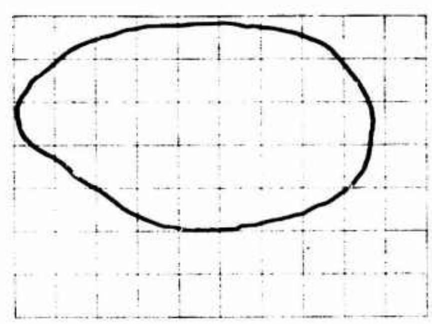


BEFORE IMPACT

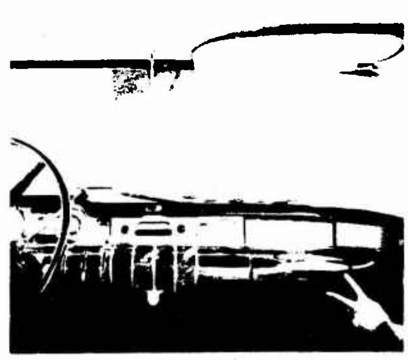
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . | 25.6 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES). . . . | $4\frac{1}{2}$ |
| PADDED. . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 1 |
| AREA (SQ. INCHES) . . . . . . . | 31.9 |
| YEAR AND MAKE OF CAR . . . . . | 55 BUICK |

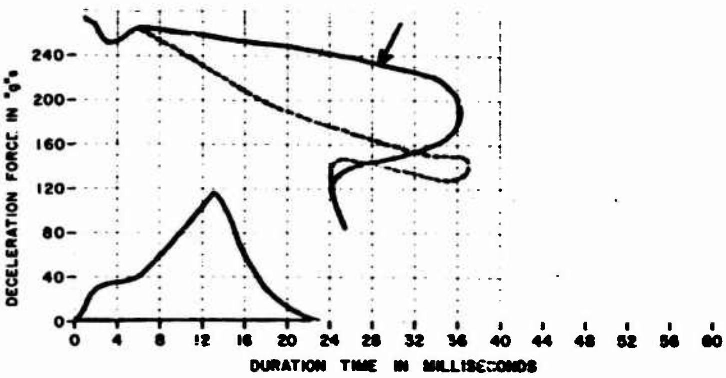


SHAPE AND AREA OF DEPRESSION

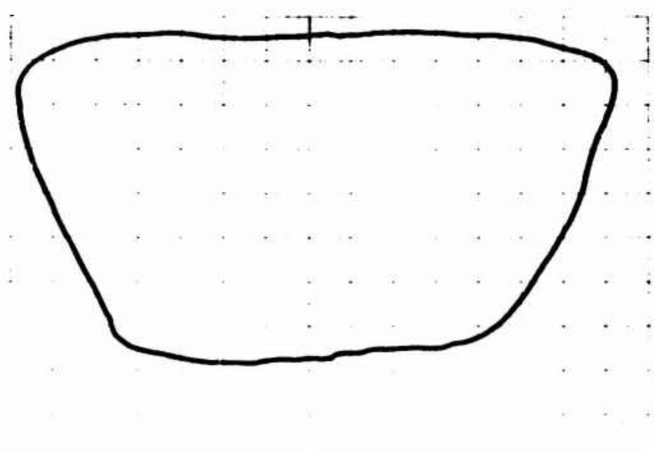


BEFORE IMPACT

AFTER IMPACT

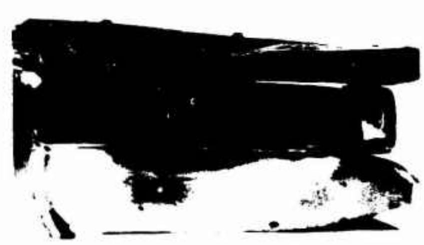



| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . | 25.6 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . | .049 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES). . . . . | 10 1/2 |
| PADDED. . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 1 5/8 |
| AREA (SQ. INCHES). . . . . . . | 86.7 |
| YEAR AND MAKE OF CAR . . . . . | 57 DODGE |

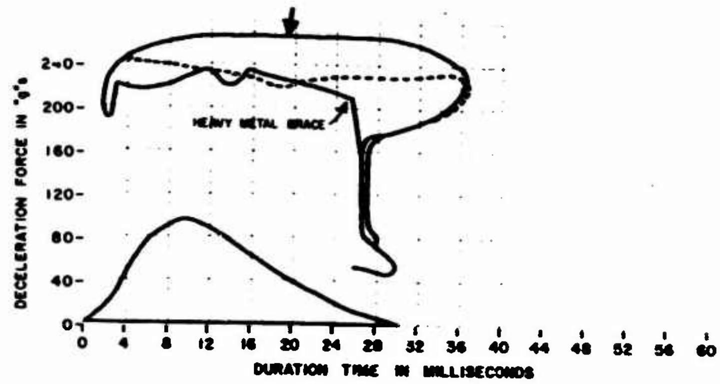


SHAPE AND AREA OF DEPRESSION

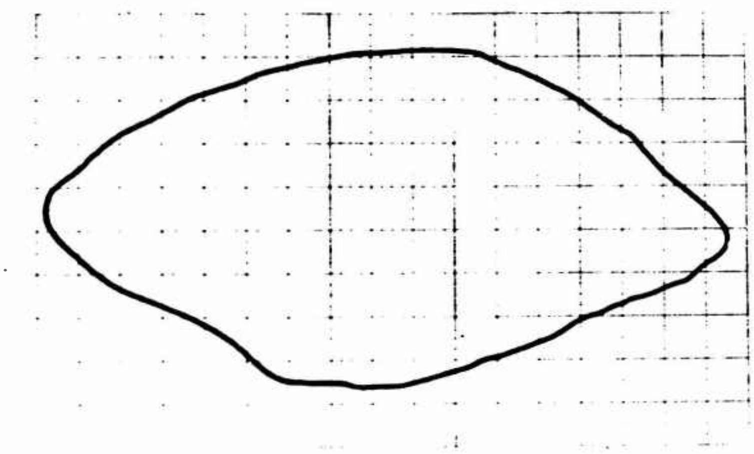
BEFORE IMPACT



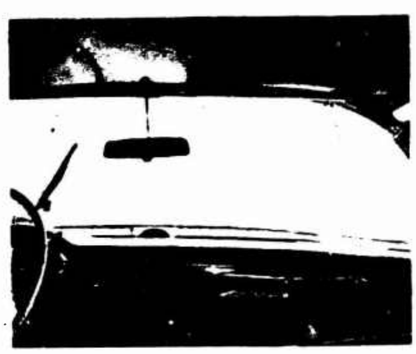
AFTER IMPACT



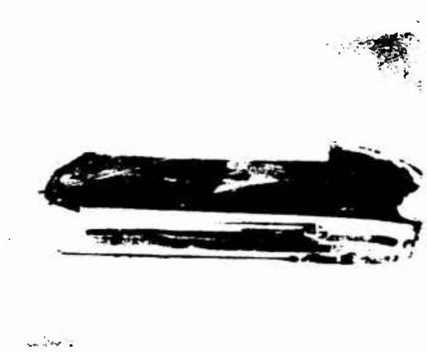

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 26.0 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . | .043 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES). . . . . | 19 |
| PADDED. . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | $1\frac{1}{4}$ |
| AREA (SQ. INCHES) . . . . . . . | 86.8 |
| YEAR AND MAKE OF CAR . . . . . | 57 OLDS |



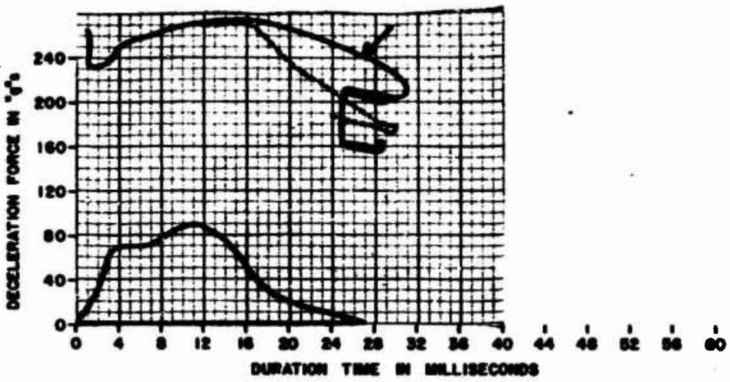
SHAPE AND AREA OF DEPRESSION



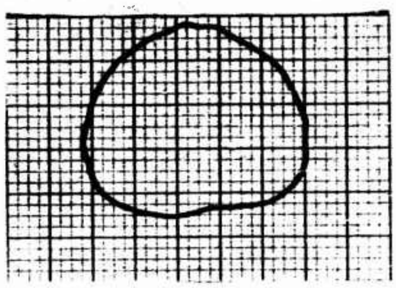
BEFORE IMPACT



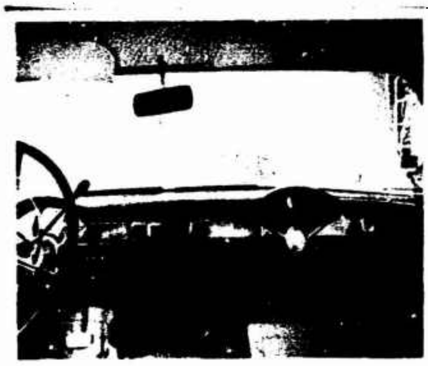
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 26.0 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . | .037 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES). . . . . | 7 |
| PADDED. . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 1 |
| AREA (SQ. INCHES) . . . . . . . | 18.0 |
| YEAR AND MAKE OF CAR . . . . . | 56 CHEV |

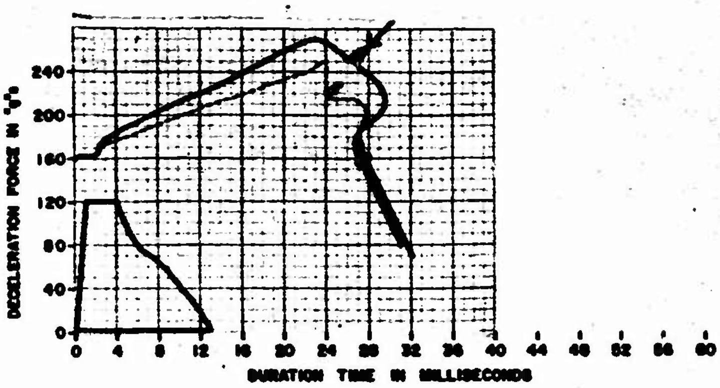


SHAPE AND AREA OF DEPRESSION

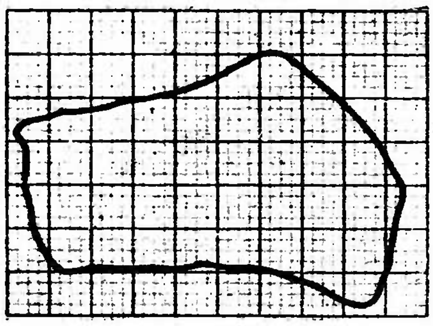


BEFORE IMPACT

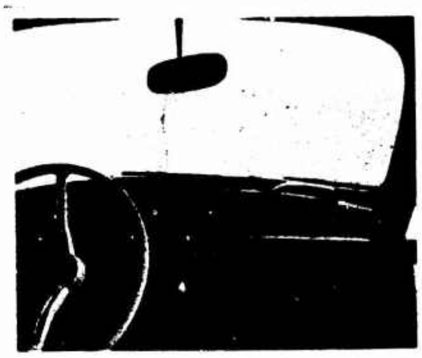
AFTER IMPACT



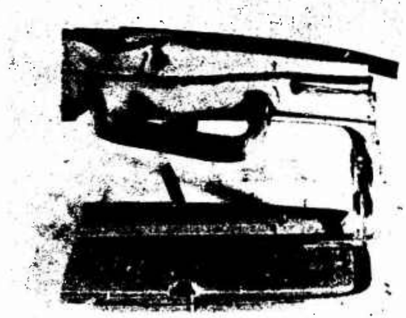

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 26.4 |
| METAL THICKNESS (INCHES) | .038 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | FLAT/PROT. SHARP EDGE |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1 |
| AREA (SQ. INCHES) | 35.5 |
| YEAR AND MAKE OF CAR | 63 VW |



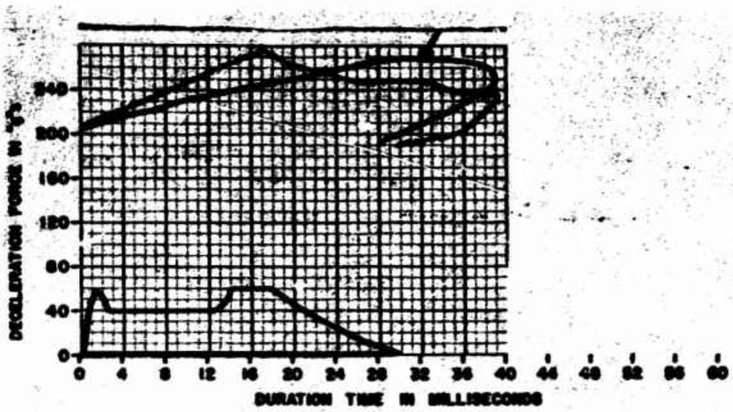
SHAPE AND AREA OF DEPRESSION



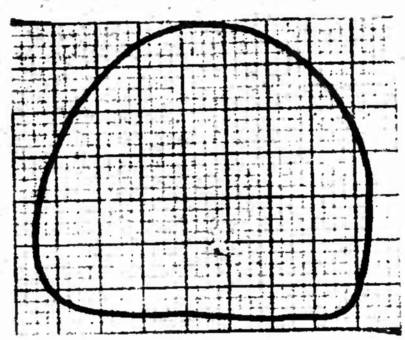
BEFORE IMPACT



AFTER IMPACT



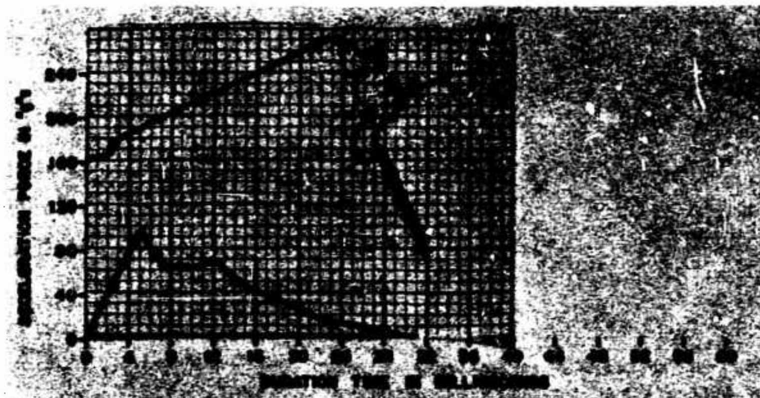

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 27.2 |
| METAL THICKNESS (INCHES) | .045 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 7 1/2 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 5/8 |
| AREA (SQ. INCHES) | 42.5 |
| YEAR AND MAKE OF CAR | 56 BUICK |



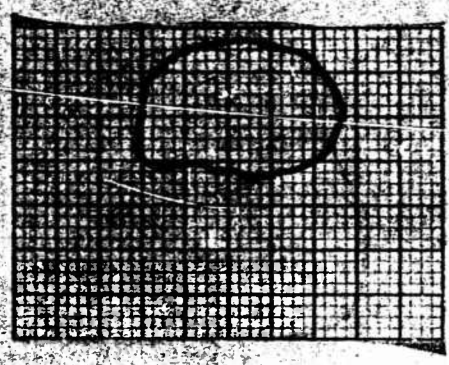
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

AFTER IMPACT

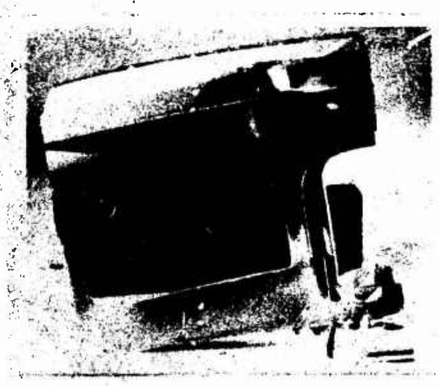


| | |
|---|---|
| VELOCITY OF IMPACT [illegible] | 27.2 |
| [illegible] | .088 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . | 1/16 |
| PADDED . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 3/16 |
| AREA (SQ. INCHES) . . . . . . . | 11.5 |
| YEAR AND MAKE OF CAR . . . . . | 63 VW |

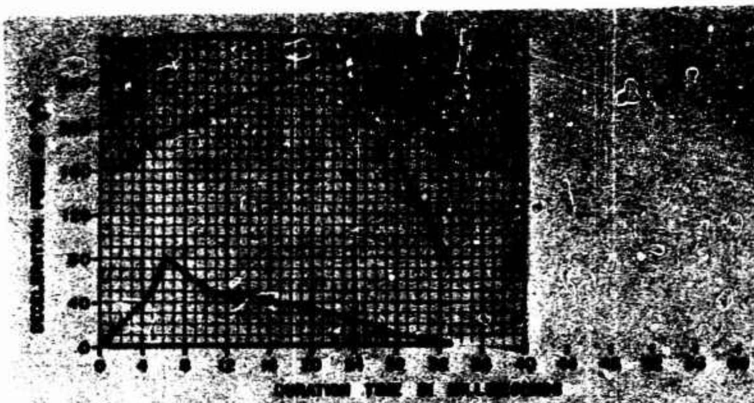


SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT



AFTER IMPACT




MAXIMUM DEPRESSION:

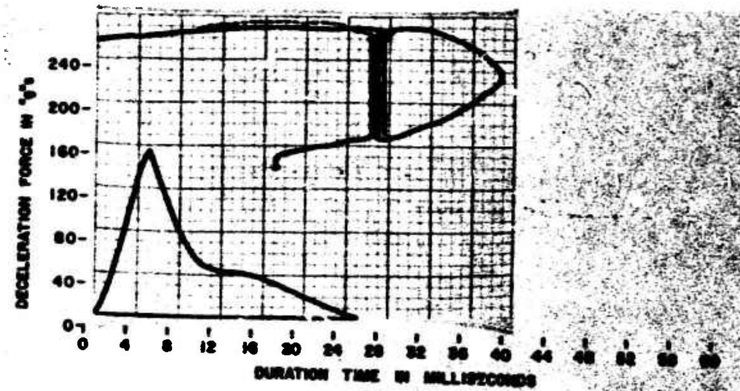
AREA (SQ. INCHES) ........ 13.7

YEAR AND MAKE OF CAR ..... 63 VW

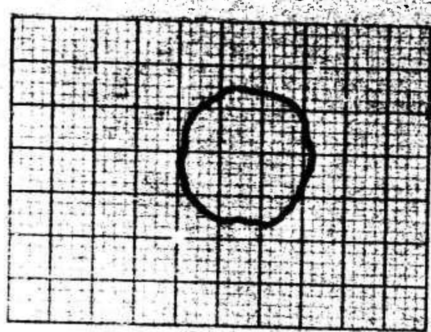
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

AFTER IMPACT



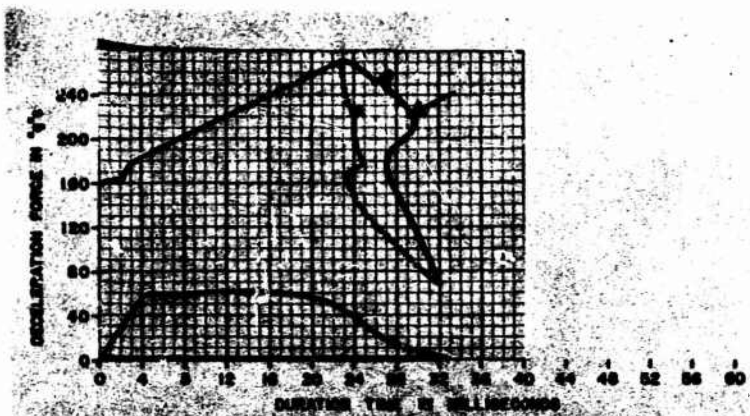

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 27.3 |
| METAL THICKNESS (INCHES) | .045 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 1.20 |
| PADDED | YES |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1/4 |
| AREA (SQ. INCHES) | 7.5 |
| YEAR AND MAKE OF CAR | 58 BUICK |



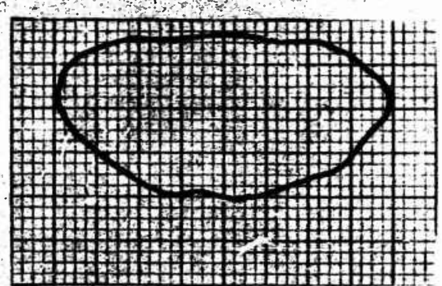
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

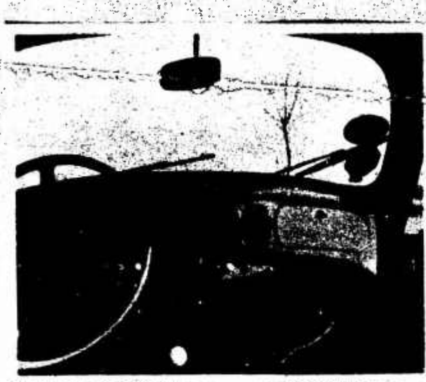
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) ............... | 27.3 |
| METAL THICKNESS (INCHES) ................ | .038 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) ..... | 1/4 |
| PADDED.................. | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES).......... | 1 1/2 |
| AREA (SQ. INCHES)....... | 22.4 |
| YEAR AND MAKE OF CAR ..... | 63 VW |

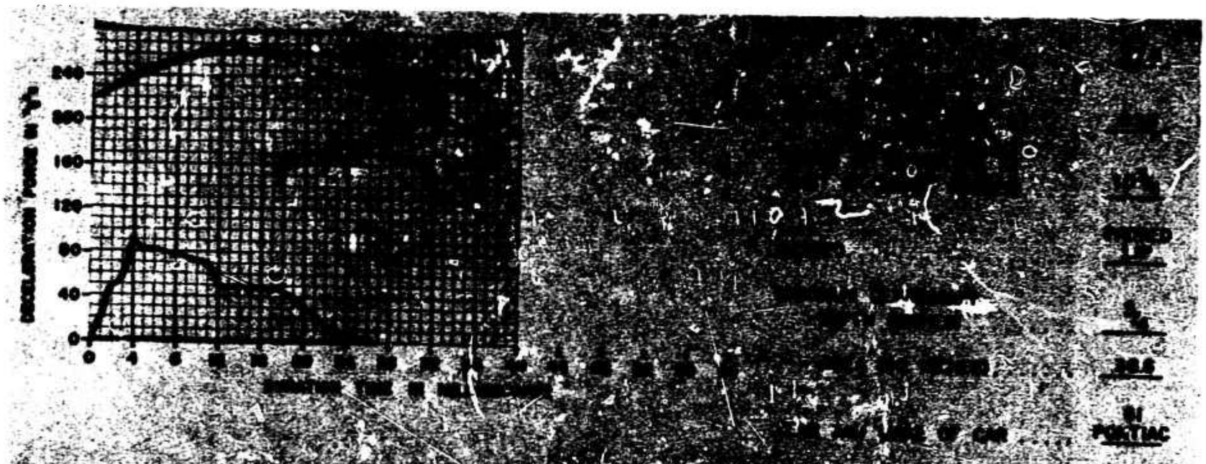


SHAPE AND AREA OF DEPRESSION



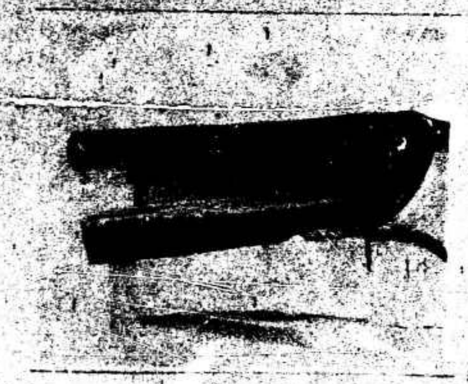
BEFORE IMPACT

AFTER IMPACT.

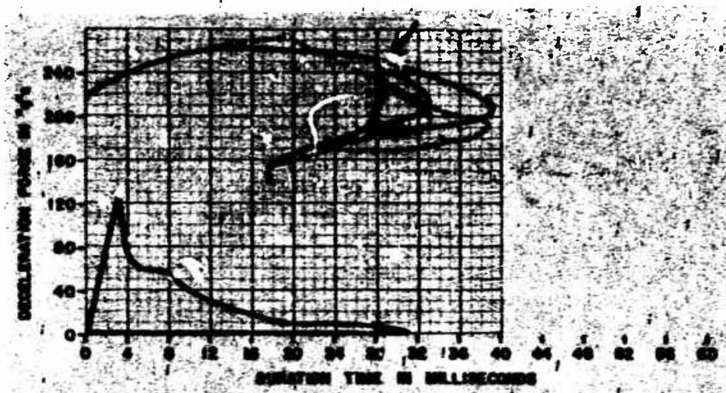


SHAPE AND AREA OF DEPRESSION

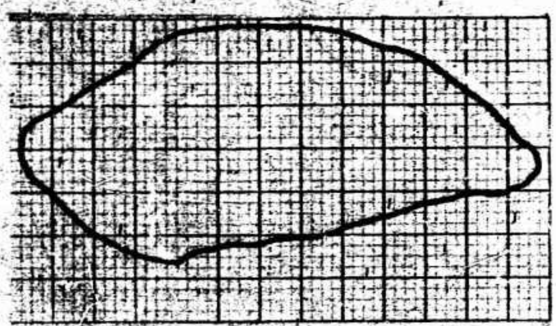
BEFORE IMPACT



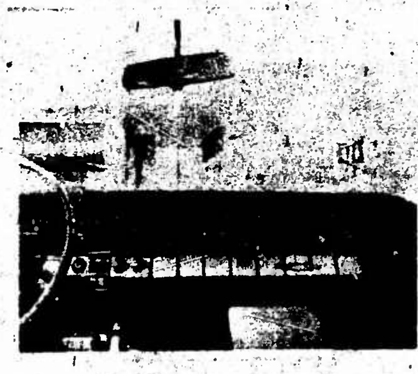
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 27.5 |
| METAL THICKNESS (INCHES) | .038 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | $10\frac{3}{4}$ |
| PADDED | PADDED LIP |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | $\frac{1}{2}$ |
| AREA (SQ. INCHES) | 45.4 |
| YEAR AND MAKE OF CAR | 61 PONTIAC |

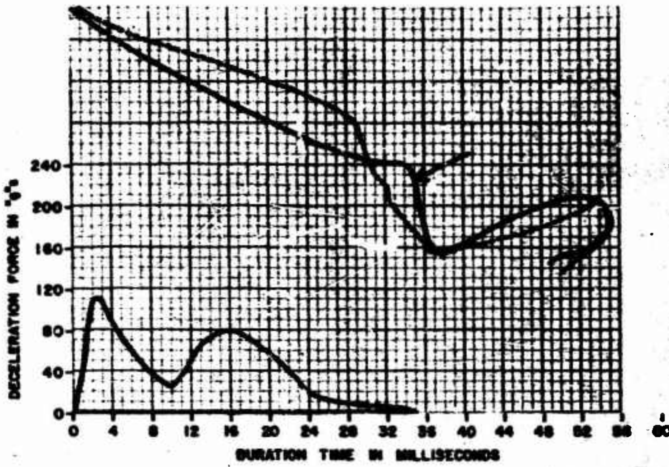


SHAPE AND AREA OF DEPRESSION

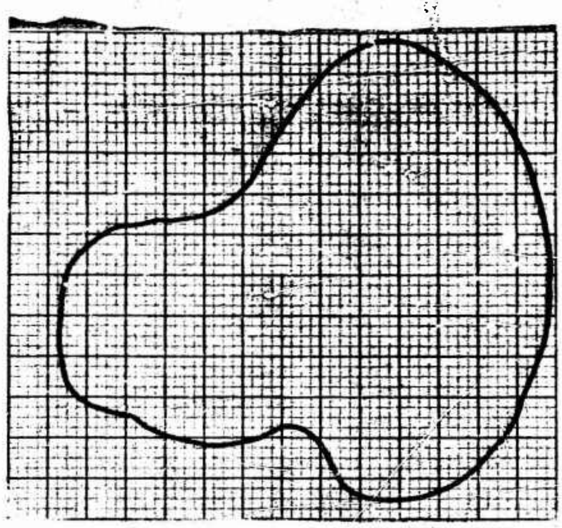


BEFORE IMPACT

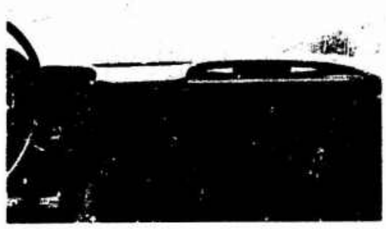
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 29.07 |
| METAL THICKNESS (INCHES) | .043 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 1/2 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 3/4 |
| AREA (SQ. INCHES) | 90.8 |
| YEAR AND MAKE OF CAR | 59 CHEV |

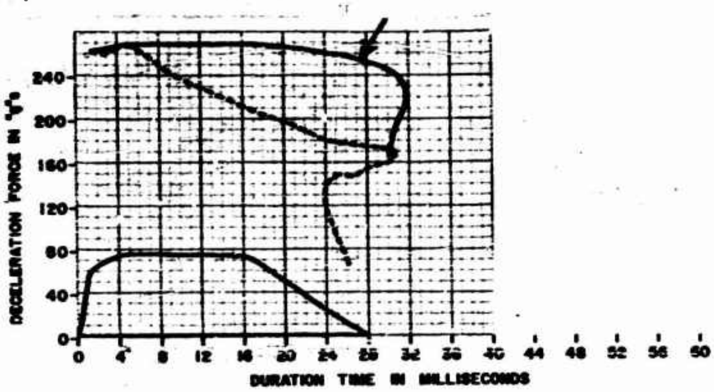


SHAPE AND AREA OF DEPRESSION

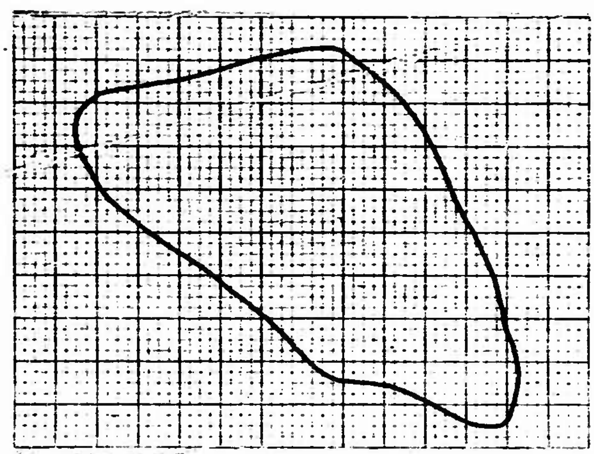


BEFORE IMPACT

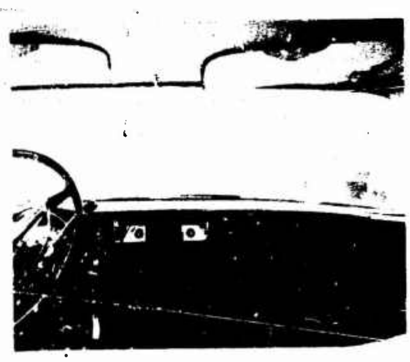
AFTER IMPACT



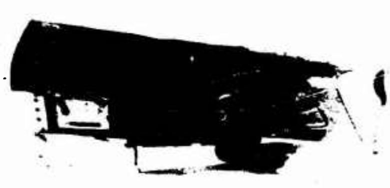

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 29.15 |
| METAL THICKNESS (INCHES) | .044 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 5 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 2 |
| AREA (SQ. INCHES) | 53.9 |
| YEAR AND MAKE OF CAR | 55 PONTIAC |



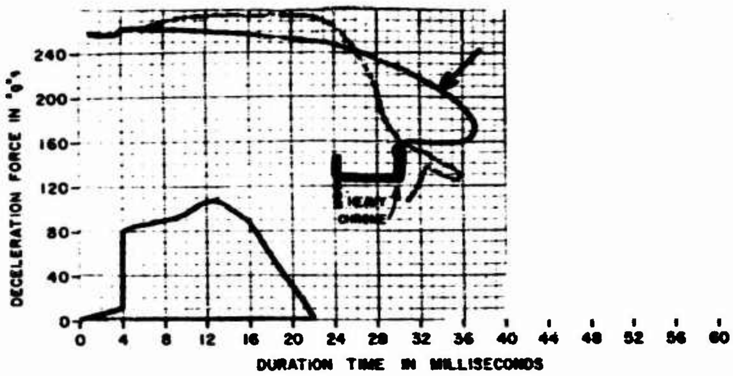
SHAPE AND AREA OF DEPRESSION



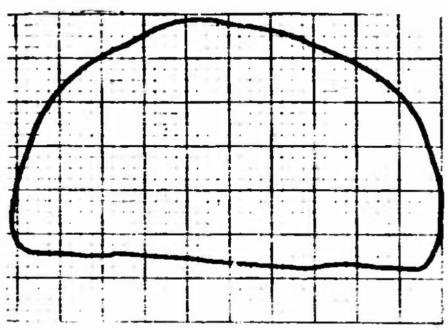
BEFORE IMPACT



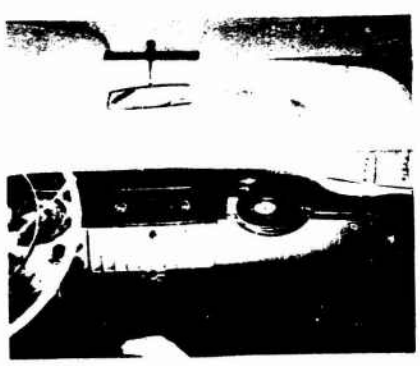
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 29.15 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . | .049 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . . | $2\frac{1}{8}$ |
| PADDED . . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | $1\frac{1}{2}$ |
| AREA (SQ. INCHES) . . . . . . . | 45.2 |
| YEAR AND MAKE OF CAR . . . . . | 54 OLDS |

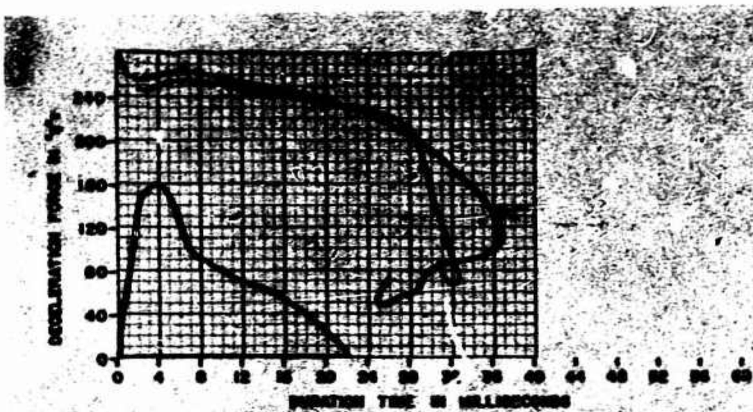


SHAPE AND AREA OF DEPRESSION



BEFORE IMPACT

AFTER IMPACT




VELOCITY OF IMPACT (FT/SEC) .................... 30.1

METAL THICKNESS (INCHES) .................... .039

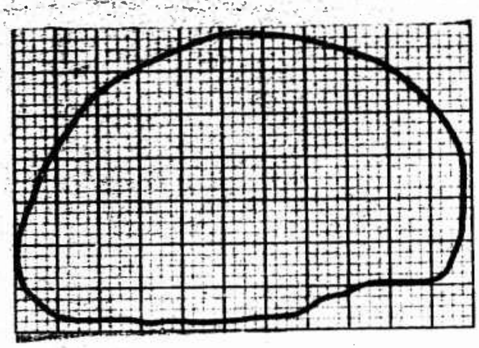
RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) ..... 3/4

PADDED .................... NO

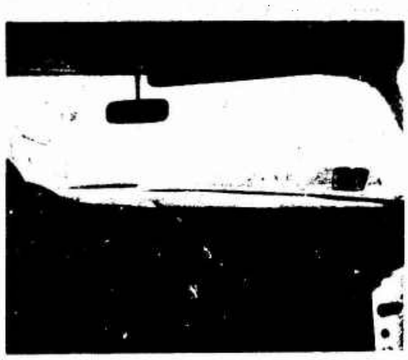
MAXIMUM DEPRESSION:
DEPTH (INCHES) .......... 1 1/4

AREA (SQ. INCHES) ....... 56.7

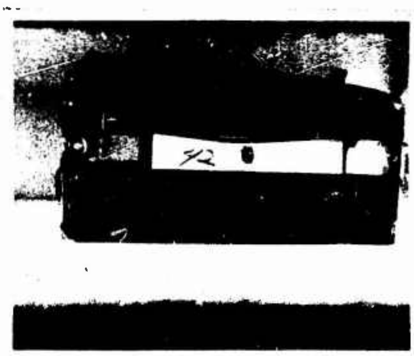
YEAR AND MAKE OF CAR ..... 57 FORD



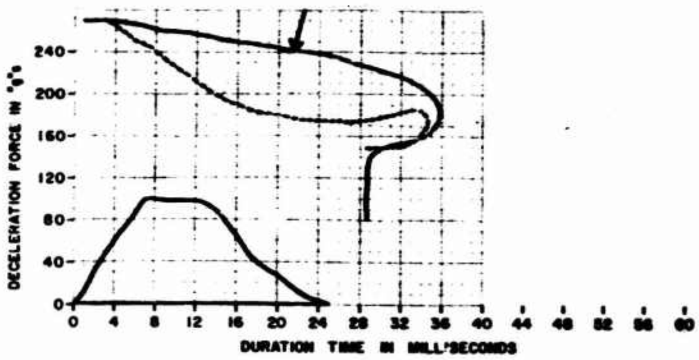
SHAPE AND AREA OF DEPRESSION



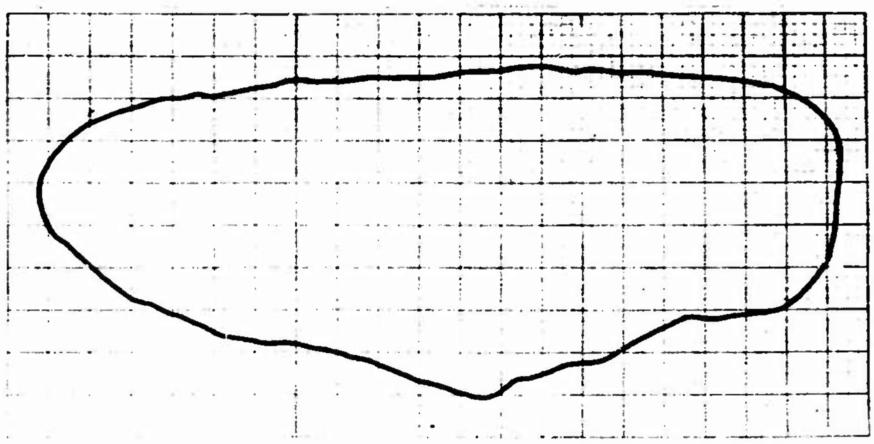
BEFORE IMPACT



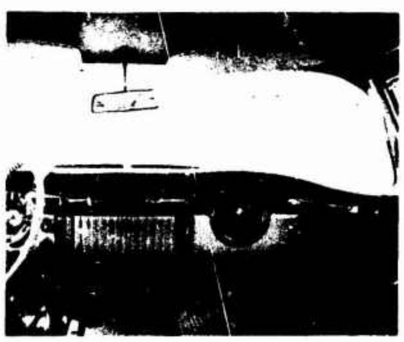
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 30.3 |
| METAL THICKNESS (INCHES) | .042 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 1-½ |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1½ |
| AREA (SQ. INCHES) | 112.0 |
| YEAR AND MAKE OF CAR | 55 OLDS |

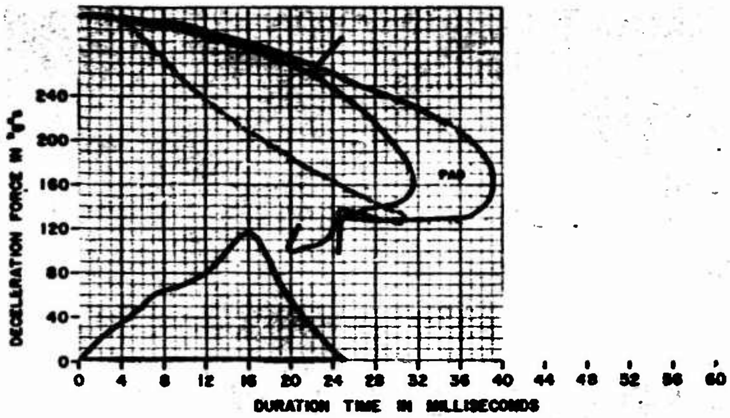


SHAPE AND AREA OF DEPRESSION

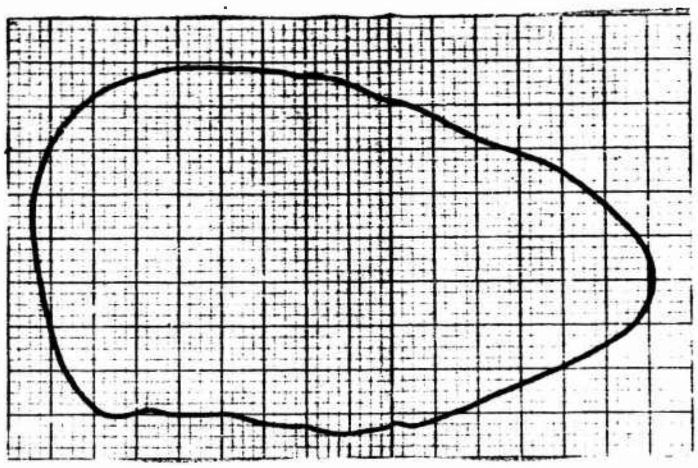


BEFORE IMPACT

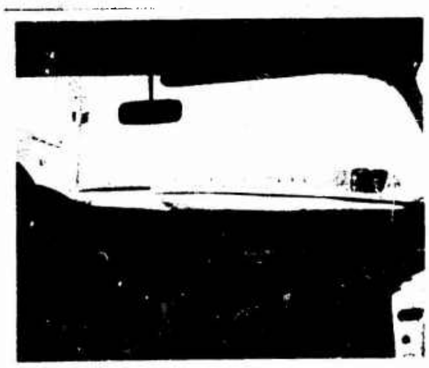
AFTER IMPACT



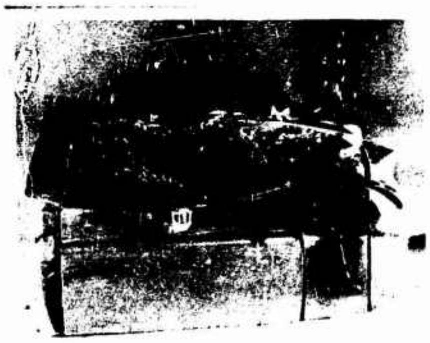

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 30.4 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . . | 9 1/4 |
| PADDED . . . . . . . . . . . . . . . . . . . | YES |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 1 3/4 |
| AREA (SQ. INCHES) . . . . . . . | 92.7 |
| YEAR AND MAKE OF CAR . . . . . | 57 FORD |



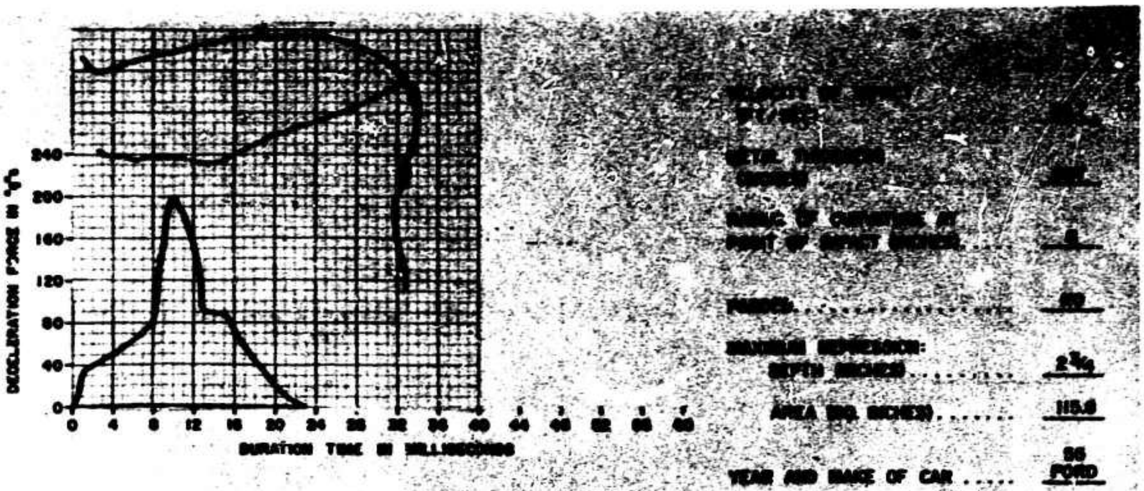
SHAPE AND AREA OF DEPRESSION

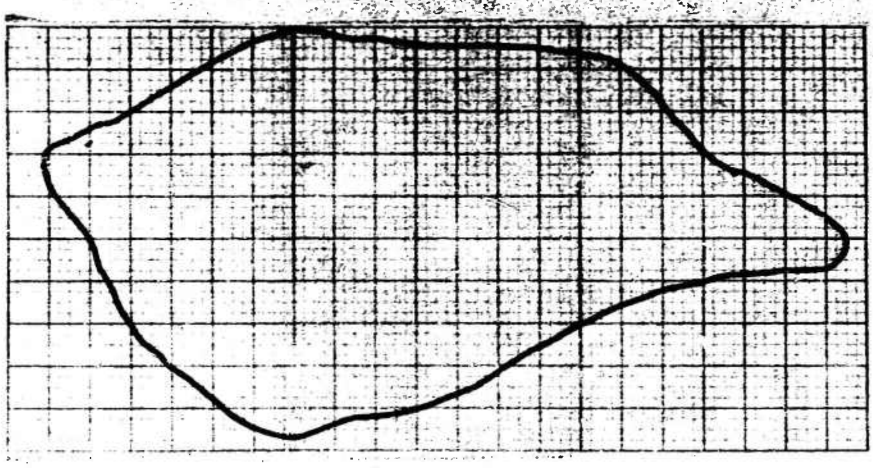


BEFORE IMPACT

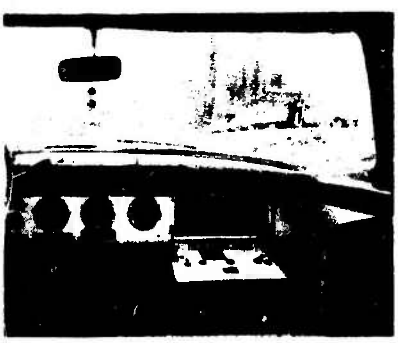


AFTER IMPACT

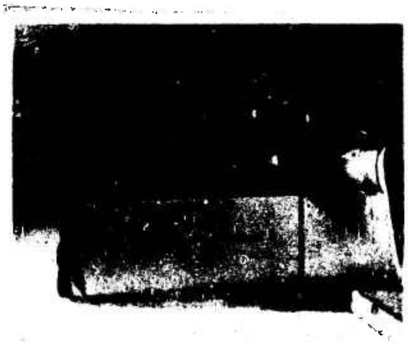


SHAPE AND AREA OF DEPRESSION

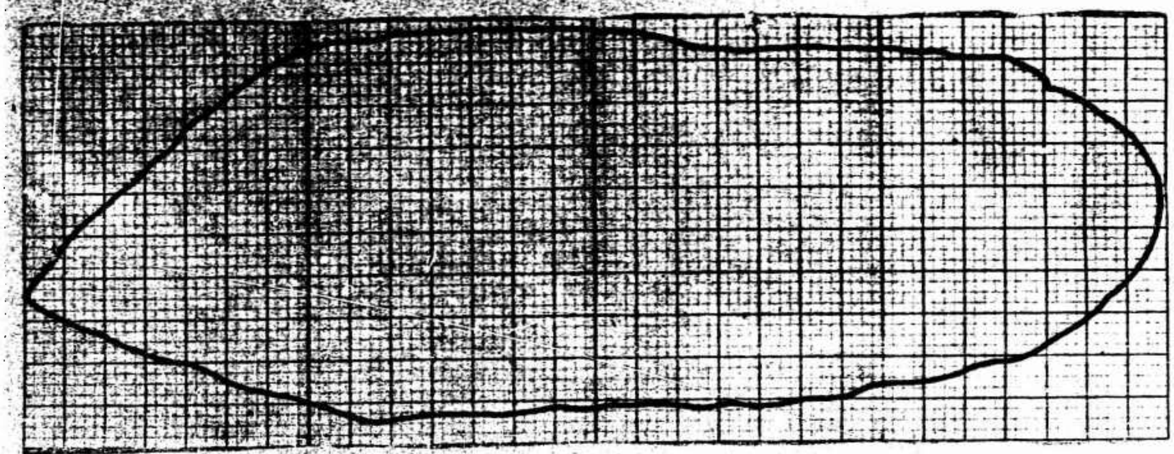


BEFORE IMPACT



AFTER IMPACT

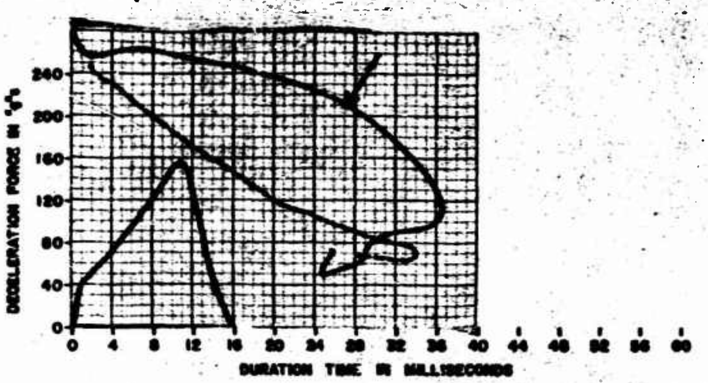
| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) ........ | 30.76 |
| METAL THICKNESS (INCHES) ........ | .047 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) ..... | $19\frac{1}{2}$ |
| PADDED ........ | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) ........ | 2 |
| AREA (SQ. INCHES) ........ | 199.2 |
| YEAR AND MAKE OF CAR ..... | 55 PONTIAC |



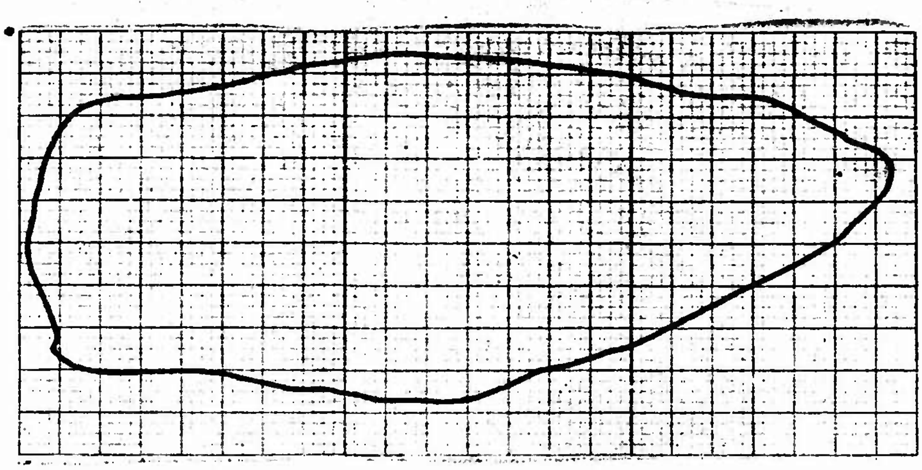
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

AFTER IMPACT



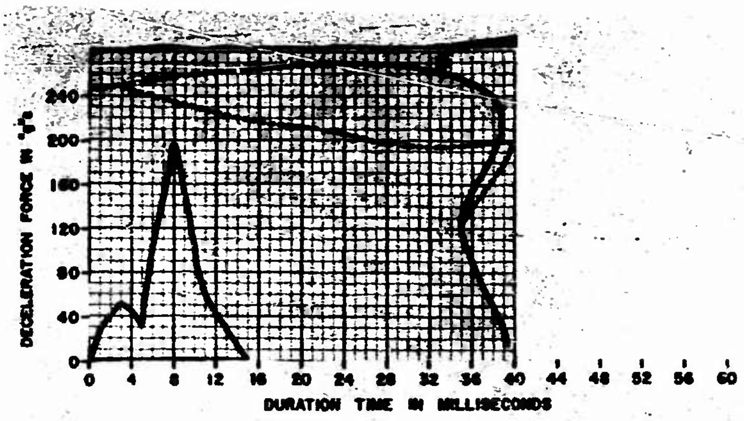

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 31.2 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . . | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES). . . . . | 9 1/4 |
| PADDED. . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | 2 3/4 |
| AREA (SQ. INCHES) . . . . . . . | 133.4 |
| YEAR AND MAKE OF CAR . . . . . | 57 FORD |



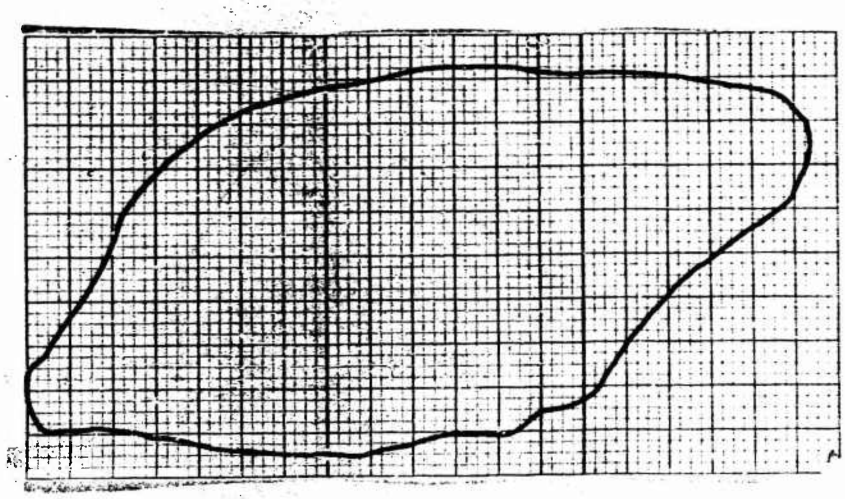
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

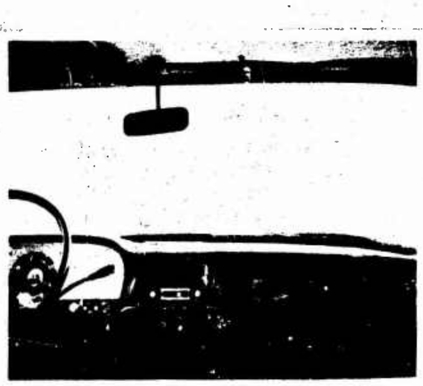
AFTER IMPACT



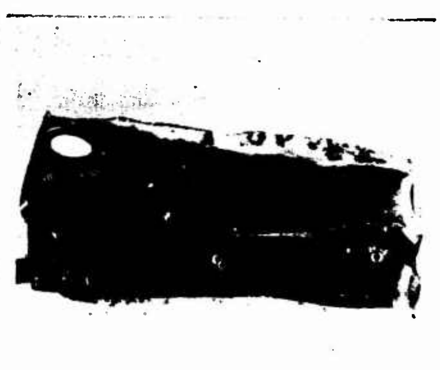

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 31.4 |
| METAL THICKNESS (INCHES) | .037 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 4 1/4 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1 3/4 |
| AREA (SQ. INCHES) | 113.6 |
| YEAR AND MAKE OF CAR | 61 FORD P/U |



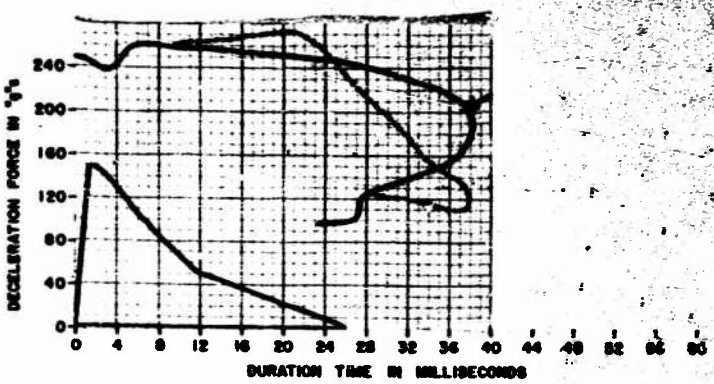
SHAPE AND AREA OF DEPRESSION



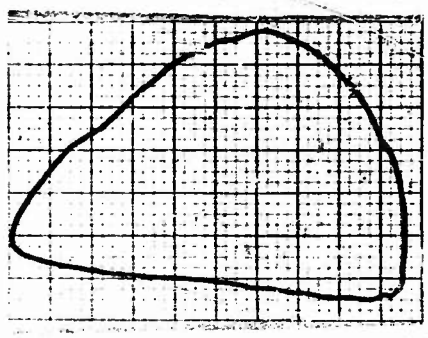
BEFORE IMPACT



AFTER IMPACT

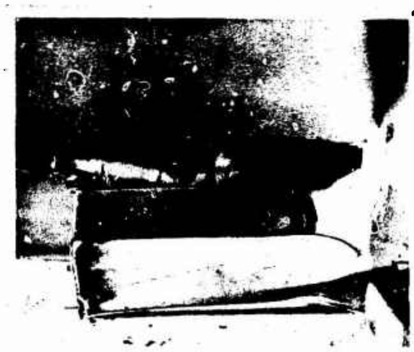



| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 31.4 |
| METAL THICKNESS (INCHES) | .044 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 3/8 |
| PADDED | NO |
| MAXIMUM DEPRESSION: | |
| DEPTH (INCHES) | 1 1/2 |
| AREA (SQ. INCHES) | 40.7 |
| YEAR AND MAKE OF CAR | 57 DODGE |

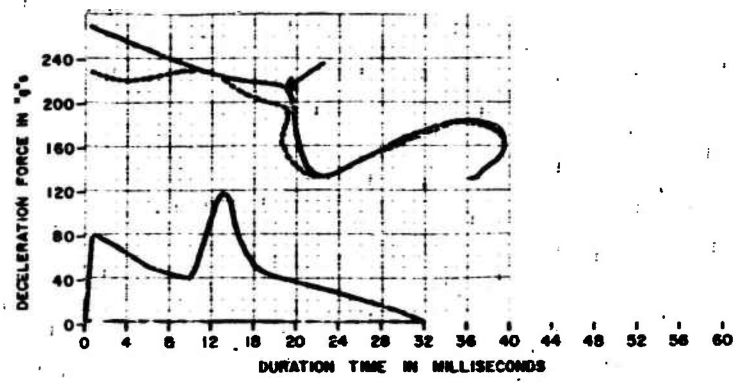


SHAPE AND AREA OF DEPRESSION

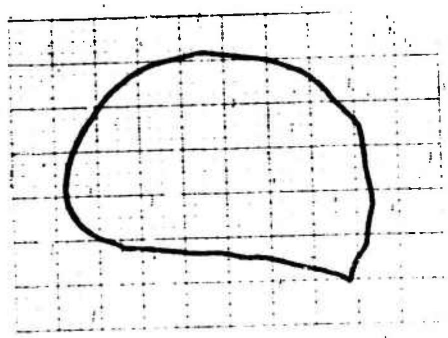
BEFORE IMPACT



AFTER IMPACT



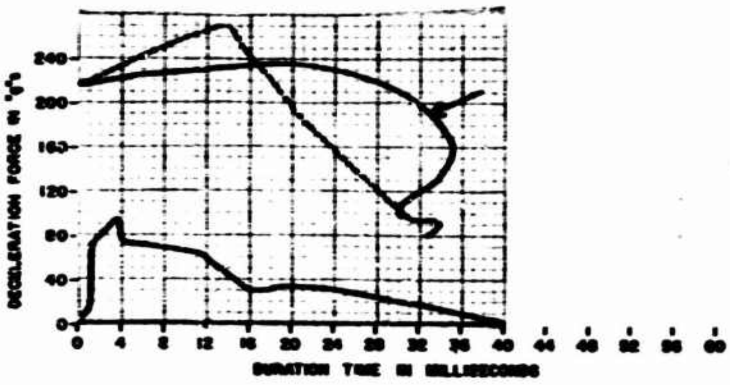

| | |
|---|---|
| VELOCITY OF IMPACT: (FT/SEC) | 31.5 |
| METAL THICKNESS (INCHES) | .043 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 1/2 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 3/8 |
| AREA (SQ. INCHES) | 27.3 |
| YEAR AND MAKE OF CAR | 60 CHEV |



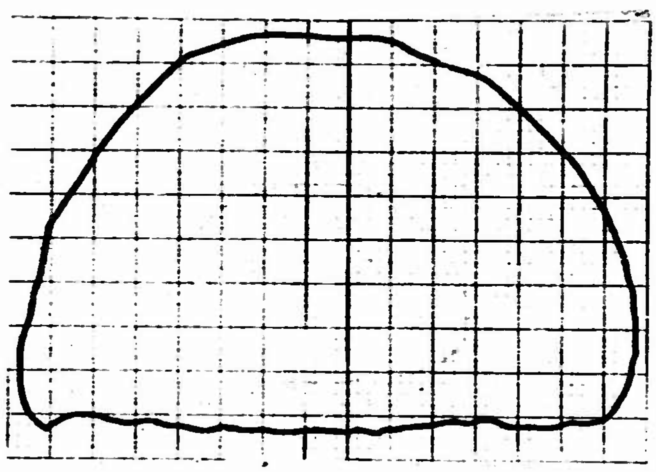
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . . | 31.6 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . | .036 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . . | 3 |
| PADDED . . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | $2\frac{1}{8}$ |
| AREA (SQ. INCHES) . . . . . . . | 93.7 |
| YEAR AND MAKE OF CAR . . . . . | 58 FORD |

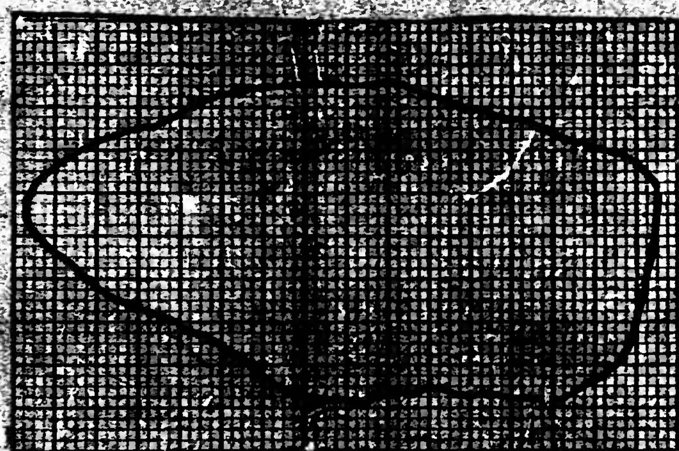


SHAPE AND AREA OF DEPRESSION

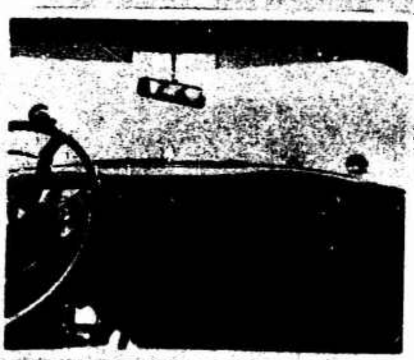
BEFORE IMPACT

AFTER IMPACT

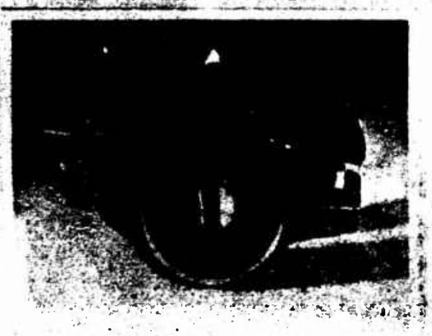

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . | 31.6 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . | .045 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . | 8.5 |
| PADDED . . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . . | $1\frac{3}{8}$ |
| AREA (SQ. INCHES) . . . . . . . | 84.7 |
| YEAR AND MAKE OF CAR . . . . . | 54 OLDS |



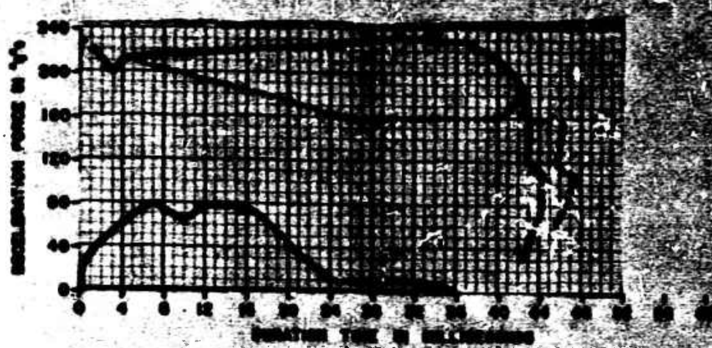
SHAPE AND AREA OF DEPRESSION



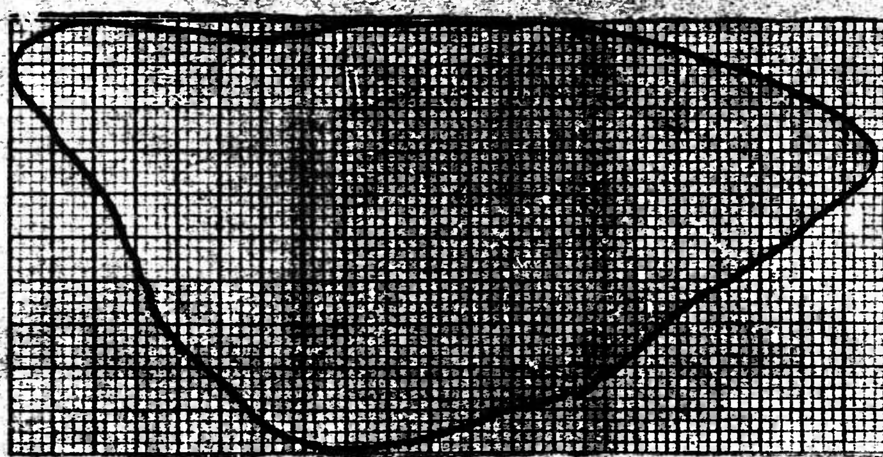
BEFORE IMPACT



AFTER IMPACT



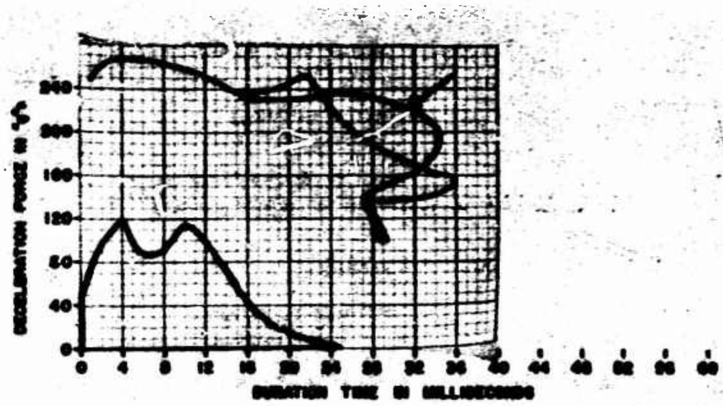
| | |
|---|---|
| [illegible] | 31.7 |
| [illegible] | .046 |
| [illegible] AT [illegible] | $4\frac{1}{2}$ |
| [illegible] | 80 |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | $1\frac{3}{4}$ |
| AREA (SQ. INCHES) | 138.4 |
| YEAR AND MAKE OF CAR | 57 PLYM |



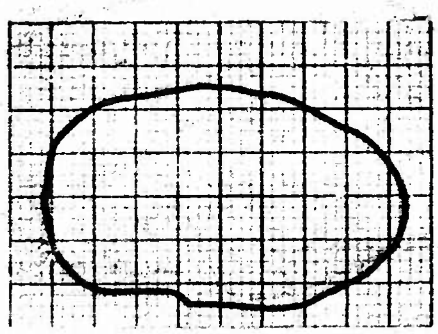
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

AFTER IMPACT



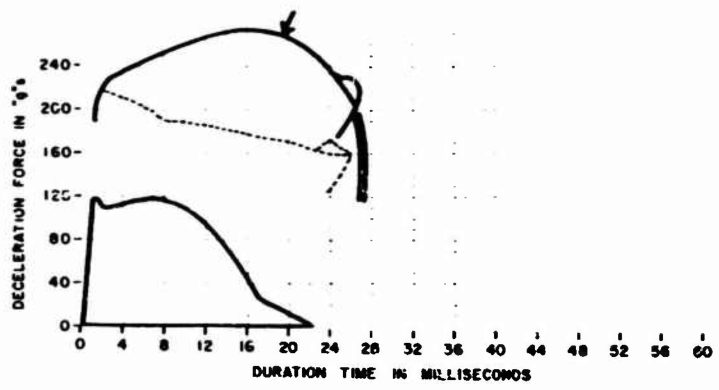

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) ............... | 31.8 |
| METAL THICKNESS (INCHES) ............... | .045 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES)..... | 2 1/4 |
| PADDED.................... | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES).......... | 1 1/8 |
| AREA (SQ. INCHES)....... | 32.5 |
| YEAR AND MAKE OF CAR ..... | 58 PLYM |



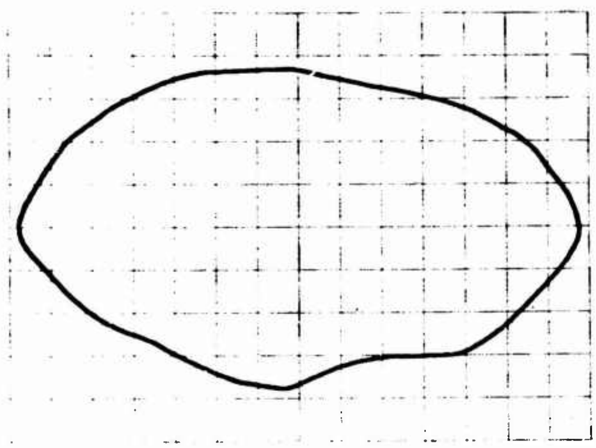
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

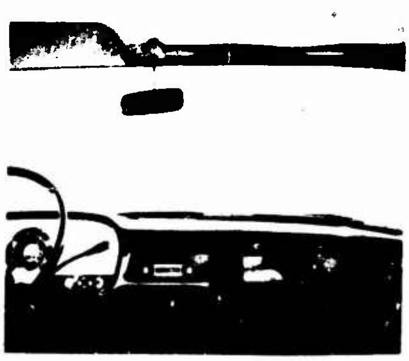
AFTER IMPACT



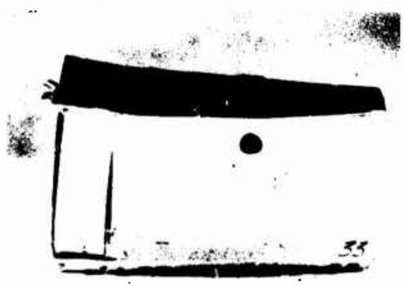

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 31.8 |
| METAL THICKNESS (INCHES) | .045 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 3 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 2 3/8 |
| AREA (SQ. INCHES) | 71.0 |
| YEAR AND MAKE OF CAR | 54 MERC |



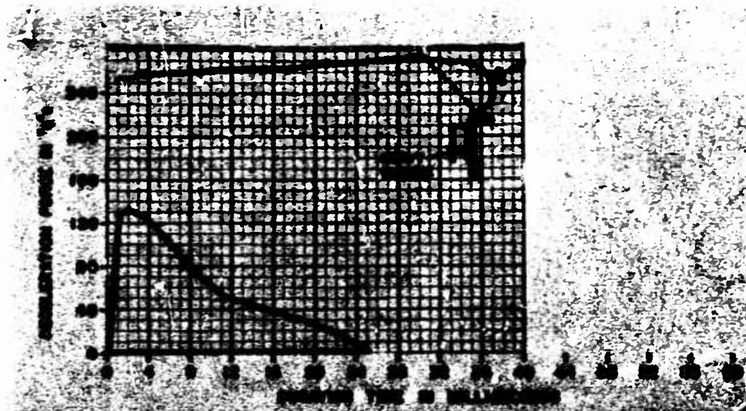
SHAPE AND AREA OF DEPRESSION



BEFORE IMPACT

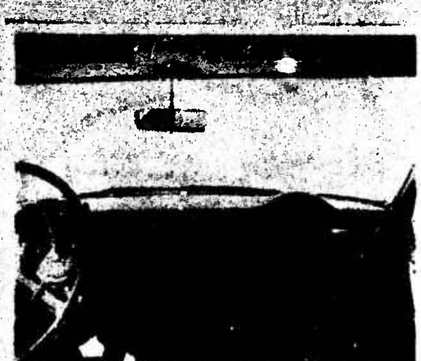


AFTER IMPACT

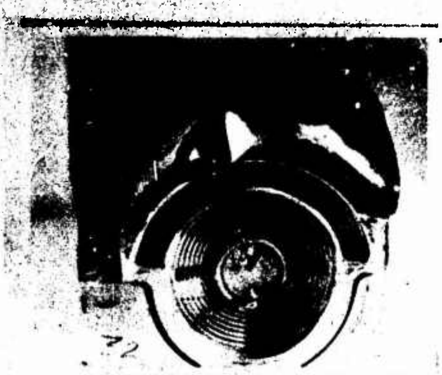


| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . . . | 31.8 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . . . . | .044 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES). . . . . | 1/2 |
| PASSED. . . . . . . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES). . . . . . . . . | 5/8 |
| AREA (SQ. INCHES). . . . . . . | 6.0 |
| YEAR AND MAKE OF CAR . . . . . | 53 OLDS |

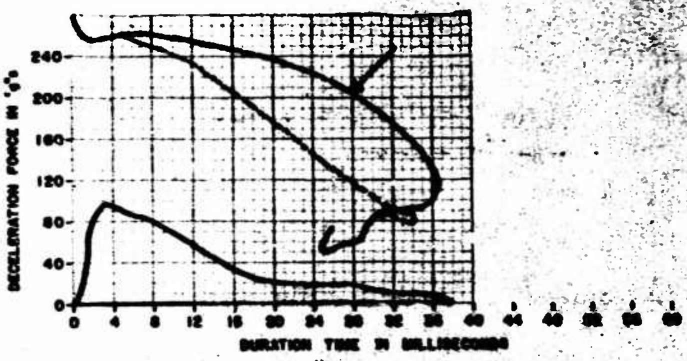
SHAPE AND AREA OF DEPRESSION



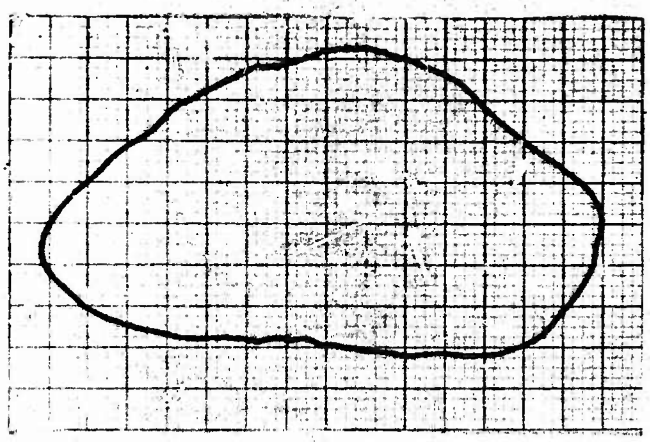
BEFORE IMPACT



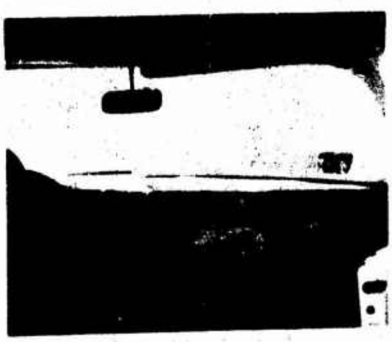
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 31.8 |
| METAL THICKNESS (INCHES) | [illegible] |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | $9\frac{1}{4}$ |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | $1\frac{3}{8}$ |
| AREA (SQ. INCHES) | 74.7 |
| YEAR AND MAKE OF CAR | 57 FORD |

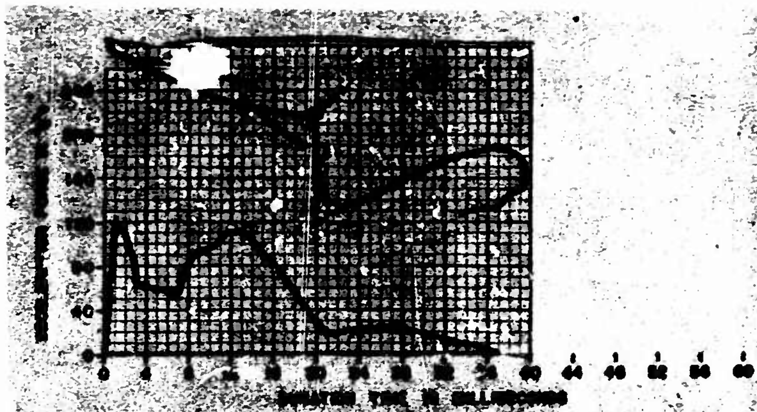


SHAPE AND AREA OF DEPRESSION

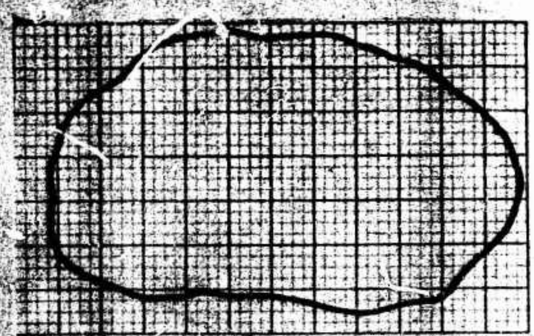


BEFORE IMPACT

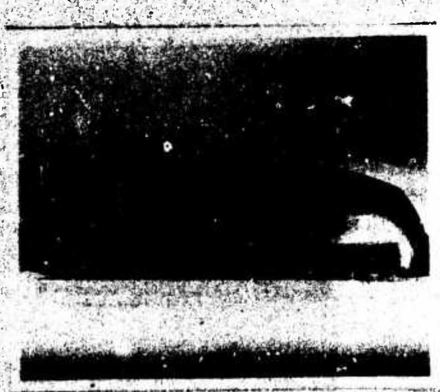
AFTER IMPACT



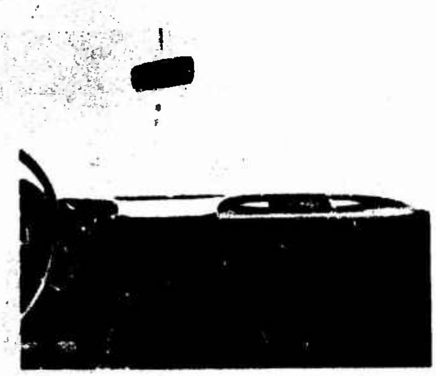

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 31.95 |
| METAL THICKNESS (INCHES) | .043 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | ½ |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | ½ |
| AREA (SQ. INCHES) | 54.7 |
| YEAR AND MAKE OF CAR | 59 CHEV |



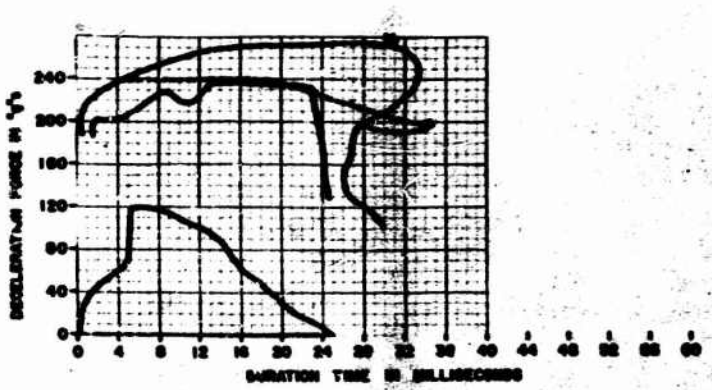
SHAPE AND AREA OF DEPRESSION



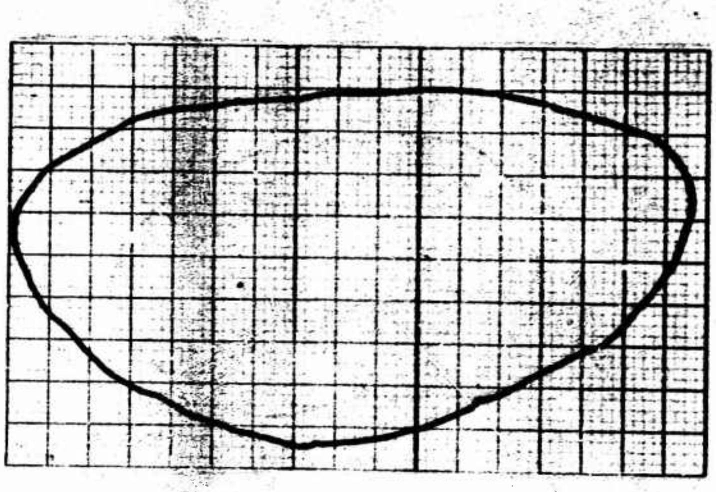
BEFORE IMPACT



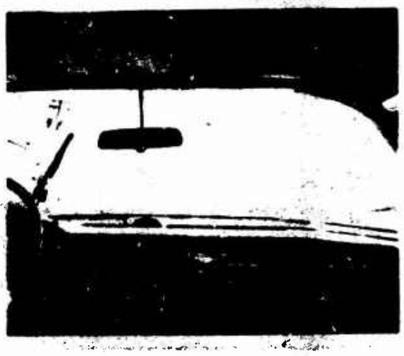
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) ........................ | 31.95 |
| METAL THICKNESS (INCHES) ........................ | .062 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) ..... | $1\frac{1}{2}$ |
| PADDED ........................ | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) .......... | $1\frac{1}{2}$ |
| AREA (SQ. INCHES) ........ | 101.9 |
| YEAR AND MAKE OF CAR ..... | 57 OLDS |

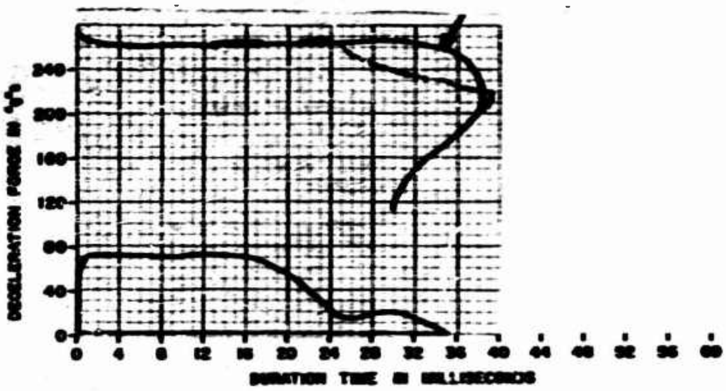


SHAPE AND AREA OF DEPRESSION

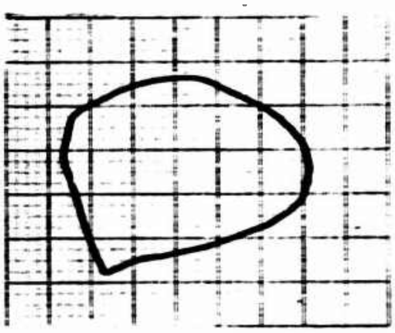


BEFORE IMPACT

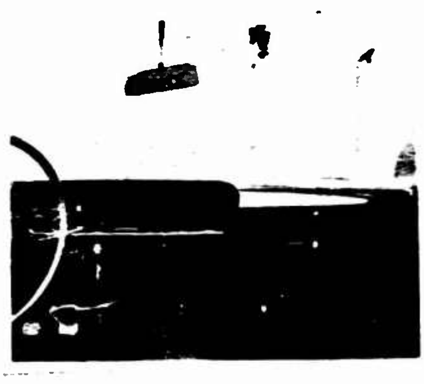
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 32.0 |
| METAL THICKNESS (INCHES) | .036 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 1 1/4 |
| PADDED | NO |
| MAXIMUM DEPRESSION DEPTH (INCHES) | 3/4 |
| AREA (SQ INCHES) | 17.4 |
| YEAR AND MAKE OF CAR | 62 CHEV |

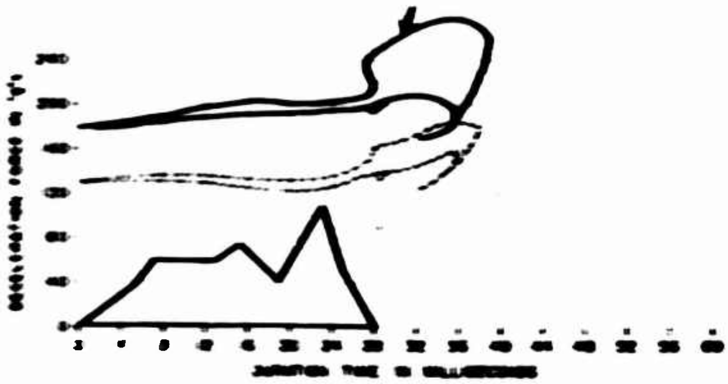


SHAPE AND AREA OF DEPRESSION

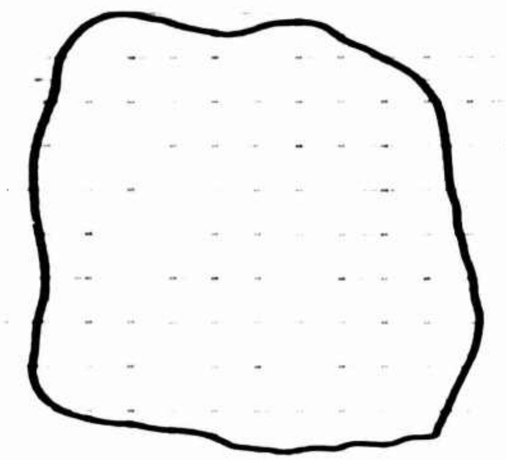


BEFORE IMPACT

AFTER IMPACT



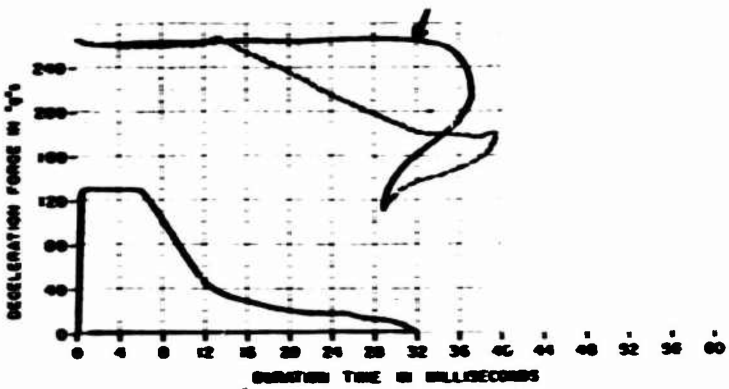
| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 37.6 |
| METAL THICKNESS (INCHES) | .036 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 2 |
| PADDED | YES |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1 1/2 |
| AREA (SQ INCHES) | 80.1 |
| YEAR AND MAKE OF CAR | 61 FORD |



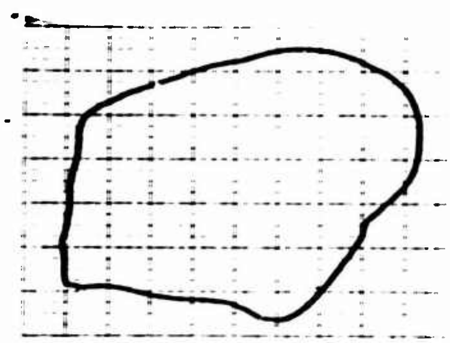
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

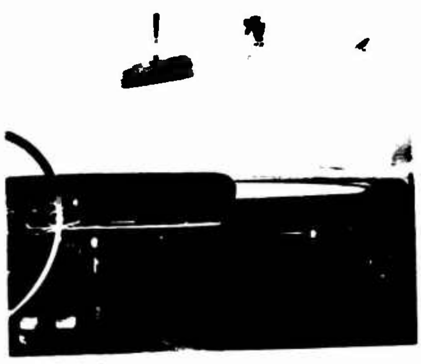
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 37.5 |
| METAL THICKNESS (INCHES) | .036 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | $1\frac{5}{8}$ |
| PADDED | NO |
| MAXIMUM DEPRESSION DEPTH (INCHES) | 2 |
| AREA (SQ INCHES) | 38.5 |
| YEAR AND MAKE OF CAR | 61 CHEV |

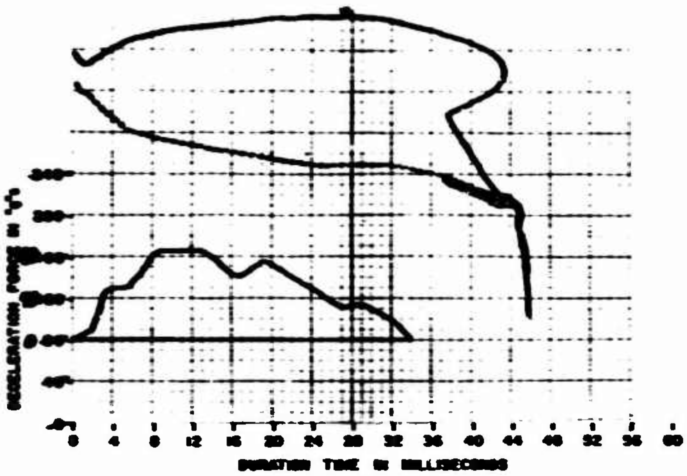


SHAPE AND AREA OF DEPRESSION



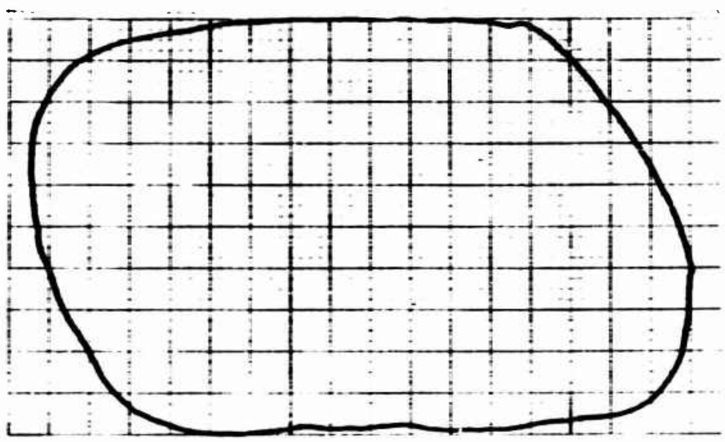
BEFORE IMPACT

AFTER IMPACT



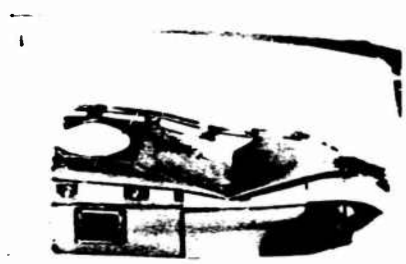

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 42.6 |
| METAL THICKNESS (INCHES) | .039 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 14¼ |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 3¾ |
| AREA (SQ. INCHES) | 150.7 |
| YEAR AND MAKE OF CAR | 57 FORD |

NOT REPRODUCIBLE

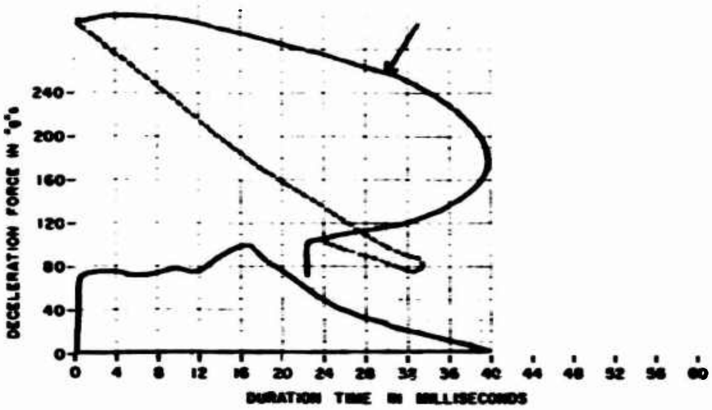


SHAPE AND AREA OF DEPRESSION

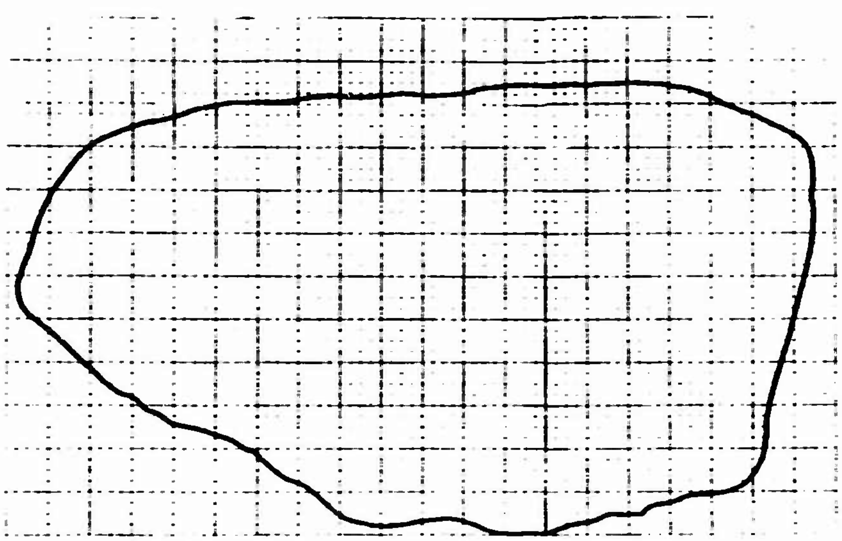
BEFORE IMPACT



AFTER IMPACT



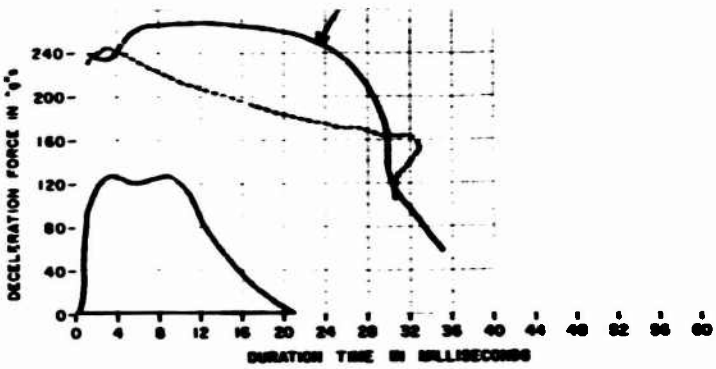

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 42.9 |
| METAL THICKNESS (INCHES) | .044 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | $10\frac{1}{4}$ |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | $3\frac{1}{2}$ |
| AREA (SQ. INCHES) | 156.7 |
| YEAR AND MAKE OF CAR | 57 CHEV |



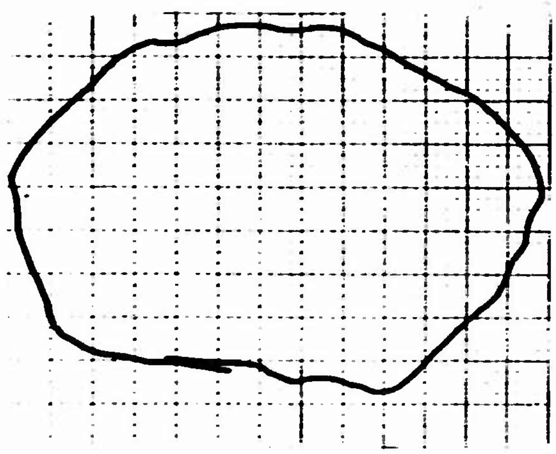
SHAPE AND AREA OF DEPRESSION

BEFORE IMPACT

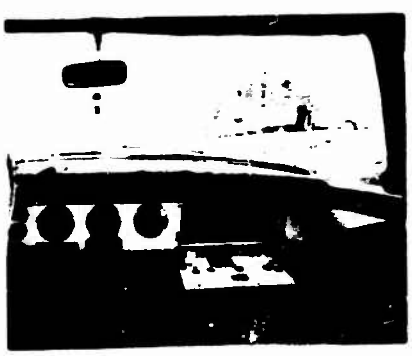
AFTER IMPACT




| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 43.3 |
| METAL THICKNESS (INCHES) | .044 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 3 1/8 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 1 3/4 |
| AREA (SQ. INCHES) | 80.1 |
| YEAR AND MAKE OF CAR | 55 FORD |

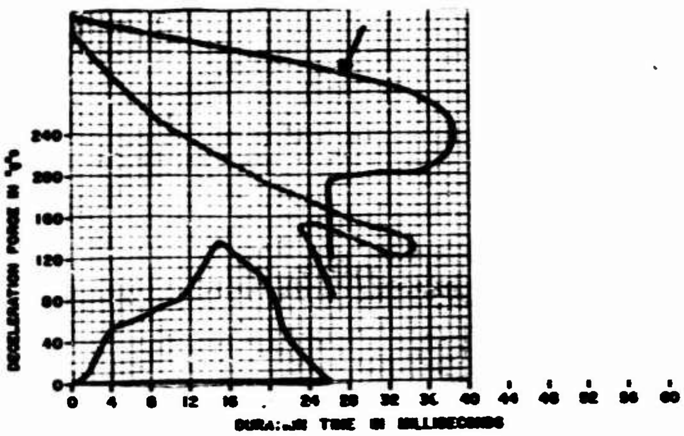


SHAPE AND AREA OF DEPRESSION

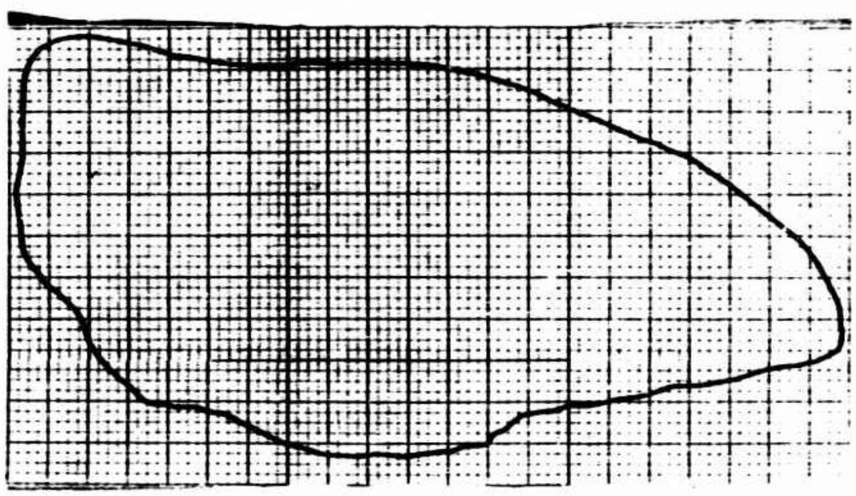


BEFORE IMPACT

AFTER IMPACT



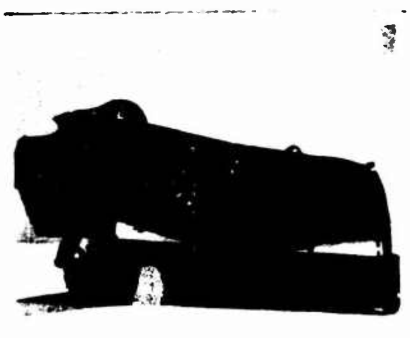

| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 43.5 |
| METAL THICKNESS (INCHES) | .038 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 18 1/2 |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | 3 1/4 |
| AREA (SQ. INCHES) | 146.9 |
| YEAR AND MAKE OF CAR | 56 FORD |



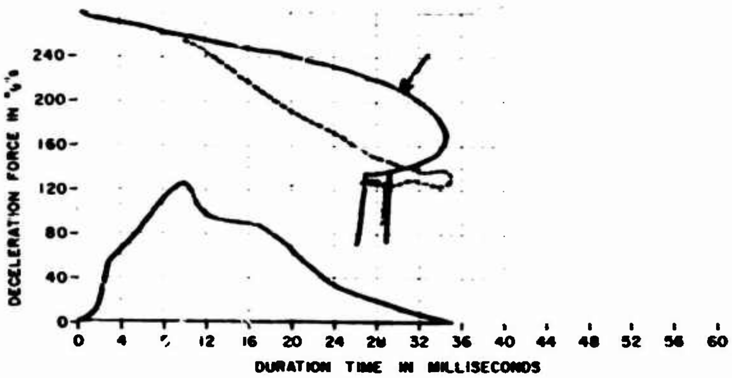
SHAPE AND AREA OF DEPRESSION



BEFORE IMPACT

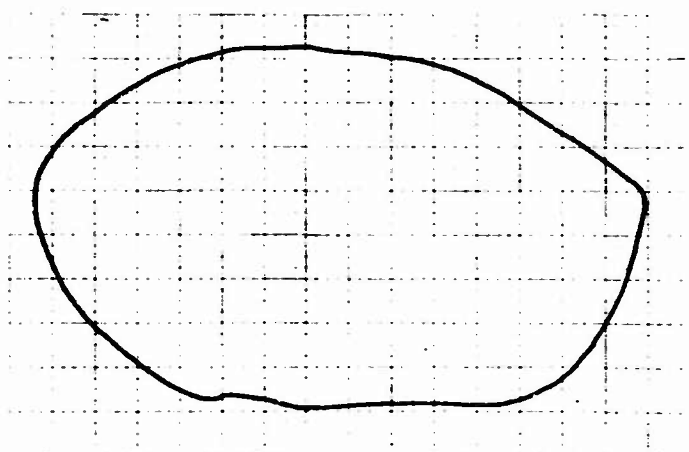


AFTER IMPACT

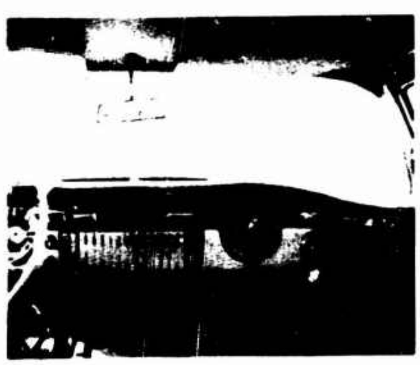



| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) . . . . . . . . . . . . | 43.7 |
| METAL THICKNESS (INCHES) . . . . . . . . . . . . . . | .046 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) . . . . | 4 1/8 |
| PADDED . . . . . . . . . . . . . . . . . | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) . . . . . . . . | 1 5/8 |
| AREA (SQ. INCHES) . . . . . . . | 92.2 |
| YEAR AND MAKE OF CAR . . . . | 55 OLDS |

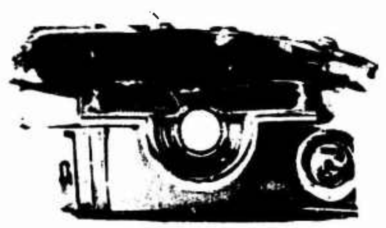




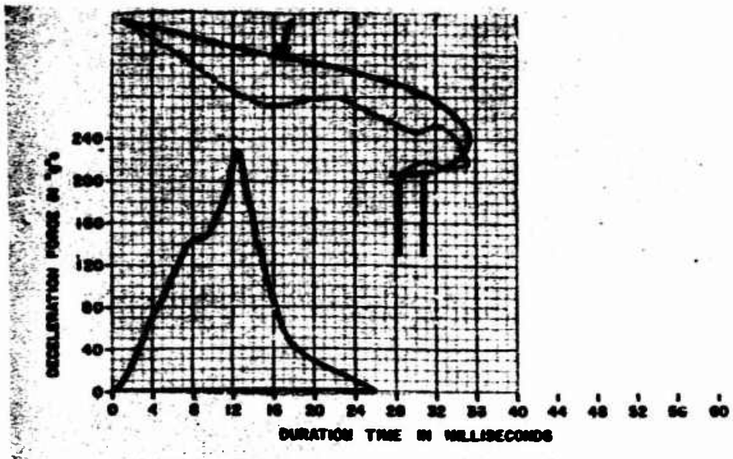
SHAPE AND AREA OF DEPRESSION



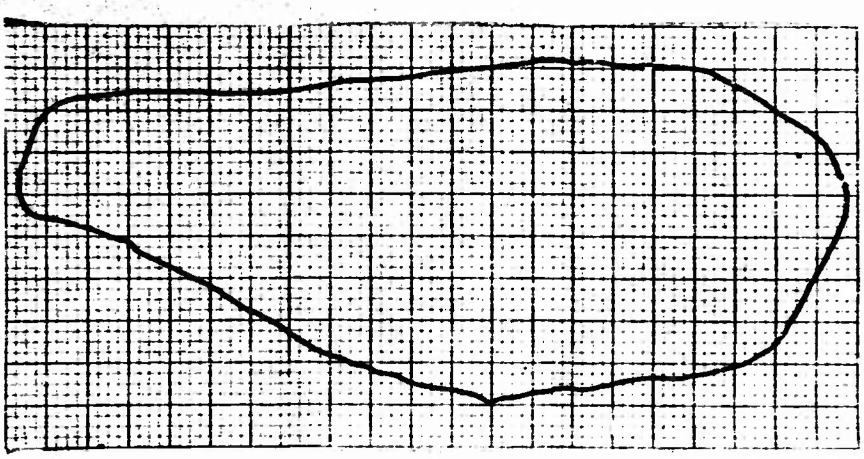
BEFORE IMPACT



AFTER IMPACT

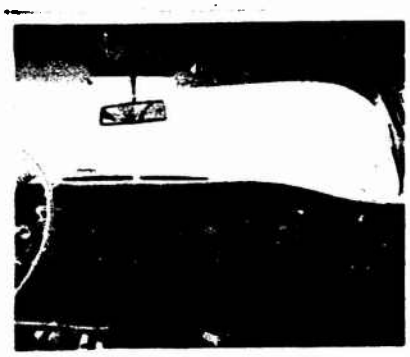



| | |
|---|---|
| VELOCITY OF IMPACT (FT/SEC) | 43.7 |
| METAL THICKNESS (INCHES) | .045 |
| RADIUS OF CURVATURE AT POINT OF IMPACT (INCHES) | 2i |
| PADDED | NO |
| MAXIMUM DEPRESSION: DEPTH (INCHES) | $1\frac{1}{8}$ |
| AREA (SQ. INCHES) | 111.3 |
| YEAR AND MAKE OF CAR | 55 OLDS |

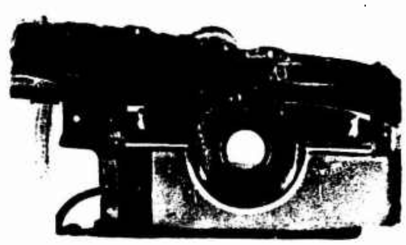


SHAPE AND AREA OF DEPRESSION





BEFORE IMPACT



AFTER IMPACT