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GENERAL AVIATION STRUCTURES DIRECTLY RESPONSIBLE FOR TRAUMA IN CRASH DECELERATIONS

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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 behind that for the automobile that death rates per 100,000,000 passenger miles in light aircraft are at least seven times those for automotive transportation. The author concludes, after many detailed analyses in this study, that many present-day general aviation aircraft with their rigid instrument panels studded 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,

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*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 ¼ "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.

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*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