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COCKPIT DESIGN FOR IMPACT SURVIVAL

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I. Introduction.

The authors estimate that as many as half of those now lost annually in survivable aircraft accidents would survive should existing data on tissue protection during impacts be incorporated more extensively in aircraft design. The economic and other benefits to the aviation community attending the return to flying of these accident victims (aside from the humanistic aspects), makes it highly desirable that future aircraft contain available bioengineering design advances.

If the interior of a typical light aircraft is scrutinized, myriads of pointed and sharp-edged protruberances are seen. Under static conditions, these objects cause little problem, but, during impact circumstances, they produce punctures, creases, and fractures in the protoplasm pressed against them. Pearson provides a broad analysis of this matter.[7]

With some experience in accident investigation, one can almost "read" the make of aircraft by viewing the "impact signature" left by the respective aircraft on the occupants of specific seats.

Considerable attention has been given to the prevention of impact injury and death in ground vehicular and aircraft accidents.[1, 3, 5, 10] This aspect of preventive medicine can be improved, and this paper will discuss possible approaches to effecting the further incorporation of cockpit-design safety features.

II. Discussion.

The aircraft interior portrayed in Figure 1 represents a composite picture of the latent capacity of various existing layouts to maim or kill pilots. For example, circuit breakers or toggle switches line the lower portion of the instrument panel, somewhat similar in appearance to teeth and capable of inflicting toothlike injuries.

FIGURE 1.

Also, the rudder pedals and associated structures, as often constructed at present, are conducive to serious injury during their entanglements with the lower legs subsequent to impacts.

Additionally, pilots may be found on occasion impaled upon a portion of the control wheel, as on the horns of a bull, especially in cases where the wheel is constructed of brittle material. In configurations where a wheel of the type illustrated is installed with the points facing the floor of the plane, the hazard to the lower trunk and thighs is obvious.

The location of the magnetic compass near the pilot's forehead is especially poor with respect to impact injury. The Piper Cherokee has good magnetic-compass location, within the instrument panel proper.

The installation of the trim-tab controls in a location not likely to injure parts of the body during impacts is an important consideration. The Cessna 150–172–182 series illustrates a desirable location for these controls, which are found on the floor between the two front seats.

Dome-light switches may be located at times just above the pilot's head, with their sharp end pointed toward his cranium. The use of flat center-pivot push switches represents "delethalization" of this problem.

Gyro-heading-indicator adjustment knobs, radio equipment knobs, and other controls, often are positioned so that they inflict puncture wounds on the face during inpacts. Countersunk control knobs solve this situation.

Drs. Gikas and Huelke report that one automobile-accident victim received fatal injuries when an instrument panel knob penetrated his calvarium and entered the frontal lobe of the brain.[3] They illustrate the case with a postmortem roentgenogram. Aircraft pilots are not immune to such occurrences.

Puncture wounds can make serious or fatal injuries. The elimination of objects within the cockpit that can produce puncture wounds represents the first of three principles of delethalization.

First Principle: Delineate the envelope of motion of the occupants in a given location and remove from this envelope, or properly modify the design thereof, all sharp, elongated, brittle, pointed, or similarly shaped objects.

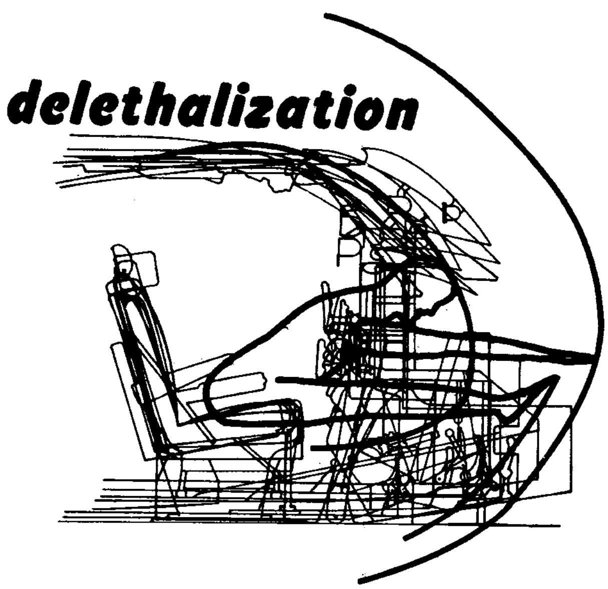

FIGURE 2.

Figure 2 shows the superimposed profiles of various civil aircraft.[12] To this is added the envelope of motion of a pilot's head and extremities. Since it is impossible to conceive of removing the parts of the cockpit that may collide with the pilot during impacts, a combination of delethalization principles and proper restraint-system design appears desirable.

A restraint system alone is not the complete answer to occupant protection, since, although the system may keep the occupant from going to the instrument panel during impacts, it does not keep the panel from going to the occupant. The restraint system is important, however, and it is herein listed as the second principle.

Second Principle: Employ a body restraint system, consisting of a belt and a shoulder harness, capable of withstanding 25 g's.[10]

This system can utilize a single-strap fixed chest strap or an inertial-reel single strap. All recent Meyers light aircraft are routinely fitted with the single-strap shoulder-harness-lap belt combination, a distinct contribution to air safety. A lightweight inertial-reel shoulder harness by Pacific Scientific of Los Angeles is currently being tested by CARI. Interestingly, the Sikorsky S-38A, issued a Type Certificate in 1928 (ATC #60), contained one of the best passenger seat belts ever used (at least four times as wide as present belts, thus covering the center of gravity of seated children).[4]

The 25-g capacity ensures that so long as the fuselage remains intect (a good working definition of survivability), the restraint system will hold (it follows that the seat should itself be capable of staying in place under 25-g all-directional loads).

It should be noted that many gliders, including those manufactured by the Schweitzer Company, have utilized shoulder harnesses to advantage. Aerial-applicator aircraft have also, and the Piper Pawnee illustrates how a good restraint-system—smooth-panel combination, have been put together.[2] Among the other "new-generation" aerial-applicator craft with good safety features are the Snow, Callair, and Ag-Cat.

Also, as Colonel Stapp points out, the Air Force policy of utilizing a 250-pound (attaired) occupant, is ideal in determining seat strengths, since this guarantees almost all persons at least 25 g's of tie-down protection.[10]

A pilot (or an airline passenger) may be figuratively seen (Figure 3) sitting in place, facing two hazards: a sledgehammerlike hard structure directly ahead, flanked by various sharp objects. All is well if conditions remain static.

With impact, the protoplasm is seen meeting a relatively nonyeilding structure (Figure 4). According to long-established laws of physics, either the structure undergoes rearrangement during deceleration, or the protoplasm gets rearranged, or some rearrangement in both occurs.

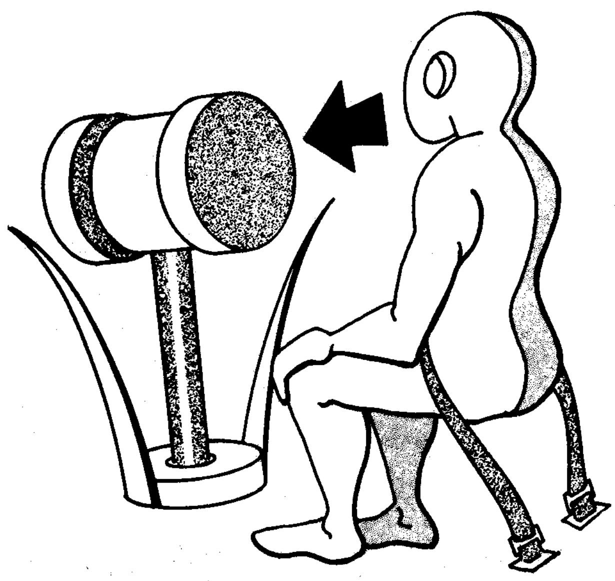

FIGURE 3.

FIGURE 4.

Therefore, the third principle of delethalization is concerned with producing, during impacts of living and nonliving material, the major amount of the alterations in the nonliving substance.

Third Principle: Provide a means of producing a prescribed body-segment deceleration distance within the portions of the cockpit structure likely to be struck by the respective body segments during impacts.

Note how the peak g force in Figure 5, which represents a deceleration force generated by a relatively nonyielding substance (hard wood), far exceeds that generated in the "sandwich" material (Figure 6). These data are representative of that being obtained by Mr. Swearingen at CARI, in a continuing study of: (1) The upper survival tolerances of human beings to impacts; and (2) The best combinations of energy-absorbing materials for survival under specific conditions?

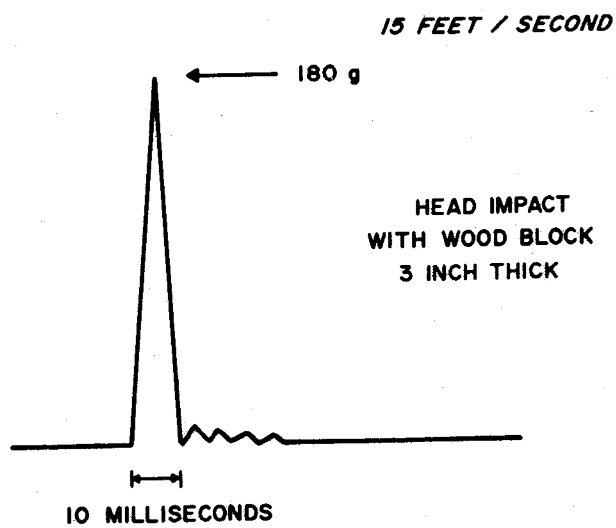

FIGURE 5.

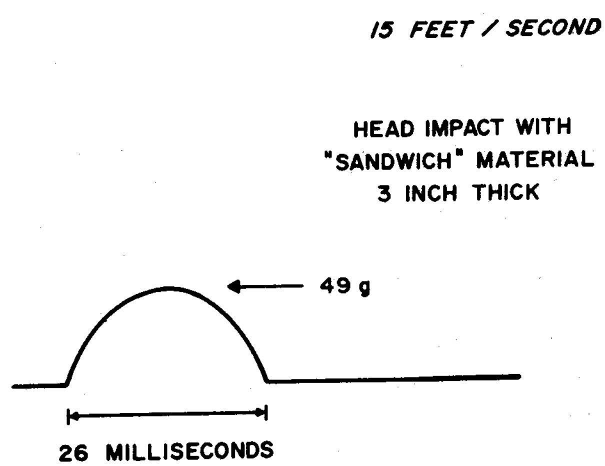

FIGURE 6.

Note that we speak of the survival level, not merely the much lower "no injury" level. Recent data concerning several thousand survivors of free falls, varying in fall heights from a few inches to thousands of feet, indicate that the human tolerance to impacts is far higher than previously suspected.[8, 9] This is a happy circumstance, in that we can now approach the "design for survival" issue in a hopeful state. Philosophically, it appears worthwhile to trade a certain number of recoverable injuries for what previously were fatal protoplasmic alterations.

Our approach to enhancing survivability in aircraft design is to start with the occupant. For purposes of illustration, we shall concentrate on the head.

The pilot's head is a globular structure, having roughly three external layers adhering to the skull. The living skull is itself slightly elastic, and can flex a bit under pressure. The brain is loosely encased inside, cushioned by the cerebrospinal fluid.

Avoiding hazardous punctures of various body parts have been mentioned. In the head, these include the globular, fluid-filled eyeballs and the frontal lobes of the brain. Just below the head, the larynx is a crucial organ, and certainly, perforation of the jugular veins or carotid arteries is serious. Prior to any anticipated impact, spectacles, if worn, should be removed. Of course, if he is accomplishing a forced landing over bad terrain and has a considerable uncorrected refractive error, he will tend to keep his glasses on, down to ground contact.

The pilot might be found in any one of a variety of types of aircraft, and each aircraft, by virtue of its internal dimensions, equipment, and mission, will require its own approach to interior survival design.

Actually, one of the most delethalized cockpits in aviation history is found in the Aeronca C–3 of the early 1930's. Good padding was placed in line with the pilot's head, should an impact occur, and the instruments were low, and back, under and the instruments were placed low, and back, under the padding.

To some extent, pilot physical characteristics will differ, and our approach will encompass the 170-pound adult male as hypothesized in the Federal Aviation Regulations (although some day the Air Force 250-pound standard may be adopted). CARI anthropologists are studying the feasibility of obtaining anthropometric data on pilot populations, in both air-transport and general-aviation categories, including both sexes and all age groups. Such data will be invaluable in future aircraft design. Already, hundreds of center-of-gravity measurements have been made on all age groups. This data is essential to proper restraint-system design.[13]

Viewing the major supporting structural elements within our subject's head, we see the skull (Figure 7), comprised of 29 bones (the total body has 206). Note that these bones are so united with one another that a spheroidal vault of great strength exists. Note also that the lower jaw is hinged in a fashion that allows considerable motion during impact, thus forestalling fracture or disarticulation.

FIGURE 7.

The skull provides very little skeletal contribution to the nose of the human, a situation that enables the nose to serve as an impact attenuator. The presence of cartilage in the human nose assists further in this function.

Enshrouding the skull, lying on its fibrous periosteum, are 51 external muscles (Figure 8). These muscles, their tendons, ligaments, and fascia lie over various portions of the skull, interdigitating with one another, and impart considerable strength to the skull-muscle system. They have considerable impact- attenuation properties.

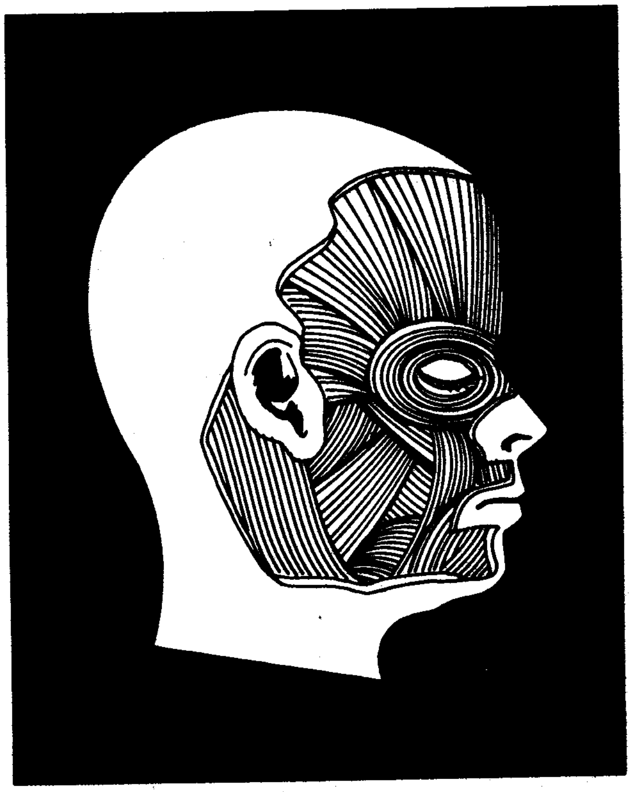

FIGURE 8.

Moving exteriorly from the muscle layers, we encounter the subcutaneous tissue, comprised of fat and fibrous elements, and consisting of a strength somewhat less than that of the muscles.

The skin and its appendages (for example, hair) constitute the final external layer surrounding the skull. As is true of most skin, considerable water normally exists in this layer.

Thus, in achieving the accomplishment of the third principle of delethalization, we have already been provided by nature with certain physical characteristics leading to the progressive attenuation of deceleration energies. Thus, although dozens of g's of decelerative force may be delivered to the face, the brain may receive but a small portion of these.

Our task is to help nature in its effort to protect and preserve the brain and return to the national aviation system as many of those as we can who, through unfortunate circumstances, are obliged to experience impacts in their aircraft. So long as man is mortal, impacts remain a possibility. Also, even though the major portions of the airframe itself have been designed to progressively obliterate the impact forces through crumpling and loss of structural components, the possibility exists that the internal cockpit environment may generate high g forces locally. Therefore, cockpit-interior improvements in delethalized design result in further extending and enhancing the upper survivability levels accomplished through the incorporation of safety features int he major airframe design.

III. Mirror-Image Sandwich Construction.

At CARI, we are undertaking an empirical and theoretical approach to understand better how impacts may be survived. Involved in this approach is what appears to be a promising means of enabling the progressive layers of the head to "share" successively in the buildup of impact forces and to avoid, insofar as possible, excessive loading of a given layer.

Figure 9 shows the "mirror-image" approach to impact protection. The outer layer of the seat (or instrument panel) is equivalent in texture and "softness" to facial skin, multiplied by a

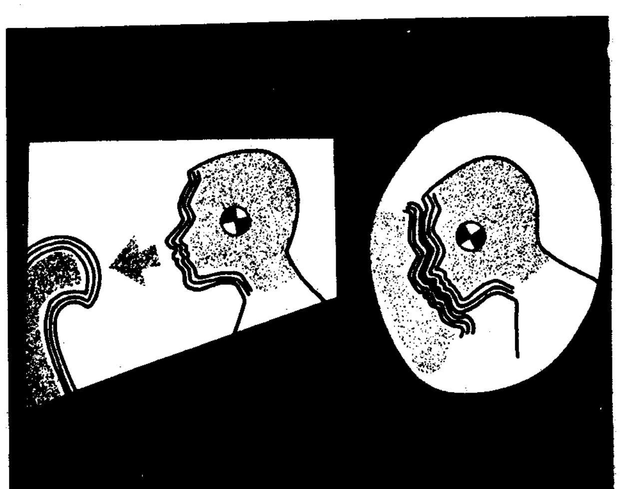

FIGURE 9.

factor determined by the prescribed peak of g forces, which is anticipated to be the point at which additional rising forces will be traded into the next layer, the subcutaneous layer. This factor is determined by the viscoelastic property of skin that results in a buildup of resistance to deformation from sudden rapidly applied decelerations.

Similarly, the next underlying layer of the structure bears a physical equivalency to the subcutaneous tissue, and the third structural layer is matched with the facial muscles.

These various layers may be made of different substances, including Ensolite, Stafoam, honeycomb aluminum, foamed aluminum, honeycomb nonmetallic materials, or other substances that deform to pressure but "recoil" as is the case with rubber.

The fourth layer matches the skull in strength, and provides the basic support in bringing the head to a stop within a sublethal deceleration-time profile.

This fourth layer may be constructed of a malleable material, including such substances as sheet aluminum. Behind the fourth layer is a filler material capable of being rapidly displaced during impacts to spread the impact forces over the greatest possible "interface" area.

IV. Feasibility.

Is it technologically and economically feasible to produce aircraft with further delethalized interiors?

Examples of partial compliance with Principles One and Two can be found in almost all production aircraft, present and past, civil and military. Many desirable features are incorporated in U.S. Army light aircraft.

Almost every specific recommendation within the context of these first two principles can be found utilized in one or another production aircraft, illustrating the feasibility of these principles.

In other words, Principles One and Two can be immediately implemented to increasing extents and can begin to appear more extensively in forthcoming aircraft. Our approach is prospective, therefore.

Implementing Principle Three will take a bit more time. The design engineer needs mathematical quantities. He needs to know the tolerances of vairous portions of the human body to impacts of various magnitudes and durations. CARI is preparing this data, a certain portion of which comes from the automobile-accident experience. Also, the appropriate materials must exist, be economically within reach, and be amenable to production techniques.

Lastly, the spirit must exist in both the seller and the buyer to "get on with the job of crash safety in an aggressive fashion."

Figure 10 illustrates an hypothetical light-airplane cockpit incorporating aspects of all three principles. A mockup is now being constructed at CARI in the interest of demonstrating in a tangible fashion various means of delethalizing the cockpit. The chief worker on this mockup is Mr. A. Howard Hasbrook, who coined the word delethalization in 1951.

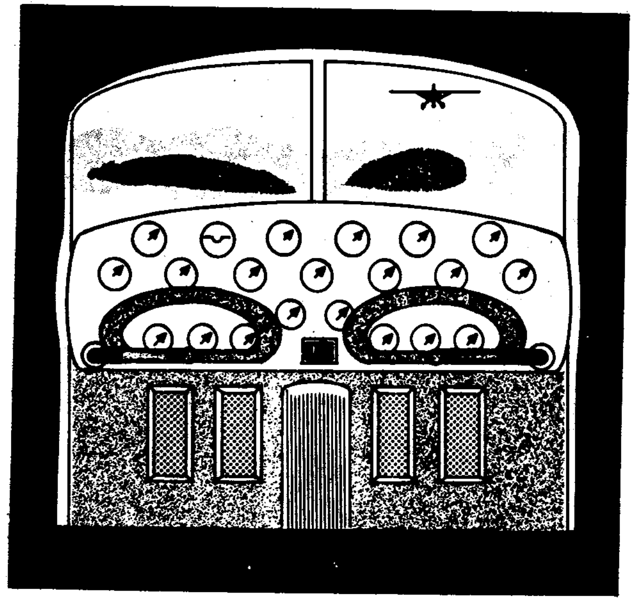

FIGURE 10.

The following are among the features contained in the CARI cockpit:

1. Noninjurious broad-surface wheel (with back-side grooving), possibly of transparent material.

2. Side-hinged push-pull rod, longitudinally telescoping, with impact "band-away" feature.

3. Countersunk throttle and propeller controls, countersunk attitude and gyro-heading-indicator adjustors, and "press-button" piano-key flush switches.

4. "Pop-back" instruments, surrounded by "mirror-image" sandwich material.

5. Center-line stand console for switches, transistorized radios, circuit breakers, fuel and trim controls, and other flight operation adjuncts.

6. Internal "back-lighted" instruments (no "eye-brow" lights).

7. "Organ-bellows" rudder pedals with smooth sandwich-material lining of the leg and foot "cul de sac" (some preliminary work with Cessna Aircraft Company on delethalized rudder pedals has recently been undertaken by CARI (Mr. Hasbrook) and Project Little Guy personnel).

8. Impact-absorbing "25-g all-directional" seats (these can be built for the 250-pound attired occupant at very little weight cost,[10] will incorporate pelvic ischial tuberosity pressure-point support,[11] and will include the features of the new BOAC delethalized seat[6]).

9. Seat-belt—shoulder-strap restraint system.

10. "Bird-proof" nondistortion, double-layer windows, providing low interior sound level and wide vision.

11. Rollover cabin-structure capability.

Subsequent to the completion of the mockup and following possible additional or revised concepts in its construction, it is anticipated that a prototype cockpit will be constructed within an actual airframe, and high-speed impact tests with anthropomorphic dummies and accelerometers undertaken.

The results of these tests will then be available to all manufacturers who may incorporate proven crash-safety features in their future aircraft. A marked decrease in the morbidity and mortality of aircraft accidents is anticipated.

Actually, in many present aircraft, the buildup of high forces during impacts is an obvious occurrence, since, for specific bones, specific maximum forces are required to produce fractures. For example, the lower tibia requires about 1,000 pounds of force applied normal to its long axis to result in a fracture.[12] Other bones have their own fail points, and one can almost calibrate the forces that accurred within the cockpit of a crashed aircraft from a study of which bones are fractured in what places.

V. Summary.

Three principles for accomplishing a high delethalization quotient within the cockpit are given and discussed.

Specific examples of existing crash-safety-design features are presented.

Finally, a description of the delethalized CARI cockpit is provided with accompanying comments relevant to future aircraft design.

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