THE DEVELOPMENT OF A NEW CONCEPT FOR PILOT PROTECTION

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Abstract

It is argued that improved protection structures and energy dissipation systems could reduce fatalities in aviation. In this paper, methods to improve survivability of pilots during likely accidents are proposed.

A study of common causes of fatalities and human body tolerance limits led to the proposal of supporting a pilot in the rather unusual prone position within a protective structure. In addition, the containing structure is designed to deflect a number of the most likely crash scenarios into a primary crash attitude, which offer increased pilot protection.

Finally, improvement of the pilot restraints is suggested, and proposals for energy-absorbing mechanisms and materials for the containing structure are made to satisfy certain design considerations.

1. INTRODUCTION

Aviation in general is considered dangerous because of the huge amount of energy involved in flying. The challenge of pilot protection arises in the management of energy at the end of the flight. The potential energy component of an aircraft can, however, be dissipated into the atmosphere during the descent, and in special cases, a portion of the kinetic energy can also be dissipated prior to touchdown.

The Exulans is an ultra-light, tailless glider under development at the University of Pretoria and has an aerodynamic layout that allows the execution of a high angle of attack (AoA) landing. This action releases some of the kinetic energy into the atmosphere but leaves the glider with enough energy, which during an accident might injure or kill the pilot. In this project, pilot protection is emphasized, and therefore a cockpit must be designed to promote survivability. An investigation of frequent aviation fatalities, human body tolerance limits, common crash scenarios, and several design considerations led to a cockpit design which incorporates energy-absorbing materials and mechanisms into an adequate structural layout.

The US Army conducted several studies on this topic, including crash testing and accident analyses, which led to the establishment of crashworthy requirements for Army rotorcraft and small fixed-wing aircraft. The US Military's SH-60 B Sea Hawk, UH-60 A Black Hawk and AH-64 A Apache helicopters were designed in accordance with the crashworthy requirements and were equipped with energy-absorbing (EA) crew seats [I].

The EA crew seat design featured a moveable seat bucket attached to the aircraft structure through an energy absorber, which displaces or "strokes" towards the helicopter floor to absorb some of the energy during a high impact event [2]. Much of the work in the past focused on the protection of normally seated pilots, where the main objective of the EA seat was to prevent spinal injury to the aviator [3].

In addition, this paper proposes a new-concept pilot protection system where the pilot is supported in the prone position. The conditions needed to avoid fatalities during a crash are investigated in context with this position. Avoiding injury or death to a pilot during an accident requires the knowledge of how and why pilots die in accidents and, for this reason the major causes of pilot fatalities are investigated.

2. CAUSES OF PILOT FATALITIES

The major causes of pilot fatalities can be classified into four categories [4].

2.1 Thermal

Half of all fatalities in aviation accidents result from thermal injuries, which involve burning and smoke inhalation. Although a physical solution to post-crash fire is not presented in this paper, it can be argued that avoiding injury to the pilot will increase the ability to evacuate the cockpit in time.

2.2 Intrusive

Intrusion into, or loss of, occupiable space has caused, for example, decapitation by electrical wires or fences. Penetrations into the body by intruding elements can lead to excessive bleeding or fatal organ damage.

2.3 Impact

This type of injury is explained as impact of the body into an object, or visa versa, causing a local deceleration and impact force. Frequently reported injuries are concussion or skull fracture due to the head of a pilot impacting onto the instrument panel. Internal organ damage caused by seat belts or by the controls is also common. Impact can also result in internal bleeding due to lacerations caused by bone fracture.

2.4 Decelerative

The organs of the human body are very sensitive to high decelerations. Fatalities can occur due to fracture dislocation of the neck (C1 on C2 at 20-40G), or organs tearing loose, e.g. Aorta transection (80-100G).

3. HUMAN BODY TOLERANCE LIMITS

Tolerable deceleration forces imply that the crash forces do not exceed those tolerable by the human body. Aircraft accident investigators describe three-dimensional crash forces acting on the human body in terms of imaginary eyeball movement. For example, an ejection seat will cause an eyeball-down scenario, while an aircraft carrier landing will cause an eyeball-out scenario.

Studies of the human impact tolerance limits revealed that the human body can tolerate the highest G-forces in the G_X or eyeballs-out direction (Figure 1). A pilot can tolerate exposure of 45 G's for up to 0. 1 seconds in the eyeballs-out direction without serious injury. Compare this to the vertical (eyeballs-down) limit of 25 G's over 0.1 second which, when exceeded resulted in numerous spinal injuries.

Would it not, therefore, make sense to support the pilot in the prone position (Figure 2), which will offer increased tolerance to decelerations and less vertical body volume for organs to displace? Additionally, during a likely crash event with components of high horizontal and vertical velocity, the loads transmitted to a pilot in the prone position will not act along the spinal columx, but, rathers transverse to the spine. Compression and elastic dynamic response of the vertebrae will therefore be restricted due to the direction of the applied forces.

4. CRASH SCENARIOS

Having a good idea of why pilots die, and also knowing the human body tolerance limits, can lead to a preventative approach in the design of the protective system. Injury mechanisms can be identified and prevented by investigating likely crash scenarios.

Consideration of this information can result in a good cockpit design. It is important, however, to realize that it is an impossible task to design a cockpit for every possible crash scenario., Eight of the most likely high-energy crash scenarios conceivable with the Exulans, are therefore specified below.

4.1 High-impact Belly Landing

This scenario would follow from bad judgement by the pilot during a landing attempt.

4.2 Nose Impact

A nose impact would follow from a stall at a low altitude or from spinning into the ground. The impact angle is specified between 00 and 900 with respect to the impact surface.

4.3 Tail Impact

This scenario could happen during the execution of a high AoA landing. If this maneuver is not well executed, the glider will gain some height from which it will fall back in a tail slide.

4.4 Pitch-Over

The friction force on the undercarriage in rough terrain can cause the glider to pitch over the nose.

4.6 Ground Loop

This generally results from retarding of one wing on the ground, causing a rotation around the yaw-axis.

4.6 Wing-Tip Impact

Not keeping the wings level during a landing approach or while flying on a low-level on sloped terrain, or any asymmetric contact with an object, will cause the glider to rotate around the wing and nosedive into the ground.

4.7 Mid-air Collusion

Flying into an object.

4.8 Parachute Landing

The Exulans is equipped with a ballistic parachute, which brings down both pilot and airframe with parachute-descent velocity. When deployed at an insufficient altitude, this would be a high-energy impact scenario.

5. DESIGN CONSIDERATIONS

Designing an aircraft cockpit for maximum survivability requires the consideration of five design factors known as the CREEP factors.

5.1 Container

The container of an aircraft is the living space or protective shell around the occupants.

Impediment on the living space during the dynamic portion of the crash will drastically reduce the survivability of the occupants.

The structural layout of the Exulans container is shown in Figure 3. In addition, the container is designed to deflect a number of the specified crash scenarios into an attitude where energy absorption can proceed in the most efficient way, which offers maximum tolerance to deceleration of the pilot.

5.2 Restraint

Occupants in a moving vehicle must be restrained to protect them from being thrown against the sides of the container. When restraining humans, it is important that the restraint system not contribute to injuries in the attempt to prevent undesired movement.

5.2.1 Torso Restraint

Statistics indicate that serious injury is most frequently sustained in the head. This can be attributed mainly to the lack of adequate torso restraint, which causes the head to gain a greater relative velocity than the surrounding cabin. This phenomenon is termed dynamic overshoot, and causes unrestrained portions of the body to strike objects in its path with a high velocity. This is especially true for aviators sifting in the cockpit environment facing the instrument panel and flight controls.

5.2.2 Lap Restraint

The lap belt is used to restrain the pelvic joint, which is the portion of the body best able to withstand high G loads. Lap belts providing restraint at the wrong place will either put excessive loads on the stomach and other internal organs, or are likely to allow the pilot to be squeezed through the gap between the belt and seat, which is referred to as "submarining".

In the prone position, the pilot will be supported on a rigid plate that is molded to the shape of the chest. The plate will act as a passive restraint system where the pilot has continuous contact with his restraining surface. Compare this system with a conventional three or four-point active restraint system where 2.5-inch webbing and steel buckles are used to restrain the torso, and which has failed or has caused additional injury in the past.

Some other advantages of the passive chest plate support system is that it limits dynamic overshoot of the head due to improved torso restraint, and it eliminates the potential for "submarining". Additionally, support provided over a large surface will result in a much lower pressure distribution, that will decrease the probability of impact injuries. The rigid chest plate would also avoid penetration of the upper body.

5.3 Energy Absorption

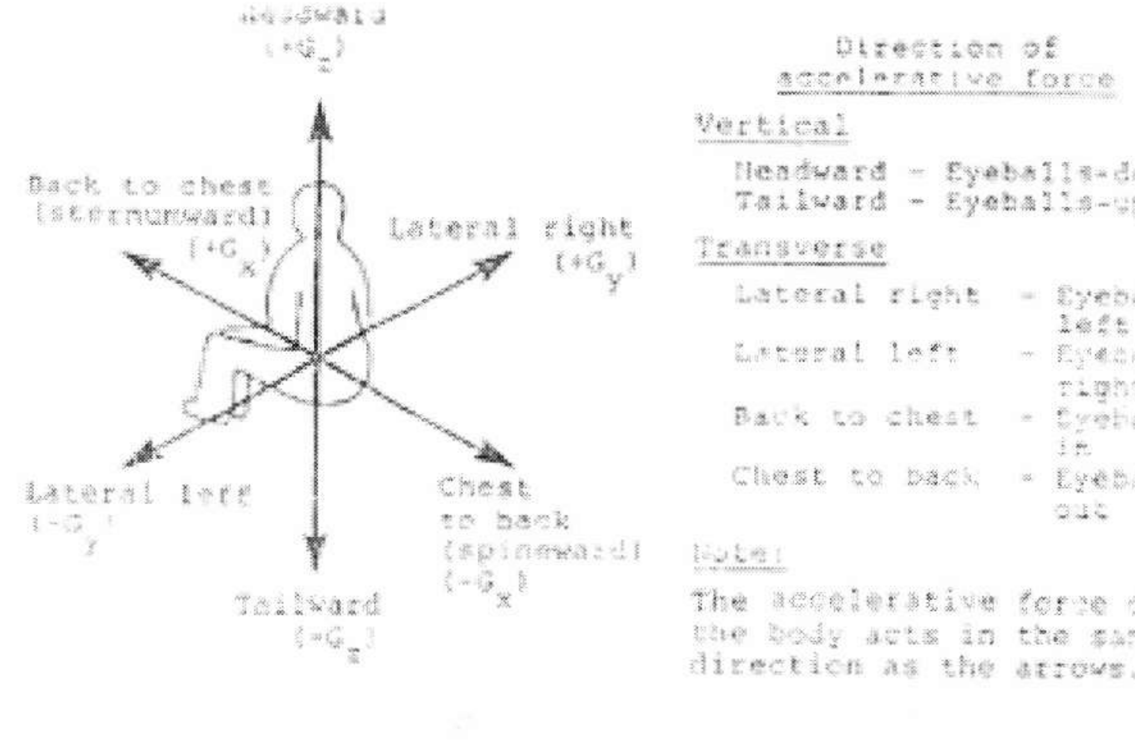
Even in the presence of a safe living space and adequate restraint, impact forces during a crash can be high enough to cause serious or fatal injury. Energy-absorbing materials and mechanisms must be provided in an attempt to attenuate impact forces to tolerable levels.

5.3.1 Materials

The use of correct materials in the construction of the fuselage structure will promote energy absorption. Numerous studies have shown that high energyabsorption per unit mass is possible with composite materials which fail when compressed. In some circumstances, these energy-absorbing properties exceed those which can be obtained from metal structures of similar size [6]. A typical value for the specific energy absorption (E,) of carbon fiber-lepoxy tubes is 100 kJ/kg as against the 80 kJ/kg of similar geometry aluminium tubes [5].

5.3.2 Mechanisms

The Exulans will be equipped with a collapsible landing skid operating on the principle of a Parallelogramming Motion Energy Absorber, which constitutes the absorption of energy through the elongation of a diagonal EA element



Direction of accelerative force

Vertical

Headward - Eyeballs-down
Tailward - Eyeballs-up

Transverse

Lateral right - Eyeballs-left
Lateral left - Eyeballs-right
Back to chest - Eyeballs-in
Chest to back - Eyeballs-out

Note:

The accelerative force on the body acts in the same direction as the arrows.

Figure 1. Terminology System for Describing Forces on the Body

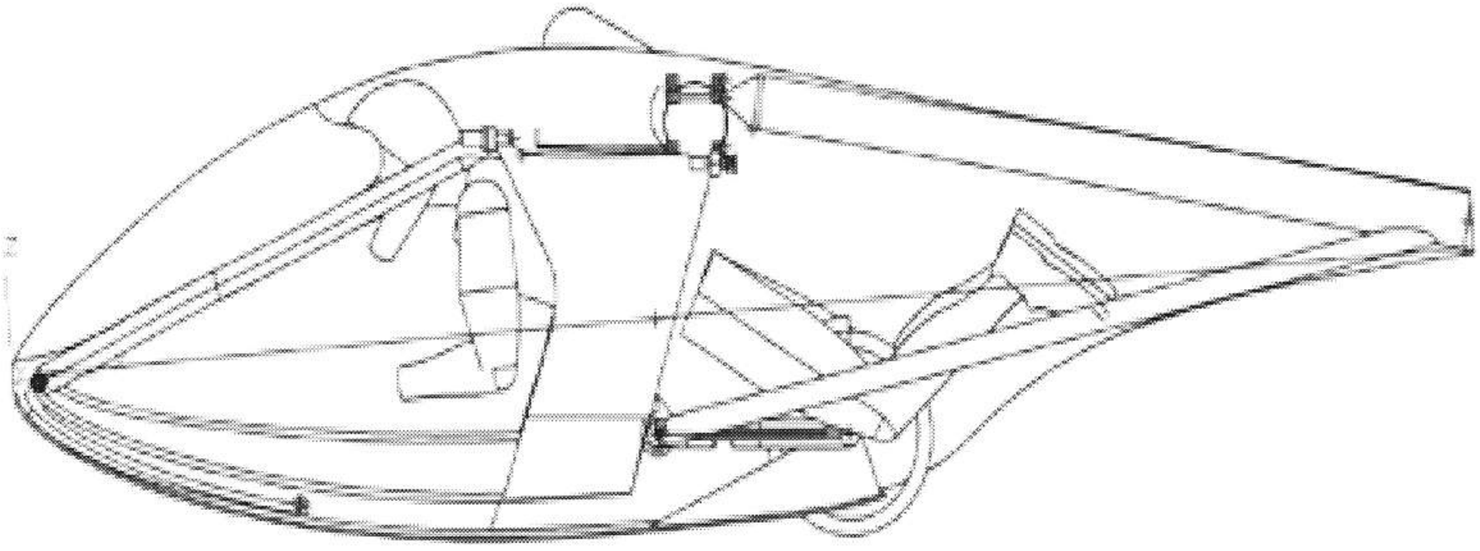


Figure 2. Pilot supported in the prone position.

while collapsing in a parallelogramming motion. The pilot will manually deploy the retractable landing skid, which will absorb excessive energy in the event of a bad landing. Crash protection of the pilot is achieved by mounting the chest plate on a guided vertical-stroke energy- absorber.

5.4 Environment

The flailing envelope of the occupant is defined as the volume through which unrestrained portions of the body can move. A "clean" environment in the flailing envelope should be provided. This will include the elimination of any potential harmful objects including sharp points and edges. Padding or energy-absorbing materials can be provided at potential impact surfaces.

5.5 Post Crash Factors

All too frequently, occupants survive the dynamic portion of the crash only to suffer additional injury or death because they could not exit the aircraft in time. Apart from the major factor responsible for post-crash fatalities (post-crash fire), other scenarios should also be considered.

The time taken to evacuate could be much reduced if a pilot could be protected during the dynamics of the crash. In addition, the Exulans fuselage will be equipped with a "quick release" back part, and will also be made buoyant (water landings) to assure swift exit and accessibility to the pilot.

6. CONCLUSION

Based on studies of frequent fatalities in aviation and human body tolerance limits, a proposal to support the pilot in the prone position is made. Investigating likely crash scenarios also promoted the suggestion of this pilot position, which offers both improved tolerance to G-loads and potential for more efficient restraint.

Considering the five design CREEP factors, a protective structure that will deflect a number of the specified crash scenarios into a more efficient energy-absorbing attitude is proposed as a design. Additionally, by incorporating energy-absorbing mechanisms and the correct materials into a fuselage with an adequate structural layout, will increase survivability during an accident.

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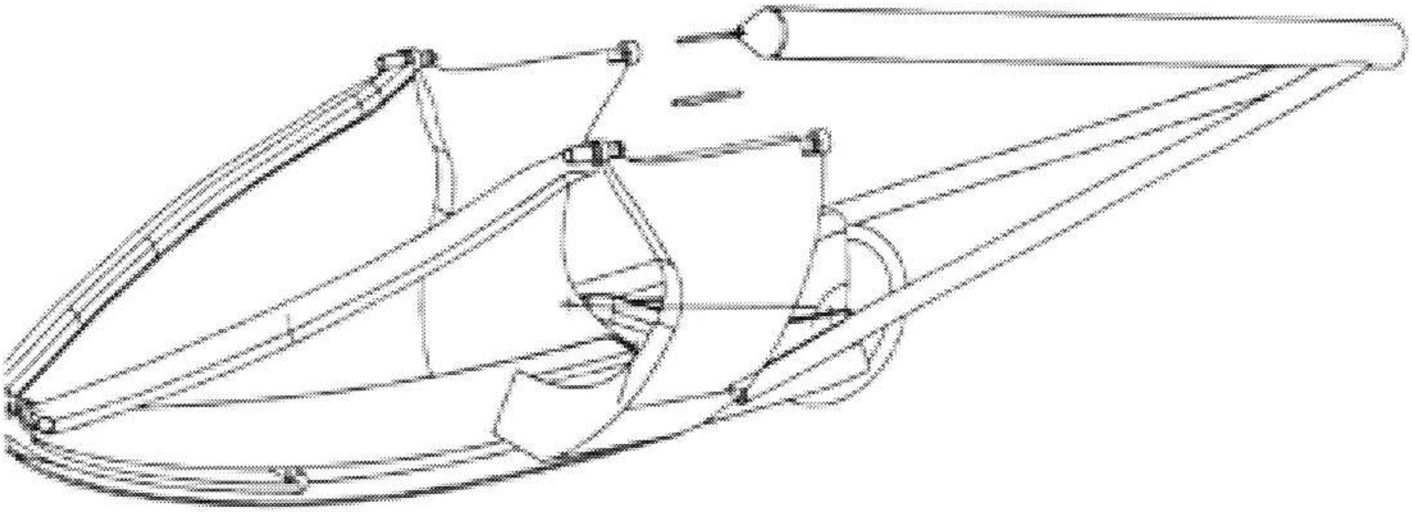

Figure 3. Exulans fuselage structural layout

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