PILOT SAFETY AND SPINAL INJURY

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This article studies the safety of the pilot seated in the cockpit of his glider. Fracture of the bones of the spinal column may occur in an accident. Damage to the fragile nerve-fibres of the spinal cord may follow; this can cause permanent paralysis of the lower body and legs. Three factors that may reduce the risk of spinal injury are considered. First, fully supporting the pilot's back. The seat structure should have no projections into the pilot's back, but should be smooth. The parachute pack should be long enough to support the spine, especially the lower (lumbar) spine. Second, the natural curvature of the lower (lumbar) spine should be maintained by a firm lumbar support pad, or by a fiberglass or plastic lumbar support shell. Third, soft foam seat cushions should not be used, as they cause an increased load on the spine, together with rebound in an accident. Instead, energy absorbing foam cushions should be used. Successful tests on energy absorbing foam cushions have been carried out at the Royal Air Force Institute of Aviation Medicine, Farnborough, England. Suggestions for improving pilot safety in the next generation of gliders are put forward.

Introduction

Glider wings have got longer and longer and penetration greater and greater. If the ace pilot at the controls of this super glider has an accident, he may be severely injured. Unprotected from injury, he slides forward underneath his safety harness, his legs being simultaneously crushed as the glider nose collapses and broken by the sharp lower edge of the instrument panel. Compressing his soft foam cushion he strikes the hard seat, just as his glider is rebounding upwards from the original impact. Sitting curved forward, his spine has little resilience. If he is wearing a short parachute pack with a hard sharp lower edge, there is a stress concentration at this level. The bones of his spinal column fracture. Next, the fragile nerve-fibres in the spinal cord are severed, resulting in life-long paralysis of the legs and lower body and loss of bladder control. Our pilot, full of youth and skill and love of life, ends his days in a wheelchair.

An exaggeration you say? Not at all. An English pilot stalled in a PIK20D in April 1984 from a height of 70 feet. He incurred a fracture of the spine and damage to the spinal cord (containing the nerve fibres). To quote his letter:

"I have had a lot of time to reflect. I was hospitalized for six months and remain paraplegic, although some recovery in feeling, natural functions and limited movement has taken place over the two years since to enable me to walk a little on calipers each day. My parachute pack left the lumbar (lower) spine unsupported. I would thoroughly support your recommendations for proper seat padding, careful attention to the parachute pack to ensure continuous support for the spine and "progressive collapse" zones built into the seat pan of gliders. There could continue to be severe injuries to the spine (with all the misery that such an injury implies) unless we recognize the need and do something about it."

For the past two years a study has been taking place at Lasham Gliding Center, England, with the assistance of the Royal Air Force Institute of Aviation Medicine (IAM), Farnborough, on reducing spinal injuries in gliding accidents. There are three factors of importance: (1) Fully supporting the back, (2) Maintaining the lumbar curvature of the spinal column, (3) Using energy absorbing seat cushions.

All these safeguards can be simply and cheaply installed in present-day gliders. Even greater safeguards against pilot injury can be incorporated in new glider design with little, if any, penalty in performance and cost.

Strength of the spine

This has been thoroughly researched in military studies for use in ejection seats. The healthy human spine can withstand 25 g in compression, with a maximum rate of rise of g of 300 g/second.

No one knows the actual forces and acceleration involved when a glider crashes. The IAM is willing to crash-test a glider containing an instrumented anthropometric dummy. A suitable written-off modern fiberglass glider is required. Once the forces involved are known, suitable airworthiness requirements could be drawn up for new glider designs to give the pilot increased protection in an accident.

Seating position

There are two seating positions in gliders. First, the upright seating position, as in the ASK-13. There is only a small "bearing-area" on the seat, and the entire vertical force of a crash compresses the vertical axis of the spinal column.

In modern low profile gliders the pilot is in a semi-reclining position. This has two advantages. The "bearing area" on the seat is greater. Next, because of the resolution of the forces involved, only a fraction of the vertical force of a crash acts along the vertical axis of the spine. However, the head and neck become vulnerable and a head-support is essential.

Support of the spine

In some gliders the seat structure projects into the back of the pilot. An example is the lower edge of the parachute cut-out in the ASK-13. At Lasham, this cut-out has been filled with a removable plywood fillet to give smooth support to the back when no parachute is worn.

Modern parachutes are usually thin, with a supple outer cover and are long enough to support the entire spine of even a tall pilot; the parachute pack has a soft lower edge. This design of parachute is to be recommended.

Many parachutes in use in gliding clubs are surplus large military canopies for cheapness. This results in a thick parachute pack, often with an inflexible outer cover to cope with the hard use of a gliding club. The parachute pack is often short, so the lower spine of even a moderately tall pilot is left unsupported. The hard lower edge of the parachute pack gives a stress concentration on the spine. In the event of a crash, the spine may fracture at this level.

Short pilots, and this includes most women, require cushions behind them, so they can reach the controls and instruments. These cushions should not be made of soft foam. A suitable cheap alternative is to use Dunlopillo D76 firm chipfoam. (This chipfoam is not energy absorbing, see below.) One female pilot at Lasham reports an incident in a two-seater glider in the old days when she sank back into the soft cushions she was using and was unable to exert full forward stick movement. She had to hand over control to the other pilot. One wonders if some unexplained accidents have been caused by pilots sinking into soft cushions at high load factors and being unable to exert full control movements.

Support of the lumbar spine

The late Dr. Stedfeld of Germany in his reports to OSTIV in 1978 and 1981 stressed the importance of maintaining the curvature of the lumbar spine. This enables the spine to maintain its natural resilience and resist a considerable vertical force. If the spine is bent forward, as it is for a pilot seated in most gliders, there is little natural resilience remaining and the spine will fracture at a low vertical compression loading.

Studies have been carried out in the United States by shooting cadavers up an ejection tower. This work has shown that a lumbar support pad strengthens the spine in compression by 50%. It is not known if the same result would be obtained with live human subjects.

The late Sir James Martin of the Martin-Baker Company carried out studies in 1945 in England on the importance of keeping the spine straight so as to absorb maximum energy, and limiting maximum acceleration and the rate of rise of the acceleration. One cannot help but wonder how many pilots have suffered fractured spines unnecessarily in the past forty years due to this simple finding being forgotten. Will it be another forty years before anything is done?

There are several different methods of supporting the lumbar spine. IAM has developed a simple method of making a fiberglass shell shaped to fit each individual pilot's back. This fits between the pilot and the parachute, and is the method recommended by Dr. Stedfeld.

Alternately, and more cheaply, a lumbar support pad can be made from firm material, such as DLR 90 foam (see below) in a cotton cover. This can be fastened around the

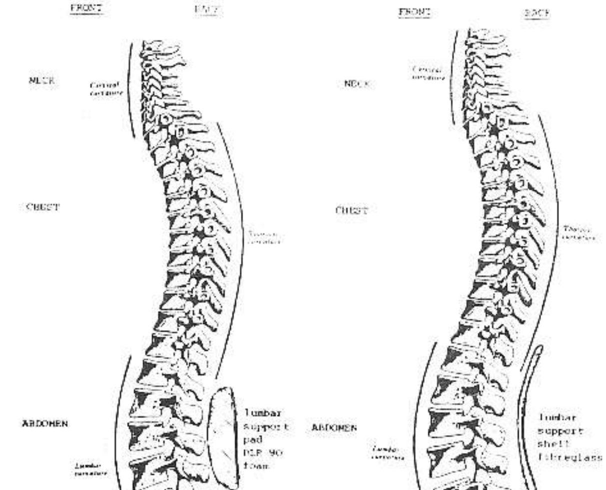


FIG.2 The Spinal Column, side view-Gray's Anatomy, 36th Edition

waist with a strap, or attached to the back of the parachute pack with velcro or a flap of cloth, allowing the position of the lumbar support pad to be altered to suit the pilot's comfort.

If a parachute is not worn, a lumbar support pad can be glued to the seat back.

Crash landing and the glider structure

In a letter to me in August 1985, David Gilson of the Royal Aircraft Establishment wrote: "In a crash landing, the resilience of the cushion is just one element in a complex assembly of resiliences (both elastic and plastic) which may include the ground itself, the undercarriage wheel or skid, local deformation of the fuselage at the impact point and more general distortion of the fuselage, eg, "ovalling," distortion of the seat attachment point, distortion of the seat structure, deformation of the flesh of the buttocks and deformation of the intervertebral discs of the spine. Thus, the shock absorbing effect of thin foam may only provide a fraction of the absorption of the overall system, therefore adjustments to the foam cannot make a dramatic difference to the overall loading of the spine. However, every little helps, and it is certainly true that any foam should be firm."

Energy absorbing seat cushions

Many pilots sit on soft foam cushions for comfort and to improve their view from the cockpit. In the event of a heavy landing the cushion will compress until it becomes solid. This results in a peak acceleration, and also rebound may occur. This rebound may coincide with the glider rebounding from crash resulting in even greater loads on the spine.

Dunlopillo (Dunlopillo Division U.K., Hirwaun Industrial Estate, Aberdare, Glamorgan, South Wales, CF44 9UR, U.K.) has developed energy absorbing foam for use in ejection seats. It is an excellent material to use for glider seat cushions. This Dunlopillo Low Resilience Foam — DLF foam 0 is a high density polyether-based polyurethane molded foam, specially formulated to give suitable energy absorbing properties. It is supplied to Lasham in two grades, one inch thick hard DLR 100 and half inch thick firm DLR 90.

Under load, the DLR foam compresses gently and slowly, then gradually recovers. As long as the foam is not overloaded, no rebound occurs.

Some problems remain with the DLR foam, but I thoroughly recommend its use as it has great advantages over the foams currently in use. The problems are as follows: It is inflammable, so if used in motorgliders or in light aircraft it should have a fire-resistant cover. It is fragile and deteriorates in ultraviolet light, so a cushion cover should be used. The foam becomes considerably harder at temperatures below 10 degrees C. The effect of this increase in hardness on the energy absorbing capacity of the foam is not known; tests need to be carried out on this point. This is important as people glide in varied climatic conditions and the cockpit gets cold at high altitude. In practice, the heat of the pilot's body softens the foam after a minute or so, and makes it comfortable.

Tests on energy absorbing cushions

In December 1985 and January 1986, two series of tests were carried out at the IAM, by courtesy of The Commandant, Air Marshal P. Howard, using the decelerator track and the helmet research laboratory facilities. The experimental team involved were Wg. Crd. David Anton, Ft. Lt. Ian McKenzie and Higher Scientific Officer Roger Gilkes.

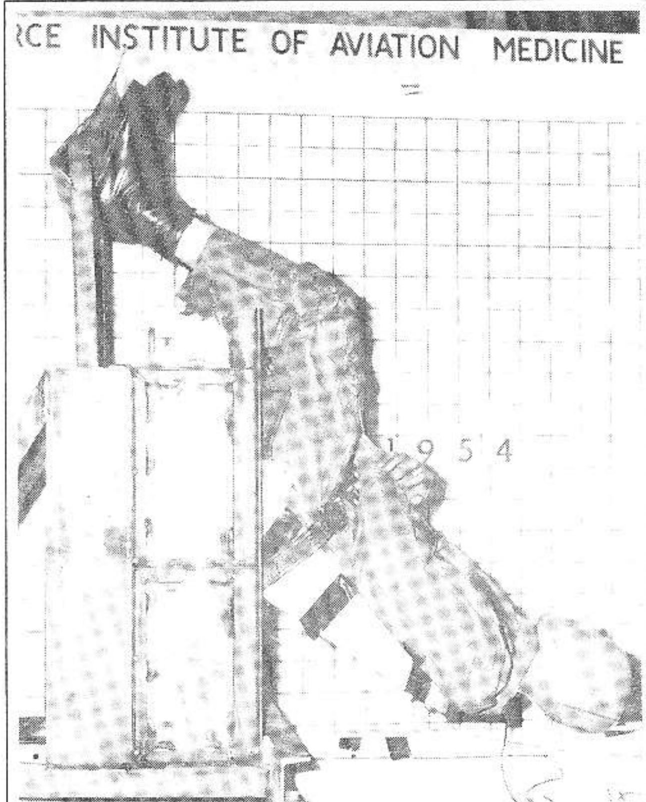


FIG. 1 The anthropometric dummy pilot is strapped to an aircraft seat. The airccraft seat is mounted on the test vehicle on the decelerator track. The cushion under test is placed between the dummy pilot and the aircraft seat. Photo-Crown copyright.

Decelerator track

The test vehicle runs on a 120 ft. long track propelled by elastic bungies and is stopped by hydraulic rams. An aircraft seat is mounted on the test vehicle. Strapped to the seat is an instrumented anthropometric dummy weighing 165 pounds. The peak g readings recorded by an accelerometer mounted at the base of the spine were as follows:

1. Bare seat. Peak g was 35 g. Rate of rise of g was 2,600 g/second.
2. Ordinary soft foam cushions, two and a half inches thick. Peak g was 45 g. Rate of rise of g was 4,350 g/second.
3. Sandwich of half inch thick DLR 90 on one inch thick DLR 100 energy absorbing foam cushion. Peak g was 26 g. Rate of rise of g was 1,100 g/second.

The tests had to be carried out within the limits of the decelerator track which meant the rate of change of g was very high as was the velocity at impact of 8.1 m/second. The aircraft seat was rigidly mounted on a solid metal structure, so there was no give as there would have been in a glider crash. However, the figures clearly show the increase in loading on using an ordinary soft foam cushion and the enormous improvement if an energy absorbing cushion is used.

Helmet research laboratory

A series of 30 tests were carried out dropping a 5.16 kg weight from various heights onto foam placed on a metal anvil. The readings from an accelerometer in the weight were displayed on an oscilloscope, which was photographed on Polaroid film. The most important results are as follows:

1. The weight was dropped from a height of 0.1 m onto flat plywood, representing a glider seat without cushion. There was no initial energy absorption. There was a high peak loading of 300 g over 0.2 milliseconds, followed by excessive rebound.

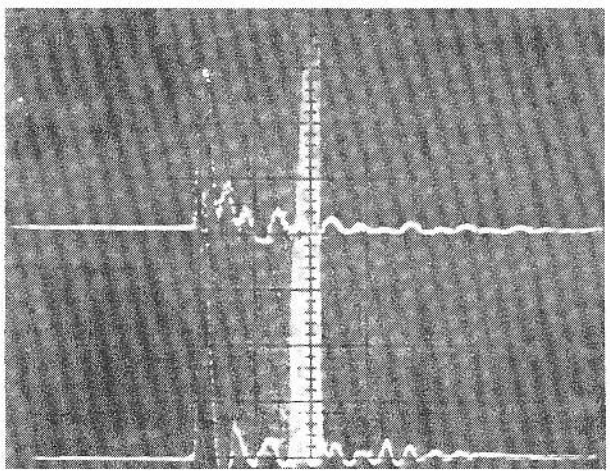
2. The weight was dropped from 0.5 m onto unloaded soft foam 2 1/2 inches thick. There was little initial energy absorption. There was a high peak loading of 480 g over one millisecond followed by excessive rebound.

3. The weight was dropped from a height of one meter onto a sandwich of half inch thick DLR 90 foam and one inch thick DLR 100 foam. (A lower test drop was not carried out because, during the course of the tests, it was obvious that the material could easily cope with a lower energy drop.) There was a prolonged plateau of low g (20 g) lasting four milliseconds building up gently to 80 g over a further five milliseconds. No rebound occurred.

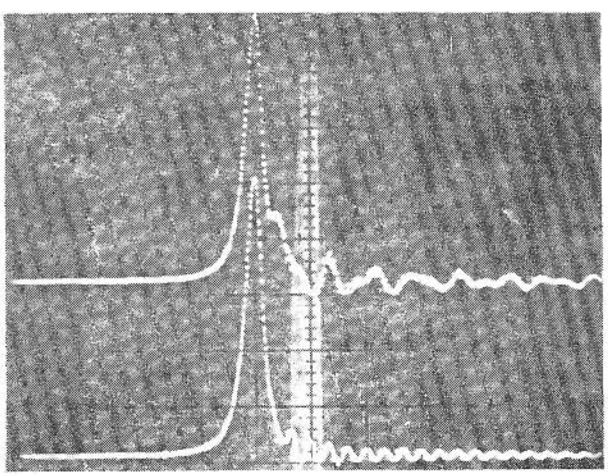
Although these tests are not directly applicable to the pilot/glider situation, it is clear that soft foam cushions should no longer be used but should be replaced by energy absorbing cushions.

FIG. 3 Drop Tests, Helmet Test Laboratory, I.A.M. Farnborough

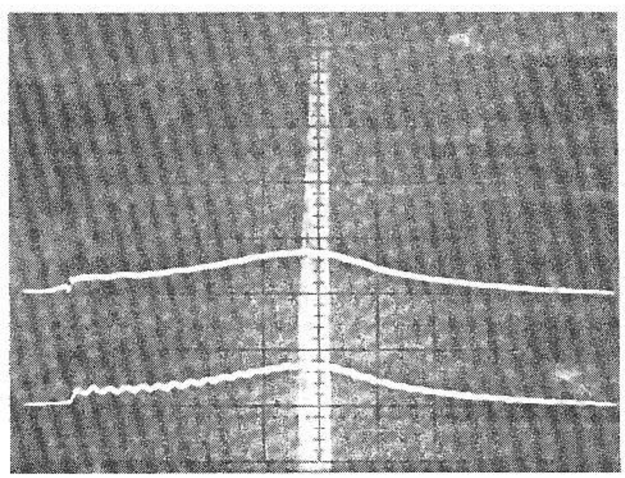
Flat Impactor Weight-5.16 kg
Horizontal Time Scale-1 large square = 2 millisecs
Vertical Scale-Upper Trace-Accelerometer in weight-1 large square = 100 g
Lower Trace-Load cell in anvil-1 large square = 10,000 Newtons



Flat Plywood
Drop Height = 0.1 metre



Soft Foam Cushion 2 1/2 Inches Thick (Unloaded)
Drop Height = 0.5 metre



Energy Absorbing Cushion1/2 Inch DLR 90 on 1 Inch DLR 100
Drop Height = 1.0 metre

Suggestions for fitting DLR cushions

An efficient cushion can be made from a half inch layer of firm DLR 90 foam on a one inch layer of hard DLR 100. As well as being comfortable, this gives a stepped effect, with gentle prolonged energy absorption. Tall pilots will find this cushion too thick, and their heads will hit the canopy.

At Lasham, a one inch thick layer of hard DLR 100 has been used in the ASK-13s. Although initially, it feels hard, after a few minutes it moulds to the pilot's shape and becomes very comfortable for prolonged use.

DLR 100 foam is very firm, and if it slips forward it could prevent free movement of the control column. It should, therefore, be securely fixed to the seat by press-studs or ties. It should not be glued to the seat, as it is an open cell foam and will absorb water. DLR 90 foam is soft enough not to interfere with movement of the control column; nevertheless, it should be securely fixed to the seat.

In low-profile gliders, I feel an inch layer of firm DLR 90 foam is satisfactory. It will mould easily to the complex seat-pan shape of the glider, and is comfortable for long flights. In theory, this cushion should extend the full length of the pilot's back. However, this would be expensive and would also lift the pilot's head nearer the canopy. Probably, the cushion should extend up to the point where the back becomes more vertical; it should be gently tapered off at this point.

Safety in the new generation of gliders

During the course of this study, a large number of pilots have made suggestions for improving pilot safety.

1. The legs should be protected by a strong structure in front of which is an energy absorbing zone.
2. The legs should be protected from impact with the lower edge of the instrument panel, which should be broad and suitably padded.
3. The canopy should be high enough for a lumbar support to be worn, and for energy absorbing cushions to be used.
4. An energy absorbing seat should be installed. This could be made of metal or plastic honeycomb material. Space should be left free of glider structure and control runs beneath the seat to allow for this installation. The amount of energy absorbed depends on the depth available. A compromise would have to be reached between the requirements for increased fuselage depth to give greater depth to the seat, against the increase drag and consequent reduced performance of having a deeper fuselage.
5. Two adjustable "negative g" straps should be fitted passing between the thighs and attached to the seat-harness coupling. These will prevent "submarining" out of the seat harness in low-profile gliders. They will also stabilize the set harness as a whole.
6. There should be no projections at the rear of the cockpit on which the parachute pack or harness may catch.
7. It should not be possible to undo the parachute harness in error when releasing the seat harness in an emergency.
8. The landing wheel should be sprung, and be well damped to reduce rebound.
9. Provision should be made for the secure fitting of ballast. This fitting should be able to withstand the loads imposed by a crash landing.
10. The fuselage below the pilot should be strengthened to prevent penetration injury on a heavy landing on a rough surface.
11. The canopy should be strengthened to prevent injury by wire fencing.

Use of safety seating in Lasham/ASK-13s

These have now been in intensive use for the past one and a half years. The instructors have to suffer repeated heavy landings at the hands of their pupils; the instructors report that their backs are much more comfortable at the end of a hard day's instruction. The pilots are held firmly in the glider, so they feel much more part of the machine. The pilot's eye level is slightly higher as he does not sink into the seat cushion and his back is straighter; he will have to monitor his speed carefully for the first few flights, as the nose of the glider will be in a different position relative to the horizon.

Heavy landing accident at Lasham

A few months ago, an ASK-13 dived into a field at the end of the runway at Lasham. The pupil had pushed the stick forward at the last moment, and the instructor had no time to correct. The glider was approaching at 65 knots and made a six-inch depression in the soil of the field; it then bounced and landed heavily. The glider was extensively damaged, but the pupil and instructor were completely unharmed. In the opinion of the Manager of Lasham and the Safety Officer, the fact that the crew of the glider did not receive spinal injuries resulted from the use of the safety seating.