designing a sailplane safety cockpit

All accidents involve the ground sooner or later, the pilot can be protected by an energy-absorbing "Formula 1" type cockpit

Tony Segal
from *Sailplane & Gliding*

Safety features may be built into new gliders with little or no effect on performance, but fitting some of these improvements into existing gliders is more difficult. Moreover, the incentive for the manufacturers to fit safety features in new gliders as standard has to be led by pilot demand.

Survivable loads on the pilot

The survivable load on a pilot depends on the direction of the impact, the acceleration, and the duration of the impact. A load in the direction of the pilot's spine (the z-axis) is the limiting case compared with the fore-and-aft case (the x-axis). The sideways impact (along the y-axis) is considered to be less significant.

During a z-axis impact there is a risk of severe spinal injury as well as injury to the internal organs; a vertical impact causes the heart, diaphragm and liver to move up and down as a single unit. If the heart tears away from its main connecting blood vessels, the pilot will die.

The effect of deceleration and duration of the impact are shown in the Eiband diagram (Figure 1) where deceleration in terms of g (g = 9.81 m/s/s) is shown with respect to the duration of that deceleration in seconds. It will be seen that the shorter the duration of the deceleration, the higher the value of sustainable deceleration the pilot can tolerate, and vice versa.

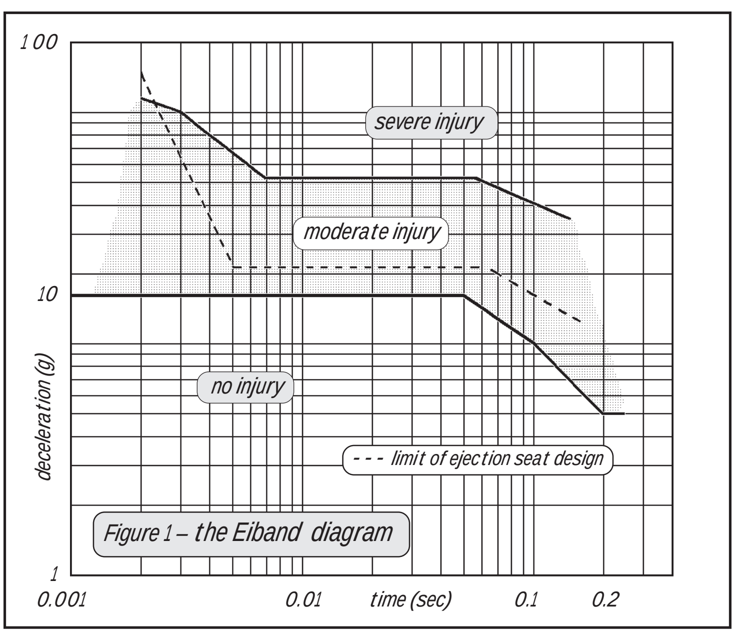


Figure 1 – the Eiband diagram

There are three areas shown: the bottom represents the area of voluntary human exposure, (ie, the amount of g to which we are voluntarily prepared to expose ourselves) after which we remain uninjured and undebilitated. The shaded middle area represents an area of moderate injury, such as slight injury to bones of the spine. This is the region to which the limits for military ejection seats are designed.

Lastly is the area of severe injury or death. One special region is shown at 0.2 seconds (5 Hz); this is the frequency at which the spine resonates and to which we have an especially low tolerance.

These limits apply to young, fit, seated, harnessed pilots. The limits are reduced for the elderly, for those with previous spinal injury, or for those in an unfavourable seating position. Yamada produced a table showing the reduction in the breaking load of lower spinal (lumbar) vertebrae with age, as follows:

Age	*Breaking load, kN (lbs)*
20–39	*7.14 (1605)*
40–59	*4.67 (1050)*
60–79	*3.01 (677)*

The aim of improved aircraft design is to ensure that a pilot is exposed to forces arising from only the bottom and middle areas of the Eiband diagram. Initially, design to minimize decelerations along the x-axis (the fore and aft direction) will be considered.

Impact in the fore & aft direction

Cockpit improvements are based on the concept of a strong survival cage around the pilot, with an energy absorbing structure in front. This is the method used in modern car manufacture. In 1991, I asked Frank Irving if he would calculate the effect on drag and hence performance of increasing both the length and depth of the glider fuselage by 0.5 metres. The decrease in maximum L/D was 5%. The decrease in L/D at 80 knots was 10%. Clearly this decrease in performance was not acceptable; I devised the aphorism, "better broken legs than dead".

The structure from the nose cone to the plane of the control column should collapse progressively on impact, with a consequential risk of injury to the legs. The cockpit structure aft of the control column should form a strong cage protecting the vital organs of the pilot's body. The external design of the glider would be unaffected, as would the length and fittings of the glider trailer.

In 1997, Prof. Loek Boermans, of Delft University in Holland, studied the effect on fuselage drag of extending the nose alone (the fuselage depth remaining unaltered). Prof. Boermans showed that the increased drag is insignificant when the depth of the fuselage is not altered.

This finding offers the opportunity of extending the energy absorbing nose of the glider without adverse effects on performance, and hence offering some protection to the pilot's legs.

Test of a new cockpit design

Martin Sperber, of TuV Rheinland, Cologne, carried out a significant test in January 1998. A glider cockpit was designed using Formula-1 racing car technology, the test impact being into a skip of earth. I was invited to observe the test.

Eight out of ten glider accidents in Germany occur on grass or bare soil. Allowing the glider to penetrate the soil would help to absorb the energy of the impact. This theory required the provision of a very stiff cockpit structure. A skip of "standard earth" was provided, the load-bearing power of its compacted soil being tested by an ingenious Russian instrument usually used to test airfield surfaces. The cockpit was built from a composite material consisting of carbon fibre and *Dyneema,* a polyethylene fibre.

The cockpit was built in a Glasflügel Hornet mold, although the final construction was, of course, entirely different from that of the standard glider (Figure 2). Two upper spars passed from the nose cone, along the cockpit sills, to the rear wing-mounting bulkhead. Two lower spars passed from the plane of the control column back to form the support for the seat, then to the front wing-mounting bulkhead. In front of the control column was a strong crossbeam and a bulkhead. There were bulkheads in front of and behind the undercarriage area, supporting the wing fore and aft cross tubes. This region had a strong roof, forming a box behind the pilot to prevent the wings folding forward and crushing him. A ring structure lies between these two bulkheads supporting the structure to the rear of the cockpit which also acted as a roll bar. The longitudinal midline joint of the fuselage had considerable overlap and was very strong.

The crushable nose cone was attached to the front of the cockpit, separated from the pilot's space by a bulkhead. The aerotow hook had to be attached to the main cockpit structure rather than the nose cone as tests showed that the hook would interfere with the energy absorption.

A pilot manikin was not used, but the mass of the pilot's feet and thighs were simulated by sandbags. It was considered that the mounting points for the seat harness were so strong that testing wasn't needed. An accelerometer was fitted at the CG behind the cockpit. The wings, rear fuselage, and pilot loads were simulated by metal bolted to the wing mounting area.

The test simulated a fully loaded glider weighing 525 kilograms of 15-18 metre wingspan hitting compacted earth at 45° at 70 km/h (45 mi/hr), a considerably greater velocity than that specified for car impact testing.

The accelerometer trace showed an ideal trapezoidal pulse shape, with an easily survivable 18 g maximum deceleration. The distance from the front of the nose cone to the forward bulkhead was 0.3 m. The nose penetrated 0.9 m into the earth, in line with the longitudinal axis of the glider. The cockpit structure was intact following the test, excepting for slight delamination, but without displacement of either cockpit sill. The forward bulkhead had failed, but this was known to be weak before the test; it is to be strengthened. Earth entered through the open cockpit (no canopy was fitted) and the broken forward bulkhead.

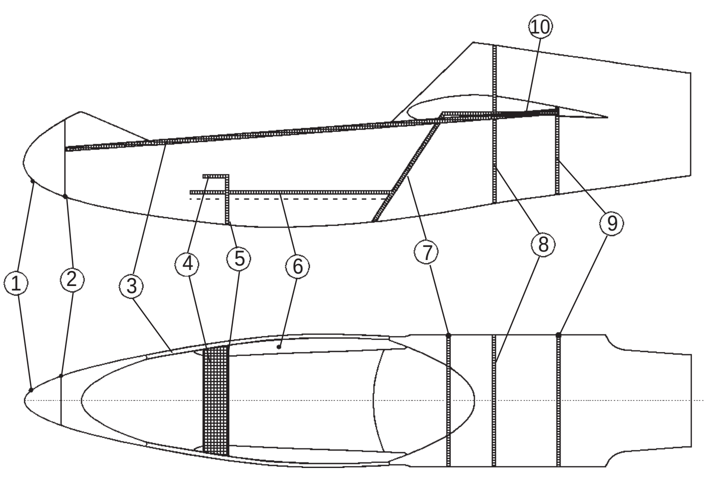
The test was considered to have been highly successful, but more tests need to be carried out with a longer nose and the glider impacting onto a hard surface. The rollover structure needs to be tested as the stiffness of the cockpit results in a greater risk of rollover. Finally, the canopy has to remain in place and not be broken by the earth and stones thrown up during the impact. This might require that the canopy transparency be made of stretched acrylic, polycarbonate, or a laminated material.

More on avoiding injury in a fore-and-aft impact

The pilot should be prevented from 'submarining' down and forward under his seat harness, which can be achieved by the use of a five or six point harness. Alternatively, Martin Sperber has devised a method using a steeply raked seat pan and a suitably positioned lapstrap (avoiding the use of crotch straps) for which the lap strap passes from the pilot's hip down to the anchorage point at an angle between 0-20° from the vertical.

A head restraint should be provided. The OSTIV Airworthiness Standards give detailed requirements for head restraints: each head restraint must not be less than 250 mm wide; it must be faced with energy absorbing material; it must be able to withstand an ultimate load of 3 kiloNewtons (kN); and it should not foul the parachute

Figure 2 – Reinforced cockpit design



1 *Nose cone*
2 *Forward bulkhead*
3 *Upper spars*
4 *Cross beam*
5 *Bulkhead*
6 *Lower spars/seat pan support*
7 *Front wing mounting bulkhead*
8 *Roll bar*
9 *Rear wing mounting bulkhead*
10 *Top of undercarriage box*

during an emergency exit. Where possible, head restraints should be mounted integrally with seat backs.

To protect the pilot in emergency landings, moveable parts such as batteries should be restrained to withstand 20 g. There should be no sharp edges in the cockpit, such as those often found on the lower edges of instrument panels, or sharp fittings such as switches or catches.

Impact in the direction of the pilot's spine

Undercarriage design

Gerhard Waibel observed that, under severe perpendicular impact, an undercarriage first collapses then comes to a sudden halt, imposing a considerable load on the pilot's spine. He has designed an undercarriage that, rather than reaching the end of its travel with a jolt, collapses progressively from there on, thus avoiding sudden loading on the pilot (Figure 3). The resulting distorted undercarriage tubes are easily replaced.

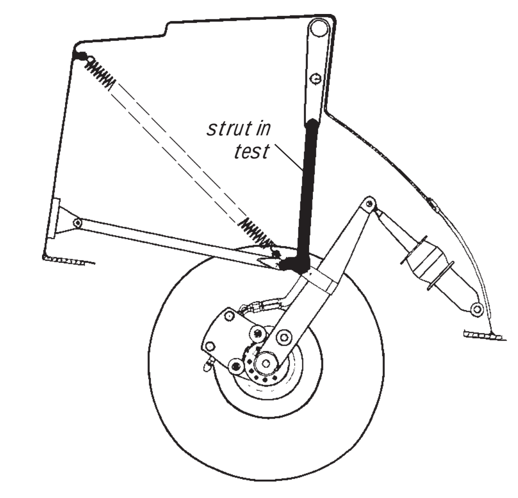


Figure 3 – Waibel's collapsing undercarriage design
Source: Technical Soaring, Vol 15, #4, p105

As mentioned before, the spine is susceptable to resonance at 5 Hz (five cycles per second) at which frequency its strength is greatly reduced. Vibration at 5 Hz should therefore be avoided in the design of the undercarriage and the wings of the glider.

Seat pan design

In modern gliders, the pilot is semi-reclining rather than sitting vertically in the cockpit. Impacts directly along the axis of the spine must also be taken into consideration. Studies at TH Aachen by Prof. Wolf Roger, and at TuV Rheinland by Martin Sperber, have both shown that aluminum honeycomb material placed under the seat pan makes maximum use of the limited crush distance available between the seat pan and the undersurface of the fuselage. The load should be applied as far as possible along the axis of the honeycomb to prevent it buckling prematurely.

Martin Sperber has designed a seat pan suspended from the cockpit wall by four swinging arms (Figure 4). The resulting movement of the seat pan means that the seat will be correctly aligned. The honeycomb material can be easily replaced after an accident.

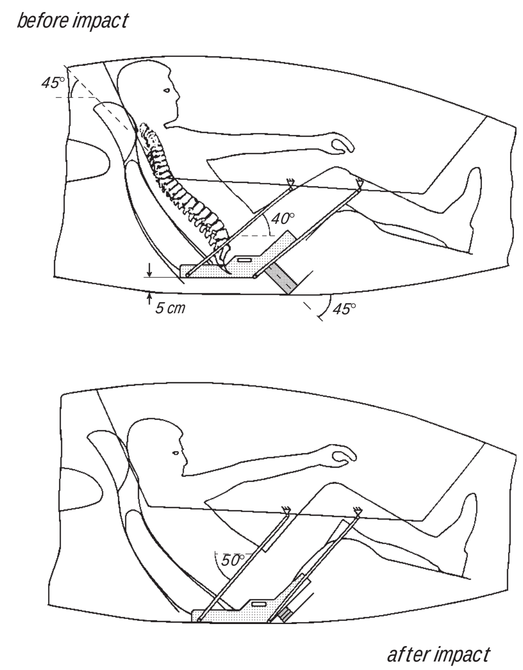


Figure 4 – Collapsible honeycomb under the seat pan
Source: Technical Soaring, Vol 19, #2, p52

An energy absorbing cushion may be used on the seat pan, in conjunction with the aluminum honeycomb. The cushion will absorb the effects of minor impacts and heavy landings, leaving the aluminum honeycomb unaffected and in reserve to deal with serious accidents.

A test using *Dynafoam* (called *Sunmate* in the USA) was carried out at DERA, Farnborough in 1994. The impact was at 17 g with an impact velocity of 9.4 m/s (21 mi/hr). Using 1" thick *Dynafoam* at room temperature, the following resultant forces were obtained:

manikin	*no cushion kN (lbs)*	*1" Dynafoam kN (lbs)*
Light female	*5.558 (1250)*	*4.619 (1038)*
Medium male	*7.198 (1618)*	*5.985 (1346)*
Heavy male	*8.993 (2022)*	*7.520 (1691)*

Use of a 1" energy-absorbing seat cushion reduced the load on the pilot by about 17% throughout the range of pilot weights. In addition, if the seat back structure and parachute pack fully support the spine, risk of injury will be further reduced. A lumbar support pad, to maintain the shape of the curve of the spine, will increase the compression loading strength of the spine by 80%!

There have been great advances in the study of crashworthiness, but unless pilots insist on them being incorporated into their new gliders, avoidable injury and death in gliding accidents will continue. *(See p19 for additional safety comment.)* ❖

Safety Comment

Age dramatically reduces the strength of your back

A recent accident in Edmonton in which the two pilots suffered back injuries, and the article on the safety cockpit in this issue, are reminders to us all to look to our seating. The article shows that, as we age, the ability of the spine to successfully absorb the shocks of a heavy landing is dramatically reduced. From the 20-39 year age group to the 60-79 age group, the injury-free force on the spine reduces from 7.14 kiloNewtons (1605 lbs) to 3.01 kN (677 lb). If we estimate the weight supported by the spine to be about 100 lbs, then the deceleration required to damage the spine becomes 16 g for the younger group and only 6.8 g for the older pilots. This is not difficult to reach! Food for thought, eh?

Anyone who has ridden on a snowmobile can attest to the discomfort of repeated bumps. In a glider the hard ride of unsprung wheels and the vertical posture of the pilot(s) can be damaging, and the more we fly the more the damage accumulates. The article highlights the value of using energy-absorbing seat cushions. Many of us can recall a heavy landing and the pain suffered by the pilot. We can also remember the long-term effects of many instructional landings on hard runways! These injuries can be reduced or avoided by using better cushioning materials.

Confor energy-absorbing foam is readily available in Canada, and all clubs and private owners are urged to obtain this material for the club two-seaters and their own sailplanes. A one inch thickness is the minimum to give protection. This material is very comfortable, and on long flights is surprisingly supportive because it spreads the pilot's weight effectively over a larger area than a standard compressible soft foam cushion (I can say this as we have *Confor* foam in the syndicate Puchacz!). In fact "standard" cushions amplify the shock of a landing by compressing readily, resulting in the pilot being hit hard by the rebounding glider. Such cushions should be banned from the club and private gliders ... so why not embark on a hunt for them now? Cushions of energy-absorbing foam are cheap compared to injuries, hence they are well worth the cost. *(public service announcement – contact Ulli Werneburg below for details on the grades and cost of Confor foam. ed)*

It has long been established that maintaining the proper curvature of the spine is vitally important if we wish to avoid back problems as we sit. A second and very effective way to reduce back injuries is to support the spine more effectively. A lumbar support pad made of stiff energy-absorbing foam should be about 25 mm thick (1 inch) and 100 mm (4 inches) high. The width should extend across the back. Placed between the back and the parachute or rear cushion, or when instructing kept in place under the shirt, it will help maintain the correct curvature of the spine. Sewn into a simple bag, it can be held in place with *Velcro*.

Alternately, Tony Burton describes below a simple and effective lumbar support that you can carve out of a piece of insulation board, customized to your back shape and seat.

In 1993 we thought the correct curvature of the spine with such a pad increased the strength of the spine by 60%. I see from this latest article that this is now 80% — well worth the effort! For best effect a pilot should avoid leaning forward when landing.

As the article infers, insist on proper back support to avoid avoidable injuries!

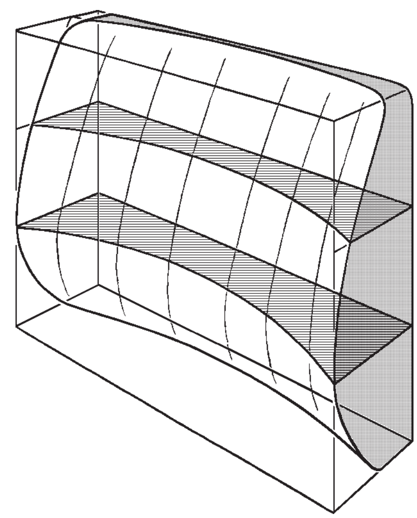
Ian Oldaker
Chairman, Flight Training & Safety committee

A lumbar support that works

If the seat/chute combination in the sailplane you usually fly gives poor lower back support, sitting can become very uncomfortable in a short time. Hard landings and crashes in gliders are also notorious for producing injuries arising from poor alignment of the spine. Pieces of rolled up foam, and other soft material is often used to alleviate this back support problem, but it is an unsatisfactory solution because such material is not firm under load and never stays in the right place.

My experience was that without additional back support for the RS-15 seat geometry, a flight became terrible after a couple of hours. Other gliders may have similar problems with varying degrees of discomfort (my personal opinion is that 1-26 and 2-33 seats should be illegal!).

You can custom build a firm, simple lumbar support for yourself from a piece of "blue board" Styrofoam insulation. The diagram shows its general size and shape (somewhat exaggerated in thickness). Starting with a 10"x12" piece of 2" board, carve the saddle-shaped surface into it using a long bladed knife such as a bread knife. Note that the thickest part is about a third up from the bottom. Experiment a bit with the support in place while you are seated in the glider and trim until it feels right. If the seat pan is curved the back side of the support will also have to be shaped.



When you wear a chute, the support must be placed between it and your back, and it must be as low as possible when you are seated.

When the fit is correct, you won't even notice it after a while (telling you it's doing its job perfectly), though at first it may feel odd. Once the shape is right for you, strap it with a few windings of duct tape to protect the fragile corners and fit it into a cover made from an old towel or other similar cloth to keep the support clean and absorb sweat.

A more ambitious project is to use the support as a mold for a fibreglass model once it has conformed itself to you and the seat back after some use.

Tony Burton