Making Accidents Suvivable...with a Racing-car Cockpit in your Glider

Dr. Antony M. Segal

Tony Segal flies at Lasham and began researching glider crashworthiness 13 years ago

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All accidents involve the ground sooner or later, but serious injury to the pilot can be avoided in two particular types of accident: the pilot can be protected by an energy absorbing cockpit upon impact with the ground (as discussed in this article); if the accident occurs in mid-air (the result of structural failure, collision or control disconnection) a glider-parachute might save the pilot's life; this will be discussed in a future article.

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 (Fig. 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.

There are three areas shown in Figure 1: green represents the area of voluntary human exposure, (i.e. the amount of g to which we are voluntarily prepared to expose ourselves) after which we remain uninjured and undebilitated. The blue 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, in red, is the area of severe injury or death. One special region is shown at 0.2s (5Hz); 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 Range (years)	**Breaking Load** (kN)
20-39	7.14
40-59	4.67
60-79	3.01

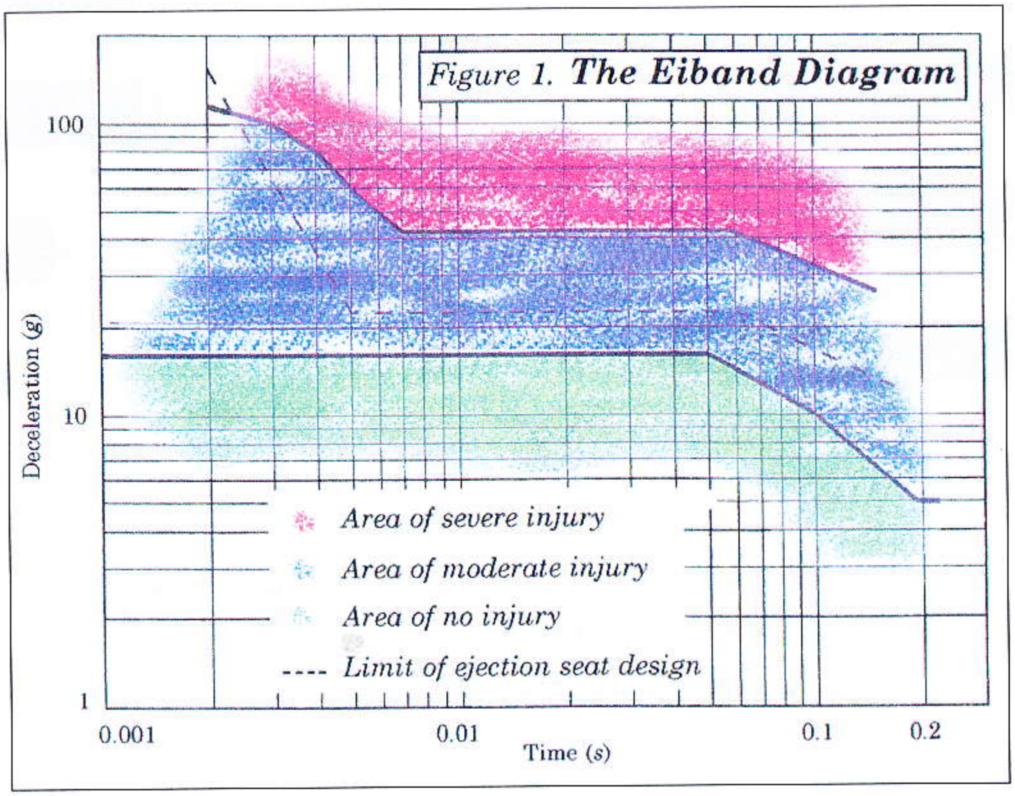


Figure 1. ***The Eiband Diagram***

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

Impact in the Fore & Aft Direction

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 0.5m. The decrease in maximum L/D was 5%. The decrease in L/D at 80kts 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, 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 Design of Cockpit

Martin Sperber, of TüV Rheinland, Cologne, carried out a significant test in January 1998. A glider cockpit was designed using Formula-I 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 fibre (Dyneema is made out of polyethylene).The cockpit was built in a Glasflugel "Hornet" mould, although the final construction was, of course, entirely different from that of the standard glider (Fig.2, at end of article). 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 cross beam and a bulk head. 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, also acting as a roll-over 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 aero-tow 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 sheets bolted to the wing mounting area.

The test simulated a fully loaded glider weighing 525 kg of 15 metre/18 metre wingspan hitting compacted earth at 45° at 70 kph (45mph), a considerably greater velocity than that specified for car impact testing (Fig. 3).

The accelerometer trace showed an ideal trapezoidal pulse shape, with an easily survivable 18g maximum deceleration. The distance from the front of the nose cone to the forward bulkhead was 0.3m. The nose penetrated 0.9m 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 the cockpit through the open cockpit (no canopy was fitted), and through 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 roll-over 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 is made of stretched acrylic, polycarbonate, or a laminated material.

Further Points of interest to avoid 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 250mm wide; it must be faced with energy absorbing material; it must be able to withstand an ultimate load of 3kN; and it should not foul the parachute during an emergency exit. Where possible, head restraints should be mounted integrally with seatbacks.

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

Impacts 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 movement with a jolt, collapses progressively from there on, thus avoiding sudden loading on the pilot. The resulting distorted undercarriage tubes are easily replaced. (See Fig. 4)

As mentioned before, the spine is susceptable to resonance at 5Hz (five cycles per second) at which frequency its strength is greatly reduced. Vibration at 5Hz 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 FH Aachen by Prof. Wolf Roger, and at TüV Rheinland by Martin Sperber, have both shown that aluminium honeycomb material placed under the seat pan makes maximum use of the limited crush distance available between the seat pan and the under surface of the fuselage. The load should be applied as far as possible along the axis of the honeycomb to prevent it buckling prematurely. (See Fig. 5)

Martin Sperber has designed a seat pan suspended from the cockpit wall by four swinging arms. 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.

An energy absorbing seating cushion may be used on the seat pan, in conjunction with the aluminium honeycomb. The cushion will absorb the effects of minor impacts and heavy landings, leaving the aluminium 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 17g with an impact velocity of 9.4m/s (21 mph). Using 1" thick Dynafoam at room temperature, the following resultant forces (kN) were obtained:

Pilot Manikin	*No Cushion*	*1" Dynafoam Cushion*
Light female	5.558	4.619
Medium male	8.993	7.520
Heavy male	7.198	5.985

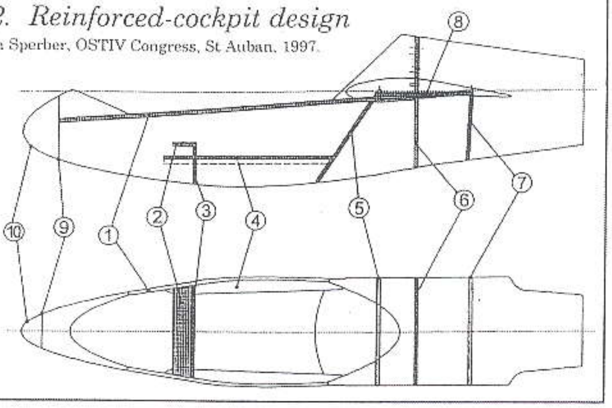
The use of an energy absorbing seat cushion significantly reduced the load on the pilot throughout the range of pilot weights.

In addition, if the seat back structure and parachute pack fully support the spine, risk of injury will be reduced. A lumbar support pad, to maintain the shape of the curve of the back, will increase the compression loading strength of the spine by 80%.

There have been great advances in the study of crashworthiness, and unless pilots insist on them being incorporated into their new gliders, avoidable injury and death in gliding accidents will continue.

Figure 2. Reinforced-cockpit design

Source: Martin Sperber, OSTIV Congress, St Auban, 1997.



① Upper spars
② Crossbeam
③ Bulkhead
④ Lower spars/seatpan supports
⑤ Front wingmounting & bulkhead
⑥ Rollover bar
⑦ Rear wing-mounting bulkhead
⑧ Roof of undercarriage box
⑨ Forward bulkhead
⑩ Nose cone

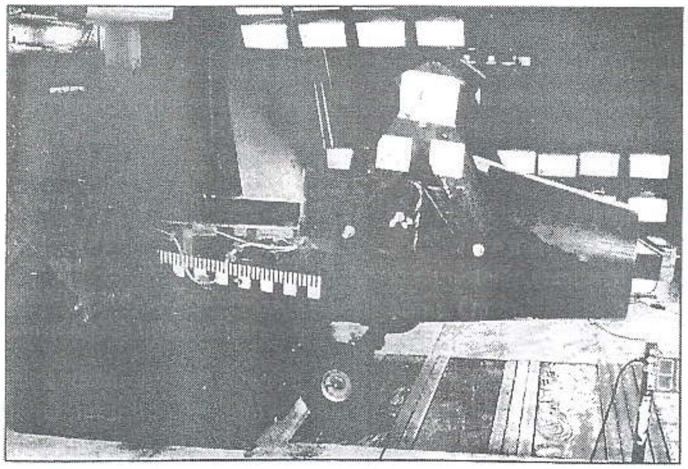
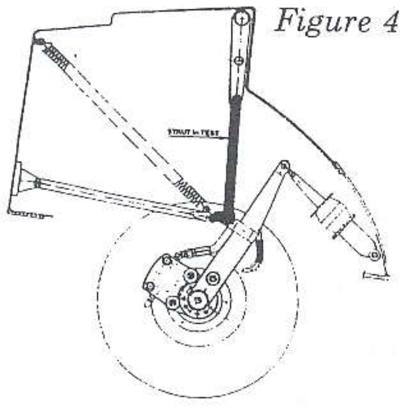


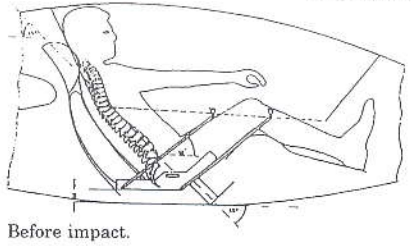
Figure 3: Martin Sperber's 'racing car cockpit' being tested at TüV Rheinland in January 1998. Photo: Jochen Ewald

Figure 4.

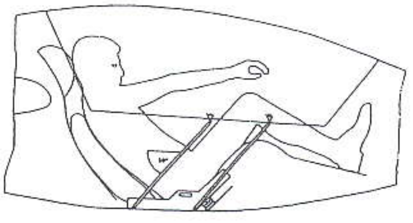


Waibel's collapsing undercarriage design
Source: *Technical Soaring*, Vol 15, No. 4, Oct 1991, p. 105

Figure 5.



Before impact.



After impact.

Collapsible honeycomb under the seatpan
Source: *Technical Soaring*, Vol 19, No 2, April 1995, p.52

Surviving Mid-air Accidents

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Tony Segal is a retired GP. He has researched safety issues for many years.

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During the 1914-18 war a brave pilot of the Royal Flying Corps, who had the misfortune to be shot down with no parachute in his Sopwith Camel, could decide whether to jump regardless, or to burn.

Introduction

By World War II, fighter pilots were equipped with personal parachutes but survival was rarely possible below 1,000', over 200kt airspeed, or from an aircraft undergoing significant rotation or acceleration. The Luftwaffe Dornier 335 fighter was first flown in 1943, and was fitted with an ejector seat. After the war the Martin Baker Aircraft Company developed the modern military ejection seat and, these days, a pilot escaping from a 'severe' situation has a 95% chance of survival.

Microlights and Hang-gliders

Microlight and hang-glider pilots have been using 'whole aircraft parachute recovery systems' for many years; the low mass and high drag of these aircraft, coupled with the low velocity reached in a dive, makes them particularly suitable. Worldwide, 14,000 such systems are in use and 124 lives have been saved. In the UK the British Hang Gliding and Paragliding Association reported that by 1994 the lives of 23 BHPA members had been saved by these recovery systems. Of 47 deployments, 17 were accidental, 23 were successful and 7 failed; it is clear that no system can give a 100% recovery rate.

Sailplanes

In comparison with a microlight, a sailplane has a high mass, low drag and rapidly reaches a high speed in a dive. The cockpit is clear of surrounding structures and it would appear, at first sight, to be easy for a pilot to climb out and operate his personal parachute. Until recently these assumptions turned attention away from the use of whole-aircraft parachute recovery systems in gliders.

Research in Germany

The Bundesministerium für Verkehr (BMV), the German Federal Ministry of Transport, became concerned about the number of fatalities following mid-air accidents in gliders. In 1988 a study was financed by the Ministry and undertaken by Prof. Wolf Roger at the Fachhochschule Aachen (FH Aachen), the Aachen University of Applied Sciences, and is still in progress under Roger and his colleagues.

The Problems of Bailing Out

Roger carried out an analysis of the mid-air glider accidents in Germany for the years 1975-1988. There were thirty-four accidents, the majority clearly being collisions between two gliders. In total fifty-eight gliders were involved, of which 14 landed safely. Sixty-four pilots were involved, of which 28 were fatally injured. Thirty two pilots jettisoned the canopy, or were seen trying to do so, and of these, 19 survived and 13 were killed. The remaining fifteen deaths occurred in the cockpit without any evidence of the pilot trying to bail out.

Following this study, Roger investigated the problems involved in bailing out of a glider cockpit. The short time interval between the accident and the glider hitting the ground is an obvious problem.

Canopy Jettison

A series of experiments was carried out involving pilots aged 20-60 years. A three-lever jettison system took 3.5 seconds to operate. A one- or two-lever system, operated simultaneously by both hands, only took 2.5s. One second was saved if the canopy were pulled away by the airstream. The age of the pilot had no effect in these tests.

Getting Out

The time taken to get out of the cockpit, after releasing the seat belt, *was* affected by age, physical condition and load factor. Getting out took a well-trained fit young person 2.6s, and an older person 4.5s. When a load factor of 1.5g was simulated, by attaching lead weights to the pilot's body, a young person took 3.5s, and an older person took 7.2s. Under this load factor some people, aged 40 years or more, were unable to get out at all. The instrument panel and the height of the cockpit wall also affected the exit time.

Load Factor - Wind Tunnel Tests

Experiments were carried out in the wind tunnel at FH Aachen to investigate the aerodynamic loads on the canopy during jettisoning. The experiments were carried out with a rear-hinged, front opening canopy. With a small forward opening of less than 3cm the air-flow past the cockpit produced low pressure inside the cockpit. The resulting force tended to move the canopy forward and held it down on the fuselage. If the front of the canopy were raised above 6cm the airflow lifted the canopy away from the cockpit and tended to move it backwards. Opening the cockpit ventilation and closing the clear vision panel, raised the air pressure inside the cockpit, assisting canopy removal. The internal pressure was raised even more during a side-slip.

Full-size Glider Tests

Prof. Roger carried out tests using a full-size LS4 fuselage mounted on the roof of a car which was driven down the runway of the NATO airfield at Geilenkirchen. The canopy was released and its motion and flight path recorded on video.

Front-opening Canopies

The first tests were carried out with the canopy being raised mechanically, operated by the car's front seat passenger. A front-opening canopy, in position and unlocked, remained in place regardless of the angle of attack. Above 85kt, the canopy lifted off the fuselage. With side-slip of greater than 15°, the canopy separated slowly from the fuselage, hit the instrument panel, hit the pilot, hit the wing and then the rudder.

The test was repeated with the front of the cockpit raised by 20cm. The canopy lifted off, pitched nose down and returned to the fuselage aft of its original position. The airflow then held the canopy closed so preventing exit. With side-slip the raised canopy separated from the fuselage, but the front of the canopy turned into the cockpit, hitting the pilot.

Side-opening Canopies

The left side of the canopy was released and raised slightly. The canopy hinged on the right side, then released and lifted away. It flew off the fuselage with a nose down movement, across the cockpit to the left side, without gaining height, and hit the pilot. The canopy then flew over the left wing, over the rear fuselage, finally hitting the tail on the right side.

Clearly, this can not be considered satisfactory. An alternative method is to release, and push upwards, the left side of the canopy. The canopy rotates 180° around the right hinges until they break off. The canopy flies back, passing below the right wing and then hits the tail, but passes clear of the pilot without injuring him. This method of jettisoning a sideways-opening canopy is recommended over the method of jettisoning both sides together. There is, of course, a danger that the hinges won't break, in which case the canopy would slam shut.

Real Pilot Tests

All the above tests were carried out with the canopy released by a mechanical device. Tests were then carried out with a pilot in the cockpit and a forward opening canopy. Two handles were fastened to the canopy frame forward of its centre of gravity.

The canopy was released and the handles were easily pushed upwards. The airstream then pushed the nose of the canopy down (the centre of lift of the canopy is to the rear of the centre of gravity) and it was not possible for the pilot to control this movement; within 40 milliseconds the canopy struck the cockpit blocking the pilot's emergency exit.

The next test was a pilot-operated canopy release with a side opening canopy. The pilot was wearing a leather jacket and a crash helmet, and the canopy strut was also padded. The pilot pushed the canopy quickly to the right. There was a nose-down pitching movement, and a nose-inward yaw of the canopy. The nose of the canopy turned into the front of the cockpit, slid up the pilot's arms towards the pilot's face. The pilot was Wolf Roger himself.

This series of tests showed that during manual jettisoning of the canopy the pilot is unable to control its movement and there is a high risk of injury.

Improved Canopy Hinge

To improve the situation, the nose down movement of the canopy has to be transformed into a nose up movement. Three methods are available to achieve this. In the first method an additional weight at the rear of the canopy would move the canopy's centre of gravity (CG) to the rear of the centre of lift. However, a weight of 18lbs (8.2kg) would be necessary, so this method is not feasible.

The second method is to change the canopy's aerodynamic shape. A theoretical study was carried out of forty-six different canopy shapes, confirmed by wind tunnel tests. One design of canopy produced a slight nose up movement over the whole range of angle of attack and airspeed. However, it would only be of use for the rear cockpit of a two-seat glider.

The third method involves a hinge situated between the rear of the canopy frame and the rear of the cockpit opening: the hinge is designed to disengage at about a 30° opening angle of the canopy. The pilot grasps two handles situated to the front of each side of the canopy frame, and lifts up the front of the canopy which immediately rotates upwards around the hinge. At about 30° the canopy separates from the fuselage, flies clear of the pilot, then passes well above the rudder.

If sideslip is present, the canopy takes a similar flight path but displaced to one side. The "Roger hinge", as it is now called, is the recommended method of attaching the canopy frame to the cockpit.

Ballistic Parachute Recovery

There are two methods of ballistic parachute recovery. In the glider rescue system (GRS), the entire airframe, with the pilot remaining in the cockpit, is lowered to the ground by parachute. In the pilot rescue system (PRS), the glider is first stabilised by a small parachute. This parachute then extracts the pilot from the glider (after automatic canopy jettison and seat belt release). The pilot is then lowered to the ground either by the small parachute, or by his own.

Glider Recovery System (GRS)

Roger analysed 42 mid-air accidents involving gliders in Germany from 1975-1990. Most of these accidents involved collisions. Half the gliders involved lost a wing or part of a wing; one third lost their elevators, and the rest their rear fuselages and tailplanes. The wing-root area mostly remained intact, and the recovery system should, therefore, be installed in this area.

GRS - Flight Path After Damage

Following the loss of part of a wing, the glider rolls into a spiral dive, with the intact wing initially being upper-most. The steepness of the dive depends on the amount of the wing that has been lost. In extreme cases, a negative angle of attack may be reached.

If the elevator is lost, or the tailcone and tail unit is lost, the glider dives into a negative loop - a bunt. The glider accelerates rapidly, the airspeed increases rapidly, and might exceed V_{NE}. These findings were confirmed at FH Aachen by computer simulation, and by drop tests on model gliders.

GRS - Parachute Deployment

T-shaped tails are common in gliders. The deployment system must first pull the parachute bag out of its storage compartment in the fuselage. It must then lift it clear of the tailplane, even when the glider is at a negative angle of attack. The constituent parts of the parachute must then be streamed and stretched in order - the bridle, the risers, the canopy suspension lines, and the canopy itself - in order to avoid the lines tangling and fouling the tail unit. A high-lift drogue parachute would have poor inflation in the turbulent air close to the fuselage, and would have poor dynamic stability. A ram-air drogue parachute will not fill at high speed, or if spinning, and requires a large canopy area that might collide with the tail during inflation. Neither is suitable for parachute deployment.

For conventional glider designs, a spring or compressed-gas operated device would not supply enough energy to enable the parachute bag to clear the tailplane. A high energy device is required. This can be either a mortar, a gun, or a rocket. A mortar or a gun will cause recoil that might damage an already weakened airframe. The favoured method is therefore a solid fuel rocket.

GRS - Static Stability

Three or four parachute risers are needed to ensure that the damaged glider remains stable as it descends. These should be grouped around and above the glider's CG. However, if part of the glider structure is lost, the CG position will alter: if the tail or part of the rear fuselage is lost, the glider will pitch nose down; if a wing, or part of a wing, is lost the glider will tend to roll. The glider will hang so that the CG is below the intersection points of the risers. To minimise the change of pitch produced by loss of glider structure, simple geometry shows that the risers should be as long as possible.

The angle of attack of the aerofoil affects stability. A glider descending under a parachute has a most unusual relation to the airflow which comes from under the wing instead of the normal direction. Roger has shown that for any given aerofoil, static stability is only possible at the following angles of attack:

a) The normal flight range up to	+13°
b) A range of	+20°-30°
c) From	+50°-70°

The length of the fore-and-aft bridles should be adjusted, as they are installed, to give an angle of attack in this range. The third option also gives a satisfactory attitude for ground impact.

These results were based on computer simulation and eighty free-flight tests with a scale model glider (scale 1:4.8) dropped from a tethered barrage balloon. A steady state descent of 20'/sec was obtained. The results were analysed from a flight data recorder and analysis of video film.

GRS - Forebody Wake Glider Rotation

The wing of the descending glider is deeply stalled, and so is producing large wingtip vortices. These hit the side of the parachute canopy, causing the canopy to oscillate and thus lose drag.

The disturbed air is known as forebody wake, and the effect can be reduced by the length of the parachute risers being longer than a wingspan. With this increase in riser length the parachute efficiency is increased.

A further advantage of a long riser is that it will compensate for rotation between the parachute and the glider, as in a spin or a spiral dive. It obviates the need for a heavy swivel. In any event, a swivel is not "failure tolerant", so is not the best solution to the problem of rotation.

GRS - Effect of 'Opening Shock'

When a parachute is deployed, the canopy, suspension lines, and risers are first stretched taut. This produces the "opening snatch". Air then enters the canopy and impacts the crown of the canopy, producing the "opening shock".

The damaged glider might be in any attitude when the parachute deploys. Each riser and its attachment to the airframe must therefore be able to withstand the entire opening shock.

The parachute canopy in its bag is first lifted upwards so as to clear the tail unit. The airflow then moves it in line with the fuselage. In the event of the loss of the tailplane, the glider will start a bunt, with a downward rotation of the nose, and a negative angle of attack. This will result in the parachute opening below the line of the fuselage. A further factor is that the risers are attached above and in front of the CG of the glider. The result of this is that the opening shock produces an upward rotation of the nose of the glider. A good effect of this is that the air speed of the glider is reduced. A bad effect is that a violent pitching movement will be produced. This pitching movement will have almost no damping in the absence of the tailplane. In the event of a very violent opening shock, the glider might even start to loop and then fall into the parachute lines. Clearly, this would be disastrous.

When the parachute deploys more or less in the line of the fuselage, the opening shock will produce a rapid deceleration of the fuselage. The inertia of the wings will result in forward movement of the wing-tips. This in turn will produce a load on the main spar and on the wing root fittings for which they are not primarily designed. The resulting structural failure could crush the cockpit and the pilot.

A further problem occurs if the pilot delays the operation of the system, and the parachute deploys when the glider is flying inverted at the bottom of the bunt, following loss of the tailplane or rear fuselage. The parachute canopy will exert a force in the direction of the airflow, causing the nose of the glider to drop into the second part of a positive loop. The glider will then fly through or rotate until it is the right way up. The complete flight path will be "S-shaped". Roger believes that the rotation would be very rapid, and little loss of height will occur. It is clear that the pilot must operate the system as early as possible.

It is vital that the opening shock is as small as possible. A large canopy opens more slowly than a small canopy, but the opening shock might be greater. A "reefing" system must be used - this controls the volume of air entering the canopy, increases the opening time of the parachute, and reduces the opening shock.

GRS - Ground Impact

This is a critical phase of the rescue, especially regarding spinal injury. A 60-year-old pilot can withstand a compression load on the spine of 6751b force. At a nose down attitude of the glider of 20° - 45°, and a descent velocity of six metres per second, the impact load on the spine should be below this value. This attitude of the glider ties in very well with the angle of attack of the wing required to give stability to the descending glider.

A modern crashworthy cockpit should ensure the pilot does not suffer injury due to the ground impact. The pilot may receive minor injury in an older type of cockpit.

GRS - Suitable Systems
The systems are supplied in three types of pack:

CANISTER. This consists of a light-weight aluminium cylinder housing the parachute canopy, which is pressure packed to 20 tons, and is waterproof. It can be left for six years between factory repacks.

VERTICAL LAUNCH SYSTEM (VLS). This is a low-profile fibre glass container with a frangible cover, for mounting on the top of the airframe. Parachute canopy repack cycle is every four years.

SOFTPACK. These are mounted on a steel tray, and can fit into awkward spaces. Canopy repack cycle is between one and three years depending on the application.

I understand that eight out of ten new gliders in Germany are equipped with an engine. When the recovery system is installed, the rocket can be angled by up to 15° to left or to right of the vertical. I suggest this be done, to reduce the risk of a deploying parachute tangling with the motor pylon. The manufacturers stress that the engine must be shut down prior to system activation.

GRS - Rocket attachment
The rocket must have a means of escaping from the glider airframe. Fabric covers are easily penetrated. Dacron is stronger and requires a velcro-closed panel. Plastic, fibre-glass or aluminium would need a blow through panel.

Ignition is by dual redundant mechanical igniters. No electricity is required. The activation handle requires a force of 451b.f. A dual action is required which makes inadvertent operation unlikely.

The canopy should be matched to the all-up weight of the glider. At sea level, a descent rate of 6.4m/sec is obtained. At 5,000', a descent rate of 7.6m/sec is obtained. (see Table 1 at end of paper)

The all-up weight of some typical gliders, including water ballast where applicable, is as follows:

Nimbus	1,650 lbs (comp. weight)
Discus	1,156 lbs
Junior	838 lbs
ASK 13	1,166 lbs

A problem is the relatively low maximum deployment speed of the systems. The peak deployment load for the GARD-150 is 3g, so the attachment points for the parachute risers will have to be designed to withstand 4.5g. A further point is the increased opening shock at altitude. This will require calculation, and will require an increase of design strength of the riser attachment points. It may be possible to design energy absorbing attachment points, so reducing the required design load.

Pilot Rescue System (PRS)

This is an alternative to the glider parachute rescue system. A high energy system deploys a small drogue parachute. Simultaneously, locking clamps on the glider canopy and the seat harness are released. The drogue parachute stabilises the damaged, tumbling glider. The attachment of the drogue is transferred from glider to the pilot. The drogue first pulls away the glider canopy and then the pilot from the cockpit. The glider then falls safely away from the descending pilot. Roger recommends that the drogue parachute then lowers the pilot to earth. This implies that the drogue parachute has to be as large as a conventional personal parachute.

Mike Woollard, Chairman of the BGA Technical Committee and a past Technical Director of Irvin Parachutes, presented a paper at the OSTIV Congress at St Auban discussing the different rescue systems. He favoured the Pilot Rescue System, but suggested that the pilot, having been extracted from the cockpit, was then lowered to earth by his own personal parachute. This would enable the drogue parachute and the personal parachute to each be optimised for its particular function.

The extraction of the pilot from the cockpit has been studied on a test rig at FH Aachen. The instrument panel needs to be raised or jettisoned with the glider canopy. The test extractions showed there was no risk of collision between the pilot and the cockpit structure. There was no risk of injury to the knees of the pilot. However, at a nose up attitude of +20°, the pilot's head jerked backwards. The load on the pilot was low, being 1.5-5g.*

After the pilot has been extracted, the glider will drop freely in an uncontrolled flight path without a parachute. In the special case of the glider losing one wing it will roll, and there is a danger that the rising, intact wing will strike the pilot, or his parachute.

Minimum Height for Survival System Operating Times

Modern gliders have low drag, and hence gain speed rapidly in a dive, as after a mid-air collision. Assuming the glider is in a vertical dive and has no drag, starting at an initial velocity of zero it will have attained a speed of 95kt after 5s. After 7.5s it will be flying at 145kt. At 10s it will have reached 190kt, beyond the V_{NE} of most gliders: It is clear that the pilot must initiate the rescue as soon as possible after the accident.

Comparing the two types of ballistic recovery system, the glider recovery system and the pilot rescue system, they both have an improved capability over a personal parachute.

The minimum height for successful deployment depends on the reaction time of the pilot, and the canopy inflation time. The glider recovery system decelerates the glider immediately, but the large parachute required takes time to fill. The pilot rescue system operates slowly at first due to the complicated mechanical release system, but the small parachute opens rapidly. The pilot rescue system is slightly faster than the glider recovery system.

It is of interest to compare the personal parachute with the glider recovery system (see Table 2). The figures are taken from the St Auban OSTIV paper of Mike Woollard. The time advantage of the glider recovery system over the personal parachute is clear.

Roger considers that after a mid-air accident in level flight, at 50kt and with a pilot reaction of 2.5s, the minimum deployment height is 650'. In level flight at 80kt airspeed, the extra kinetic energy results in a lower minimum deployment height of 400'. A vertical dive will result in a greater height loss, especially at high speed. At 80kts, in a vertical dive, a minimum deployment height of 1,100' is necessary.

The effect of the mass of the glider is of only slight significance. A glider mass of between 200kg and 750kg will only result in a difference in minimum deployment height of 100'.

A parachute reefing stage holding back half the drag area for half a second reduces the opening shock by half. Considering a glider diving vertically at 80kt, the minimum deployment height will only be increased by 70' by the reefing system.

At high altitude, such as 16,500' (5,000m), the opening shock is much greater, but the question of minimum deployment height does not apply.

System Design

The system of ballistic parachute recovery used needs to be carefully designed to reduce the risk of failure. A Failure Mode and Criticality Analysis should be carried out to demonstrate its reliability.

Airworthiness Standards

The German authorities have recommended that the systems should be designed to operate at up to 4,000m (13,000'), and up to V_{NE}.

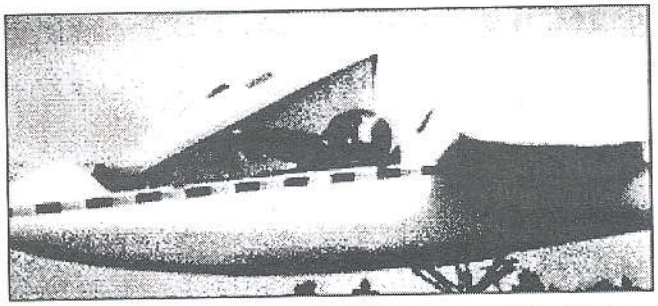
The OSTIV Airworthiness Standards recommend an operating height of 5,000m (16,500') to allow for the generally higher ground level of some areas of the USA. The velocity is set at the Design Speed, a higher figure than the German requirement.

The two systems are otherwise very similar.

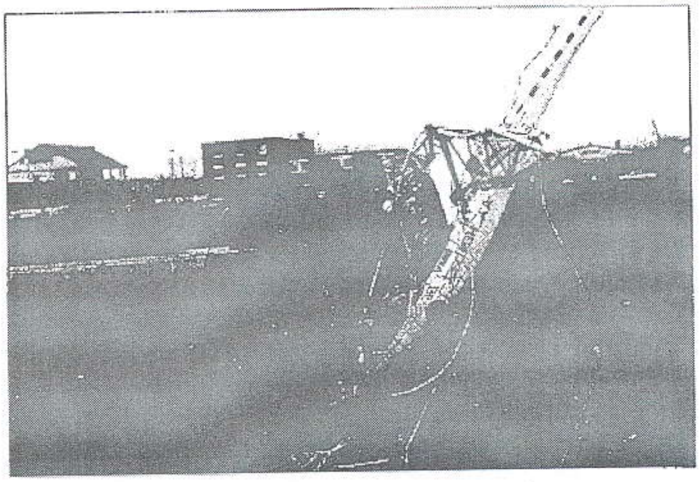
Conclusion

In many critical situations, such as mid-air collisions, these devices could save many more lives than the use of conventional personal parachutes.

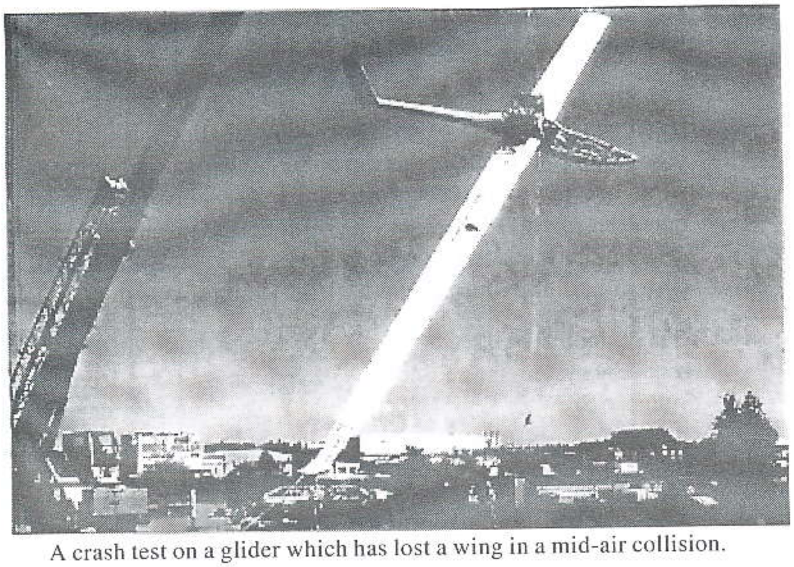
*Normal parachute opening shock is 20-25G, of very short duration.



Wolf Roger trying to jettison the LS4 canopy at Geilenkirchen.



Glider ground-impact tests at FH Aachen, Germany



A crash test on a glider which has lost a wing in a mid-air collision.

Table 1. Technical details of various GRS systems (numbers are approximate)

System	Max, glider AUW (lbs)	Max. deployment speed (knots)	System weight (lbs)	Canopy diameter (feet)
BRS-500	500	70	20	24
BR5-750	750	86	22	28
BRS-900	900	119	25	28
BRS-1050	1050	136	27	30
BRS-1200	1200	127	32	32
BRS-1500	1500	127	40	36
GARD-150	1645	120	43	40

One of the recovery tests: dropping a glider from a tethered balloon.

Table- 2. Times taken in seconds to reach safety.

Action to be taken	Personal Parachute	Glider Recovery System
Decision to abandon flight	1.5	1.5
Undo straps	1.0	n/a
Jettison canopy	1.5-20.0	n/a
Exit glider	3.0-4.0 (or much longer)	n/a
Pull ripcord operating handle	1.0	1.0
Parachute canopy opening time	1.5	2.5
Time to safe rate of descent	1.0	1.0
Total Time	10.0-30.0 (or longer)	6.0

Six-point Belt on Test

Dr. Antony M. Segal

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Dr. Tony Segal has been back to the crash-test rig to examine a new six-point harness. He reports on the results of his tests.

The Sopwith Camel in 1914-18 was initially fitted with a lap strap seat harness. Under negative g, the pilot slid upwards in relation to the cockpit, and was thus unable to make full control movements. So shoulder harness was introduced to solve the problem, resulting in a four-point seat harness. The father of Dr. Peter Saundby - the BGA's current medical advisor - was involved in its flight trials.

To prevent submarining and to maintain the geometry of the harness, a fifth (crotch) strap has been used for many years in military aircraft, aerobatic aircraft and in gliders. This five-point harness has been most satisfactory in aircraft with an upright seating position. The fifth strap passes down and forward to the anchorage point on the cockpit floor, clear of the crotch of the pilot. The fifth strap works by opposing the upward pull of the shoulder straps on the lap strap. The lap strap remains in position on the pelvic bones, instead of being pulled upwards on to the soft, vulnerable abdomen. Modern gliders have a semi-recumbent seating position: the glider frontal area is reduced in order to give a better flight performance. This seating position results in the fifth strap pressing directly on to the pilot's crotch as the strap passes forwards and down to the anchorage point on the cockpit floor. The strap may therefore cause injury to the crotch in an impact accident.

The German Federal Ministry of Transport financed a study by Dipl. Ing. Martin Sperber of TüV Rheinland, Cologne, to see if this risk of injury could be reduced. Martin Sperber concluded that by redesigning the shape of the seatpan and by specifying definite lap strap anchorage points, a four-point harness would prevent submarining. This seat and harness design is now used in many modern gliders.

In January 1999, the German glider manufacturer DG Flugzeugbau ceased fitting five-point harness in their gliders - a decision they reversed in February 2000. The removal of the option to fit a fifth strap had caused concern in the UK, and Dr. Peter Saundby asked me to carry out an experimental study on seat harness, carried out in May 1999 at the Centre for Human Sciences, DERA, Farnborough, with the help of Leslie Neil, Graham Reece and Philip Murtha.

A Nimbus 3DM front seat pan was used. Although representative of modern seat design, this had a larger transition radius, between the inclined thigh ramp and the horizontal portion of the seatpan than specified by Martin Sperber. As the pilot's buttocks cannot fit into this narrow space, I do not consider this to be of significance in affecting the validity of my experimental results. I Fixed the H- point using a seated 50th percentile male dummy, and drawing the intersection of the centre lines of the torso and thigh. The attachment point for the lap strap, so marked, coincided with the flat on the seat pan designed for this purpose by the manufacturer. (See pictures at end of this paper.) Martin Sperber has designed a device for marking the position of the H-point on the seat pan. When I used it, I obtained a different position from that I obtained using the dummy. Again, I do not consider that this affects the validity of my results

Three pilot dummies - a 50th percentile male, a 5th percentile female and a 95th percentile male - were seated statically in turn in the glider test seat.

In each case, with a five-point harness, the lap strap remained in position on the pelvic bones. When the fifth strap was released, and the harness used as a four-point harness, the lap strap rotated upwards under the unopposed pull of the shoulder straps and came to rest lying on the soft abdomen.

The effect of negative g was then simulated. The 50th percentile male dummy was fastened in the glider seat and the entire test rig was then inverted. The dummy was left hanging vertically in the seat harness. The separation of the buttocks of the dummy from the seat pan was measured. The following values were obtained:

Five-point, tight	24mm separation
Ditto, slack	31mm separation
Four-point, tight	51mm separation
Ditto, slack	83mm separation

It is clear that the five-point harness is superior under conditions of negative g.

The effect of a vertical accident impact - the most severe situation as regards submarining - was then simulated on the test track. The impact was at 10m/s at 16g. A 50th percentile male dummy was used. Five- and four-point harnesses were both tested tight and slack. With the five-point harness, tight and slack, the lap strap remained in the correct position on the pelvic bones following impact. With the four-point harness, tight and slack, the lap strap moved upwards until it was lying pressed under the rib cage following impact. Serious injury could be caused to the vital organs situated in the upper abdomen.

The load on the harness straps was recorded during the impact. The peak load in the fifth strap was 2068 Newtons. There are 4.45 Newtons to a pound force, so the load exerted on the crotch was about a quarter of a ton. Clearly this presents a grave risk of injury to the organs in the crotch region caused by the fifth strap in an impact accident.

This experiment showed that the fifth strap is essential to prevent the lap strap moving up into the vulnerable abdomen in an impact accident. However, the same fifth strap could cause serious injury in the crotch. This dilemma was resolved by the next experiment.

Terence Willans of Willans Harness Manufacturing Ltd, an expert on racing car seat harness, kindly modified a racing car harness for use in a test rig. This six-point harness consisted of two lap straps, two shoulder straps and two crotch straps. The latter passed upwards between the thighs from the anchorage points on the test rig of the glider. They then passed sideways through two rectangular buckles sewn to the lap straps. The crotch straps ended in webbing loops which passed inward towards the quick release fitting (QRF). The webbing loops were anchored to the QRF by the metal lugs of the shoulder straps.

An experimental test was carried out in January 2000 at the Centre for Human Sciences, DERA, Farnborough, with the technical assistance of Leslie Neil and Graham Reece.

The harness was tested for ease and speed of emergency egress under positive g and under negative g. No problem was experienced under either condition.

A test was carried out to show the effect of negative g on the performance of the six-point harness, the test rig being inverted. The separation of the buttocks of a 50th percentile male dummy from the surface of the seat pan was measured by a probe. The results were:

Six-point, tight	13mm separation
Six-point, slack	25mm separation

This is a better result than that found for a five-point harness.

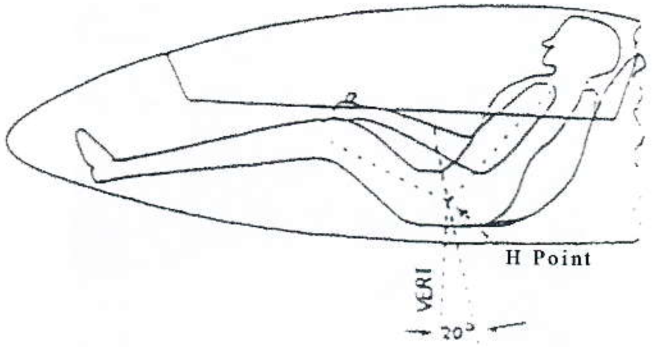
The effect of a vertical accident impact was then simulated on the test track, using a 50th percentile male dummy. The impact was at l0m/s at 16g. The six-point harness was tested tight and slack. It remained in the safe position on the pelvic bones.

I conclude that a four-point harness is unsatisfactory under conditions of negative g and on impact. Submarining of the pilot may take place. A five-point harness will perform well under negative g, and will prevent pilot submarining in the accident case. However, injury may be caused to the crotch of the pilot in the case of an accident.

A six-point harness works well under conditions of negative g, and will prevent submarining of the pilot in an accident. There is no risk of injury to the crotch of the pilot. The male pilot can pass urine in flight without altering his harness.

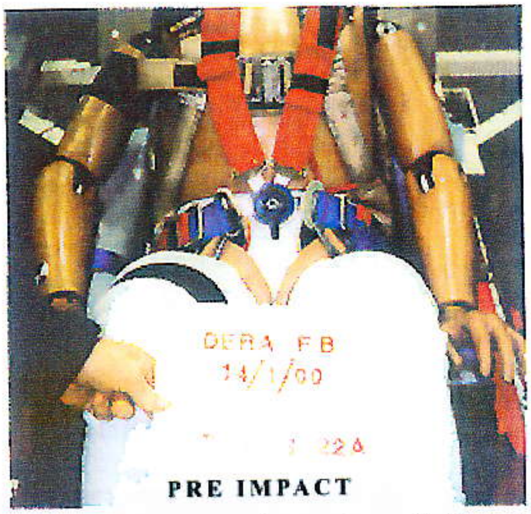
Flight testing was carried out in February 2000 at the Joint Service Adventurous Training Glider Centre, RAF Bicester, with the kind permission of the Officer-in-Command, Sqn. Ldr. (ret.) Ted Norman. The harness was installed in the rear seat of a K-21; no modification to the anchor points was required. I, as pictured (next page), in the rear seat, was flown by Ian Tunstall in the front seat. Two flights were made, one with the harness tight, the other with the harness slack. The test went to -3g, and tail slides were flown. The harness performed well in both flights. It is now being assessed by the Bicester gliding instructors in routine club flying.

With minor modifications, the Willans six-point harness should be suitable for widespread use in gliders.



The OSTIV airworthiness standard for lap straps, showing the location of the H point.

This six-point harness has two lap straps, two sholulder straps.and two crotch straps. But how does it perform in simulated crashes and in flight?



PRE IMPACT

A four point harness on the test rig, ready for testing.

POST IMPACT

After impact, the shoulder and lap straps are out of position. There is potential for serious injury to be caused to the vulnerable abdomen by the movement of the lap strap.