Drop-testing a Two-seater

Dr. Antony M. Segal

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Dr. Tony Segal reports on an investigation into why in some accidents the instructor in the rear seat can be severely hurt while the front pilot isn't.

Many of you will have completed glider accident forms conscientiously as club officials, pilots or witnesses. I wish to assure you that your efforts are taken seriously and acted upon. As a member of the BGA Safety Committee I picked out three "interesting" accidents. The accidents involved two-seat gliders impacting heavily onto the main wheel. The rear pilots in each case received a spinal injury, serious in two cases, while the front seat pilot was unharmed or received only minor injury. This contrasted with the more common accident where the glider impacts on the nose and front of the cockpit, resulting in injury to the front pilot with little or no injury to the rear pilot.

By an act of serendipity, I was woken at 8am one morning by a telephone call from Tim MacFadyen, CFI of Bristol & Glos GC. He informed me that he and Terry Joint (who had arranged the insurance of the glider) had decided that following an accident the club SF-34 two-seat glider was a write-off. "Would I like the two-seat fuselage for my tests into glider crashworthiness?"

Before I had time to think, in a state of drowsy stupor, I replied: "Yes, please." A year later, the impact test duly took place.

The fuselage arrived at Lasham, minus the wings, which had been donated to Bristol University. The rear fuselage and tailplane were also missing. The club had retained the seat harnesses. Nevertheless, the fuselage was, to me, of a value beyond rubies.

People involved in glider crashworthiness studies have their own little Mafia, so I was aware of work at Aachen Technical University (Fachhochschule Aachen) under the supervision of Prof. Wolf Roger. Wolf invented the Roger hook for glider canopies and has carried out extensive studies on glider parachute recovery systems. One of his students, now Dipl. Ing. Niels Ludwig, had designed and constructed two welded tubular structures to which metal weights were attached, to represent the mass of the wings in a series of cockpit crashworthiness tests of single-seat gliders. My wife, Liz, and I put a couple of canoe racks on the roof of our car and drove to Germany to collect the wing stubs. Wolf and his wife Marlis were most hospitable. Our supper was made to grandmother's recipe, cabbage and smoked belly of pork simmered slowly for 24 hours - delicious. Wolf hijacked me to give a lecture (in English) on the recent sad fatal accidents in the UK. The girder structures on the roof of our car looked like surface-to-air missile launchers, but no one batted an eyelid as we emerged from the Channel Tunnel.

The wing stubs were adapted to fit the wide two-seat fuselage by Dave Dripps, ground engineer of Lasham Gliding Society. Maintaining the MT equipment of LGS is rather like painting the Forth Bridge, a never-ending job, so I got the distinct impression Dave greatly enjoyed doing something out of the ordinary routine. One of the fittings connecting the lower portion of the wing stubs to the wing attachment points on the fuselage was missing, so Dave machined a replacement out of solid metal. He also had to widen the spacing between the wing fittings so they would fit on the fuselage. The upper part of the wing stubs were meant to be bolted together above the fuselage. However, they were too narrow and too low to fit. A welded metal structure and high tensile bolt filled the gap. An oval hole was cut in the top of the fuselage behind the cockpit to accommodate the metal structure. I surrounded this gap with ten layers of fibre-glass. I was concerned there would be a stress concentration where this stiff structure met the thin material of the rear fuselage, but there were no problems during the test. Two sets of reconditioned seat harness were also supplied by Lasham.

The test was carried out at RAFGSA Bicester, the home of the joint Services Adventurous Training Gliding Centre, by kind permission of the officer i/c, Ted Norman. All members of his staff were most enthusiastic in supporting the project, and I made full use of their skills. I was grateful for being made an honorary member of the Crew Room. My original full-size Libelle glider impact test in 1988 was carried out in this hangar, and the flight testing of a six-point harness was carried out in a Bicester glider. Working in the hangar at Bicester felt like returning home.

The wing stubs fitted onto the fuselage very smoothly. To take the rebound load on impact, Ian Tunstall, a member of the Bicester staff, suggested fitting metal tubes around the high tensile bolts of the wing stubs. He made and fitted these tubes, and the wing stubs stayed firmly in place during the subsequent test. Ian was also responsible for constructing the cable suspension rig. I was keen to avoid having a solid test rig, as this would interfere with the video of the test. Wolf Roger had suggested that if I allowed the glider to drop freely, the inertia of the glider would maintain its lateral and fore-and-aft stability until it hit the ground. Four suspension cables, made from winch launch cable, were used, attached to a common shackle. This was attached to a weapon slip (bomb release) itself attached to a chain hoist in the hangar roof. Two suspension cables were fastened to the wing stubs, and two to the front of the fuselage, near the strong front transverse bulkhead.

Four steel weights, each weighing 10kg, were fastened to each wing by U-bolts. "Foxy" Fox showed me how to use the Bicester workshop pillar drill, and I spent a day drilling 32 holes through the tough metal . One learns something new every day. I bolted 33kg of lead to the rear fuselage, the glider then being just tail heavy. Because the rear of the fuselage was missing, the moment arm of the fuselage was shortened, so I required more lead than the weight of the original tail structure. A new inner tube was fitted to the main wheel. The main wheel was inflated to 3 bar, the nose wheel to 2.5 bar. The undercarriage had been damaged in a previous accident. Following this, the gas struts of the undercarriage suspension had been replaced, and the tube to which their upper ends were attached was replaced by a stronger tube.

Technical support was provided by The Centre for Human Sciences, QinetiQ, Farnborough. Les Neil (Senior Consultant Engineer, Occupant Impact Protection), was in charge. Graham Reece was responsible for the instrumentation. Phil Murtha was the test engineer. Les Neil had been in charge of technical support for my original Libelle drop test in 1988 - we have worked together as a team for a long time.

Two pilot dummies were provided, both being 50th percentile Hybrid 111 manikins, each weighing 79kg. They were seated directly on the fibreglass seat, no cushion being used. No parachutes were fitted. The backrest of the front seat was attached at its upper end to an adjustment cable; this probably enabled some extra movement of the manikin to take place. The backrest of the rear seat was not adjustable, so the manikin reclined backwards at a greater angle than the front manikin. There was no time to construct a solid backrest to correct this. Instead, I placed a firmly rolled blanket behind the manikin's upper chest.

Transmission of load via the pelvis and lumbar spine would not be affected, although the transmission to the thorax and head would be altered. As I was not measuring the latter values, this did not matter.

An accelerometer was attached to a solid structure on the floor of the glider in front of the wheel box. Another accelerometer was attached to the floor of the cockpit in front of the forward bulkhead.

These instruments measured in the X axis (the longitudinal axis) and the Z axis (the vertical axis) of the glider fuselage. Units of g, the acceleration due to gravity, were used.

An accelerometer was placed in the pelvis of each manikin, again these measured in the X and Z axis. A load cell was in position in the lumbar spine of both manikins. These measured the load in the X and Z axis using Newton units. The load cells also measured the lumbar spine rotation (moment) around the Y axis (the transverse axis), the units used being Newton/metres.

One complication was that the load cells were angled at 22° to the spinal axis of the manikins. The hybrid 111 manikin is designed for use in motor vehicle impact research, and the manikin is assumed to be leaning forward towards the vehicle steering wheel at an angle of 22°. I have made a correction for this, multiplying by the secant for 22°.

Three video cameras were used, one normal speed to give a general view, and two high-speed digital cameras. One of the latter recorded the entire cockpit area, the other focussed on the main wheel. A "sight screen" to be placed behind the test site to enhance the video photography was constructed by my wife Liz: wood strips measuring six feet by one inch were painted black and then nailed together at one foot centres to give a square lattice. The structure was backed by white paper secured by drawing pins. This inexpensive structure measured six feet by eighteen feet.

The centre of gravity was found by dropping a plumb line from the weapon slip. It was 300mm aft of the datum, the wing leading edge. The c of g range is given as from 199mm to 367mm aft of the wing leading edge. The weight of the glider with both manikins in place was measured as 473 kg.

The design maximum all-up weight (AUW) is given as 540kg. The AUW of the test glider was less than the design maximum AUW required by JAR22, Joint Airworthiness Requirements relating to gliders and powered gliders. JAR22 give the following standards for undercarriage loads:

JAR22.725 Level landing

a) The shock absorbing elements (including tyres) must be capable of absorbing the kinetic energy developed in a landing without being fully depressed.

b) The value of kinetic energy must be determined under the assumption that the weight of the sailplane corresponds to design maximum weight with a constant rate of descent of 1.5m/s, wing lift balancing the weight of the sailplane.

c) Under the assumption of (b), the CG acceleration must not exceed 4g.

Assuming the glider is in free fall with no aerodynamic drag, calculation gives the following impact velocity for the given drop height. The test coding for each impact is given alongside the figures:

10cm (4 inches)	1.4 m/s	G01
20cm (8 inches)	2.0 m/s	G02
30cm (1 ft)	2.4 m/s	G03
40cm (1 ft, 4 in)	2.8 m/s	G04
50cm (1 ft, 8 in)	3.1 m/s	G05
60cm (2 ft)	3.4 m/s	G06

It was decided to commence with a drop height of 10cm (4 inches), until the under-carriage collapsed or serious structural failure of the glider occurred.

Cedric Vernon has kindly given me the history of the development of standards for glider undercarriages. Prior to WWII, the standard in Germany or Poland was 1 m/s descent rate of the glider. In 1959 Beverley Shenstone (Chief Engineer for BEA) and Cedric (aerodynamicist for Handley Page) wrote a first draft quoting this figure of 1 m/s. In 1962, this was accepted as the OSTIV Airworthiness Requirement (OSTIVAR). In 1966, a recommendation was made that the OSTIVAR should be increased to 1.4m/s. In 1971, the OSTIVAR was increased to 1.5m/s. In 1977, the OSTIVAR rate of descent was not altered, but it was made clear the undercarriage had to cope with 3g, the wing lift accounting for 1g, a combined total of 4g. The 1999 OSTIV Airworthiness Standards (OSTIVAS) gave a figure of 1.6m/s for two-seat gliders used for training and 1.5m/s for other gliders at maximum dry mass, the g loading being as before. A further condition was added - that the shock-absorbing elements (including the tyres) must not be fully compressed at a rate of descent 1.1 times the above figures. This gave a measure of reserve energy in the undercarriage requirement.

The JAR22 figure arose in 1975, in the German publication LFSM, paragraph 3411 *(Airworthiness Rules for Gliders and Motorgliders).* The figure of 1.5m/s descent rate at design maximum weight was given, with 4g at the CG, made up of 3g for the undercarriage and lg from wing lift. At the present time, the JAR22 Study Group are actively considering the provision of reserve energy in the undercarriage. JAR22 is mandatory, whilst OSTIVAS is advisory.

I was pleased to welcome the following observers to the test: David Cockburn (Safety Promotion Officer, Civil Aviation Authority), Jonathan Mills (Chairman, BGA Safety Committee), Dr. Peter Saundby (BGA Medical Advisor) and Jim Hammerton (BGA Chief Technical Officer). The following comments on test conditions should be noted. There was clearly no wing lift during the test. Following on the impact on to the main wheel, the fuselage rotated forward and down around the axis of the mainwheel, on to the nose-wheel. In the absence of aerodynamic damping from the missing horizontal tail, the force resulting from this rotation was increased.

Test Findings

The video

The behaviour of the mainwheel tyre under the impact load could be clearly seen on the high-speed video. While the shock-absorbing gas struts themselves could not be seen, their behaviour could be inferred from the downward movement of the fuselage relative to the main wheel.

In Test G01, the tyre and the gas struts absorbed the energy without being fully compressed in accord with JAR22. The fuselage rotated gently forward onto the nosewheel.

Test G02 was less clear. The tyre and gas struts may have been just fully compressed. If so, it was a very gentle full compression. Again, forward rotation occurred.

In Tests G03, G04 and G05, both the tyre and gas struts were fully compressed. The tyre was in contact with the wheel hub, and the bottom of the fuselage touched the ground. Forward rotation of the fuselage occurred. The fuselage bounced upwards until the mainwheel was clear of the ground, due to stored energy causing re-expansion of the tyre and gas struts.

Collapse of the undercarriage occurred in test G06. The cross-tube to which the upper end of the gas struts were attached broke away from its mountings to the fuselage side wall. The wheel box was damaged. A U-shaped frame to which the cross-tube was attached was split. The fuselage made one gentle bounce, the main wheel staying in contact with the ground as it was no longer constrained by the gas struts. The fuselage rotated forwards.

The instrument tracings

Two records were made of each reading, one with a time base of 0.6 seconds to show the impact clearly, the other with a time base of 2.5 seconds to show any rebound. This gave a total number of instrument traces of 72! 1 will concentrate my discussion on *the floor pan acceleration in the Z axis* (the vertical axis), and *the lumbar spine force in the Z axis* (the axis of the spine).

In test G01, both instruments showed a low value, with a gentle rise to a peak. The front reading was delayed by 0.15 seconds following impact as compared with the rear ending. This showed the load on the front pilot was due to the nosewheel making contact with the ground following rotation of the fuselage, and not due to direct spread of the load in the cockpit structure.

All other readings, from G02 to G06 showed large peak values, with a high rate of rise or "jolt". The peaks in both rear and front positions occurred at the same time following the impact, showing the load was transmitted through the cockpit structure. The duration of these peaks was 0.01 seconds to 0.02 seconds. It was not possible to recognise the effect of nosewheel impact.

All readings in the rear and front positions were of approximately equal magnitude, until Test G06.

Test G06 showed very high values, with a high rate of rise. Both rear and front peaks were at the same time following impact. The value in the rear position was much greater than in the front position. This finding was very significant.

The acceleration in the Z axis at the rear of the cockpit floor in test G01 was within the JAR22 limits; these limits were exceeded in all the other tests.

The acceleration values in the Z axis of the pelvis of the manikins paralleled, but at a lower value, the acceleration readings in the cockpit floor.

The lumbar spine rotation around the transverse axis was of very low value.

All the instruments recording the X axis (the longitudinal axis of the glider, and the fore-and-aft axis of the manikin) showed a reading of moderate value. In the case of the lumbar spine load, this was partly due to the angle of the load cell in the spine. The forward rotation of the fuselage may have had some effect. Les Neil suggested that these loads in the X axis may result in a shear load where the lower lumbar spine joins the pelvis. I believe this is the first time this has been suggested.

Fracture of the lumbar spine

The mean breaking load in compression of the lumbar (lower) spine by age groups is as follows:

20-39 years	7140 Newtons
40-59 years	4670 Newtons
60-79 years	3010 Newtons

Both rear and front pilots, if over the age of 59 years, involved in an accident under test conditions G04, G05 and G06 would have received fractures of the lumbar spine. Pilots of a younger age group would need to be involved in a more severe accident to suffer a spinal fracture.

Conclusions

When the impact was within the limits of JAR22, force and acceleration values were low, with a low rate of rise. The impact on the front manikin was due to impact of the nose wheel with the ground.

As soon as JAR22 values were exceeded, high peak values with a high rate of rise resulted. The peaks occurred at the same time after impact in rear and front manikins, showing the load was transmitted directly through the cockpit structure.

The magnitude of the values in the rear and front manikins were approximately the same. The nose wheel impacts were gentle, and could not be recognised on the instrument tracings.

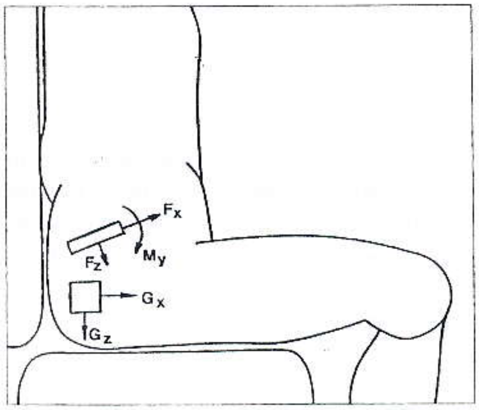
A significant change occurred when the mainwheel collapsed. High peak loads occurred in the rear and front spinal lumbar loads, with a high rate of rise. The load in the spine of the rear pilot was much greater than the load in the spine of the front pilot. This explains the severity of the injury to the rear pilot in the accidents discussed at the start of this report.

Similar injury to the lumbar spine of the rear pilot of a two-seat glider could occur in the following circumstances: rounding out too high then stalling, or failing to round out and then ballooning, followed by a heavy landing.

Recommendations

The vertical velocity for undercarriages in JAR22 should be increased. There should be no sharp stop at the limit of stroke. The ultimate breaking load of the undercarriage should be increased. These values will have to be set by what can be complied with by the manufacturers.

I intend to make these findings available to the JAR22 Study Group, and to the OSTIV Sailplane Development Panel.

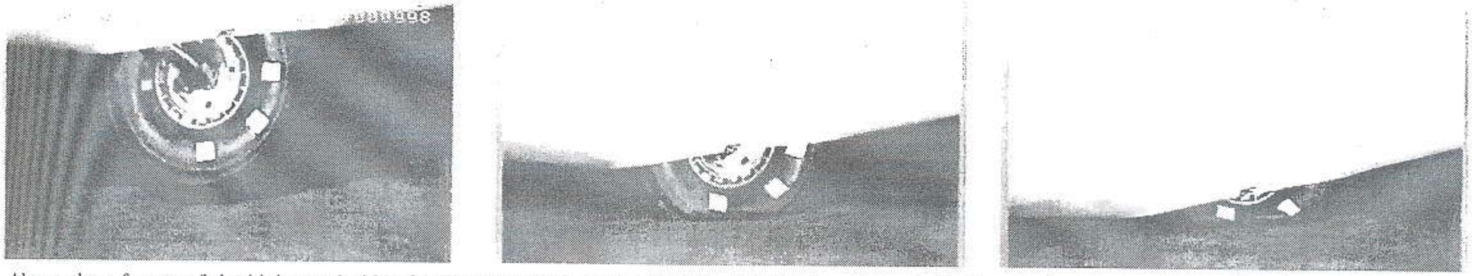


The rectangle represents the lumbar load cell at an angle of 22° to the spinal axis; the square represents the pelvic accelerometer.

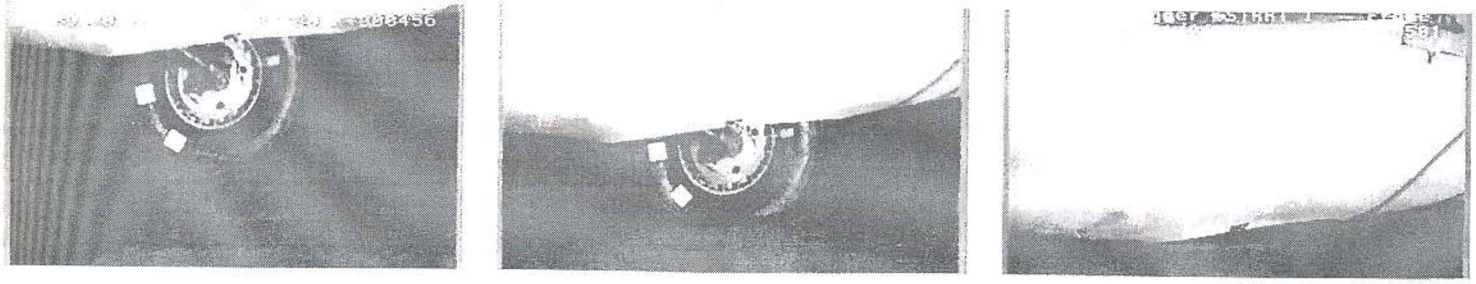
Les Neil (left) and Dr. Tony Segal (far right) during testing of a two-seater undercarriage at RAFGSA Bicester

The two-seater hoisted in position for a test against the backdrop of the sight screen. The lights enabled the use of high-speed video to record each of the six tests.

The glider after the final test, when the structure broke. The girders, borrowed from Germany and brought to the UK on a car roofrack, simulated the weight of wings.

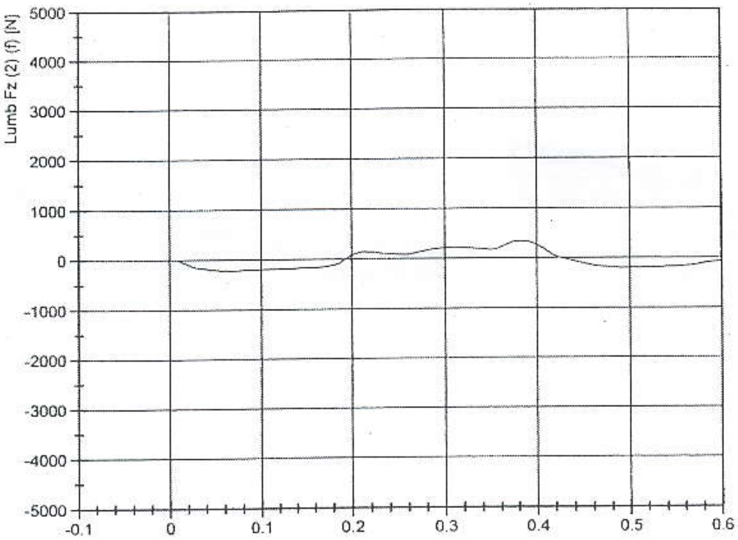


Above: three frames of the high-speed video for test GO1 (drop from 10cm/4in). The fuselage drops (left); the wheel compresses (centre) but does not compress fully (right). This drop height is what the international airworthiness standards currently stipulate.
Below: threee frames of the high-speed video for test GO6 (drop from 60cm/2ft). The fuselage drops (left); the wheel compresses (centre) then the structure fails.This test was the last of six and instrumentation showed that in this case the rear pilot takes the brunt of the impact.

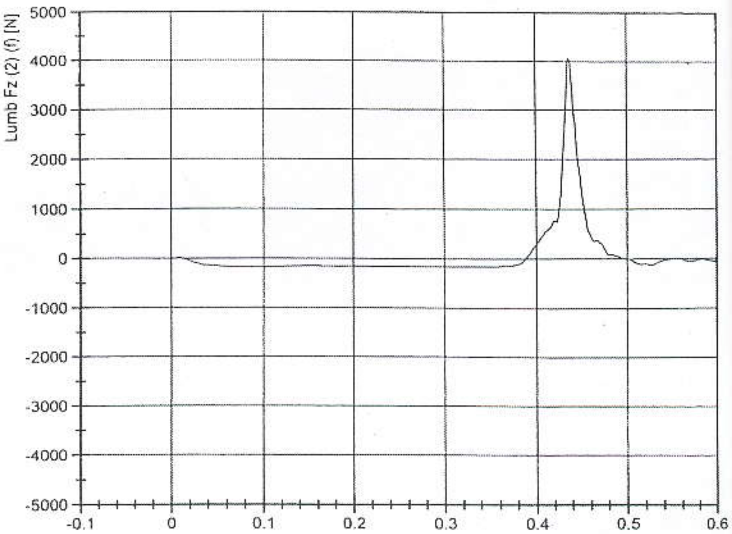


Parameter	Manikin position	**Test number** G01	G02	G03	G04	G05	**G06**
Cockpit floor acceleration (g)	Rear	2.1	11.6	24.5	34.2	42.9	**42.2**
	Front	4.6	11.8	24.2	31.5	38.0	**24.6**
Manikin pelvis acceleration (g)	Rear	1.8	4.1	8.8	13.7	13.8	**21.0**
	Front	3.0	2.9	8.8	14.6	16.9	**15.2**
Lumbar spine load (Newtons)	Rear	373	877	2032	3191	3155	**4391**
	Front	563	636	2025	3240	3201	**3022**

Note: More graphics next page.



In test GO1, there was a low peak load, as the graph showing the lumbar spine force in the Z axis (in the rear) shows. The shock was absorbed by the main wheel and by the gas struts.



In the last test, number G06, when failure of the undercarriage occurred, a sharply-peaking force with a high rate of rise was felt in the lumbar spine Z axis in the rear cockpit. It was much greater than the load in the spine of the front pilot.

Above: Les Neil of QinetiQ (formerly DERA) hoists the test glider with manikins into position at RAFGSA Bicester

Changes to JAR 22 will Double the Energy-absorbing Capacity of the Undercarriage

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Following on from Tony Segal's article on drop-testing a two-seat glider (Drop-testing a glider. April-May 2002, p22), Dipl. Ing. Helmut Fendt has provided its author with the following information (agreed in November 2001) concerning changes to glider landing gear requirements that will be incorporated into the next amendment to JAR 22. Helmut is the Chairman of the JAR 22 Study Group, and is the official of the LBA (the German equivalent of our Civil Aviation Authority) responsible for certifying gliders, motorgliders, balloons and airships in Germany. He is also a keen aerobatic glider pilot.

1. At design maximum weight, the selected limit vertical inertia load factor at the c g. of the sailplane may not be less than that which would be obtained when landing with a descent velocity of 1.77m/s (note, this has been increased from 1.5m/s).

2. The landing gear must be able to absorb 1.44 times the energy described in the above paragraph without failure, although it may yield during the test (note, this is a new requirement).

3. At design maximum weight, at a constant rate of descent of 1.77m/s, and with wing lift balancing the weight of the glider, the c.g. acceleration must not exceed 4.5g (note, this has been increased from 4.0g).

The justification for these changes is as follows:
The descent velocity of 1.5m/s has not been changed since the earliest requirements for gliders, although the wing loadings have been raised.

Accident statistics show that approximately 50 per cent of injuries affect the spine. In most typical crash cases the landing gear is the main element to absorb the energy. Improving the energy-absorbing capacity of the landing gear will make a significant contribution to lowering the number of injuries.

Important for safety is the increase in total energy-absorbing capacity, including the undercarriage yielding without collapsing.

The amendments together double the energy-absorbing capacity of the undercarriage.

Dr. Tony Segal

Survivable Loads on the Pilot and the Crashworthiness of Glider Cockpits

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Introduction

The interface between the sea and the land is named the intertidal zone, and is a fascinating area for study. Similarly, the region of contact between the pilot and the glider is equally interesting. I will be dealing with this subject in my lecture. Some of the information in my talk is based on the work of my friends and colleagues - Prof. Wolf Roger of Fachhochschule Aachen, Germany, and Dipl. Ing. Martin Sperber of TüV Rheinland, Cologne, Germany. My experimental research has been carried out at QinetiQ Farnborough, England, with the assistance of Mr. Leslie Neil, Mr. Graham Reece and Mr. Philip Murtha.

The following topics will be discussed in my lecture:

1) A: Types of glider accident
   B: Survivable loads on the pilot
2) Cockpit design
3) Seat harness
4) Undercarriage design
5) Spinal injury
6) Other key subjects

1 A) Types of Accident and Accident Statistics

This section is based on the work of Dipl.Ing.Martin Sperber. In Germany from 1987-1989, 90% of a total of 558 accidents were described as follows:

High hold-off	29%
Failure to round-out	33%
Wingtip striking the ground	7%
Stall or spin	21%
Total	90%

Injuries incurred by the pilots involved were as follows:

No injury	72.4%
Slight injury	6.5%
Severe injury	16.1%
Fatal injury	5.0%
Total	100.0%

Between 1973-1990 in Germany, 94% of the severe injuries incurred in heavy landing accidents were spinal injuries. Due to these findings, I have concentrated on methods of reducing spinal injury in my experimental studies.

1 B) Injury to the Pilot

This deals with injuries caused by abrupt deceleration forces. The following factors will be considered:

1. Acceleration
2. The direction of the impact
3. The site of the impact on the pilot's body
4. Coupling of the pilot's body to the aircraft seat
5. The age of the pilot

1. Acceleration

The following values are of importance - the rate of rise of g, the peak value of g, the duration of g, and any subsequent rebound.

The "Eiband Diagram" is of significance. Eiband is a scientist who worked for NASA. He showed the severity of pilot injury was related both to the duration and the severity of the acceleration. He described three injury zones - no significant injury, moderate injury (including ejection seat injury), and severe or fatal injury. At an acceleration duration of 0.2 second, 5 Hz, the spine was specially vulnerable. This was due to 5Hz being the spinal resonance frequency.

2. Direction of the Impact

The direction is described in relation to the pilot's body, as follows:

The spinal axis	Gz
From the front to the back of the pilot's trunk	Gx
Transverse to the trunk, in line with the shoulders	Gy

Gz impacts are of the greatest significance. First, compression loading of the spine occurs. Next, the vital organs of the body - the heart, liver and spleen - are relatively free to move up and down in the body cavity. This can be considered as resembling the movement of a piston in a cylinder. The heart is especially vulnerable as it may tear away from the main blood vessels in the back of the chest.

The body is less vulnerable to Gx impacts as the vital organs are held in place between the back and the body wall.

Gy impacts may cause neck injury but are otherwise of less importance.

3. Site of the Impact on the Pilot's Body

The pilot's back and buttocks are the most favourable sites for the reduction of impact injury.

4. Coupling of the Pilot to the Seat

The pilot should not bounce around on the seat, but should be firmly restrained on the seat.

5. The Age of the Pilot

This is of significance as bones become weaker with increasing age due to the development of osteoporosis. Yamada produced the following figures for the breaking load in compression of the lumbar spine (the lower spine).

20-39 years	7.14 kN	1750 lb.f.
40-59 years	4.67 kN	1144 lb.f.
60-79 years	3.01 kN	737 lb.f.

2) Cockpit Design

A modern motor car is designed on the principle of a strong safety cage to protect the driver and the passengers, and a relatively weak energy absorbing bonnet area.

Most gliders are designed so as to obtain maximum performance. The pilot's feet are a minimal distance from the tip of the glider nose cone. As a consequence I invented the aphorism "Better broken legs than dead". A distance of approximately one metre is available between the tip of the nose cone and the control column that can be utilised for energy absorption. The cockpit between the control column and the rear cockpit bulkhead can be designed as a strong cage to protect the vital organs of the body. In an accident, injury to the feet and ankles may occur, but against this the pilot will still be alive. The latest OSTIV Airworthiness Standard specifies 15g for the cockpit cage and 6g for the nose section.

As a development of this idea, Prof. Boermans of the University of Delft, Holland, has shown that increasing the length of the glider nose without increasing the cross-section area results in only minimal increase in drag. It follows that impact energy can be absorbed without incurring injury to the feet and ankles of the pilot. The incorporation of this idea promises a great advance in future cockpit safety design.

3) Seat Harness

The seat harness has two functions - to restrain the pilot against in-flight loads, and to restrain the pilot against accident impact loads.

There are two basic pilot seating positions, the upright position and the semi-reclining position. In gliders, the semi-reclining position is used to reduce the glider frontal area and so obtain improved performance. In military aircraft, this position is used to reduce the incidence of G-LOC (high-g loss of consciousness).

Considering vertical impact loads, the spine of the pilot in an upright seating position is more vulnerable to injury than a pilot in a semi-reclining position. In the case of the semi-reclining seating position the load is resolved into a vertical and a horizontal component, resulting in a reduced compression load on the spine of the pilot.

I will discuss various types of seat harness.

Four-point Harness

This works well for a pilot in an upright seating position for routine flying. It is easy to put on and to remove. With a pilot in the semi-reclining position there is a risk of the pilot submarining down and forward under the lapstrap.

Five-point Harness

This works well with both the upright and the semi-reclining seating position. The fifth, crotch, strap makes passing urine in flight difficult for male pilots. In the case of a semi-reclining pilot position, the crotch strap may cause injury to the groin in the event of an accident impact. This type of harness is widely used in military and aerobatic flying.

Four-point Harness, "H-Point Method"

This was designed by Dipl.Ing. Martin Sperber. The lapstrap passes down from the "H-Point" (the intersection of the longitudinal lines of the pilot's trunk and thigh) between vertically and backwards by 15 degrees. The front of the seatpan is designed with a steep upward slope. To be effective, this harness must remain tight in flight. There is a theoretical increased risk of the development of deep vein thrombosis due to the steep thigh ramp.

Six-point Harness

This consists of two shoulder straps, two lapstraps, and two crotch straps. This is very effective in restraining the pilot, and enables the male pilot to pass urine in flight without difficulty. However, the present design is not easy to put on and may be difficult to remove rapidly in the event of emergency egress becoming necessary.

A seat harness is only as effective as its anchor points. This is especially the case in regard to the anchor points for the lapstraps that take the main load of pilot restraint. The anchor points should be designed to securely spread the load into the main structure of the fuselage.

Tests on all the above types of seat harness have been carried out on the test track at QinetiQ Farnborough, England, using instrumented Hybrid 111 pilot manikins, by Mr. Leslie Neil, Mr. Graham Reece and Mr. Philip Murtha.

4) Undercarriage Design

In most undercarriage designs a high peak g load occurs at the limit of stroke. This can result in spinal injury. It is proposed that the structure of the undercarriage be designed to undergo planned progressive collapse at the limit of stroke, thus reducing the peak g on severe impact.

5) Spinal Injury

Site of Fracture

The regions of the spine most frequently involved in damage due to vertical impact loads are the thoracic and lumbar spine. These have opposing curves, resulting in an S-shaped spine. The region of the spine where the opposing curves meet is called the "spinal hinge" and is the region where most fractures occur.

Military pilots who eject from their fast jet aircraft have the same spinal injury as pilots involved in a heavy landing accident. The type of load on the spine is the same, except for being in the opposite direction.

Injury figures from the UK Royal Air Force for the years 1968-1983 from a group of 105 aircrew showed a total of 184 vertebral injuries (some pilots had more than one injury). The majority of fractures were grouped around the spinal hinge. This is also the site of the majority of injuries in heavy landing accidents.

Reducing the Incidence and the Severity of Spinal Injury

The following methods are available:

1. Supporting the spine
2. Maintaining the lumbar spine curve
3. The use of energy absorbing seat cushions
4. Preventing submarining
5. Improving the undercarriage

1. Supporting the Spine

The seatback should provide smooth continuous support to the back. If necessary a wooden fillet can be provided to fill in a marked hollow, such as is sometimes provided to contain a parachute pack.

The parachute pack should be of a long flexible "slimline" design so as to fully support the spine. A short stiff parachute pack gives a stress line at its lower border, at which level a spinal fracture may occur.

2. *Maintaining the Lumbar Curve*

If the pilot leans forward the intervertebral disc spaces open up, so the effect of a compression impact load is concentrated on the front of the vertebral bodies. This results in a typical wedge-shaped fracture as seen in military pilots after an ejection incident, and in glider pilots after a heavy landing accident.

By maintaining the spinal lumbar curve, the strength of the spine under compression loading is increased by 80%. The surfaces of adjacent vertebral bodies are parallel, so the impact load is distributed evenly. Further, the posterior facet joints of adjacent vertebrae meet, so providing a second load pathway.

The lumbar curve may be maintained by a firm lumbar pad. A GRP plate shaped to the spine of the individual pilot could be used. I do not recommend this for use in gliders owing to the risk of injury from the sharp upper and lower edges of the plate. I also suggest inflatable pads be not used as they could cause rebound on impact.

3. Seat Pan and Seat Cushions

A layer of aluminium honeycomb material can be attached under the seat pan. The material can be tailored to begin compressing at a predetermined level of impact load. It will make maximum use of the limited stopping distance under the seat pan. It will need to be replaced after an impact event. This method of reducing impact energy on the pilot can probably only be used in a new glider cockpit design and can not be retrofitted.

Energy absorbing seat cushions may be used on top of a firm seat pan. They are inexpensive and are simple to install and to retrofit. They function by increasing the duration of the impact load, while reducing the rate of rise of g and the peak g. They also reduce any rebound. Only part of the theoretically available stopping distance is utilised. However, studies in the USA have shown that energy is absorbed by the entire volume of the foam material, and so the amount of energy absorbed is not entirely dependent on the available stopping distance.

Tests carried out at QinetiQ, Farnborough, England, gave the following results:

The material tested is called "Sunmate" in the USA, and "Dynafoam" in Europe.

The impact parameters were 9.4 m/s and 17g.

The results on the spinal load of a Hybrid 111 male 50th percentile manikin weighing 78.15kg were as follows:

No cushion	9.035 kN	2035 lb.f.
Dynafoam 1.25 cm	8.175 kN	1837 lb.f.
Dynafoam 2.5 cm	7.520 kN	1690 lb.f
Dynafoam 5.0 cm	6.239 kN	1402 lb.f.
Dynafoam 10 cm	5.264 kN	1183 lb.f.

The test clearly showed the effectiveness of Dynafoam in reducing spinal impact load.

The cushion should be firmly attached to the seat pan but should be removable. If it were to slide forward it could restrict the full aft movement of the control column. The cushion cover should be made of a porous material. An airtight cover could cause rebound due to the trapped air.

4. Avoiding Submarining

Submarining describes the pilot sliding down and forward under the lapstrap of the seat harness and is an important contributary factor for spinal injury. As a result of the pilot sliding down and forward, the shoulder straps become slack. The shoulders and spine then bend forwards. As a result, the risk of spinal injury is increased, as is the risk of injury to the crotch and the legs. A suitably designed seat harness will prevent submarining.

5. The Undercarriage

Two factors should be taken into consideration:

The frequency of 5 Hz should be avoided in the design of the undercarriage, as this is the resonance frequency of the spine at which it is especially weak.

As previously discussed, there should be a planned progressive collapse of the undercarriage at the limit of stroke, to prevent a sudden high g loading.

6) Other Key Points

The following points will be discussed:

1. Headrests
2. Cushions behind the back
3. Lightweight small pilots. Female pilots
4. De-lethalise the cockpit
5. Loose objects
6. Emergency egress

1. Headrests

A headrest should be provided to protect the neck of the pilot from whiplash injury. The headrest should be centred at eye level. It should be part of the seatback structure, but should be adjustable. The headrest should be faced with energy absorbing foam. The parachute pack should not catch under the lower edge of the headrest, as this could interfere with emergency egress from the cockpit.

2. Cushions Behind the Pilot's Back

These cushions are required to enable short pilots, or pilots with short arms, to obtain full movement of the flight controls. They must not compress significantly under g loading. Frank Irving, Imperial College London, has calculated there is a loading of one and a third g on the ground run of a winch launch. On rotation and in the climb the loading is one and two thirds g. Fatal accidents have occurred in the UK due to soft seat cushions compressing behind the pilot under the g load of the winch launch. The pilots involved were unable to obtain sufficient forward movement of the control column, climbed too steeply, then stalled and dived into the ground. A suitable inexpensive material for seatback cushion is firm grade chipfoam. (This material is not energy absorbing, and so should not be used in cushions for the seatpan to absorb vertical impact energy).

3. Light-weight and Small Pilots. Small Female Pilots

These pilots will require the provision of securely attached ballast.

Pilots with short arms will require non-compressible cushions behind their back to enable the pilot to exert full movement of the control column.

Problems may be caused by the high operating loads in some gliders for the airbrakes, undercarriage retraction, cable-release, and the parachute ripcord handle. Historically, Hanna Reisch, the famous female German test pilot, had this problem. I understand she eased the problem by carrying out strengthening exercises and applying bungees to the controls. Designers should make every effort to keep control operating loads low.

4. De-lethalise the Cockpit

The following should be removed from the cockpit or modified, either in the design stage of new gliders, or from gliders in current use:

Sharp edges, such as the sharp lower edge of some instrument panels.

Pointed objects, such as some knobs and switches.

Sharp handles.

Objects that could cause head injury if the trunk rotates forward in an accident impact.

5. Secure Loose Objects

JAR 22/EASA 22 specify that potentially loose objects should be secured to withstand 9g. This covers objects such as batteries, the barograph, cameras, a loose radio, GPS receiver, and the oxygen cylinder if fitted.

6. Sailplane Parachute Rescue System

The research work on this subject in connection with gliders has been carried out by Prof. Wolf Roger.

In the case of unassisted emergency egress, only six out of ten pilots are able to escape from the cockpit and operate their parachute before impact with the ground. The remaining four pilots die while still in the cockpit. A sailplane rescue system enables the disabled glider, with the pilot still in the cockpit, to be safely lowered to the ground under a parachute. To prevent injury to the pilot when the parachute/glider combination contacts the ground, a modern crashworthy cockpit is required.

Still under investigation is a method of using a parachute to extract the pilot from the cockpit. This is a simplified lightweight method functioning like an ejection seat.

The Noah airbag system is of importance. When operated in an emergency situation, the canopy and the seat harness are automatically released. A cushion under the pilot then inflates, raising the pilot nearer to the level of the cockpit sill. This makes successful unassisted escape more likely.

Conclusion

I should like to quote an extract from a poem by the English poet Shelley on a small bird called the skylark. This bird is noted for its beautiful song which it sings while flying higher and higher in the sky.

"And singing still does soar, and soaring ever singest"

May we all continue to fly and soar in happiness and safety.

Nosewheel or Skid?

Dr. Antony M. Segal

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Tony Segal reports the results of his new research into whether a landing skid or a nosewheel affords more protection to the spine of the pilots of a K-13 in the event of a heavy landing on a hard surface.

Introduction

I was quietly holding wingtips and hooking on launch cables at the Lasham launchpoint when I heard a loud bang. I looked round and saw a K-13 equipped with a skid impacting on its nose. The front seat pilot suffered a spinal fracture - he is now flying again. The rear pilot had slight back discomfort.

Some of the Lasham fleet of K-13s have landing skids, others have nosewheels. Both can be considered equally airworthy. The skid was described in a technical drawing, reference L-267.10-S2, signed by Kaiser himself on 1/6/66. The nosewheel modification was described in a technical drawing, reference L-267.130.21.S1, initialed by "JUW" on 21/6/85.

Following the accident I studied the load pathway in the event of an accident such as I had witnessed. The stiff wooden skid is attached at its front end by a bolt, the rear end sliding freely into a slot in the main wheel housing. Halfway along the skid is a firm rubber mounting block attached to the fuselage frame. This block is situated directly under the front seatpan. Impact loads will be transmitted up the spine of the pilot sitting in the front seat with little reduction in force.

A further point is that the pilot has an upright seating position, so there will be no resolution and reduction in spinal load as would occur with a semi-reclining position.

In the case of the nosewheel, the tyre will absorb considerable impact energy. However, it will also cause rebound as the stored energy is released. As the wheel is situated well forward of the front pilot, further energy will be absorbed as the impact shock wave travels back along the fuselage. This function of the fuselage in absorbing energy was shown in a previous impact test, on an SF34 glider (see Drop-testing a two-seater, *S & G* April-May 2002, p22).

I decided I should carry out an experiment to measure the relative benefits and disadvantages of a skid as compared with a nosewheel. I spoke to Les Neil, Senior Consultant Engineer for Occupant Impact Protection at the Centre for Human Sciences, QinetiQ, Farnborough. I have worked with Les since my original impact test carried out on a complete Libelle glider in 1988 (see Crashworthiness test, *S & G* June-July 1989, p130). Les and his colleagues, namely Graham Reece in charge of instrumentation, and Phil Murtha the test engineer, are a highly skilled team. It was decided that floor space could be cleared under the electric hoist suspended from the roof of the test track at QinetiQ to allow a K-13 fuselage to be dropped safely.

The test was observed by Jim Hammerton, the BGA's Chief Technical Officer. The other observer was Luke Cooper-Berry, studying for his Master's Degree in aeronautical engineering at Imperial College London. For his examination project he was modelling the drop test using finite element analysis.

The test

The test glider with both manikins installed was raised from the floor by the hoist. It was found to balance exactly parallel to the floor. However, it was required to balance nose-down so that the nosewheel or skid would impact before the main wheel. Ballast was therefore removed from the tail and additional ballast secured in the nose of the glider to produce a nose-down attitude. Using the cockpit sill as a reference level, with the skid the nose-down value was 13°, and with the wheel 11.5°. Because the hoist was freely suspended from the roof of the test track, merely altering the relative lengths of the suspension cables would not have altered the attitude of the glider.

The empty weight of the glider was 316kg, compared with the official empty weight when new of 290kg. The manikins weighed 77.5kg each, giving a weight of glider plus the two manikins of 471 kg. This is within the maximum take-off weight of 480kg. The centre of gravity was within normal limits.

The tyre pressures were set to 35 pounds per square inch for the nose and main wheels, and to 30 pounds per square inch for the tail wheel.

Eight drop tests were carried out during the course of one day. The test sequence was as follows:

Wheel, skid - skid, wheel - wheel, skid - skid, wheel

This sequence was chosen so as to shorten the time taken in changing the wheel and the skid in successive tests.

The drop height measured from the lowest point of the wheel or skid was 6 inches (150mm), 12 inches (300mm), 18 inches (450mm) and 24 inches (600mm). Assuming there was no aerodynamic drag, this gave an impact velocity of:

150mm drop height	1.72 m/s
300mm drop height	2.43 m/s
450mm drop height	2.97 m/s
600mm drop height	3.43 m/s

It should be noted that the impact surface was concrete, there was no air cushioning effect in the absence of the wings, and the damping effect of the tailplane was missing.

Results

The table (following pages) shows the compression loading in Newtons on the lumbar spines of the manikins, together with the extent of forward rotation (moment) in Newton.metres.

The high-speed video showed increased rebound from the nosewheel as compared with the skid, but this was not considered to be significant.

FRONT PILOT MANIKIN

Drop Height:	150mm	300mm	450mm	600mm
Lumbar Spine Load (N)				
WHEEL	1019 N	2564 N	3269 N	3529 N
SKID	3099 N	4185 N	4559 N	5028 N
Moment (N.m)				
WHEEL	35.36 N.m	55.77 N.m	56.47 N.m	66.29 N.m
SKID	73.76 N.m	65.73 N.m	76.89 N.m	68.42 N.m

REAR PILOT MANIKIN

Drop Height:	150mm	300mm	450mm	600mm
Lumbar Spine Load (N)				
WHEEL	636 N	1330 N	1677 N	1890 N
SKID	1709 N	2671 N	'2629 N	3774 N
Moment (N.m)				
WHEEL	31.50 N.m	35.91 N.m	22.66 N.m	24.24 N.m
SKID	46.12 N.m	43.10 N.m	35.51 N.m	30.32 N.m

'this reading appears to be in error for an unknown reason

High g readings were obtained in the tail of the glider, but these were of very short duration and so of low energy and therefore also considered not to be of significance.

Conclusion

The compression loads on the spines of both front and rear pilot manikins were greatly reduced in the case of a nosewheel as compared with a skid.

The forward rotation load (moment) was also reduced in the case of the nosewheel as compared with a skid, but the change was irregular in value.

It is concluded that the use of a nosewheel instead of a skid would reduce the incidence and the severity of pilot spinal injury in the event of an accident involving impact on the nose of the glider.

Note on spinal fracture

Yamada has produced the following figures for the breaking load in compression of the lumbar spine according to age:

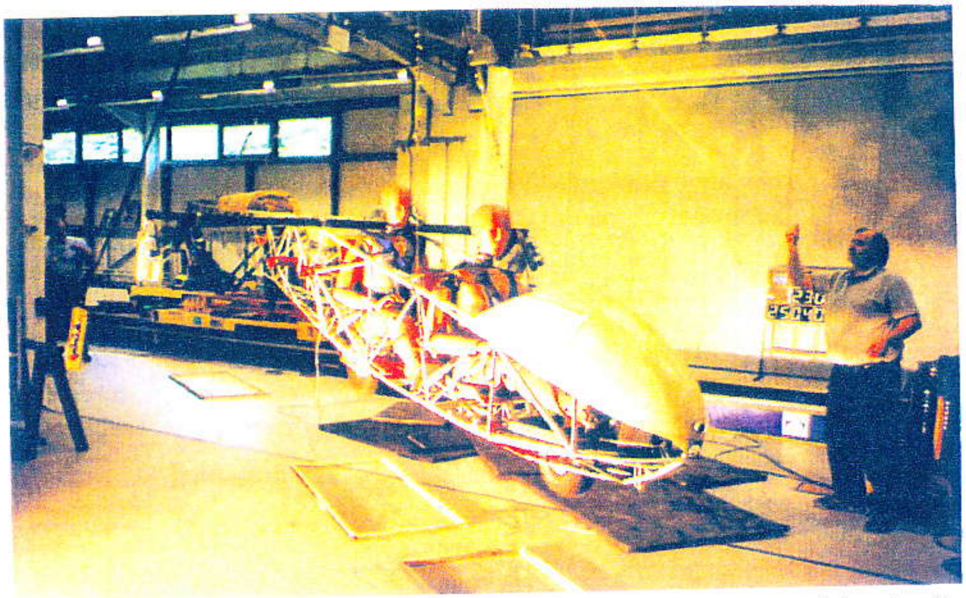
20-39 years	7140N
40-59 years	4670N
60-79 years	3010N

The usual spinal fracture found in a glider heavy landing accident is caused by a combination of vertical compression loading and forward rotation of the spine, producing an "anterior wedge fracture".

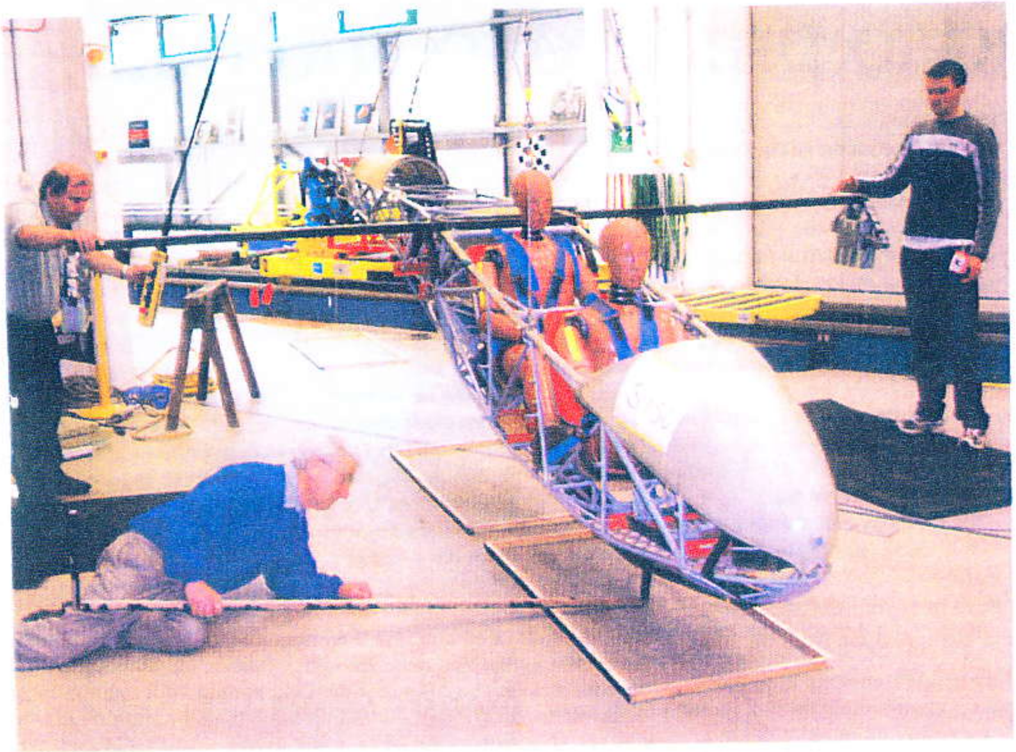
It is of interest that military pilots who eject from a fast jet aircraft are also found to have this type of fracture.

Following pages: more text on preparing the test, and more results.

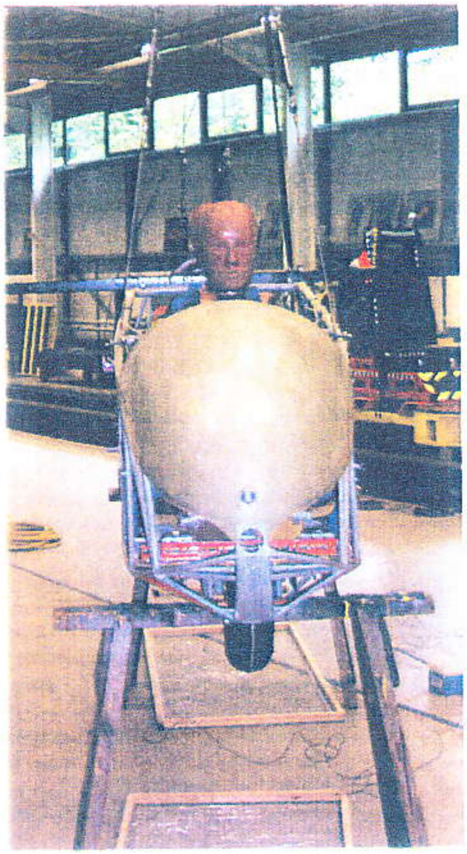
Top: the nosewheel, a modification signed off in June 1985, will absorb impact energy but also cause rebound. Bottom, the skid's rubber mounting block, directly under the front seatpan, will transmit impact loads up the spine.

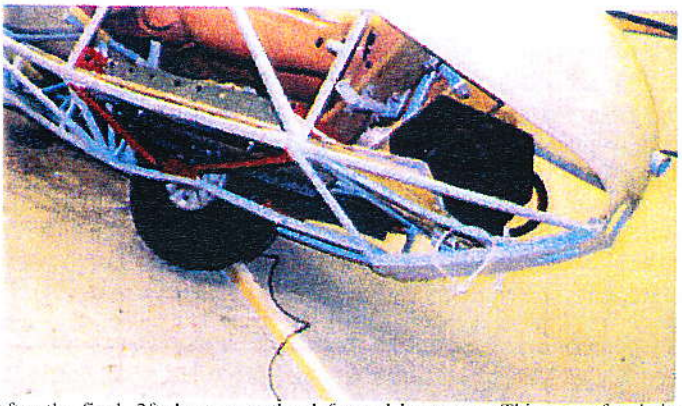


Above: Les Neil releases the suspended ASK-13 (popularly known as a 'K-13') for one of the series of tests.



Above, from left, Les Neil, a Senior Consultant Engineer at the Centre for Human Sciences, QinetiQ, Tony Segal and Luke Cooper-Berry, of Imperial College, prepare for a test. Tony is measuring the height of the drop. (Photo: Jim Hammerton)





After the final, 2ft drop, note the deformed longeron. This was after being subjected to loads well beyond what the aircraft would be designed to withstand without structural damage.
(Photo: Tony Segal)

Left, the fuselage was fitted with nosewheel or skid to compare the two.
(Photo: Jim Hammerton)

Rallying round to prepare to find out.......

K-13 Impact Test

The parts for the test K-13 were collected from all over the UK gliding community. The fuselage was obtained from the London GC. Although the fuselage was a write-off, it was ideal for my purpose. It was already at Lasham, so thanks to the engineers Phil Flack and Stuart Clay, it was moved into the aircraft workshop for fitting-out.

Dave Dripps, the Lasham MT engineer, machined an axle for the nosewheel from a solid silver steel rod, and welded the specified reinforcing tubes and axle bosses to the airframe. The added tubes stiffened the nose of the glider, but it was considered that this would not affect the test significantly.

The axle bosses were welded above the relevant longeron and not below (as in the original design) in order to avoid interference when the skid was fitted.

Lasham member Colin Raisey designed and installed the ballast weights. The wings, tail surfaces and rudder were absent from the test glider. Their weight was simulated by lead fastened to Dexion bolted to strong points on the fuselage. The resulting centre of gravity was carefully calculated to conform to the design specifications.

Adrian Emck from Lasham made a skillful scarf joint to produce a solid skid from two broken halves of separate landing skids. He also made a glider seat for the test from fibre-glass, the materials coming from Southdown Aero Services.

A main wheel and bearing were borrowed from The Soaring Centre, Husbands Bosworth. Basil Fairston kindly brought the wheel down to Zulu Glasstek from where I collected it.

A main wheel housing was obtained from Martin Breen of High Wycombe. The housing had been stored at Shenington GC. Martin also supplied the tail wheel and the energy-absorbing rubber fittings for the main undercarriage. The nosewheel was obtained from Southern Sailplanes. The wheels were fitted with new tyres and inner tubes obtained from Southdown Aero Services.

The test manikins were 50th percentile male Hybrid 111 dummies. They were placed directly on the seat-pans without parachutes or seat cushions. The hollow in each seatback was filled with a wooden fillet. A four-point harness obtained from Lasham was installed for each manikin.

The manikins and the airframe were instrumented as follows:

Both manikins had load cells fitted in the lumber spine, measuring in Newtons in the vertical (z) axis and the fore-and-aft (x) axis, and also measuring rotation (moment) in Newton.metres.

The load cells were installed in the manikin at an angle of 22° to the z axis of the manikins. Therefore a correction had to be applied to their readings, namely the secant for 22° (1.0785).

Accelerometers measuring in the z and x axes were installed in the pelvises of the manikins. Accelerometers were installed to record accelerations in the z and x axes in the nosewheel, the skid, the rear seat, the main wheel and the tail wheel.

Electric contact mats were placed on the floor under each glider wheel. The wheels had metal tape around their periphery. The resulting electric contact gave an exact impact time for each individual wheel and started the recording of the instrument readings.

Two high-speed video cameras were used, one taking a close-up of the skid or nosewheel, the other recording a general view of the impact. The cameras worked at 500 frames/second.

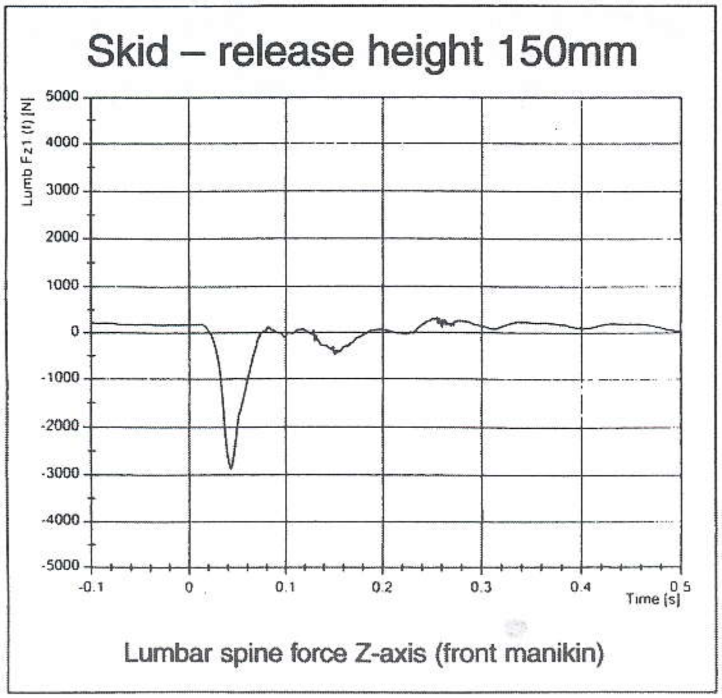
The suspension was four cables made from winch launch wire, attached to the fuselage with shackles and provided with bottle screws for fine adjustment. The cables were attached by ferrules, or by three U-bolts for each join. A sample cable with loops at each end held in place by U-bolts was tested by Dave Dripps and Colin Raisey to a load of over half a ton, higher than the all-up-weight of the test glider and manikins. There was therefore a safety factor of over four times in the cable test rig. The cables were attached by a large shackle to a weapon release suspended from the electric hoist in the roof of the test track.

Owing to the short duration of the drop following release, there was no time for the fuselage to fall over sideways before it hit the ground. This had been demonstrated previously in the test on the SF34 glider.

To prevent the fuselage rolling over completely on to its side at the end of each test drop, two V-bars designed for carrying canoes on the roofs of cars were bolted across the fuselage, with the Vs pointing down-wards and protected by firm rubber blocks. During the course of the test one V-bar broke, but by overlapping the two bars the test could continue.

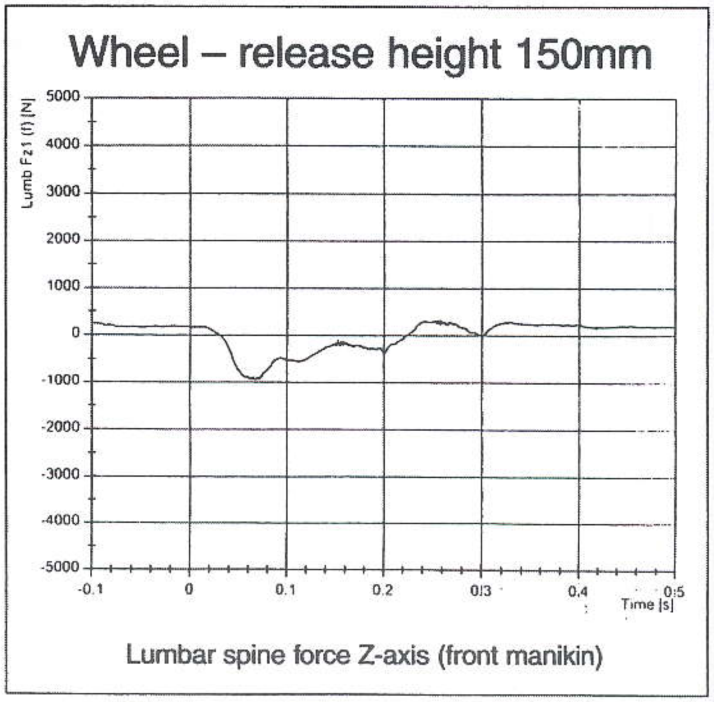
The test team (from left): Phil Murtha, Tony Segal, Les Neil and Graham Reece - and the two manikins in the background!

.....the difference a nosewheel makes



Skid – release height 150mm

Lumbar spine force Z-axis (front manikin)



Wheel – release height 150mm

Lumbar spine force Z-axis (front manikin)

XXIX OSTIV-Congress 2008 Lüsse-Berlin, Germany
6 August – 13 August 2008

www.ostiv.fai.org

Call for Papers

The XXIX Congress of the „International Scientific and Technical Organisation for Soaring Flight" – Organisation Scientific et Technique Internationale du Vol à Voile (OSTIV) - will be held at the site of the 30th World Gliding Championships in the Open-, 18m- and 15m Class, Lüsse, Germany, on

6 August- 13 August 2008

The Congress addresses all scientific and technical aspects of soaring flight including motorgliding, hanggliding , paragliding and ultralight sailplane.

Opportunity of presentation and discussion of papers is given in the following categories:

Meteorological Sessions:

Meteorology, Climatology, Atmospheric Physics.

Technical Sessions:

Aerodynamics, Structures, Materials, Design, Maintenance.

Training and Safety Sessions:

Training and Safety, Coaching, Health, Physiology, etc.

Joint Sessions:

Scientific and technical topics, review or news, presented in an informative and entertaining way for the broader interest of the World Gliding Championships and OSTIV.

Topics on instrumentation, electronics, safety, statistics and other system technologies will be included in the sessions for which the application of the technology is most relevant.

Typical and Suggested Topics are:

Meteorological Sessions:

Meteorology

- Mesoscale and small convective, baroclinic or orographically induced phenomena;
- New observations; measurements or analysis of convergence lines, cellular patterns, shear structures, standing and moving waves, short period cycles, turbulence, boundary layer in complex terrain;
- Analytical techniques of delineating thermal and mesoscale structures from routine or experimental ground or flight data, or from remote sensors;
- Modelling of thermals, mesoscale or microscale structures;
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The technical sessions will cover all aspects of design, development, and operation of sailplanes, motorgliders, ultralights and solar- or man- powered aircraft. Topics may include, but are not limited to:

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- Flight training, theory and analysis of techniques and results, psychology, objectives, training facilities and material;
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- Safety devices.

Joint Sessions:

Joint Sessions are collecting topics of general interest in the field of gliding as:

- General philosophy of competition classes;
- Documentation of badge and record flights;
- Common interests with other air sports like hanggliding, paragliding, microlights and ultralights;
- Man-powered flight; Solar-powered flight.

(continued next page)

Deadline for Abstracts and Final Paper:
The deadline for the Abstracts - max. two A4 pages including figures - was 15 May 2008. If you missed the deadline, kindly submit your abstract as soon as possible to the OSTIV Secretariat.
Letters of acceptance together with instructions for paper preparation will be mailed by 30 May 2008 and thereafter as abstracts are received.
Deadline for the paper – max. about 10 pages including figures - is July 15, 2008.

Please use the form below to send a copy of your Abstract to the OSTIV Secretariat, clearly marked by either meteorological-, technical-, training and safety- or joint session.

Oral presentations at the Congress will be limited to 30 minutes and should consist of highlights of the written paper.
The paper will be published in OSTIV's refereed International Journal of Technical Soaring (ISSN 0744-8996) after the Congress.

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At OSTIV Congresses an OSTIV Plaque and Klemperer Award is presented to the person who has made a most noteworthy scientific or technical contribution to soaring flight.
The prize for the year 2008 will be presented during the Opening Ceremony of the XXIXth OSTIV Congress.
All Active and Individual OSTIV Members can send in nominations. In making such nominations, particular attention should be given to recent contributions to soaring flight by the nominee, although earlier outstanding work will also be taken into account. Nominations should include details of the nominee's contributions and a short biography.
All nominations for the OSTIV Plaque / Klemperer Award must be received by L.L.M. Boermans, the President of OSTIV, c/o TU Delft, Fac. Aerospace Engineering, Kluyverweg 1, NL-2629 HS Delft, The Netherlands by May 15, 2008.

Form

Note of interest / Abstract **XXIX OSTIV Congress, 6 – 13 August 2008**

Send this form to:
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Fax: (+31) 15 2783533, email: l.m.m.boermans@tudelft.nl

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