AIRCRAFT (FULL-SIZE GLIDER) CRASH-WORTHINESSS IMPACT TEST

by Dr. Anthony M. Segal, Lasham Gliding Society, England

Presented at the XXI OSTIV Congress, Wiener-Neustadt, Austria (1989)

ABSTRACT

The purpose of the test was to record the forces acting on a full-size glider, a pilot manikin, and the seat harness in a representative crash. A pendulum test rig was used. High peak g loadings of short duration were recorded on the airframe and the pilot manikin. Energy was absorbed by deformation and delamination of the GRP fuselage. There was a failure in tension at the junction of a forward transverse bulkhead and the fuselage side-wall. There was considerable loading on the seat harness lap strap. The pilot manikin 'submarined' down and forward under the seat harness. This demonstrated that five or six point seat harness should be fitted.

1. INTRODUCTION

This study was directed at determining improved means of protecting the glider pilot in heavy landings and moderately severe accidents. It is not possible at the present time to protect the pilot in the more severe spin accident, as the penalty in performance and financial cost would be too great. Most glider designers and manufacturers are keen to incorporate safety features in their gliders. However, if they are to be competitive, all glider manufacturers must be under the same design constraints. Suitable OSTIV Airworthiness Standards, and JAR 22 Requirements must, therefore, be drawn up and applied to all manufacturers equally. I consider there is insufficient experimental information available at the present time to draw up such regulations.

The following methods of assessing crashworthiness are available:

1. Assessing airframe damage and pilot injury in real accidents. There are problems due to the uncontrolled situation, and the lack of experienced assessment at the accident site.

2. Full-size glider impact test, with pilot manikin. The advantages are that the accident parameters can be accurately defined, the forces on the airframe and pilot manikin can be measured, and the impact recorded on film and video. Problems are the difficulty in obtaining a glider for the test, finding a test site, and the fact that the test is 'one off'.

3. Use of a nose and cockpit section, with pilot manikin on a decelerator track. The advantages are that repeated tests can be carried out under controlled conditions, the forces on the airframe and pilot manikin can be recorded, filming can be carried out under ideal conditions, and engineering services are available on site. The test is not fully representative as the wings and fuselage have to be simulated by weights bolted to the nose section.

4. Testing scale models. This is excellent for testing changes in the airframe structure. This method is unable to show the forces acting on the pilot. Problems arise in scaling up the results to a full-size glider.

5. Finite element analysis. This would provide a forecast of likely points of failure under given loading conditions, but would be extremely difficult to apply to the structure once failure commenced.

2. THEORY OF THE TEST RIG

A pendulum test rig was used, as in the classic NASA test on Piper aircraft fuselages (ref. 1, 1980), and the test at Bretigny, France, on a Puma helicopter (ref. 2, 1985).

The tangential velocity at impact was related to the C. of G. drop height by -

$$V=\sqrt{2}\,g\,h$$

The flight path was determined by the tangent at the point where the arc of swing intersected the chord formed by the impact surface. The attitude was determined by adjusting the fore and aft suspension lines. The forward suspension lines remained attached to the glider throughout the test. They became slack as they traversed the chord formed by the impact surface. The kinetic energy of the test was absorbed by the 'upswing' of the pendulum. the aft suspension lines should have released just before impact, they failed to release during the actual test. Two suspension points were situated on a line transverse to the arc of swing.

Six suspension lines were used — Two attached to the fuselage forward of the C. of G. Two attached to the rear of the fuselage. Two attached to the wing tips.

This simple method gave a stable, well damped swing in all axes (Figure 1).

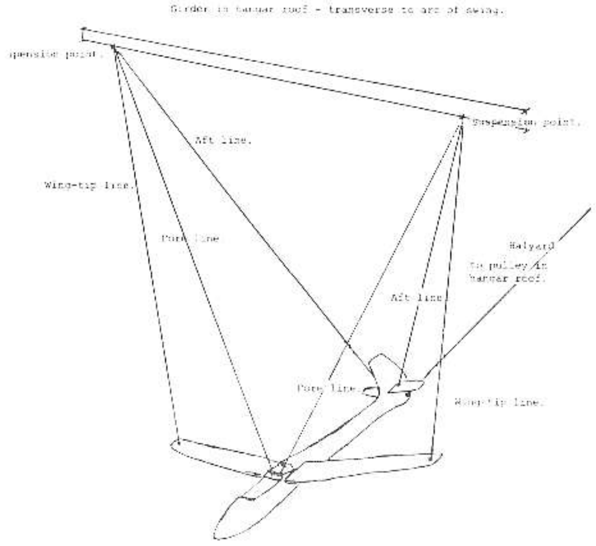


Figure 1. Pendulum test rig.

3. CONSTRUCTION OF THE TEST RIG

The suspension points were rope loops passed round a girder in the hangar roof. The suspension cables were attached to the rope loops by shackles. The suspension cables were 4.5 mm diameter steel winch cable. Short 'rope tails' of aero-tow rope were attached to the lower end of the suspension cables by shackles. These rope tails were tied to the glider giving a quick and easy method of adjustment.

The glider was released by a bomb-slip attached to the tail of the glider by rope loops. The bomb-slip pointed upwards. This enabled the control cable to pass down directly to the hangar floor, instead of having to traverse the hangar roof.

The glider was raised into the drop position by a doubled rope. The rope passed round a pulley attached to the tail of the glider, to a double pulley attached to a girder in the hangar roof. This doubled rope was removed before the test took place. This system prevented strain on the bomb-slip and possible premature release.

The aft suspension lines, attached to the bomb-slip, were operated by a micro-switch on an underwing probe, set to release just before the nose of the glider made contact with the ground. This did not work, probably due to the probe being too flexible.

4. THE GLIDER AND PILOT MANIKIN

The glider was a 15m Standard Libelle, rebuilt following an accident. The pilot manikin was a 50 percentile OGLE OPAT dummy. The undercarriage was rigid and non-standard. The glider was complete with wings and tailplane, but without a canopy. The pilot manikin was fitted with a parachute, and was seated directly on the GRP seat of the glider, without a cushion. The weight of the glider, glider repairs, manikin and parachute was 600 lbs. (272 kg.).

5. INSTRUMENTATION

Accelerometers were placed in the pelvis of the pilot manikin, and at the C. of G. of the glider (the barograph compartment was used). Gz (vertical) and Gx (fore and aft) accelerometers were used at each position. The axes were relative to the axis of the glider.

A strain gauge was placed on the seat harness lap strap, and another on the shoulder strap, and calibrated to measure loads.

A strain gauge was fastened to the inside of the cockpit belly. Two strain gauges were attached to the inside of the cockpit sill, and two to the outside of the cockpit sill (Figure 2).

A high speed video (200 frames/second) and two high speed cameras 500 and 1000 frames/second) were used. A sight screen measuring 40 feet by 6 feet (12.2 m by 1.83 m), divided into 2 feet (0.61 m) squares, was made from thin wood strips painted black and backed by white paper.

The test values for velocity, attitude, and flight path were calculated from the position of the wing tip nearer the sight screen, as measured on the high speed video. A time marker was seen on the video.

The instrument readings were amplified and then recorded on an SE labs FM tape recorder.

6. PARAMETERS OF THE TEST ACCIDENT ATTITUDE

The Jar 22 airworthiness requirements of an angle of 45 degrees appeared to be an arbitrary figure. A numerical study of the attitude at impact of a series of 911 glider accidents was carried out by TUV, Rheinland, Koln (ref. 3, 1989). Using the results of this study, an attitude of 15 degrees was chosen. This enabled maximum information to be obtained from the test, the glider impacting first on the nose, followed by the main wheel.

FLIGHT PATH SLOPE

After discussion with senior pilots, an arbitrary figure of one-in-four was chosen.

IMPACT SURFACE

This surface was the concrete hangar floor. This provided no energy absorption and only minimum friction with the nose of the glider, as compared for example with soft earth. The effect of vertical acceleration (Gz) was, therefore, increased and the effect of horizontal acceleration (Gx) reduced.

LOADING AT IMPACT

The radial loading at impact was calculated to be approximately 2 1/2 g. This loading would stretch the suspension cables by 2 inches (5 cms). This calculation was required to estimate the impact point, and hence the placing of the cameras.

7. TEST RESULTS.

The test was carried out in the hangar of the RAFGSA Gliding Center, Bicester, England, on October 19, 1988.

The actual impact point of the nose of the glider was 1 inch (2.5 cms) to port and 5 inches (12.5 cms) forward of the theoretical impact point marked on the hangar floor. This accuracy helped enable excellent films to be made of the test.

The tangential impact velocity was 9.6 m/s (18.6 kts.). This was the mean velocity over the 0.155 seconds before impact. By calculation, this gives a C. of G. drop height of 15.3 feet (4.7 m). This contrasts greatly with the height of the test rig suspension points above the hangar floor, namely 39 feet (11.9 m). The attachment point in the tail for the halyard was some distance aft of the C. of G. Similarly, the impact point on the nose was some distance forward of the C. of G. Therefore, only part of the total hangar height was effectively available for the drop height. At impact, the fuselage (upper surface of fuselage + 4 degrees) was 17 degrees nose-down.

At impact, the flight path slope was 24.9 degrees nose-down.

The center of gravity was 455 mm aft of the normal aft C. of G. limit. This was due to the added weight of extensive repairs to the fuselage, and a 4 kg lead weight in the tail-wheel fitting. The weight in the tail was added owing to concern over the stability of the glider when hoisted up into the drop position. Measurement and calculation showed the C. of G. was 70 mm vertically above the wing leading edge (with the glider in the normal attitude). In the actual test, there was no problem with stability.

The video and cine films were very clear. The nose of the glider flexed upwards on impact, then returned to its original shape. After the test, the cockpit floor was removed. There was minor delamination of the cockpit belly and side-wall. There was also a minor failure in tension at the junction of a transverse bulkhead and the fuselage side-wall, due to 'ovalling' of the fuselage.

The pilot manikin 'submarined' forward and under the seat harness, despite the harness straps being very tight, and the impact velocity low. The video showed the manikin actually 'submarining' during impact of the glider.

The load on the seat harness was high. The load on the lap-strap was partly due to the pilot manikin, and partly due to 'ovalling' of the fuselage. Maximum load on lap-strap — 2000 lbf (8900 N). Maximum load on shoulder harness — 1250 lbf (5560 N).

The cockpit strain gauge readings were as follows (Figure 2).

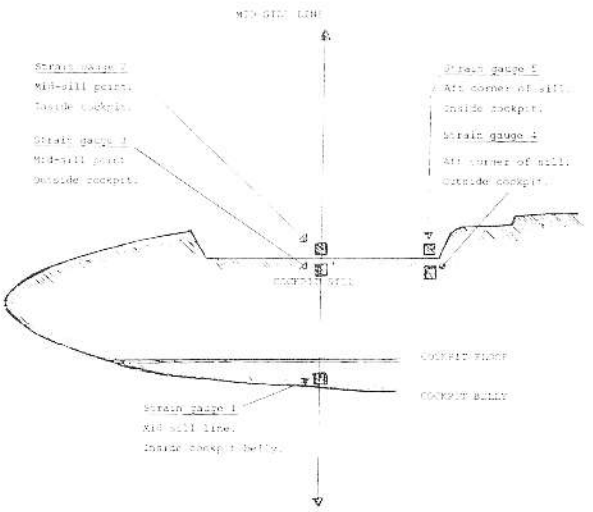


Figure 2. Site of strain gauges in cockpit.

Strain gauge 1 was situated inside the cockpit belly, level with the mid-sill point. A reading of 0.23% in tension was recorded. This was less than expected, possibly due to the strengthening effect of the cokpit floor.

Strain gauge 2 was placed inside the glider at the mid-sill point. A reading of 0.66% in compression was obtained.

Strain gauge 4 was placed externally at the aft corner of the cockpit sill. This gave a reading of 0.55% in compression. These two readings demonstrated considerable compression loading on the cockpit sill.

Strain gauges 3 and 5, on the cockpit sill to record compression loading; they were sited to show also lateral flexion of the cockpit sill. Unfortunately, they failed to record. Note all strain gauge readings are in % strain (i.e. % change in length/ unit length).

Two accelerometers were placed to record in the Gz (vertical) axis of the glider airframe and pilot manikin. After the test, it was found that two of the recording channels used were unserviceable, so the information was not recorded. A trial-run of the test was not carried out owing to doubts over the strength of the fuselage repairs and test rig. (In fact, during the test, there was no problem with the strength of the fuselage or test rig.) This loss of valuable information is a risk when carrying out a 'one off' test.

Two accelerometers recorded in the Gx (fore-and-aft) axis of the glider airframe and in the pelvis of the pilot manikin. High g readings, of very short duration, were obtained as follows:

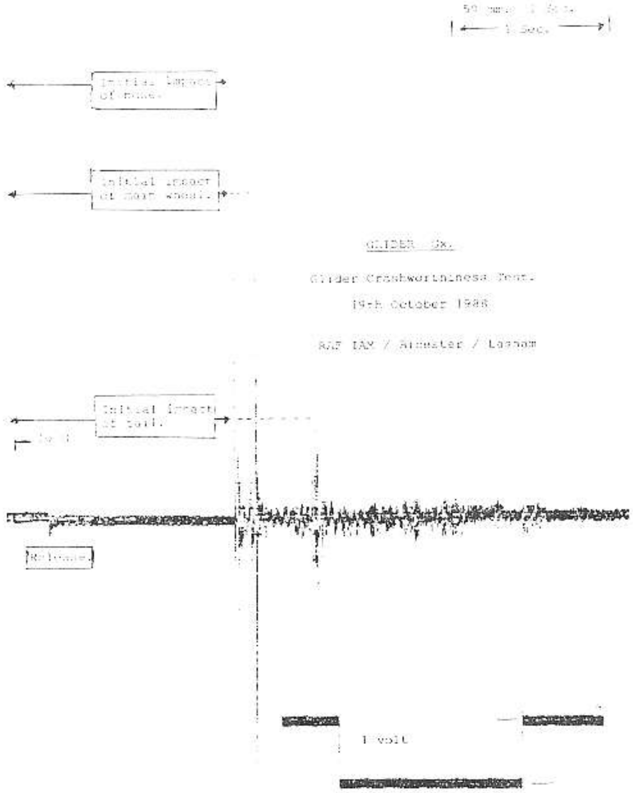


Figure 3. Cx accelerometer reading at glider C. of G.

Max. Gx readings at glider C. of G. (Figure 3)

Impact of nose	- 55 g
Impact of main wheel	- 41 g
Impact of tail	- 13 g

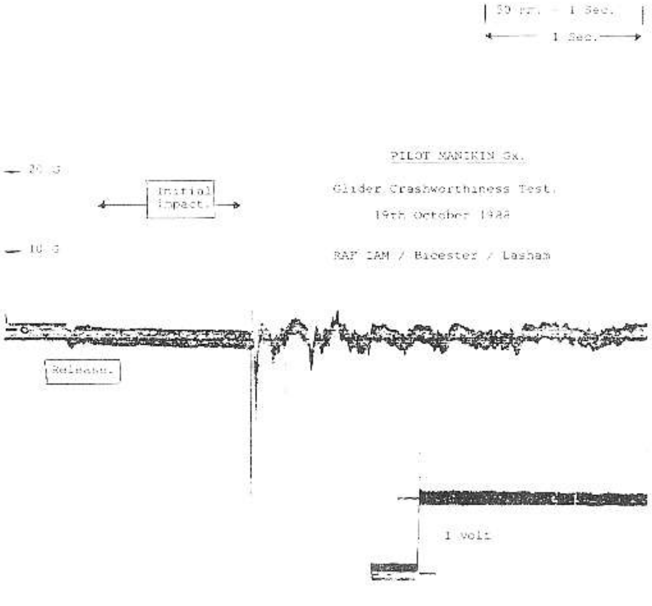


Figure 4. Gx accelerometer reading at pelvis of pilot manakin.

Max. Gx reading at pelvis of pilot manikin. (Figure 4)
Gx reading - 16 g

Owing to immediate other commitment of the recording equipment, it was not possible to 'stretch' the recorded traces so as to obtain detailed information on the time-scale of the traces.

Examining the traces closely, it was only possible to say that the peaks of g lasted 1/100 seconds or less. This gave a rate of rise of g, on impact of the glider nose, of 5500 g/sec. Similarly, the rate of rise of g, on impact at the pelvis of the pilot manikin, was 1600 g/sec. It must be stressed that these values are very approximate.

It is noteworthy that the maximum G readings in the Puma test were of the same order of magnitude as in this test (ref. 2).

8. CONCLUSIONS

A test rig constructed from materials available on gliding sites proved adequate to enable the parameters of a gliding accident to be accurately simulated. To give a higher, more realistic, impact velocity a greater drop height would be required. I suggest such a test would need to be performed out of doors.

Deformation and minor delamination of the fuselage occurred on impact, absorbing sufficient energy to give considerable protection to the pilot manikin. The tension failure between the bulkhead and cockpit side-wall also helped absorb energy.

The pilot manikin 'submarined' under the seat harness, even at the low impact velocity of the test. Also, the load on the seat harness was high. This showed the importance of fitting a securely anchored five or six point seat harness. An important experimental study has been carried out on seat harnesses by TUV, Rheinland, Koln (ref. 3, 1989).

Considerable loading in compression occurred in the cockpit sill. Prof. E. Crawley discusses this loading of the cockpit sill as a method of absorbing energy in his report on tests on scale models of glider cockpits (ref. 4, 1989).

High peak g loadings of short duration were recorded. Owing to this short duration, it is considered these loads were of low energy, and would produce only limited damage and injury. There was a marked reduction in g loading as between the pilot manikin and the glider airframe. This showed the strength and energy absorbing nature of the cockpit design and the composite material used in the construction. This probably explains the minor nature of most injuries to glider pilots in heavy landings and moderately severe accidents.

9. ACKNOWLEDGEMENTS

This study could not have been carried out without the help and advice of numerous organizations and colleagues. There are too many for a complete list to be given here, but I mention in particular the following: RAF Institute of Aviation Medicine, Fairborough: Wg. Com. David Anton, Sq. Ldr Jan McKenzie and the technical office staff. RAFGSA Bicester, Air Cdr. Peter Saundby, Wg. Cdr. Garett Cunningham, Paddy Hogg and the staff. Lasham Gliding Center, Franke Horning, Dennis Dowddl, Martin Grant and Dr. David Foster and last, but by no means least, Liz Segal.

10 REFERENCES

(1) Vaughan, Jr., V.L. and Hayduk, R.J., "Crash Tests of Four Identical High-Wing Single Engine Airplanes," NASA Technical Paper 1699, August 1980.

(2) Vettes, B., Auffret, R., and Vieillefond, H., "Puma (SA 330) Helicopter Impact Simulation: Demonstration of the Efficiency of the French Crashworthy Seat," Aviat. Space Environ. Med. 1985: 56:672-5.

(3) Pusch, D., and Sperber, M., "Investigation of Glider Safety Belt Behaviour under Accident Conditions," Technischer Uberwachungs-Verein Rheinland E.V., Koln, OSTIV Congress, May, 1989.

(4) Hansman, Jr., R.J., Crawley, E.F., and Kampf, K-P. "Experimental Investigation of the Crashworthiness of Scaled Composite Sailplane Fuselages," Massachusetts Institute of Technology, U.S.A., OSTIV Congress, May, 1989.

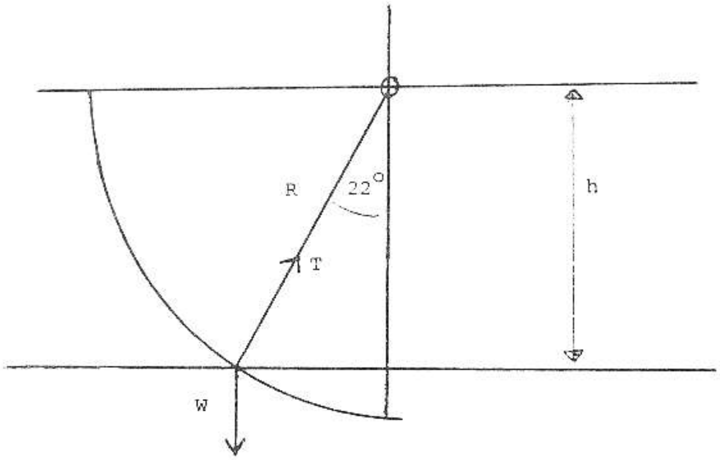
APPENDIX

PRELIMINARY CALCULATION OF THE INERTIA AND AERODYNAMIC LOADS

Frank Irving

These calculations were required to confirm that the aerodynamic lift would not over-ride the tension in the supporting cables, thus ensuring the stability of the test rig.

It should be noted that the stated velocities and the stated weight used in these preliminary calculations were not the same as in the actual experiment.



$R = \dfrac{h}{\cos 22^\circ} = 1.079\ h$

$V^2 = 2gh$ (neglecting the rotational kinetic energy).

Centripetal acceleration $= \dfrac{V^2}{R} = \dfrac{2gh}{R} = 2g \cos 22^\circ$

Radial component of weight $= W \cos 22^\circ$

Force in suspension rig (T) = sum of force required to produce the centripetal acceleration, plus the radial component of weight.

$T = 3\ W \cos 22^\circ = 2.78\ W$ (neglecting any lift - see page 16).

$W = 611$ lbs.

$T = 1698$ lbs., say 1700 lbs. (T = tension).

$V = 25$ kts $= 42.25$ ft/sec $h = 27.72$ ft $R = 29.91$ ft

$V = 35$ kts $= 59.15$ ft/sec $h = 54.33$ ft $R = 58.62$ ft

$W = 611$ lbs
$S = 100$ sq ft (wing area)
$V_s = 37$ kts $= 62.53$ ft/sec (stalling speed) - Brakes shut.

(See below) * $C_{L\ max}$ = max. lift coefficient $= \dfrac{611}{\frac{1}{2} \times 0.00238 \times 62.53^2 \times 100} = 1.31$

Zero Lift Line - α at $C_{L\ max} \sim 15^\circ$ (α = angle of incidence).

Chord line α at $C_{L\ max} \sim 11^\circ$

Chord line to be about 11° nose-down at impact.

If α is to be less than that at $C_{L\ max}$ the glider is to be more nose-down at impact.

$$\text{If } C_L = C_{L\,max} \begin{cases} \text{lift at 35 kts} = 547 \text{ lbs.} \\ \text{lift at 25 kts} = 279 \text{ lbs.} \end{cases}$$

$$\text{Tension in supporting cables: } \begin{cases} \text{35 kts:} \quad 2.78 \times 611 - 547 = 1152 \text{ lbs} \\ \qquad\qquad (1.88\ W) \\ \text{25 kts:} \quad 2.78 \times 611 - 279 = 1420 \text{ lbs} \\ \qquad\qquad (2.32\ W) \end{cases}$$

Taking into account the aerodynamic lift, the cable loads will be as above. The above values of lift are likely to be over-estimates, due to unsteady flow effects.

Note re accelerometers: the glider and the pilot manikin will be subjected to 2.78 g just before impact.

The elevator should be fully up for the test.

---

* $L = C_L \frac{1}{2} \rho V^2 S$

L = lift

C_L = lift coeficient

ρ = air density = slugs/ft^3
(1 slug = 32.2 lbs mass).

V = airspeed

S = wing area.

$C_{L\,max}$ corresponds to V_{min} i.e. to V_S the stalling speed.

Therefore $C_{L\,max} = L \big/ \frac{1}{2} \rho V_S^2 S$