

# A Pilot Restraint System for Sailplanes

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There are in Australia many imported sailplanes which have the pilots seated in a very reclining, nearly supine, position. Examples are the Polish "Foka", the Swiss "Diamant" and the West German "Ventus A", all fitted with variations of the usual four strap type of pilot harness. These gliders have been awarded Certificates of Airworthiness by the Australian DOT on the basis of their overseas certification and particular design features were not examined. Aeroplanes and gliders of local design, up to this time, have all incorporated a substantially upright seating posture.

However, the MOBA 2 glider, featuring a reclining seating position, involved the design of a special pilot restraint system. This led to the DOT airworthiness authority having to consider, for the first time, safety standards appropriate to pilot restraint in a modern sailplane. The development of a suitable design and the related standards are the subject of this paper.

## Design Standards

There are many data available on restraint systems for "upright" seating positions. Some glider and seat harness design requirements also appear to assume that the occupants are seated substantially upright (Ref. 1 through 8).

Figure 1 shows the typical geometry of an "upright" seat harness installation. Note that upper body restraint is required for forward seats in all Australian aircraft and a four strap harness is usually fitted to gliders. A pilot weight of 170 lb (77 kg) is assumed with a parachute of 20 lb (9 kg).

The harness system has to react a 9 g ultimate deceleration along the longitudinal axis of the aircraft, the design case being that produced, for example, if the glider were landing and the wings con-

tacted dense bushes. As gliders in Australia are now frequently flown over "scrub" country, where there are few suitable cleared fields, this is a very practical requirement. The "flight" design cases are less critical and are not considered further in this paper. Note that the upper straps are required to be angled upwards, within 0 degrees to 30 degrees, to avoid compressing the spine when being tightened.

Figure 2 shows the emergency alighting (crash) loads on a normal harness fit-

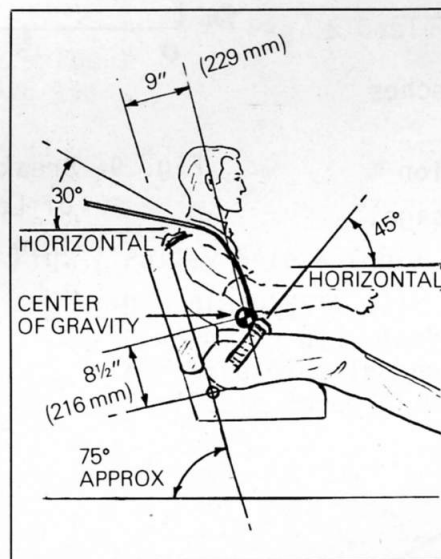


Fig. 1: Design data for normal seating.

Design pilot weight = 170 lb (77 kg)  
Parachute weight = 20 lb (9 kg)

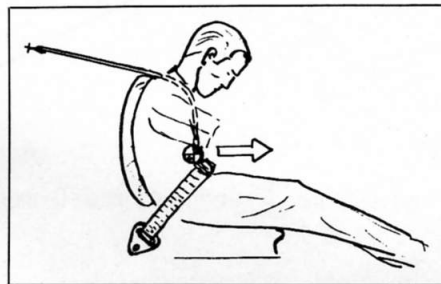


Fig. 2: Emergency alighting load, upright seat and normal harness.

Design ultimate load =  $190 \times 9$   
= 1710 lb (775 kg)

ted to a pilot seated substantially upright. Even if the harness is comparatively loose it may still be effective for this design case. The lower (lap) straps provide most of the restraint, with the upper body tending to rotate over the lap straps until the upper straps are tight. For design purposes the distribution of load assumed is 60% to the lap straps and 40% to the upper straps.

If the lap straps are not adjusted tightly the upper straps may pull them up from the pelvic region into the abdomen; in a crash severe injuries may be caused. For this reason many harnesses have the lower straps fitted with wide "belly bands" to spread the load.

Another problem associated with loose lap straps may occur under combined forwards and downwards loads (the "heavy landing" situation). Here the pilot may slide under the harness if the lap straps are loose, a result known as "submarining". This problem has always been with us but is hardly considered in the design rules, except Reference 7.

Even when the harness is tight there are major disadvantages in the "upright" pilot seating position. In most gliders the rudder pedals are positioned forward and up, almost in line with the seat pan. This throws the full weight of the body on the lower back and posterior, resulting in pilot fatigue and the strong possibility of spinal damage in the event of a heavy landing. In an upright position the spinal column is vulnerable to compression loads resulting from vertical accelerations encountered, during hard landings in particular. This has led to the development by an Australian instructor concerned about his back, of special seat cushions to alleviate the problem (Reference 9).

## Developments in Glider Seating

The development of glass and carbon reinforced plastic sailplanes has greatly improved pilot comfort and safety. This was achieved mainly by reclining the pilot seat to a back rest angle on 45 degrees or less to the horizontal (figure 3). This distributes the weight of the pilot over the area of the thighs, back and shoulders and supports the spinal column in the event of an accident.

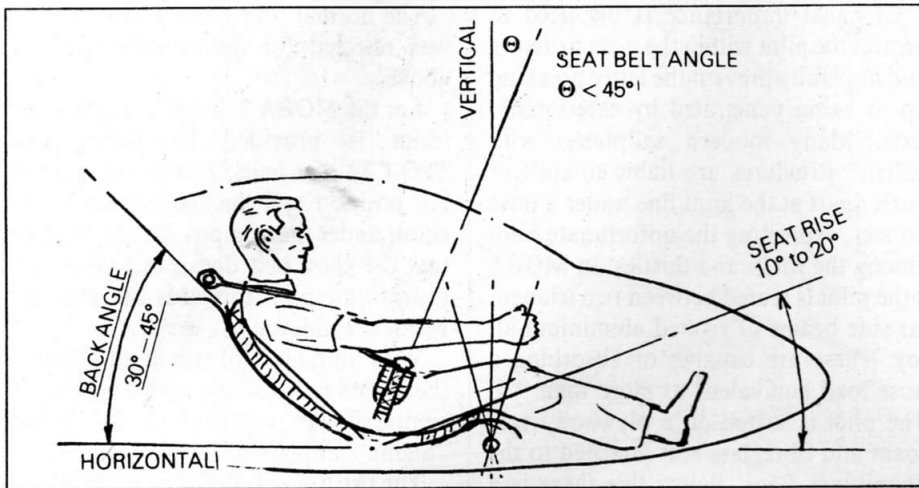


Fig. 3: Typical Sailplane Seat.

In many sailplanes safety is also improved by mounting the seat clear of the outside shell, which can then distort without transmitting shock loads to the pilot. Many old wooden sailplanes were badly designed in having very rigid structural members connecting the seat to the keel which then transmitted landing shocks direct to the occupants.

The writer was particularly thankful to be flying a modern sailplane some years ago when, through pilot error, he landed a "Libelle" in a field strewn with many large boulders. The "Libelle" did a marvellous job of absorbing the energy of landing and this pilot emerged unscathed, although the glider was severely damaged. Although a reclining seat decreases the possibility of spinal damage it does nothing to prevent "submarining" under the harness.

As can be seen from figure 3 the forward part of the seat is usually raised up and helps to locate the pilot from sliding forward in normal flight. This area is the usual location for the controls and the position of a central control column immediately forward of the seat means that the pilot must be positively restrained in an accident. However the lower harness straps must be tight to prevent the pilot sliding forward under emergency alighting loads.

Frank Irving has provided the following account of a U.K. accident which underlines the problem:

"A recent accident displayed the inadequacy of the conventional harness in 'reclining' gliders. The machine concerned

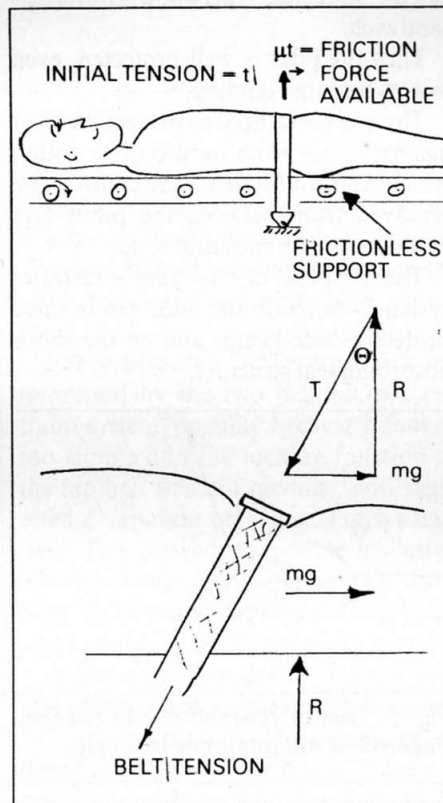


Fig. 4: Idealised belt reactions. If free to move lap belt rotates until it locks. If  $\Theta$  is known loads can be calculated.

was a 'Kestrel 19', which indulged in a pirouette at take-off on the winch: it started with a ground-loop and finished-up inverted. The pilot hit the stick in the obvious place and sustained a creaked pelvis. Afterwards, he said it was rather like banging yourself on the cross-bar of a bicycle when a boy, only nastier."

There have been similar accidents in Australia and one unconfirmed report from overseas stated that a pilot was severely injured while *in flight* through turbulence. An experienced gliding instructor and test pilot, Bob Rowe, is of the opinion that several unexplained fatal accidents may have been caused by the pilot "submarining" underneath the seat harness and bodily pushing the control column hard forward. It is thus worth considering this possibility if the seat back is at less than 45 degrees slope, although it can readily be appreciated that certain load combinations could produce the same effect, even for the more upright seating positions. Thus it is vital that the lap straps should be tight, to prevent the pilot sliding up and over the forward part of the seat while the glider is decelerating. Under these conditions the upper straps of the harness do very little, if anything, to restrain the pilot if the back rest slope is 45 degrees or less.

Two factors work against a pilot achieving the required tightened lap straps. Firstly the seat may feel so comfortable and secure that the need to have the lower harness straps fully tight may not be appreciated. Secondly the adjustments on many harnesses are so difficult to manipulate in the typical narrow glider cockpit that the pilot is discouraged from attempting to do so. For the latter reason the Gliding Federation of Australia has ruled that, from 30 August 1980 all gliders imported into Australia must be fitted with a harness featuring adjustments which pull up to tighten the lower straps (Reference 10).

### The Restraint Action of a Lap Belt

To obtain a fundamental understanding of the seat harness first let us consider the pilot restrained by a lap belt only. To simplify the argument it is assumed that the pilot is lying flat on his back, fully supine, on a bed of ball bearings, so that all the restraint is provided by the seat belt passing across the thighs. It can readily be seen that if the belt has an initial tension, this produces a friction force to move the belt should the pilot start to move forward. As the "free" end of the belt moves forwards it tightens across the hips. Figure 4 shows that static equilibri-

um may be established under these conditions and the seat belt tension can be calculated. However friction effect for the body does decrease belt load and hence restraining force. It makes no difference to security of the belt over the loins if the load application is slow, rapid, fluctuating or even reversed. The initial friction force will act to secure the belt and the only other force acting is the inertia of the belt, which is very small.

Figure 5 shows how a seat belt with bulky padding will rotate, rather than act to restrain the pilot. Thus belts with "belly bands" should not be used when the seat back is at 45 degrees or less. The width of the pad opposes the "digging in" couple: this aspect is not obvious from fig. 5.

Next consider the action of the upper restraint straps. Figure 6 shows that the upper straps of a four point harness can destroy the "self locking" capability of the lower seat belt. This will not occur if the upper straps are left suitably loose but if the upper straps are tight this tension will overcome the friction force of the lower strap and the pilot can slide forwards out of the harness.

It is normal to expect the pilot to tighten his seat harness as much as possible in an emergency situation. In the cockpit the mechanical advantage available is such that it is much easier to tighten the upper straps than the lower straps and the pilot will probably not notice that the latter are being pulled up. Thus we have the possibility of good intentions leading to the opposite result of that intended. Assuming that the pilot is clever enough to leave the upper straps relatively loose we have restraint contribution from the upper straps of a normal four strap harness.

### MOBA 2 Pilot Restraint System

The MOBA 2 pilot compartment was designed to optimise

- (i) comfort
- (ii) performance
- (iii) safety

These considerations are not in conflict and for all three reasons a low-profile seating position was adopted, having a backrest angle of 20 to 30 degrees from the horizontal.

Of equal importance is the need to protect the pilot within the nose structure and hopefully prevent the latter breaking up or being penetrated by exterior objects. Many modern sailplanes with "Shell" structures are liable to split or burst apart at the joint line under a nose impact, depositing the unfortunate pilot among the rocks and thistles. In MOBA 2 the pilot is seated between two triangular side beams of riveted aluminium alloy. These are capable of absorbing a nose load equivalent to more than 9 g. The pilot is seated on a plywood, rigid foam and fibreglass seat attached to the aluminium floor. Below this there is a space and then the nose cone itself which is a fibreglass—plywood—fibreglass sandwich.

Thus the pilot is well protected, even in a "wheel-up" landing.

There is also a need to protect the pilot against injury from hard objects within the cockpit. In MOBA 2 the controls are removed from between the pilots legs and relocated in each arm rest.

The purpose of the pilot's restraint system is to retain the pilot within these protective side beams and on the shock absorbing seat structure.



Fig. 5: Loss of restraint due to padding. Padded belt will rotate due to couple.

The normal four point glider harness was rejected for the reasons outlined above.

For the MOBA 2 design complete restraint is provided by fitting two TSO-C22 seat belts, one at the normal lap position and the second across the chest, under the arm pits (figure 7). Note that the chest belt does not only act to restrain the pilot forwards but also upwards and sideways.

With no danger of fire in an accident the two release features are acceptable. A similar design was used in the Project "Sigma" sailplane.

The rise towards the front of the seat is minimal and as a natural consequence the pilot is encouraged to ensure that lap belt is as tight as possible. Both belts are tightened readily by pulling the free ends from right to left, across the body and these actions may be accomplished without difficulty even in flight.

The two belt system is the same as the normal four point harness in principle except that the upper strap is *not connected* to the lower belt and hence cannot interfere with the self locking action of the belt as explained above.

In a forwards deceleration situation the upper body restraint will act in the normal way and restrain the upper body. The spine will curve and the head and shoulders move forward and up until the chest strap is fully tight. Considering the relative positions of the body segments the normal 60—40% distribution of seat belt load is probably still about right.

Because the lap belt acts at an angle other than 45 degrees it is necessary to resubstantiate the design of the belts as follows:

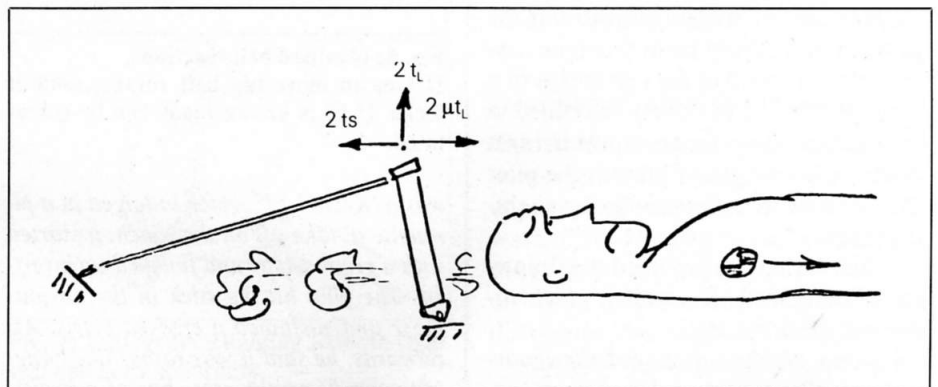


Fig. 6: "Unlocking" action of shoulder harness straps. Shoulder strap tension greater than initial friction means no restraint.

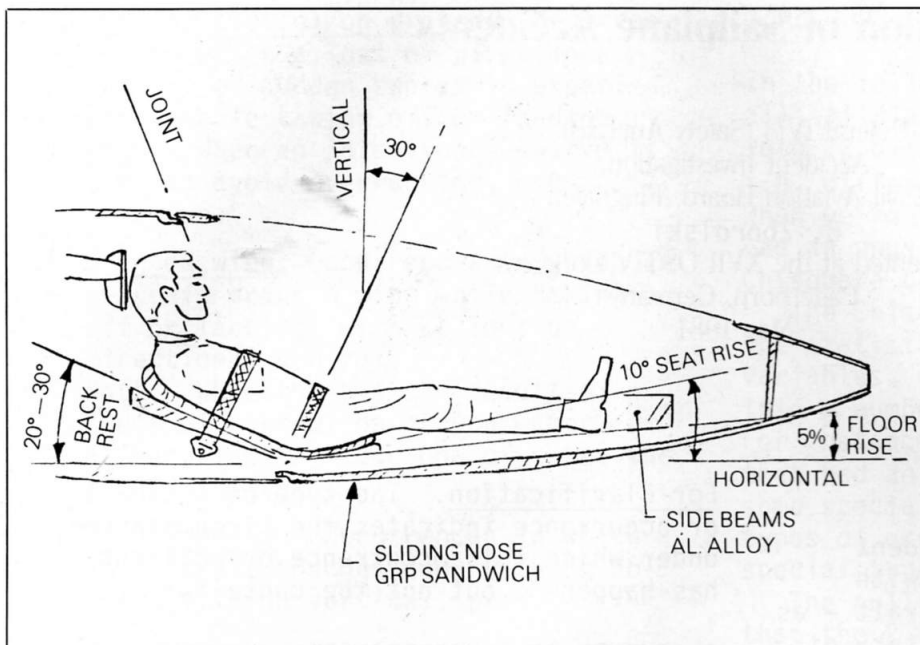


Fig. 7: MOBA 2 sailplane seat geometry.

To Check Seat Belts with Revised Angles The Lower Belt (Lap Strap) Makes an Angle of Approx. 30° to the Vertical Normal 60—40% Distribution.

$$mg = (170+20) \cdot 9 \cdot 0.6 = 1026 \text{ lb} [9 \times 0.6]$$

$$\text{Tension Load in Belt (Each Side)} = 1026 \text{ lb}$$

$$\text{TSO C22 (NAS 802) BELT } Fa = 1500 \text{ lb}$$

$$(\text{ULT}) \text{ BELT RF} = \frac{1500}{1026} = 1.46$$

Belt Attachments, AN4A Into .130" 2024 T3  
1.33 Fitting Factor Required,

$$(\text{ULT}) \text{ Bolt Shear RF} = \frac{3680}{1026 \times 1.33} = 2.69$$

[1026 × 1.33]

$$\text{Bearing } Fa = .25 \times .13 \times 120,000 = 2900 \text{ lb}$$

[0.25 × 0.13 × ...]

$$(\text{ULT}) \text{ Bearing } \cdot \text{RF} = \frac{2900}{1026 \times 1.33} = 2.12$$

[1026 × 1.33]

Chest Belt is Identical Except Load is 40% ••  
Minimum Margin of Safety = +0.46

In a practical test the author was seated in the MOBA with the lap belt comfortably firm. With one person pulling for-

wards at each arm and leg there was absolutely no tendency to move forwards at any load up to the threshold of pain. The seat belt "locks-in" to anchor the pilot without any appreciable movement.

For certification DOT were at first not impressed by the two belt MOBA restraint system, possibly because it looked too simple and the locking function of the lap belt was not obvious, and suggested a variation on a parachutist's harness. This proved impossible to design without greatly increasing both the difficulty of adjusting the harness and being able to bale out in an emergency.

A standard five point Harness was also examined as an alternative to the selected configuration. This has many of the problems of a four point harness in operation with an added possibility of injury between the legs. It was found that if the centre strap (or straps if bifurcated) tighten before the lap straps this will rotate the buckle assembly down into the pilot's groin.

This possibility was also considered by the Sigma designers as noted by Frank Irving: "One alternative considered was the five-strap harness, rather like a conventional arrangement but with an additional strap between the legs. This was rejected by the suppliers: I suspect that they thought that restraint by the fifth

strap was just as bad as hitting the stick. Anyway, the important feature of the arrangement we used was that it was evolved in collaboration with the suppliers, so we could reasonably claim that it was the result of the best advice available in the U.K. at that time. Certainly, neither they nor we felt that having to unlock two releases in an emergency was any particular disadvantage. I flew Sigma for about thirty hours and found the arrangement very practicable and quite comfortable, although I doubt if the opposite sex would agree."

These arguments were finally accepted by DOT and are summarised in an Equivalent Safety Determination, number AWB ES 4/81 (figure 8).

### Conclusion

The two belt system used in the MOBA 2C design produces a reliable restraint system. Four point harnesses normally used in sailplanes exhibit serious design faults when the pilot is not seated fully upright. Harnesses with bulky padding may be particularly dangerous. In flight these problems may not be obvious because the hump normally found at the front of the seat holds the pilot in position. Under emergency alighting loads this hump may not prevent the pilot sliding forwards if the lap straps are rendered ineffective for the reasons postulated above.

### References

- 1 BCAR Section E4-5, 4.3
- 2 FAA Basic Glider Criteria, p. 113.
- 3 European JAR 22, 22.785, 22.561
- 4 DOT (Australia) Air Navigation Orders, Section 108.42
- 5 FAA Technical Standard Order TSO-C22
- 6 British ARB/CAA Specification No. 4
- 7 FAA Advisory Circular AC 43.12.2, Chapter 4
- 8 DOT (Australia) Advisory Circulars, AAC 54-1, 62-2
- 9 "Cockpit Ergonomics" by Dr. Barry Clark, "Australian Gliding", June 1980
- 10 GFA AD 186/General 5, Issued 14 August 1980