GLIDER GROUND IMPACT TESTS

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INTRODUCTION

The German Federal Ministry of Transport (BMV) commissioned the Fachhochschule Aachen to investigate the fundamentals of a sailplane parachute recovery system. The pilot uses such a system in case of uncontrollability of the glider. After activation the following sequence starts: a parachute is deployed by a rocket or a mortar and carries the chute bag clear of the tail unit, the parachute inflates and stabilizes the tumbling glider while the pilot remains inside the cockpit. At the end of the recovery procedure the glider crashes on the ground. The fundamentals of this recovery system are presented in [1,2,3]. The most critical situation is the impact on the ground. A series of twenty full scale dynamic drop tests using different types of cockpits were performed at the FH Aachen in cooperation with the German Federal Highway Research Institute [1,4,5]. The cockpit was manned by a Hybrid 11 Dummy whereby the fuselage was equipped with accelerometers, wing dummies and a stabilizer. The glider was loaded up to a mass of about 350 kg and 527 kg. The test plane was lifted up to a height from which the selected vertical impact velocity of 6 or 8 m/s could be reached during free fall. For some tests an additional horizontal velocity of 6 m/s was produced by a slide bar. The pitch attitude angle was varied from 0° to -80°. All tests were filmed by video and highspeed cameras and dates of 37 sensors were processed on-line by computer. More details are given in [1] and [4].

HUMAN TOLERANCES

During the ground impact the deceleration occurring in the x- and z-axis of the head, the chest and the pelvis of the Dummy were recorded. Additionally the load on the spinal column was measured. The limits of the accelerations were fixed according to the ECE'-norm 49 CFR571/572 and filtered according to the SAE[2]-norm J 211 OCT 88 equivalent to the automotive branch. Acceleration peaks with a duration of 3 ms were used to rate the human injury. The limits for the resultant accelerations are: head 75 9, chest 60 g and pelvis 60 g. The load limit on the spinal column is given in [6] and depends on the human age. The acceptable magnitude decreases generally with age and depends on the physiological fitness. A value of 5 kN may be acceptable for humans up to an age of approximately 60 years.

In all of the twenty tests on different types of ground up to an impact velocity of 8 m/s the limits of the head and the chest were not exceeded whether on hard nor on soft ground. The most critical points are the pelvis acceleration and the load on the spinal column. Impacts on hard grounds or without a negative pitch attitude of the glider produce pelvis accelerations exceeding the 60 g limit and a spinal load above the tolerable average limit of 5 kN.

GLIDER AND COCKPIT STRUCTURE

The tests were performed with three types of gliders whereby the stiffness of the cockpit structure has been changed by using different composites and reinforcements (Figure 1). Two glider types were selected due to their difference in the cockpit geometry. No. 1 represents an widely open design, No. 2 a more closed one with energy absorbing nose. No. 3 is an original Mistral-C glider with a quite normal fiberglass cockpit. For glider type No. 1 two different cockpit structures were used. One cockpit (1a) was reinforced by carbon rovings along the bottom and the cockpit sills, and cockpit 1b was totally built by carbon with strong reinforcements along the sills.

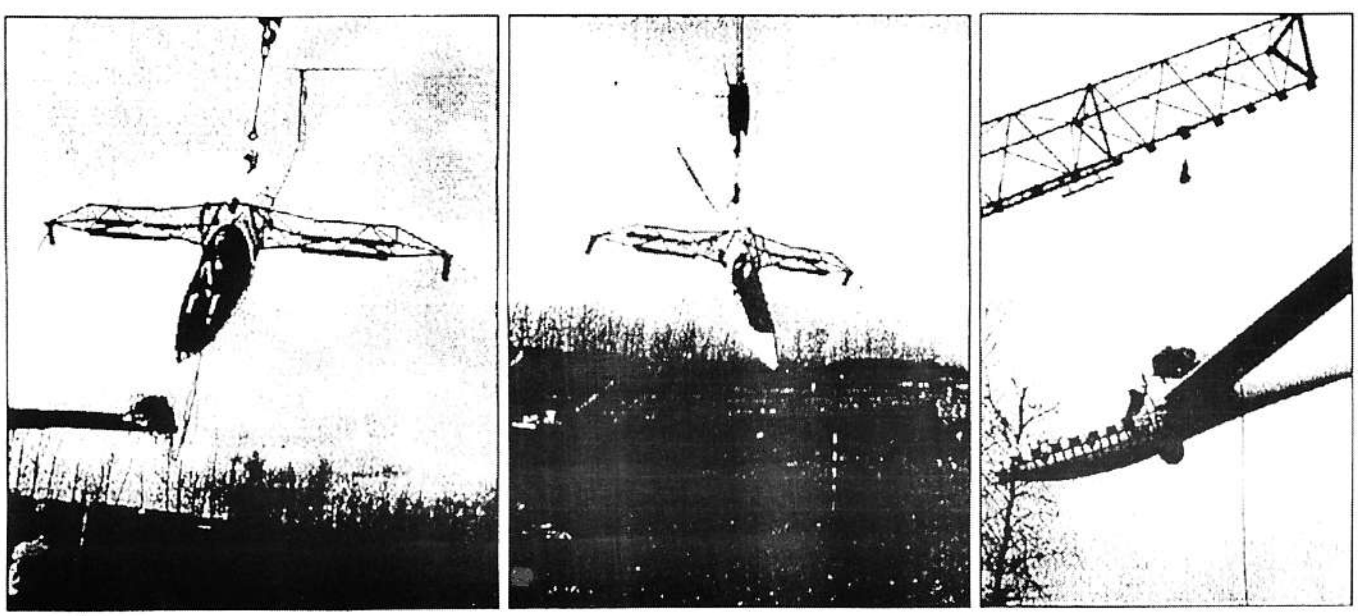


***Figure 1:** Test gliders.*

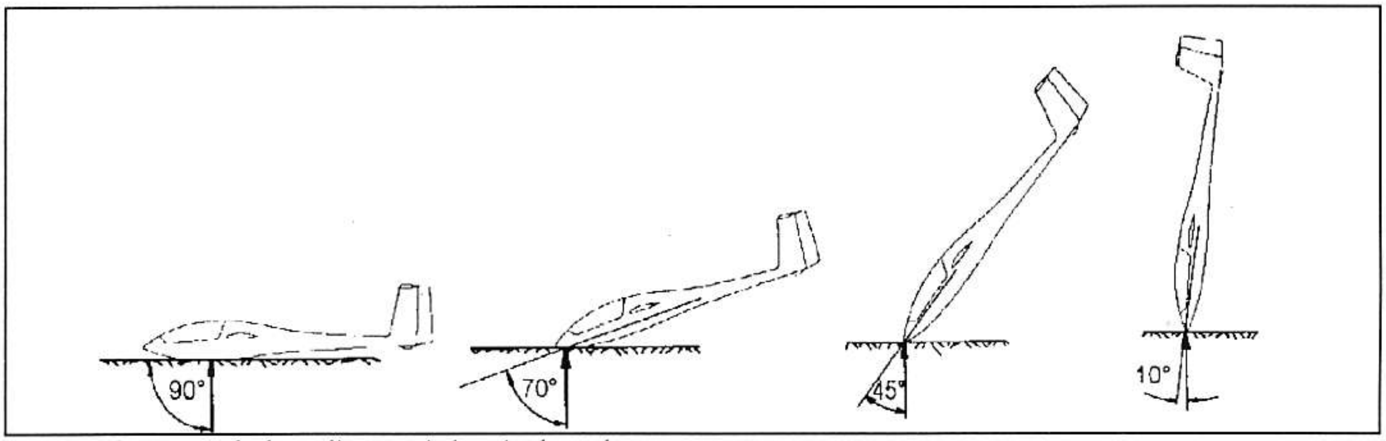


Figure 2: Impact angle depending on pitch attitude angle.

For glider No. 1 and 2 the original wings were replaced by a framework acting as wing dummies with a span of 2.5 m [5] producing the same pitch inertia moment as an original wing. The mass of the glider could be increased to 527 kg by using additional weights fixed at the wing dummies. Springs at the tip of these wings simulated the bending of the wing. Glider No. 3 was fitted with the original wings of the Mistral-C.

The test rigs were equipped with accelerometers for the x- and z-axis at the center of gravity (c.g.), at the seat, at the tail unit and at the nose. During the tests the resultant 3 ms values at the c.g. often exceeded 15 g.

TEST RESULTS

In the first series the pitch attitude angle was varied from 0° to -80° and the glider dropped on a meadow. No. 1a was used with a vertical impact velocity of 6 m/s. The glider was not fitted with an undercarriage. Figure 2 represents the direction of the impact impulse depending on the pitch attitude angle.

It was found that a pitch attitude between -20° and 45° produces the lowest pelvis deceleration and the lowest load on the spinal column. Figure 3 presents the time histories of the pelvis acceleration and the load on the spinal column at a pitch attitude angle of 0° compared with -45° and -80°. Without any pitch attitude angle the bottom of the cockpit crashed on the ground producing a high peak. The rig jumped back into the air and the bottom impacted the ground (460 ms) again. Figure 4 shows the motion of the test rig during the impact with a pitch attitude angle of -45°. The reinforcements of this cockpit avoided a breakage of the cockpit sills. Immediately after the first ground contact peaks occurred in the pelvis acceleration as well as in the spinal load. The cockpit sills bulged outwards and the glider stopped its vertical motion. At this moment a second peak (100 ms) occurred. The bulging of the cockpit sills reduced the impact velocity by low deceleration. Now the glider started to rotate around the nose so that the pilot, sitting behind the rotation point, did not stop abruptly. The glider came free from the ground, rotated nose up, hit the ground with the tail (400 ms), rotated nose down and the bottom of the cockpit crashed on the ground whereby the impact impulse struck directly into the spinal column (510 ms). In this area of the glider there is no structure for absorbing energy and not enough stopping distance to reduce the velocity by low deceleration. This impact produced the highest values during the motion due to the high pitch rotation and the impact direction. In

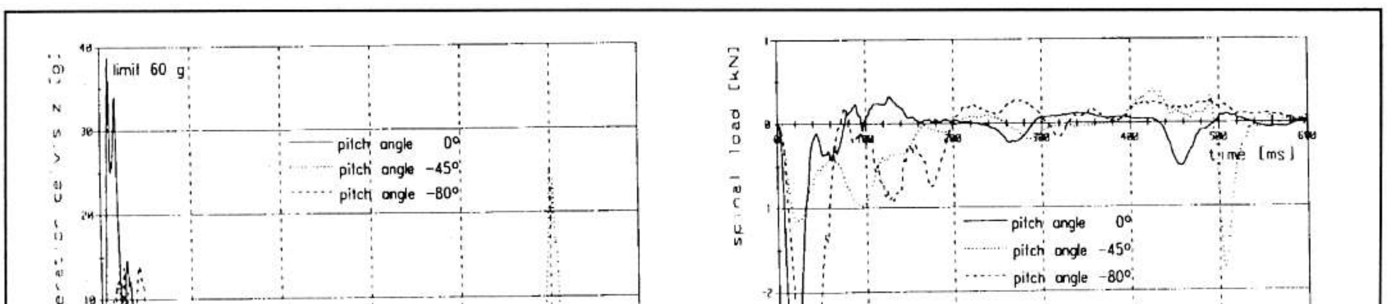


Figure 3: Pelvis accelaration and spinal load depending on pitch attitude angle glider No. 1a, mass 356 kg, impact velocity 6 m/s.

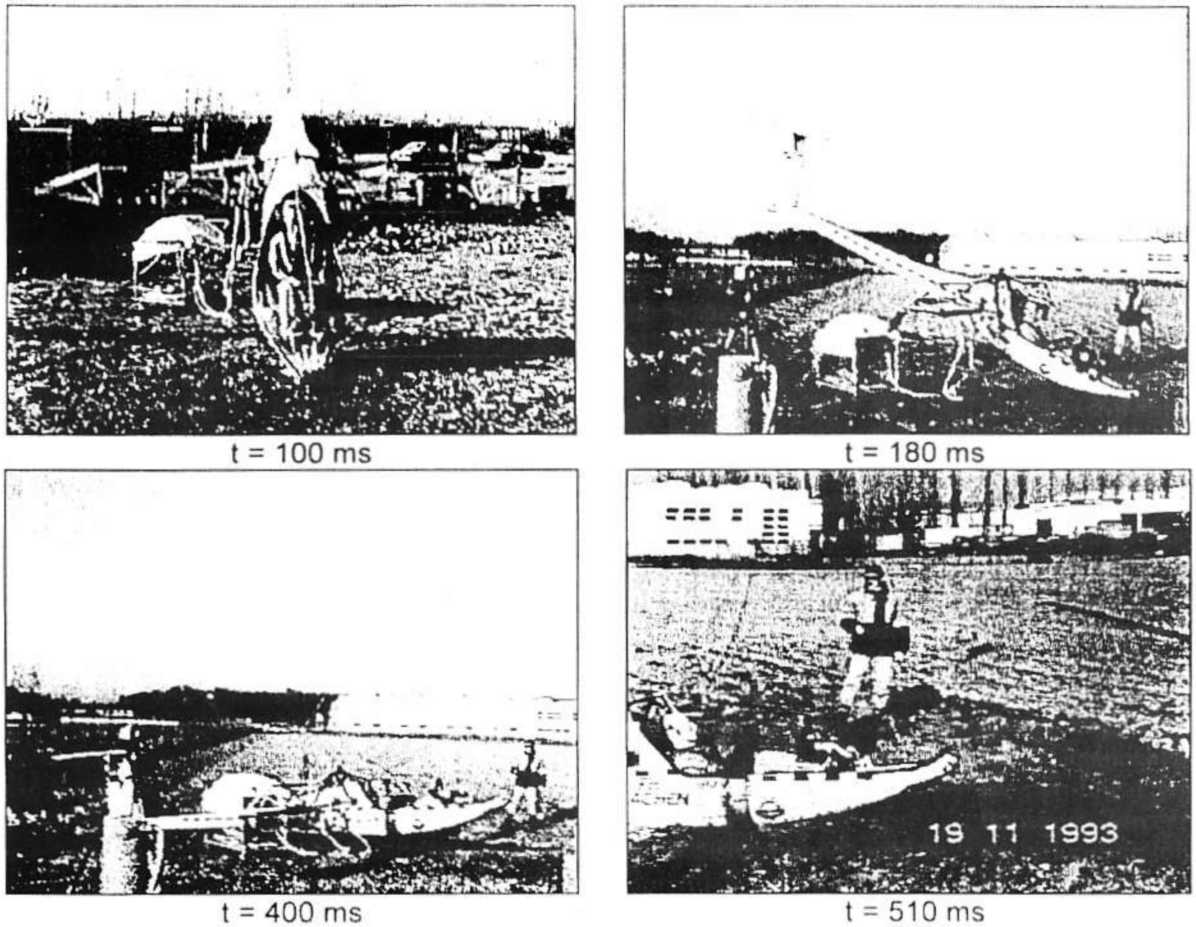


Figure 4: Sequence of drop test glider No. 1a, mass 356 kg, pitch attitude angle -45°, vertical impact velocity 6 m/s.

Figure 5 the resultant maximal 3 ms values during the total ground impact are shown. All values are below the limits mentioned in chapter 2.

The motion of the glider occurring after the first ground impact, with nose up pitch rotation, impact of the tail skid and the following nose down pitch rotation is typical for all nose down impacts.

As mentioned in [1,7] a pitch attitude angle of about -30° should be kept to obtain longitudinal static and dynamic stability during the steady state descent. At the same time this pitch attitude angle reduces the load on the pilot during the ground impact.

To get an idea of the influence of the impact velocity, the repaired glider No. 1a was also used for an impact velocity of 8 m/s whereby the pitch attitude angle was -45°. For this test the glider was fitted with an undercarriage. Figure 6 represents the time histories of the pelvis acceleration and the spinal load compared with the histories of the drop test with 6 m/s (Figure4) and in Figure 7 the situation 100 and 140 ms after the first ground contact with 8 m/s is shown. After this first impact he rig rotated nose up, touched the ground with the tire (320ms) and after the tail wheel impact (383 ms) rotated nose down and the tire again impacted the ground (850 ms). This last impact was well damped by the tire. Due to the breaking of the cockpit structure the first ground impact was shown to be critical. After the breakage the glider motion was stopped by the rear cockpit structure hitting the ground producing a second peak (150 ms). All values are below the limits. During the first impact, the destruction of the front fuselage, the breakage of the rovings and the tire absorbed energy and at the same time the front fuselage gave way to reduce the deceleration. For this reason the values of the accelerations are only somewhat higher than with an impact velocity of 6 m/s.

To demonstrate the influence of the hardness of the ground, glider No. 2 fitted with an energy absorbing nose was crashed on a meadow and onto asphalt with a pitch

position	dimension	pitch attitude angle			
		0°	- 20°	- 45°	- 80°
head	g	38	28	36	20
chest	g	38	24	36	27
pelvis	g	51	34	39	21
spinal load	kN	-3,1	-2,2	-1,7	-3,8

Figure 5: Maximum 3 ms values during impact glider No. 1a, mass 356 kg, vertical impact velocity 6 m/s.

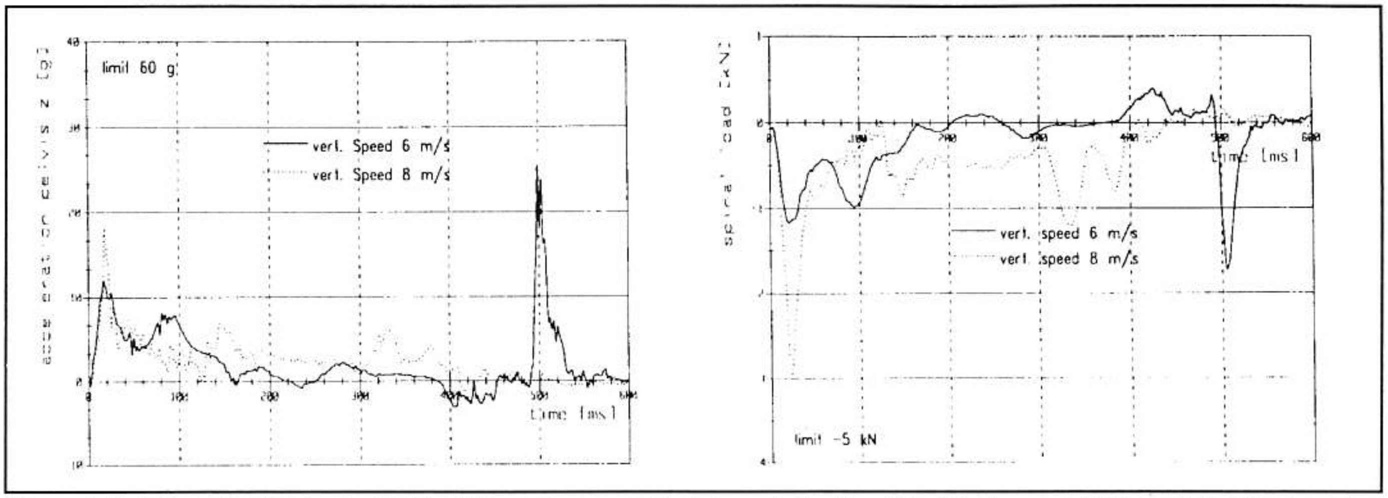
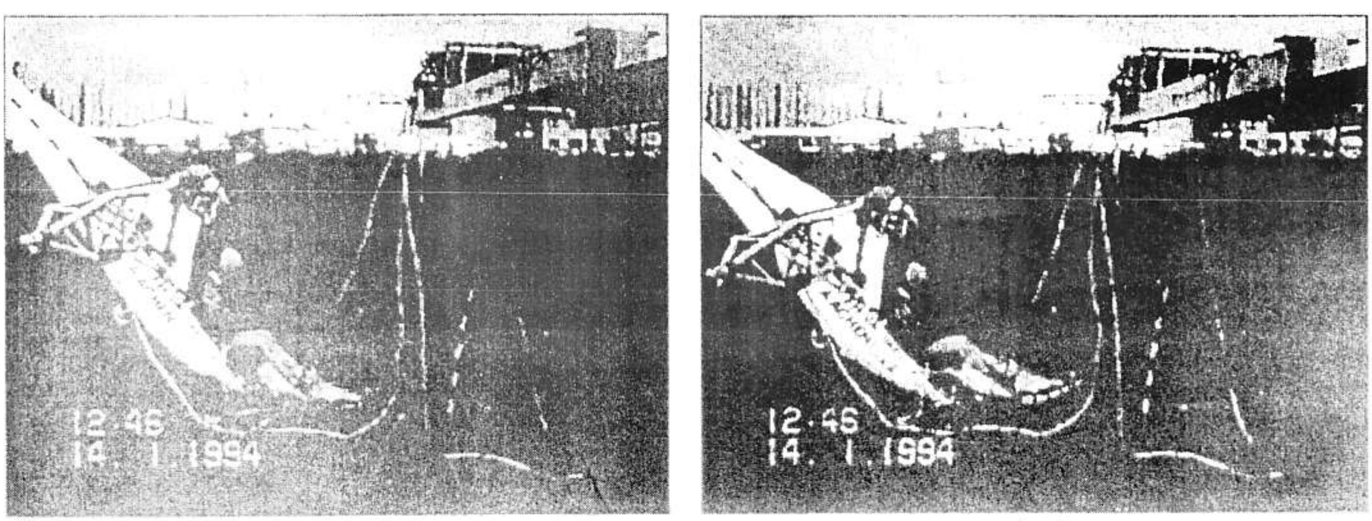


Figure 6: Pelvis acceleration and spinal load depending on vertical impact velocity glider No. 1a, mass 356 kg, pitch attitude angle - 45°.

attitude angle of 45° and a vertical impact velocity of 6 m/s. The motion of the glider during the impact was nearly the same as described above. The glider started to rotate nose up, the tail wheel hit the ground and the bottom of the cockpit crashed on the ground. Figure 8 represents the time histories. In relation to soft ground (meadow) on hard ground the deceleration of the pelvis was nearly doubled and the load on the spinal column increased by a third. The second peak occurred when the strong cockpit structure stopped the vertical velocity. The biggest increase happened during the third peak (380 ms), when the bottom of the cockpit crashed on the ground. The deceleration value was nearly four times that of the soft ground. In Figure 9 the situation with the totally destroyed nose (80 ms) and the situation shortly before the second ground contact is shown. On hard ground the impulse from the ground was higher and this resulted in a faster pitch rotation producing higher impacts during the following motion. On soft ground the third peak occurred after 455 ms and on hard ground after 380 ms. It must be mentioned that during the test on the meadow the skid crashed accidentally in a furrow. All values except the acceleration of the pelvis during the third peak on hard ground are below the limits.

According to the physical law of a spring, damper, mass system a big mass produces a lower deceleration than a small one. For confirming this effect glider No. 2 was loaded up to the mass of 527 kg. Additionally the energy was increased by choosing an impact velocity of 8 m/s. In Figure 10 the time histories of the pelvis acceleration and the spinal load are compared for tests with 355 kg and 527 kg. The test results demonstrated the correctness of the law; the values of the first impact with the heavier glider are lower. Immediately after the first peak (30 ms) there was a second peak (100 ms and 130 ms) like glider No. 1, but in case of glider No. 2 this peak was higher than the first one. For both tests the situation of the second peak is shown in Figure 11. The second peak (355 kg) occurred when the energy absorbing nose was destroyed and the motion was stopped by the stronger cockpit structure. With a total mass of 527 kg the structure of the cockpit was not able to withstand the very strong impact. The second peak occurred when the stiff rear part of the cockpit stopped the



t = 100 ms t = 140 ms

Figure 7: Drop test with a vertical impact of 8 m/s glider No. 1a, mass 356 kg, pitch attitude angle -45°.

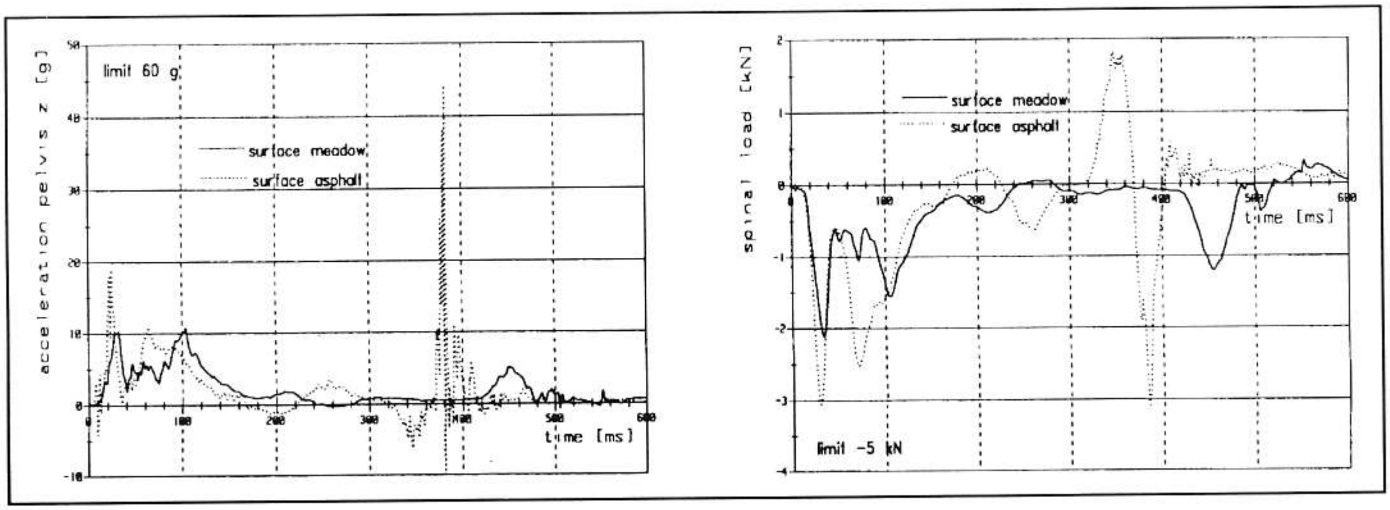
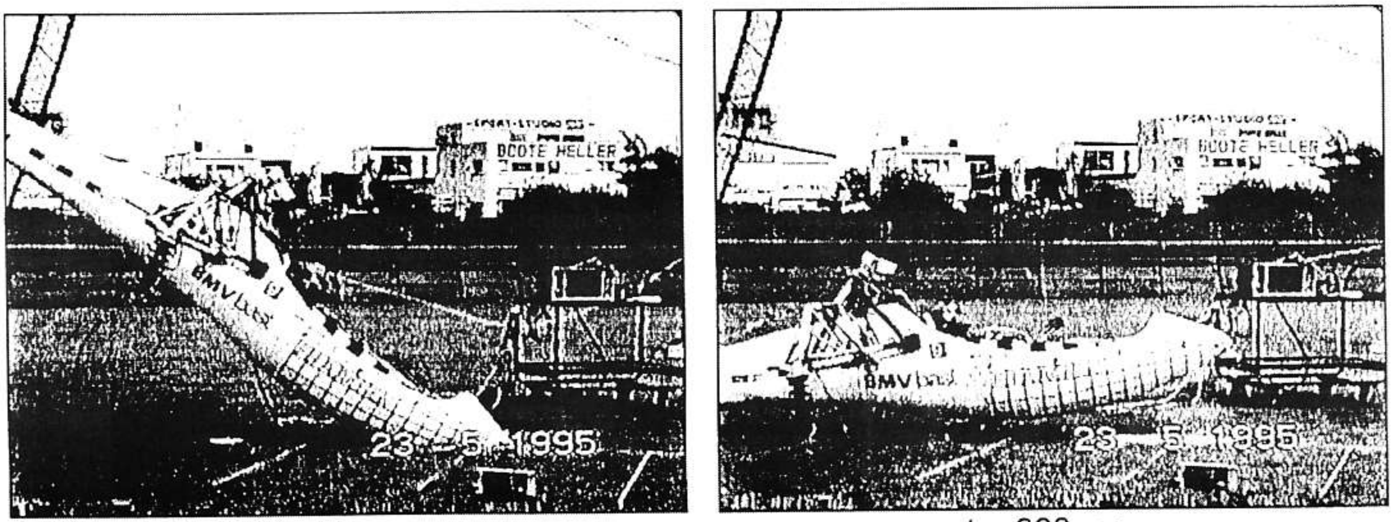


Figure 8: Pelvis acceleration and spinal load depending on hardness of surface glider No. 2, mass 356 kg, pitch attitude angle -45°, vertical impact velocity 6 m/s.

motion. At this time (140 ms) the pilot hits the ground. The peak was additionally increased by the simultaneously rebound of the cockpit shell. Due to the energy absorption of the nose the pitch rotation was not as high as glider No. 1. The tail impact and the impact of the cockpit bottom occurred nearly at the same time (355 kg: 450 ms, 527 kg: 310 ms). During the first impact the deceleration of the two tests differed by the factor 1.4. This gives the hint that the nose works more like a damper than a spring.

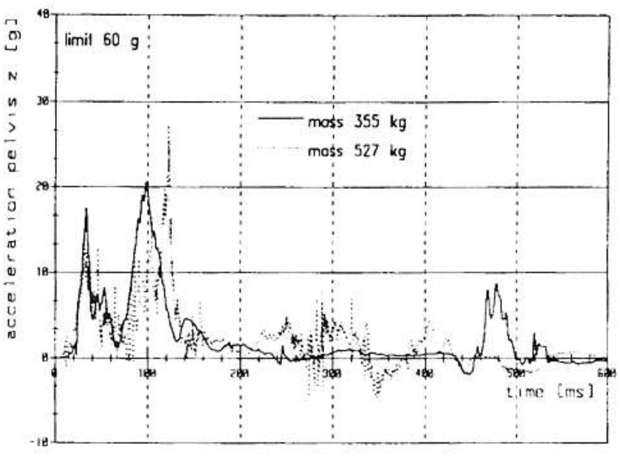
During the descent of the glider, wind may induce a horizontal velocity. For producing a horizontal and a vertical velocity a slide bar was constructed (Figure 12). The glider was connected by cables to a sled gliding down the slope. At a height of about 0.8 m above the ground the sled ran onto a stud, the cables were released and the glider fell free on the ground. With this test rig, glider No. 3 has been dropped with a forward, a backward and a sideward horizontal velocity. Figure 13 represents the pelvis deceleration and the load on the spinal column of a test with 6 m/s vertical and 6 m/s forward horizontal velocity (total integrated velocity 8.45 m/s) compared with the test results of glider No. 1a without a forward velocity (6 m/s vertical velocity, pitch attitude angle -20°). Though the impact energy was much higher with the additional horizontal velocity, the values of the pelvis deceleration as well as the spinal load were lower. In Figure 14 the crash onto the ground in the critical situation is shown. The cockpit of glider No. 3 was not able to withstand the impact and the structure of the cockpit broke down. This produced a second peak occurring when the rear part of the cockpit hit the ground and slowed down the motion. Due to the gliding along the ground the load on the pilot was reduced. On the other hand, the test (not shown here) with the sideways horizontal velocity gave higher deceleration than without a horizontal impact.

None of the cockpits used withstood an impact velocity of 8m/s without a breakage of the sills. Therefore, a very strong cockpit (1b) like a survival cell was built (s. chapter 3). This glider was tested with 6 m/s vertical and additional 6 m/s horizontal impact velocity. In Figure 15 the



t = 80 ms   t = 330 ms

Figure 9: Drop test on asphalt glider No. 2, mass 356 kg, pitch attitude angle -45°, vertical impact velocity 6 m/s.



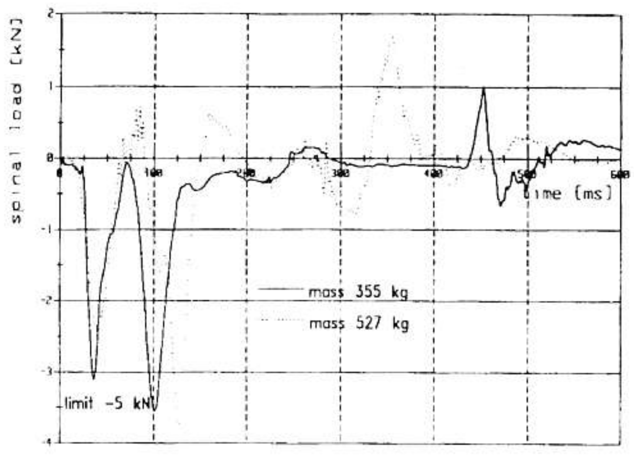
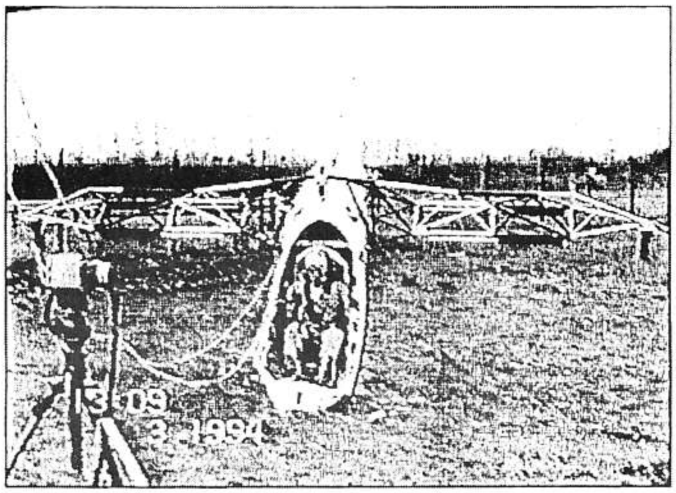
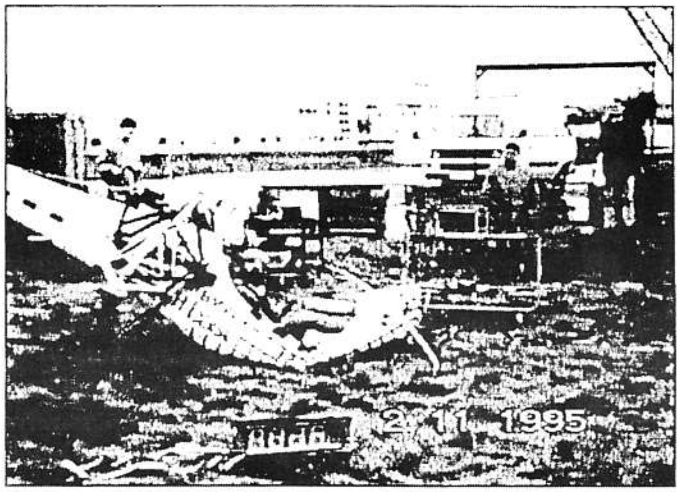


Figure 10: Pelvis acceleration and spinal load depending on mass glider No. 2, pitch attitude angle -45°, vertical impact velocity 8 m/s.

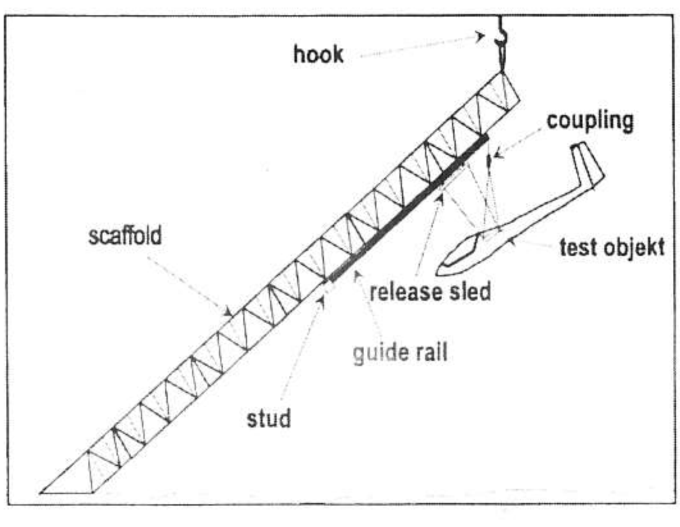


355 kg, t = 100 ms



527 kg, t = 140 ms

Figure 11: Second peak glider No. 2, pitch attitude angle -45°, vertical inpact velocity 8 m/s.



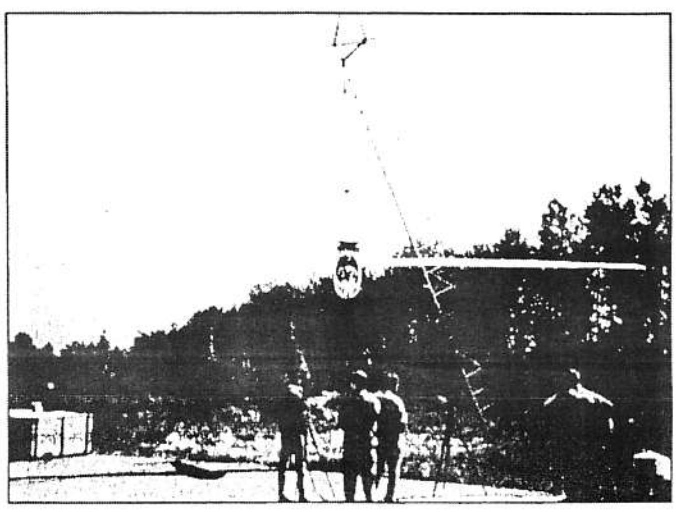


Figure 12: Slide bar.

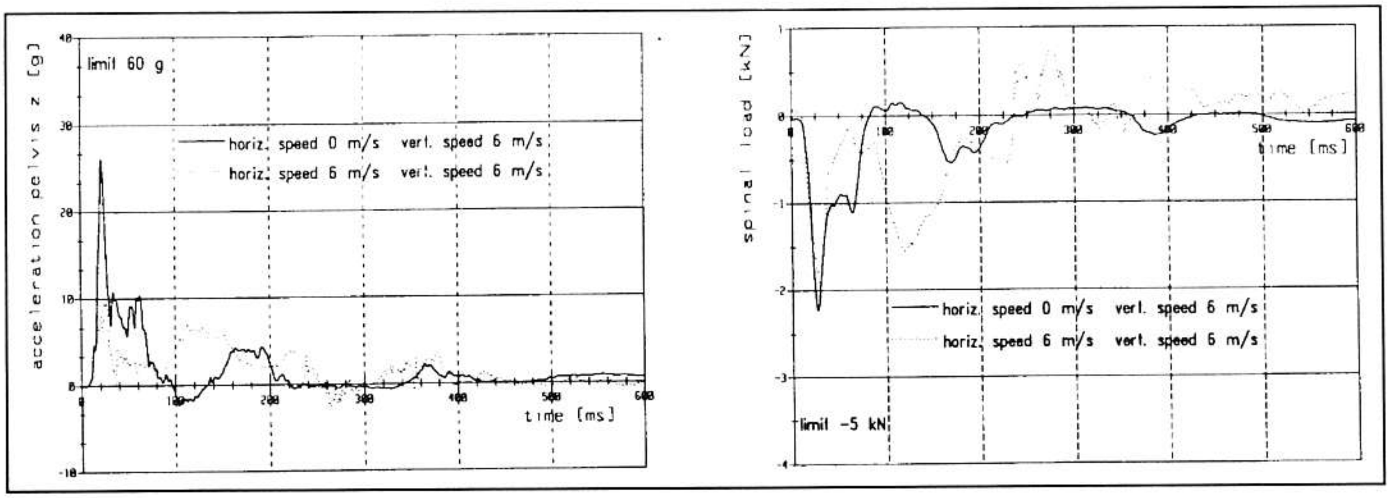
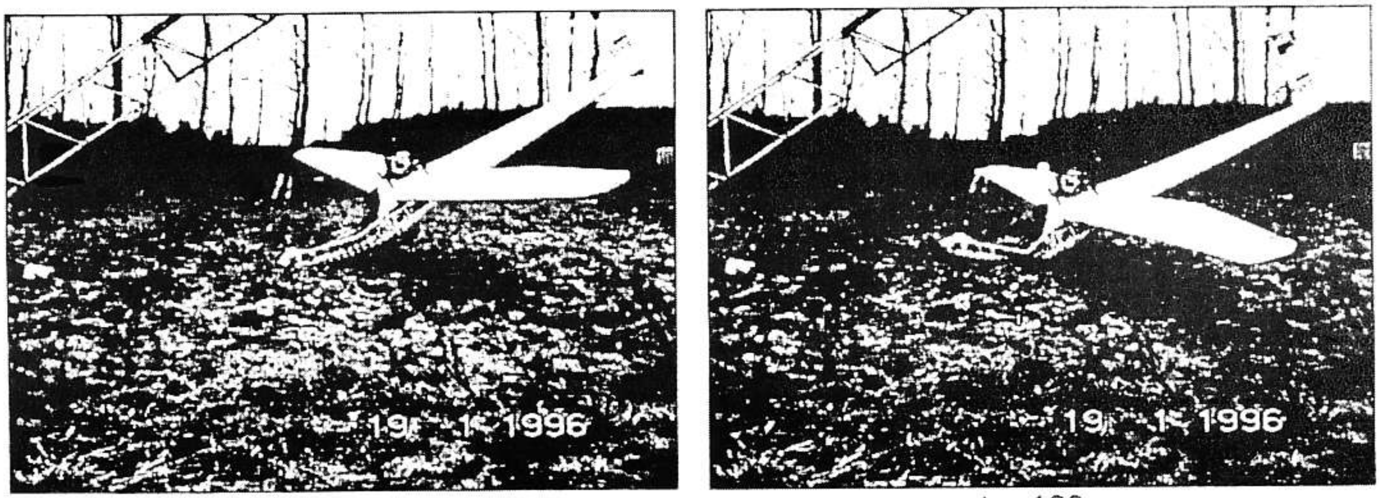
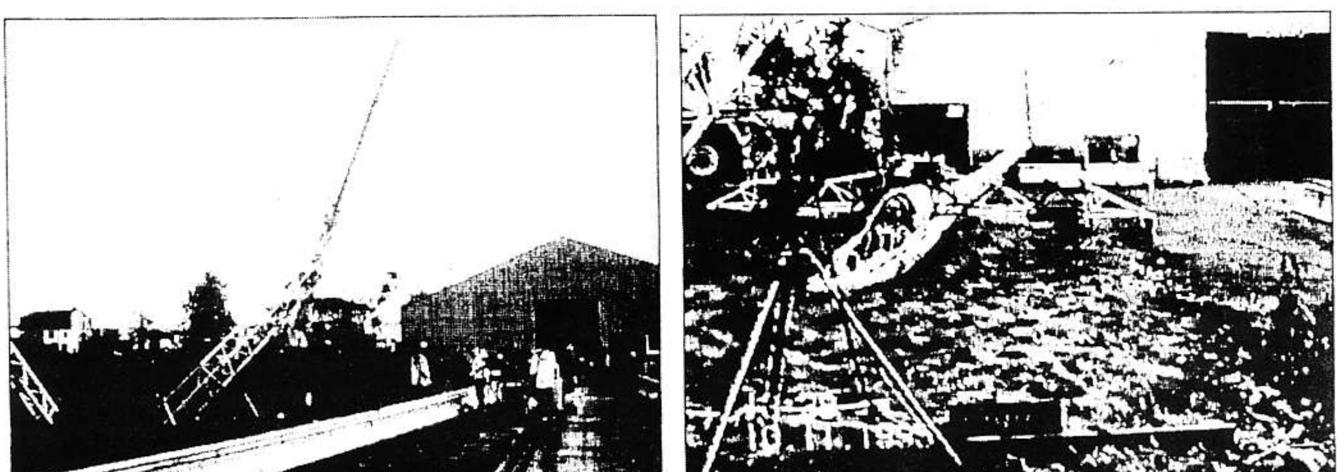


***Figure 13:** Pelvis acceleration and spinal load with and without horizontal velocity. Vertical impact velocity 6 m/s. Glider No. 1a, mass 347 kg, pitch attitude angle -20°, horizontal velocity 0 m/s. Glider No. 3, mass 357 kg, pitch attitude angle -25°, horizontal velocity 6 m/s.*



t =80 ms   t = 160 ms

***Figure 14:** Drop test with horizontal velocity glider No. 3, mass 357 kg, vertical impact velocity 6 m/s, horizontal velocity 6 m/s, pitch attitude angle -25°.*



starting position   t = 30 ms

***Figure 15:** Drop test with glider No. 1b, survival cell, mass 356 kg, vertical impact velocity 6 m/s, horizontal velocity 6 m/s, pitch attitude angle -15°.*

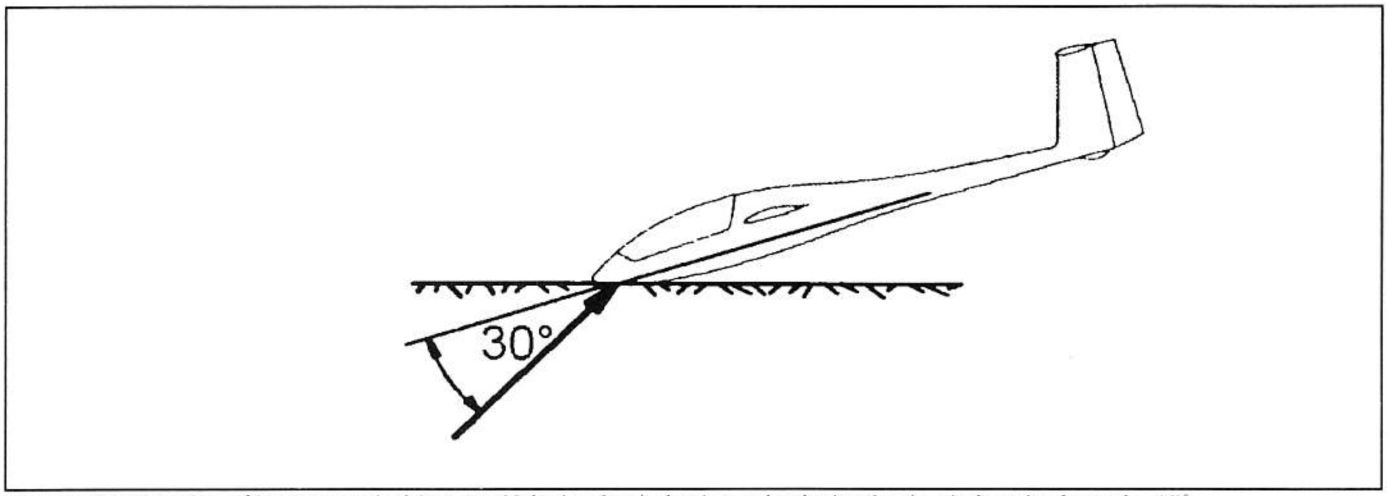


Figure 16: Direction of impact vertical impact. Velocity 6 m/s, horizontal velocity 6 m/s, pitch attitude angle -15°.

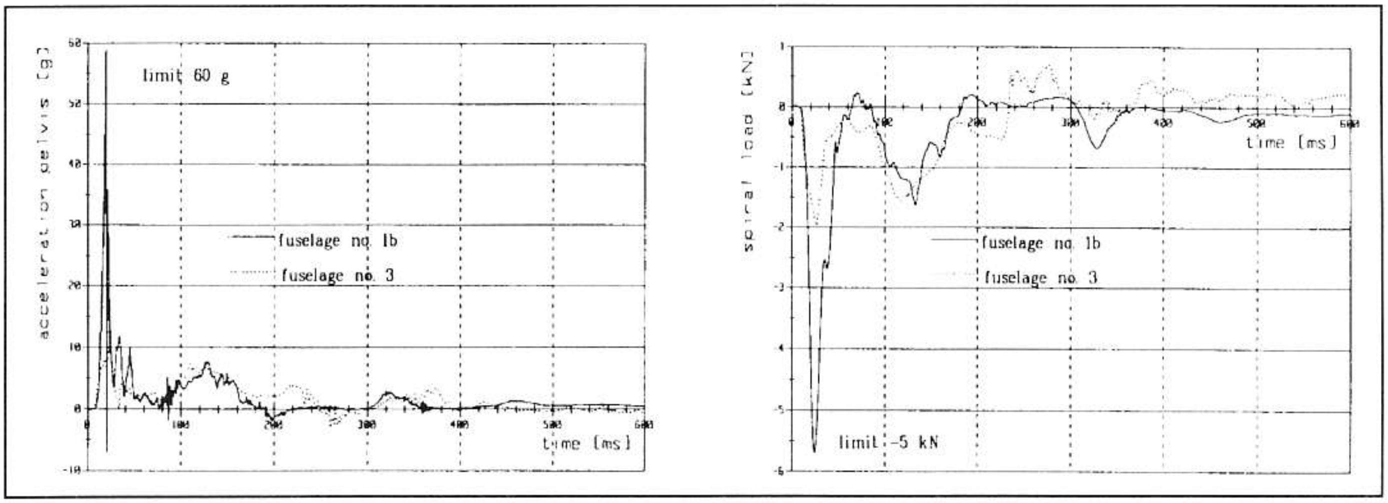


Figure 17: Pelvis accelertaion and spinal load deopending on cockpit stiffness. Glider No. 1b, pitch attitude angle -15° / glider No. 3, Mistral-C, pitch attitude angle -25°, mass 357 kg, vertical impact velocity 6 m/s, horizontal velocity 6 m/s.

glider is shown in the starting position and 30 ms after the first ground contact. The structure of the cockpit fully withstood the impact without any damage. The tail cone buckled as a result of a nose up pitch rotation starting immediately after the ground impact. The pitch attitude angle of this glider had been adjusted to -25°, but due to a mistake in the attachment, the angle changed during the test to -15°. The impact angle was therefore about 30° (Figure 16). The results of the pelvis acceleration and the spinal load compared with the test of glider No. 3 (same impact velocity, pitch attitude angle -25°) are shown in Figure 17. The impact itself looked smooth, but the first impact resulted in a high peak of the pelvis deceleration, at the same time as the spinal load exceeded the limits. Owing to the low impact angle (Figure 16) the direction of the ground impulse nearly coincided with the center of gravity, and the motion of the pilot was stopped abruptly. The motion included a small pitch rotation. The second peak occurred when the skid hit the ground, and the third peak marked the impact on the cockpit bottom. As a result of the strong cockpit there was no deformation and no damage to the structure. The strong cockpit structure did not give way sufficiently to reduce the impact velocity by low deceleration.

CONCLUSION

Using a glider recovery system it has been found that a pitch attitude angle between -20° and -45° reduces the deceleration in the human body and the load on the spinal column. The direction of the ground impulse produces a nose up pitch rotation. This differs from a crash landing whereby the impulse is directed along the longitudinal axis. The impact is reduced by a bulging outwards of the cockpit sills, or by energy absorption of the nose. Both give, way to reduce the velocity with a low deceleration. Due to the nose down pitch attitude angle, the pilot sits behind the first rotation point, and so drops further towards the ground and hence his motion is not stopped so abruptly. The tail wheel hits the ground followed by ground impact of the cockpit bottom. This impact could be very dangerous for the pilot because of the high deceleration in the z-axis.

The distance between the seat and the cockpit shell is small and there is not enough distance to yield a low deceleration. The tire is unable to reduce this impact substantially.

The ground impact produces a double peak. The first peak occurs with the impact, and the second after the sills are broken or the nose is damaged. The strong part of the cockpit then impacts with the ground. This peak may be additionally increased by a rebound of the cockpit shell.

Compared with a soft surface, on hard ground the deceleration of the pelvis is nearly doubled and the load on the spinal column increases by a third. Due to the hard ground, the impulse is higher resulting in a faster pitch rotation and a greater tail impact. An energy-absorbing nose may reduce the pitch rotation and the tail impact. A heavier glider produces lower deceleration. An energy absorbing nose works more like a damper than a spring.

Caused by wind, an additional horizontal velocity in the longitudinal axis of the glider will result in a reduced load on the pilot. In the event of the glider impacting sideways the results show higher decelerations. Using a totally stiff cockpit there is no deformation, no bulging and no damage, so no distance is available to reduce the impact, velocity by low deceleration. At low impact angles, this becomes more critical due to the absence of nose up pitch rotation.

The controlled deformation of structural parts, multiple impacts, buckling of the tail cone and collapse of the landing gear helps to absorb energy and reduces the maximum loads considerably. It is very important to design the pilot's cockpit area as strongly as possible, and make provision elsewhere for deformation and energy absorption.

In all tests up to 8m/s impact velocity the human limits are exceeded in the case of impact on hard ground, a horizontal impact position and by the use of a totally stiff cockpit.

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