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Evaluation of Improved Restraint Systems for Sport Parachutists

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Final Report

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16. Abstract

As part of a cooperative project between the Federal Aviation Administration's Civil Aeromedical Institute, the Parachute Industries Association, and the United States Parachute Association, a series of dynamic impact sled tests were performed to evaluate new types of restraint systems for sport parachutists. The traditional means of restraining sport parachutists sitting aft-facing on the floor has been to provide lap belts that are attached to the floor or sidewall of the airplane. The restraint systems evaluated in this project were designed to route through the parachute harness and attach to the floor. Thus, occupant restraint was provided by anchoring the parachute harness to the floor by means of the new restraint devices. Seven methods of attaching the restraints to the parachute harness, which included both single and dual point restraint systems, were dynamically tested. Five models of parachute pack/harnesses were included in this project. A VIP 50th percentile anthropomorphic test dummy was modified to simulate a floor-seated aft-facing parachutist. The impact test severity ranged from 5.5 gs @ 27.8 ft/sec to 9.5 gs @ 32.7 ft/sec.

Based on the results and observations acquired from this series of 12, three of the new restraint methods demonstrated better restraint performance than could be expected from that provided by the traditional lap belt method currently recommended.

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EVALUATIONOF IMPROVED RESTRAINT SYSTEMS FOR SPORT PARACHUTISTS

Typical Cabin Arrangement for Sport Parachute Operations
Figure 1.

Introduction

Sport parachuting continues to be a popular recreational and competitive activity. Recent data from the United States Parachuting Association (USPA) indicates that there are approximately 3,000,OOO jumps per year at the 297 jump zones operated in the US. Membership in the USPA, which currently is over 33,000, has grown at a rate of 10% per year during the past few years (1). The emphasis on safety in every facet of sport parachuting operations has been the key factor in the increasing popularity and remarkable safety record of this aviation activity. Obviously, effective improvements in the equipment and procedures to enhance safety must be promoted by the parachuting community as well as the Federal Aviation Administration (FAA.)

One of the unique operational features of sport parachuting is the method for occupant restraint in an airplane. FAA regulations and guidance documents (2,3) allow parachutists to sit on the floor of the airplane with the passenger seats removed, as illustrated in Figure 1. The method of seating multiple parachutists in an airplane is commonly referred to as the "caterpillar" arrangement. In this seating arrangement, the most forwardpassenger sits aft-facing on the floor with his/her back against a cabin wall. The other parachutists then sit between the legs of the person behind them in a single file stretching toward the aft end of the aircraft. This seating arrangement positions the parachutists to conveniently jump out the aft door. It also allows more passengers on board than could be accommodated in normal aircraft seats.

FAA regulations require that each parachutist must be restrained by a lap belt. Depending on the type of airplane, the attachment of the lap belts to the airplane will be to the floor or side wall of the cabin. For an aft facing parachutist seated on the floor, a lap belt routed over the anterior region of the pelvis does not provide a conspicuous means of restraining the parachutist during deceleration forces that could occur during emergency landing conditions. And, since there are no seat backs to restrain the parachutists from sliding toward the front of the airplane, the person seated

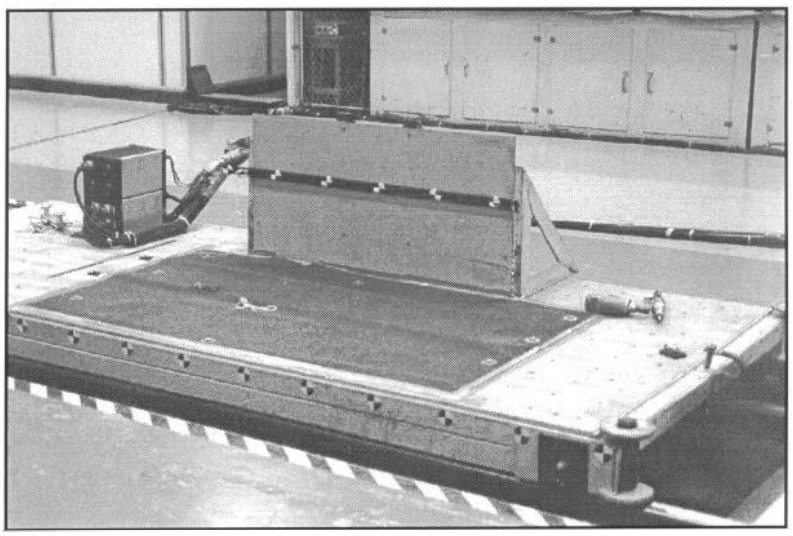
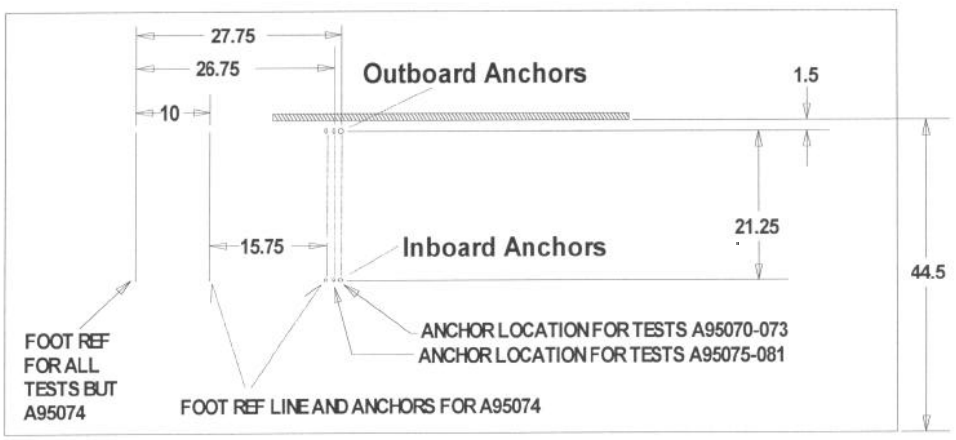
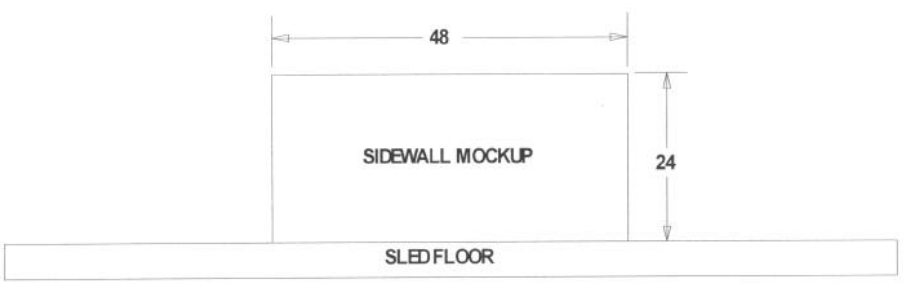


Figure 3. CAMI Test Sled Setup



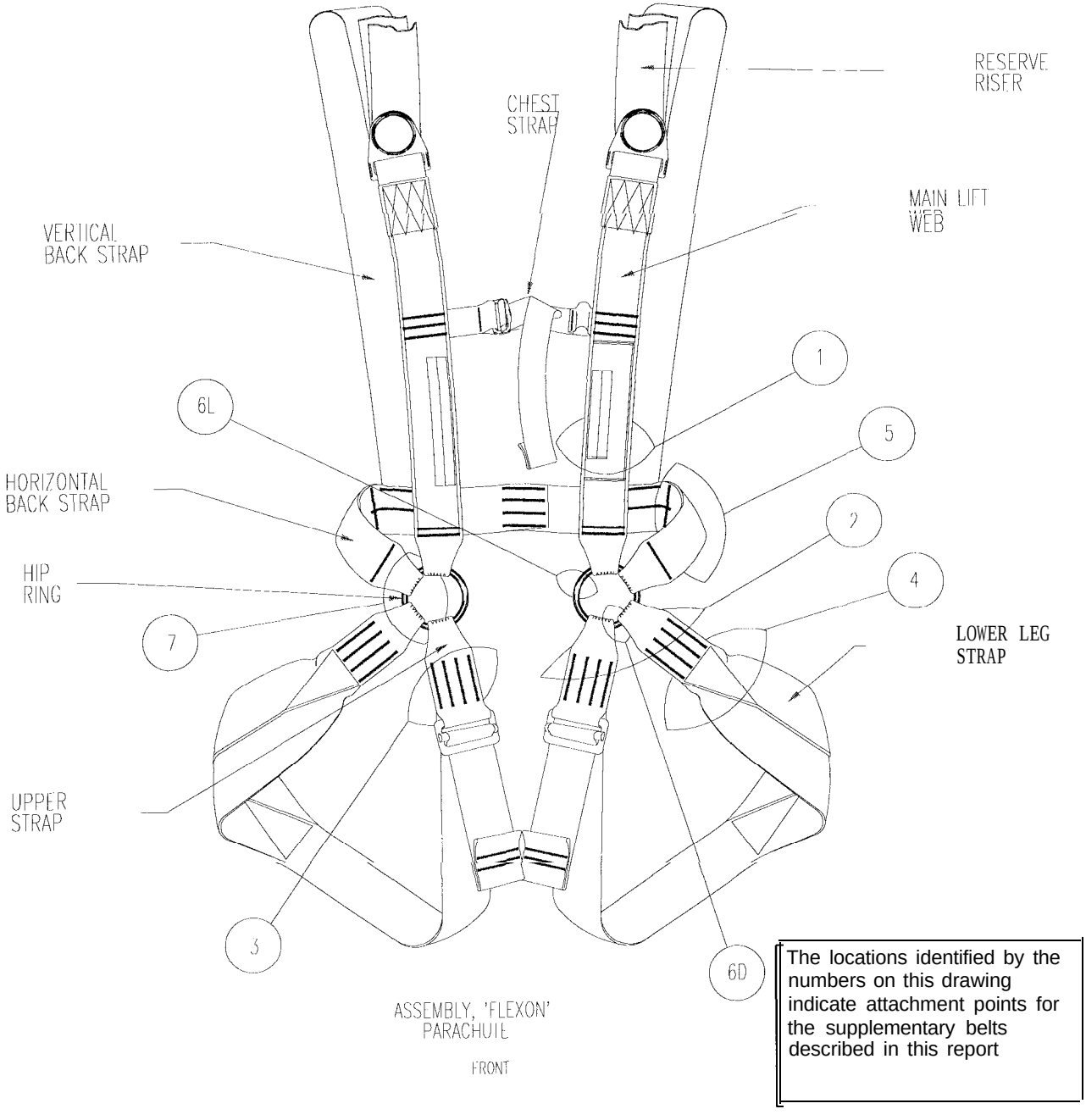
SLED TOP VIEW



SLED SIDE VIEW

(DIMENSIONS IN INCHES)

Figure 4. Test Fixtures and Dimensions



Typical Parachute Harness and Attachment Points for Floor-to-Harness Restraints
Figure 5.

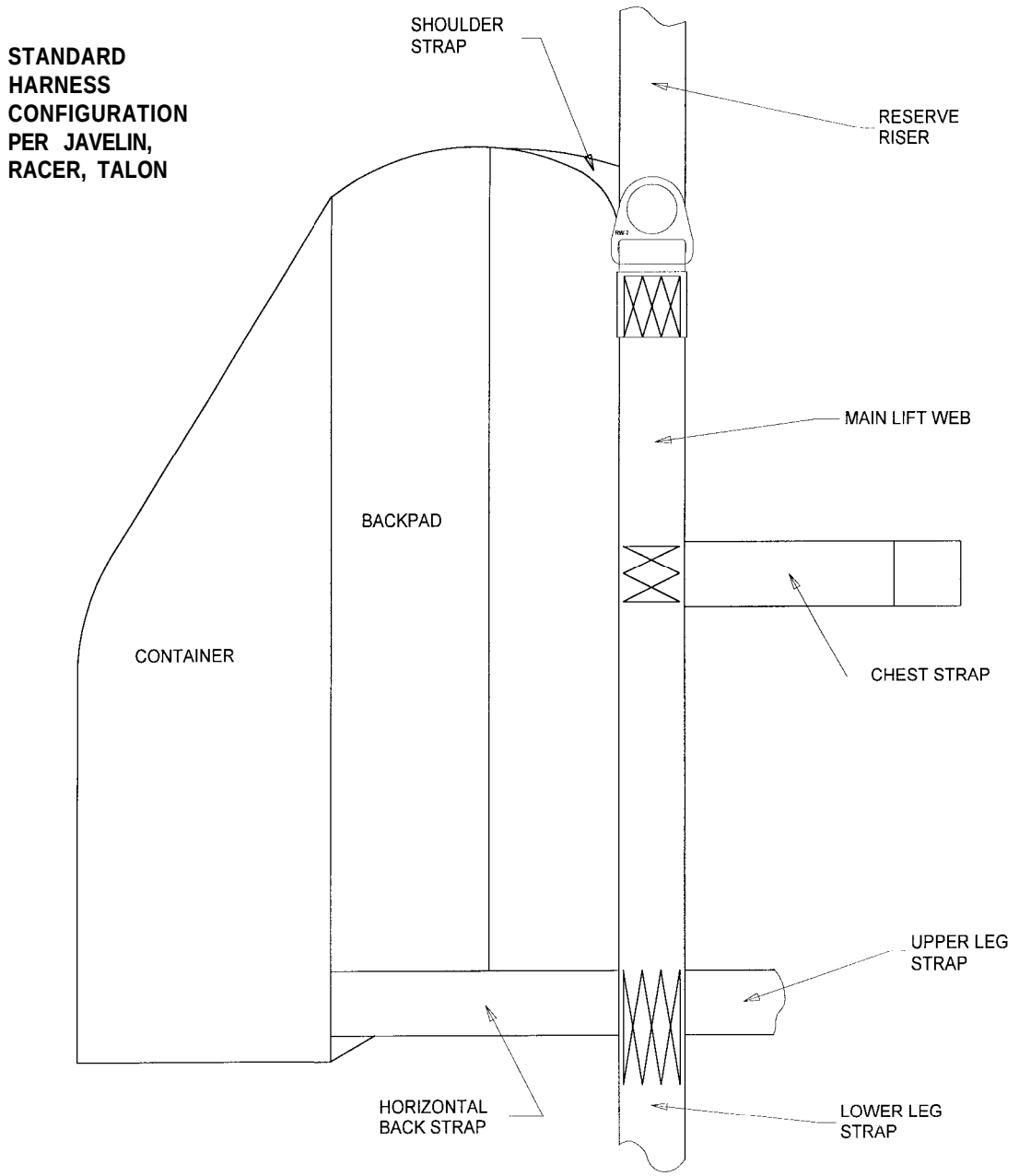


Figure 6. Standard Harness Configuration

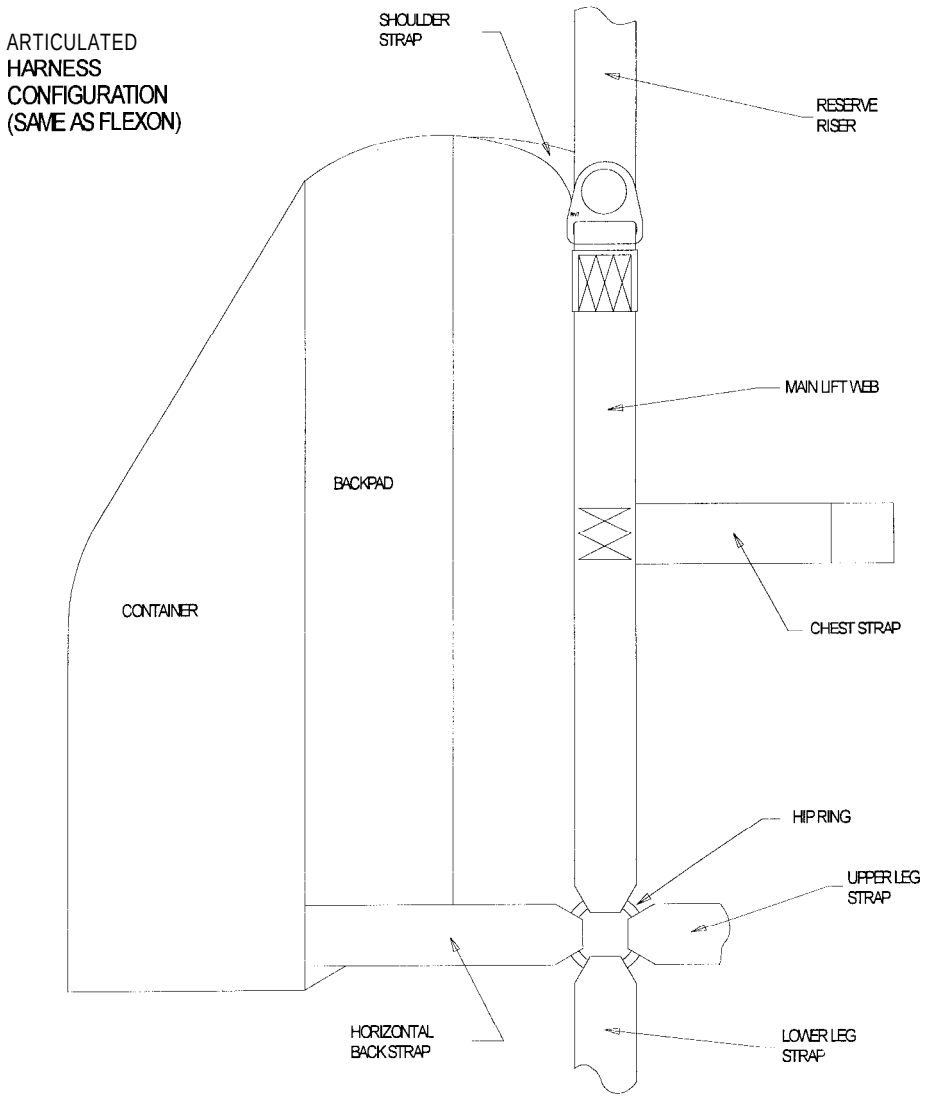


Figure 7. Articulated Harness Configuration

Test Number	Belts Attach Points *	Number of Belts	Parachute Equipment	Velocity (ft/sec)	Peak g's
A95070	1	Dual	Sunpath Inc. - Javelin	27.8	5.5
A95071	1	Dual	Sunpath Inc. - Javelin	27.9	5.5
A95072	1	Dual	Sunpath Inc. - Javelin	27.9	6.8
A95073	7	Dual	Jump Shack Inc. - Racer	27.6	6.7
A95074	4	Dual	Jump Shack Inc. - Racer	27.9	6.8
A95075	2	Single - Left	Rigging Innovations - Talon	27.6	6.8
A95076	5	Single - Left	Rigging Innovations - Talon	27.7	6.8
A95077	5	Single - Right	Rigging Innovations - Talon	27.8	6.7
A95078	6	Dual	Rigging Innovations - Flexon	27.9	6.8
A95079	6	Single - Left	Rigging Innovations - Flexon	27.8	6.7
A95080	5	Dual	Sunpath Inc. - Javelin	32.7	9.5
A95081	5	Dual	Strong Enterprises - Dual Hawk**	32.7	9.5

* Refer to Figure 5.
** Tandem harness only, used for training, no parachute pack

Table 1. Test Matrix

parachutist. The ATD was seated on the floor of the sled facing aft, with its right shoulder against the side wall mockup for all of the tests presented in this report.

Test Matrix. Table 1 is a summary of the matrix of tests conducted during this program. As shown in Table 1, eight of the tests were performed with dual belts attached symmetrically to the parachute harness, and four tests were performed with only one belt. The single belt tests were designed to evaluate the proposed belt restraint in a simulated cabin interior with only one floor track available to attach the belt.

Note also the test severity ranged from 5.5 gs @ 27.8 ft/sec to 9.5 gs @ 32.7 ft/sec. The impact pulses approximated a trapezoidal shape, as shown in Figure 8. The rational for this range of test severity was based

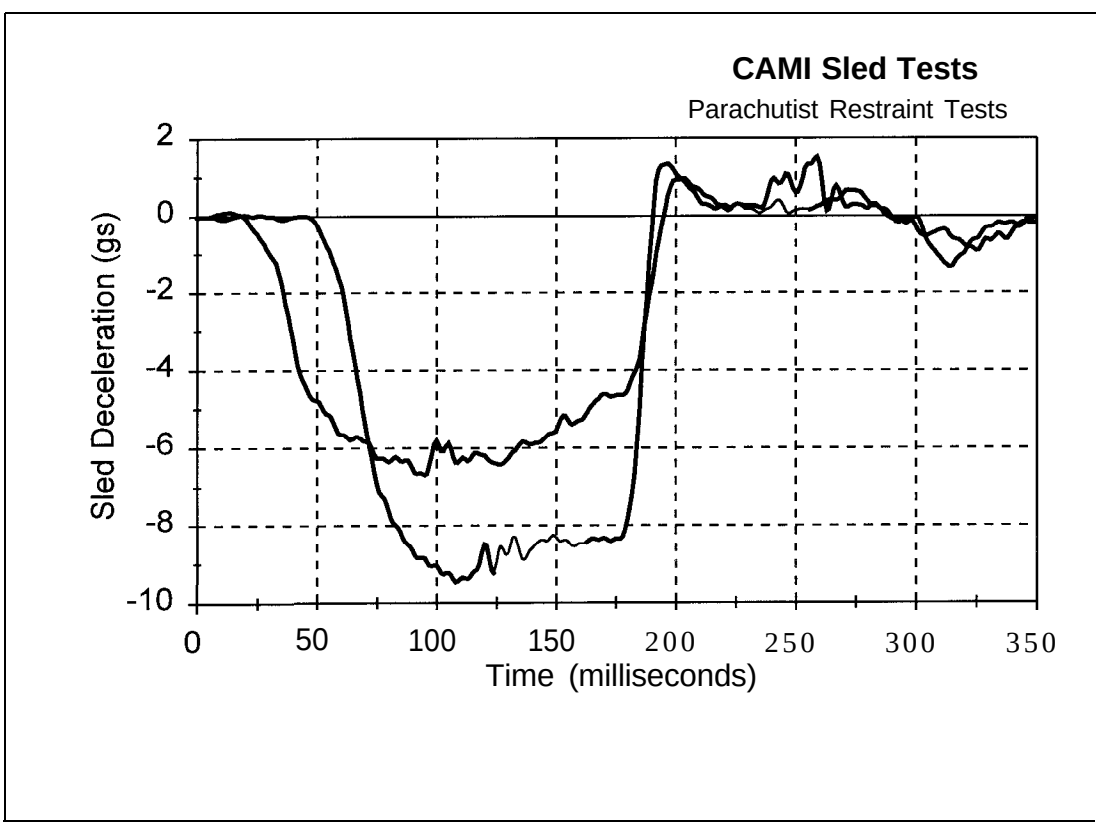
on the traditional static load requirements for seats and restraints in airplanes: 6 g limit and 9 g ultimate static loads. Although the association of static loads and dynamic responses is subject to misinterpretation, this range of dynamic test severity was selected because of the historical regulatory significance of the 6 g and 9 g static load airworthiness requirements for the types of airplanes used in sport parachuting.

Test Results and Summaries.

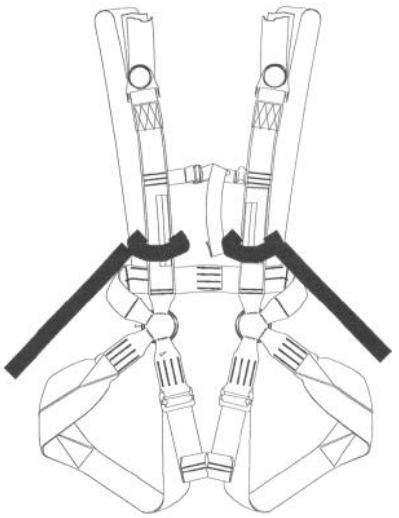
The following summaries describe the setup, restraint variation, and results noted from each of the tests. Refer to Figure 5 and Table 1 for additional details of the tests described below. The restraint methods described in the following summaries are identified by the attachment point shown in Figure 5, and the number of belts. For example, method "1D" indicates *dual* restraints were attached near the lower end of the left and right main lift webs of the parachute harness, denoted as *point 1* on Figure 5. Likewise, method "2L" refers to a single restraint belt attached to the *left* side leg straps near the hip ring on the harness, denoted *as point* 2 in Figure 5.

Restraint Method 1D: **Restraint Looped through Main Lift Web, Left and Right**

Three tests were conducted with proposed restraint method 1D as illustrated in Figures 9 and 10. In the first two tests, A95070 - 071, the ATD's upper body leaned forward (relative to its body orientation) during the acceleration phase of the test prior to impact. Light cotton string was wrapped around the torso of the ATD to inhibit the upper torso from rotating, but the string broke prior to impact on both tests. The ATD



Examples of the 2 Impact Deceleration Pulses in the Project
Figure 8.



Restraint Method 1 D: Restraint Looped through Main Lift Web, Left and Right

Figure 9. Restraint Method ID

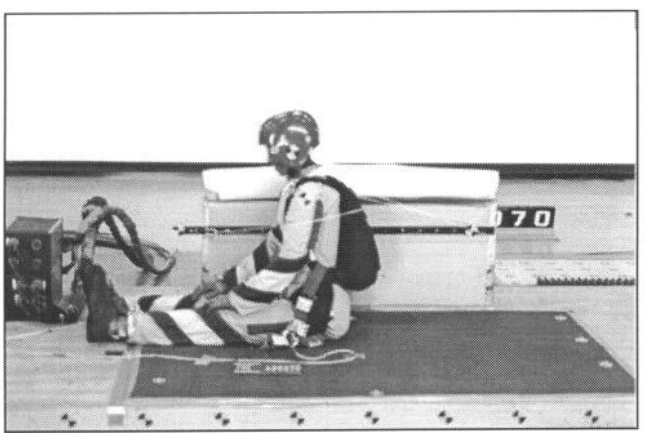


Figure 10. Pre-Test A95070

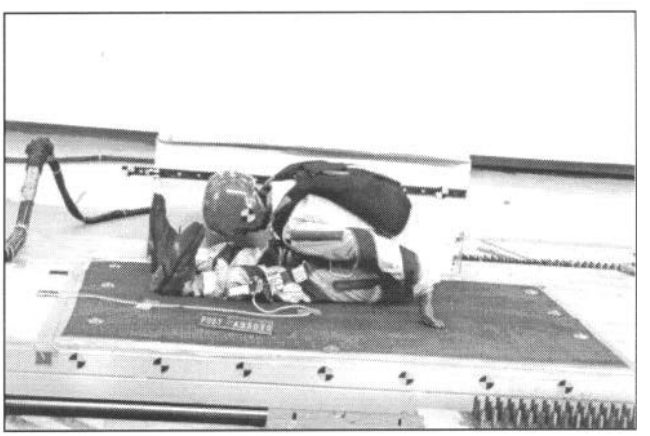


Figure 11. Post-Test A95070

was not in the desired sitting position at the start of the impact pulse. However, there was no gross flailing or excessive translation of the ATD in spite of the out-of-position posture. Figure 11 shows the post-test position of the ATD after the first test.

A stronger cord was used to support the ATD for the third test, A95072, as shown in Figure 12. The ATD remained in an upright seated posture up to the start of the impact pulse. An examination of the high speed films from this test showed the ATD slid forward until the restraints attached between the main lift webs and the floor became taut. The ATD's upper torso rotation was arrested at approximately 25° from vertical. Figure 13 shows the post-test position of the ATD from test A95072. There was no headcontact with the floor.

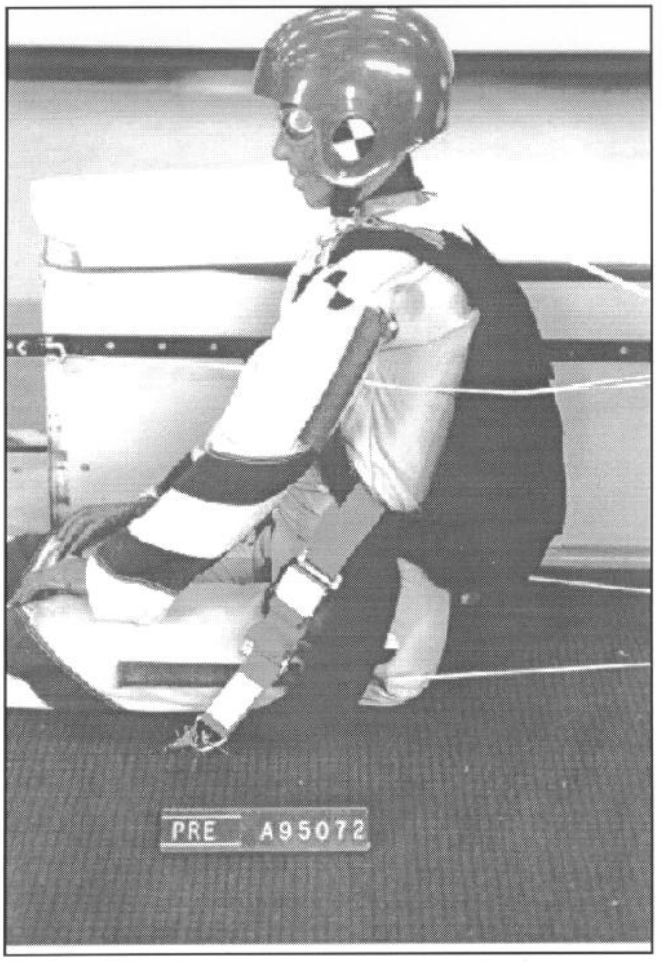


Figure 12. Pre-Test A95072

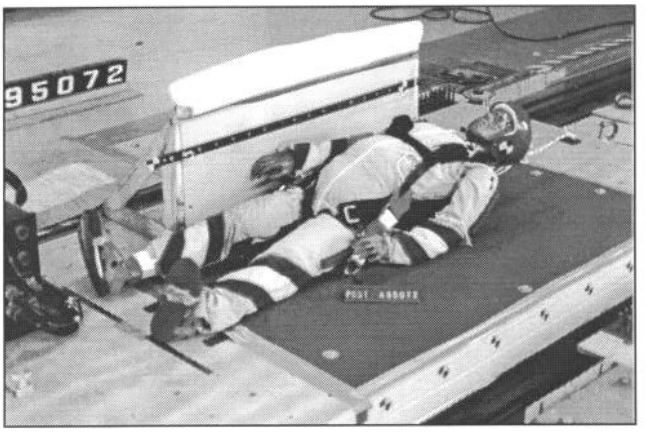


Figure 13. Post-Test A95072

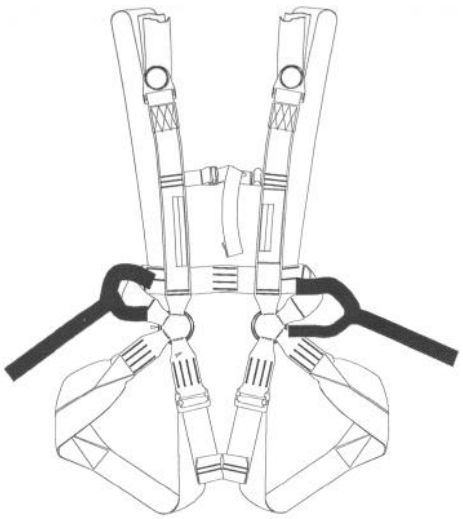


Figure 14. Restraint Method 7D

Restraint Method 7D: Restraint Looped through Horizontal Back Strap and Lower Leg Strap, Aft of Main Lift Web Junction, Left and Right

Figure 15. Pre-Test A95073

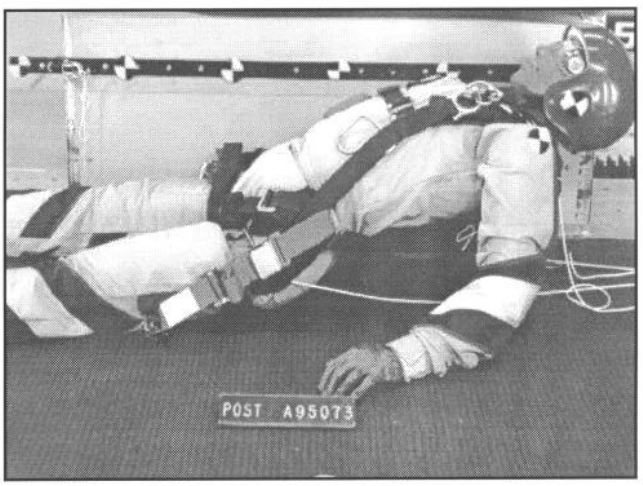


Figure 16. Post Test A95073

Test number A95073 evaluated attachment method 7D. As shown in Figures 14 and 15, this restraint consisted of a strap anchoredto the floor on either side of the ATD and looped around the horizontal back strap and the lower leg strap just behind their intersection with the main lift web, on each side of the harness. The restraints were adjusted to their minimum length but were still slack. The ATD was placed in the same pre-test posture and held in place with cord as described above for test A95072.

During the impact, the ATD's entire body slid forward and its upper torso rotated forwardin a similar manner to that noted from the previous test, A95072. In this test, however, the torso rotated further, to approximately 50° fromvertical. Less neck extension was observed when compared to the films from A95072. The reducedneck extension was most likely due to the lower harness attachment point. The post-test position of the ATD is shown in Figure 16.

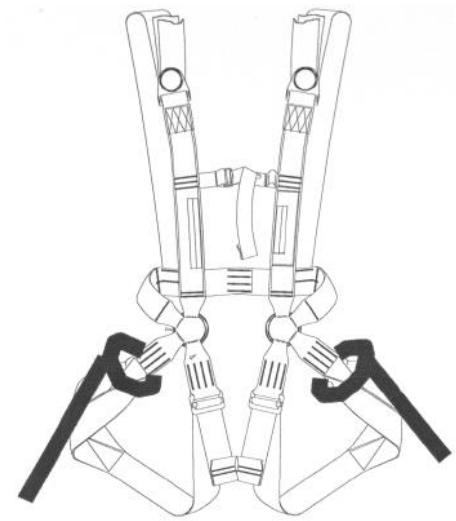


Figure 17. Restraint Method 4D.

Restraint Method 4D: Restraint Looped Around Lower Leg Straps, Left and Right.

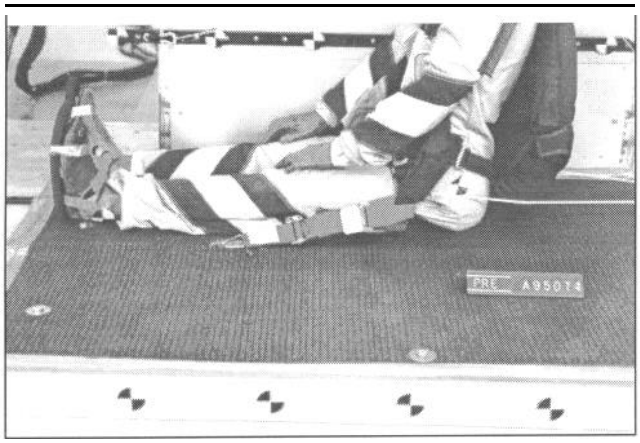


Figure 18. Pre-Test A95074

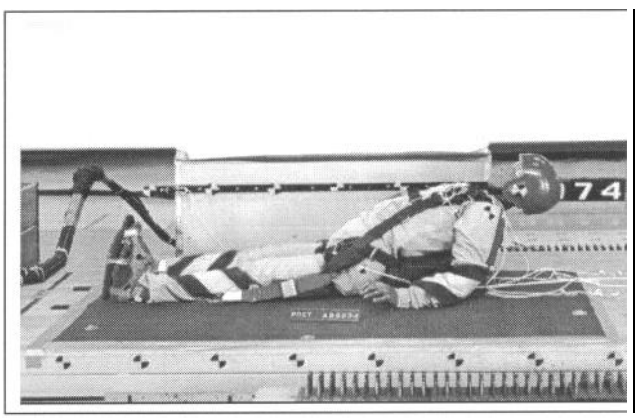


Figure 19. Post Test A95074

As illustrated in Figures 17 and 18, test A95074 evaluated attachment method 4D, which consisted of two straps anchored to the floor on either side of the ATD and looped around the lower leg straps on each side of the harness. Because of the lower harness attachment point, it was necessary to change the ATD's position relative to the restraint's floor attachment points. This was done to remove excessive slack from the restraints, while keeping them at the same length adjustment as in previous tests. The initial position of the ATD upper torso was also changed to a leaning back position (approximately 15 degrees tovertical) to better represent the actual parachutist position during takeoff.

The post-test review of the films from A95074 showed the ATD slid forward much less than noted on the previous tests. However, the forward rotation (e.g., leaning back toward the front of the airplane) of the upper torso was more pronounced, and the rotation was not stopped until the parachute pack contacted the floor. The maximum rotation of the upper torso was approximately 75° from vertical. Head contact on the floor was noted from the films. The rapid rotation was due to poor upper torso restraint afforded by the low harness attachment point. Figure 19 is a post-test photo from A95074.

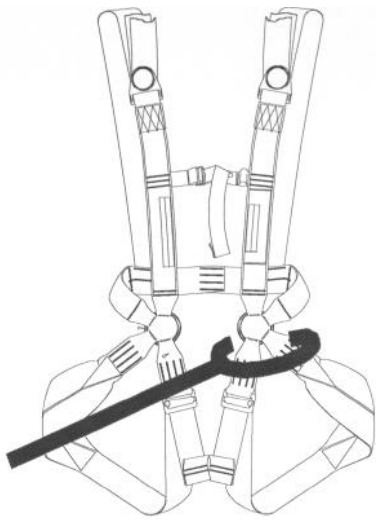


Figure 20. Restraint Method 2L.

Restraint Method 2L: Restraint Looped Around Upper and Lower Leg Straps.

Figure 21. Pre-Test A95075.

Figure 22. Post-Test A95075.

As shown in Figures 20 and 21, test A95075 was conducted with proposed restraint method 2L, which was comprised of a loop around the upper and lower leg straps just below their intersection with the main lift web on the left side of the harness. The initial position of the ATD was slightly leaning back as described for test A95074

The ATD slid forward significantly during the impact test. Then the restraint strap slid down on the parachute harness. Although the ATD legs remained aligned fore and aft, the pelvis and lower spine rotated clockwise (from above). The upper torso rotated about 60” fromvertical and onto the parachute pack, producing notable neck extension. No head strike was observed on the test films. The post-test position of the ATD is shown in Figure 22.

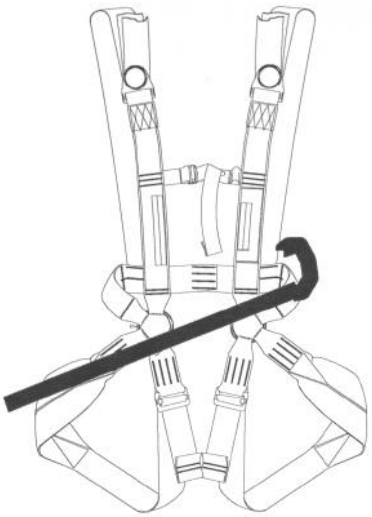


Figure 23. Restraint Method 5L

Restraint Method 5L: Restraint Looped Around Backstrap on Left Side of Harness.

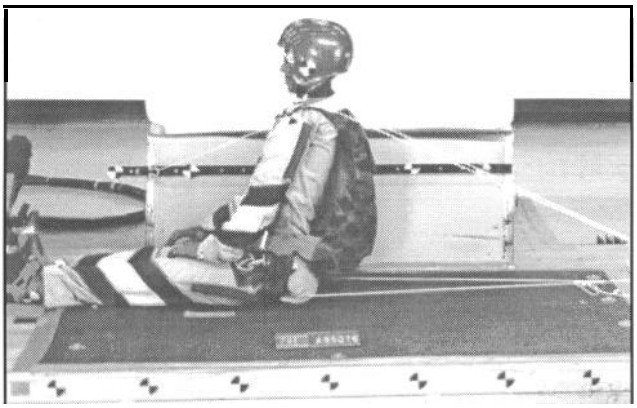


Figure 24. Pre-Test A95076.

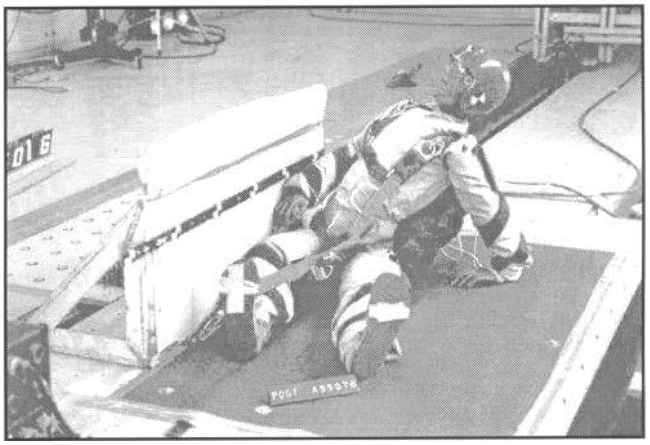


Figure 25. Post-Test A95076.

Test A95076 evaluated attachment method 5L which consisted of a single strap anchored to the floor near the side wall mockup routed up and over the lap of the ATD and looped around the back strap on the left side of the harness. Figures 23 and 24 illustrate this method. It was hoped this position would preclude the slipping seen in the previous test. The ATD positioning was the same as the previous test.

The overall kinematic motion of the ATD during this test was similar to A95075. During the test, the parachute harness web tore loose from the pack and rotated aroundthe body about four inches, worsening the overall forward translation and clockwise rotation of the ATD in the horizontal plane. Figure 25 shows the post-test position of the ATD.

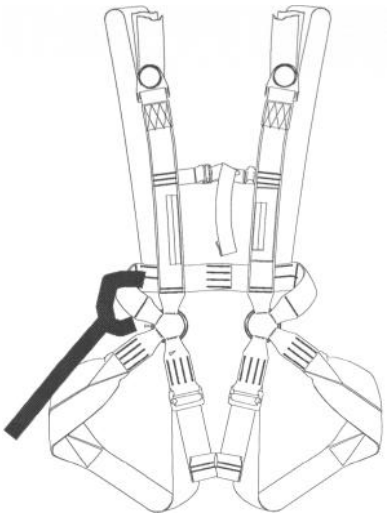


Figure 26. Restraint Method 5R.

Restraint Method 5R: Restraint Looped Around Backstrap on Right Side of Harness.

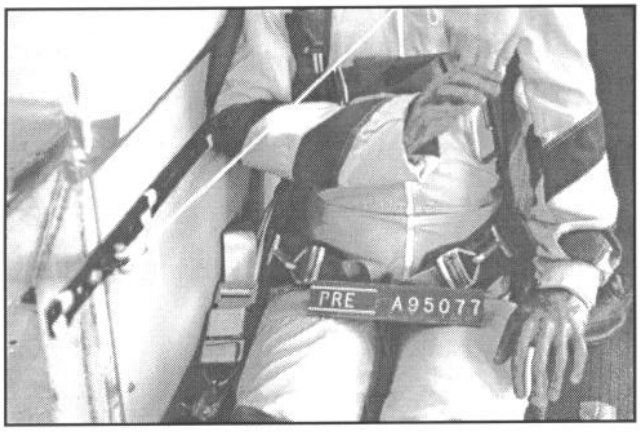


Figure 27. Pre-Test A95077.

Figure 28. Post-Test A95077.

Test A95097, illustratedin Figures 26,27, and 28, evaluated attachment method 5R, which consisted of a short single strap anchored to the floor near the side wall mockup and looped around the back strap on the right side of the harness. Figure 27 shows the restraint between the ATD and the wall fixture. The ATD positioning was the same as the previous test. During the impact, the ATD slid forward significantly, then violently rotated counter clockwise about the center of the pelvis. The upper torso rotated forward to 40 degrees from vertical and the legs flailed about the vertical axis to a position 90 degrees from initial. Figure 28 shows the final position of the ATD after this test.

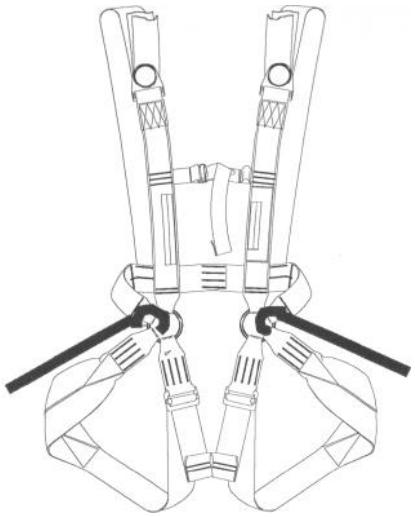


Figure 29. Restraint Method 6D.

Restraint Method 6D: Restraints Attached to Metal Ring at Webbing Junction, Left and Right Side

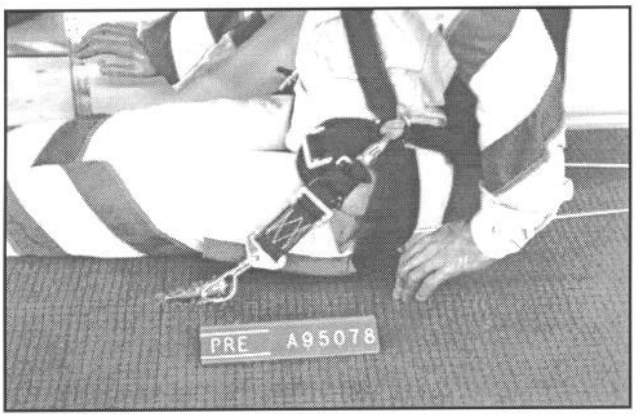


Figure 30. Pre-Test A95078.

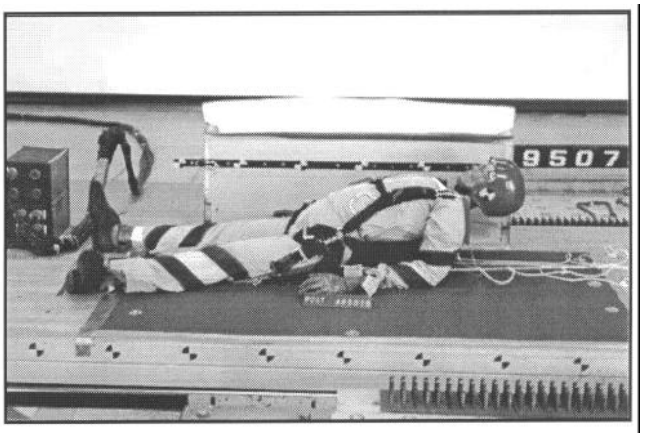
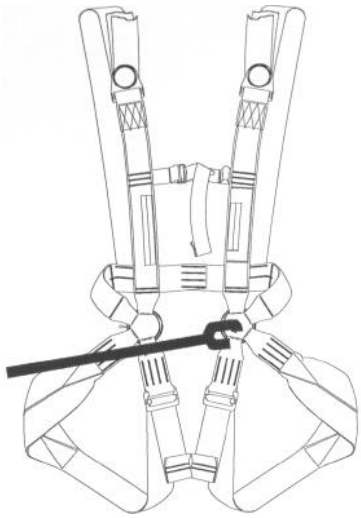


Figure 31. Post-Test A95078.

Test A95078 was performed with restraint attachment method 6D. This method consisted of two short straps anchored to the floor, on either side of the ATD, attached with clips to a circular metal ring incorporated into the harness of this particular model of parachute. This parachute, a Rigging Innovations Flexon, uses a metal ring to join the major straps of the harness at each side as shown in Figures 5, 29, and 30. The ring is located at approximately the same point as the intersection of the straps of the conventional harness. The restraint was clipped to the ring between the upper and lower leg strap terminations. There was no slack in the restraints and the ATD positioning was in the partial "lean back" posture.

During this test, the ATD slid forward, then rotated over completely onto the parachute pack producing a moderate head extension but no head strike. Forward excursion of the pelvis was much less than with the single strap configurations. The ATD's legs did not flail outward. The post-test position of the ATD is shown in Figure 31.



Restraint Method 6L: Restraint Attached to Metal Ring at Webbing Junction, Left

Figure 32. Restraint Method 6L

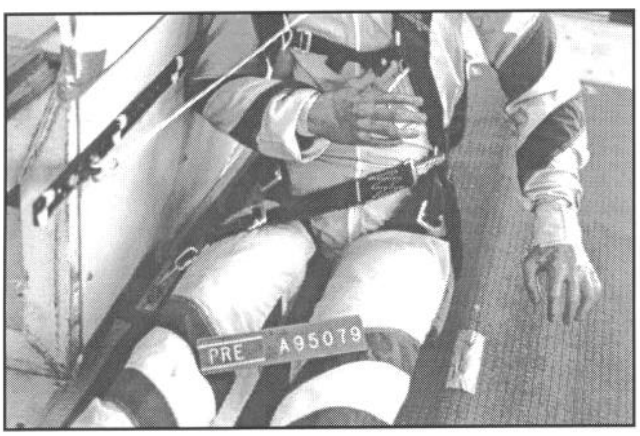


Figure 33. Pre-Test A95079

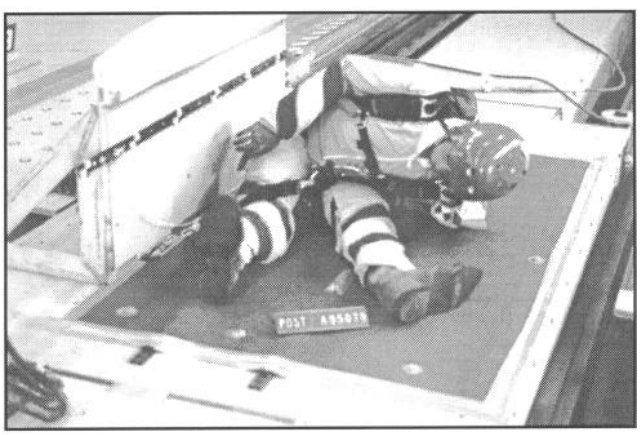
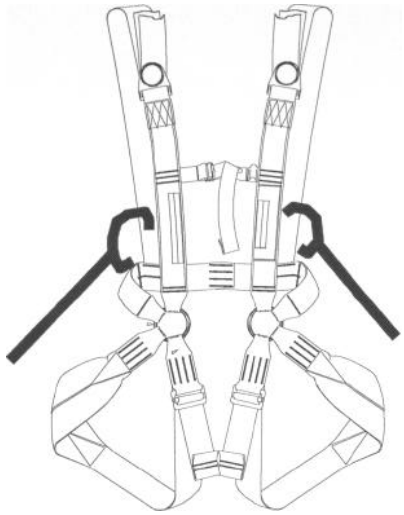


Figure 34. Post-Test A95079

Test A95079 evaluated attachment method 6L. Method 6L, illustrated in Figure 32, consisted of a single strap anchored to the floor near the side wall mockup, routed up and over the lap of the ATD and clipped to the left side hip ring of the Rigging Innovations Flexon parachute harness. The restraint was clippedto the ring between the main lift web and the upper leg strap terminations. There was no slack in the restraints and the ATD positioning was the same as the previous test. Figure 33 shows the pre-test position of the restraint over the pelvis of the ATD.

During the impact, the ATD slid forward as the harness rotated around the torso of the ATD in a similar manner to that noted in test A95076. The ATD legs remained fore and aft and the hips swiveled clockwise (from above). The upper torso rotated forward onto the parachute pack producing neck extension but no head strike. Figure 34 is a post-test photo. The overall kinematics were similar to test A95076.



Restraint Method 5D: Restraints Looped Around Horizontal Backstraps, Left and Rig ht.

Figure 35. Restraint Method 5D.

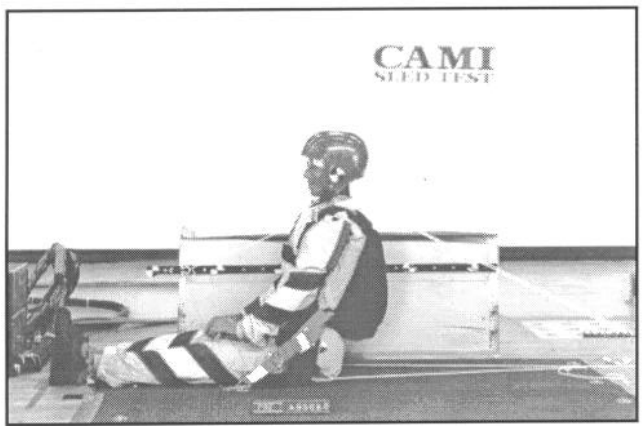


Figure 36. Pre-Test A95080.

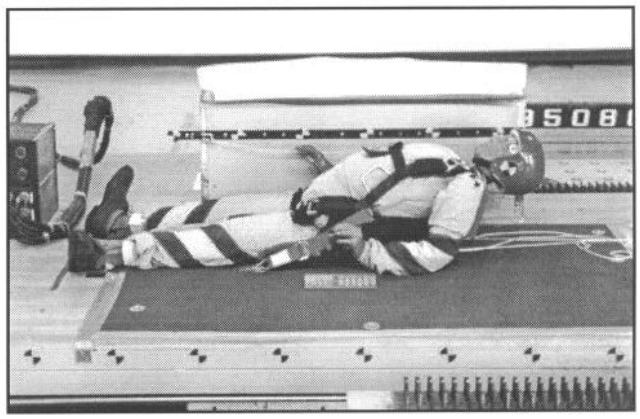


Figure 37. Post-Test A95080.

Test A95080, as illustrated in Figures 35 and 36, evaluated attachment method 5D, which consisted of two straps anchored to the floor on either side of the ATD andlooping aroundthe backstrap of the harness. The Sunpath Javelin parachute was used for this test. There was no slack in the restraints and the pre-test position of the ATD was in the "lean back" posture, as in the previous test. Confidence in the restraint method's ability to adequately restrain the occupant led to a decision to increase the impact severity to 9 Gs. During the impact, the films showed the ATD slid forward and the upper torso rotated completely forward onto the parachute pack. Moderate neck extension and head impact were noted on the films. The legs did not flail sideward, as shown in Figure 37.

An additional test, A95081, was conducted with proposed restraint method 5D, except the parachute harness installed on the ATD was a tandem passenger harness assembly. (The tandem harness is used for training.) Figures 38 and 39 show pre and post photos of this tests. The passenger harness has the same basic strap configuration as a normal parachute harness, but without the parachute or its container. This harness is made to be attached to the front of an instructor who

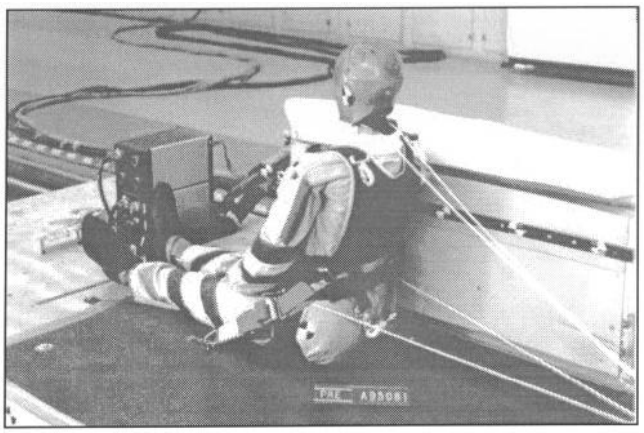


Figure 38. Pre-Test A95081.

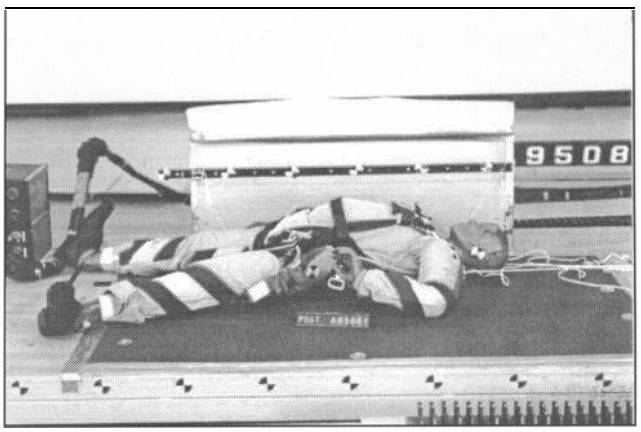


Figure 39. Post-Test A95081.

carries a parachute adequate for both of them. There was no slack in the restraints and the ATD positioning was the same as the previous test.

The ATD slid forward during the impact, and the uppertorso rotated forwardonto the sled floor. A head strike on the floor plane was noted in the films. The geometry of this tandem harness caused the pelvis to remain upright during the test, causing obvious bending of the spine during the upper torsos flailing. This tendency for the pelvis to remain upright, which was exhibited to some degree on all of the tests, may be an artifact of the ATD's pelvic construction, which is flat on the bottom.

Observations and Conclusions

Of the various methods evaluated in this project, methods 5D, 6D, and 7D appears to provide better restraint of the ATD under the test conditions described in this report. These methods produced the least flailing and bending of the body segments and the least forward translation of the pelvis. The single strap over the lap methods, 5L and 6L, while desirable due to their simplicity of use, did not provide the level of restraint offered by the dual strap methods.

The TSO-C22f, 1500 pound rated, prototype restraints used for this series appeared adequate for use in all of the methods evaluated. The same belts were used on repeated tests, and no visible signs of wear or damage were noted. Also, other than the one harness to container separation that occurred on test A95076, there was no damage or wear noted on the parachute harnesses, which were also subjected to repeatedtests. There does not appear to be a requirement for additional maintenance or inspection procedures for the harness, if used with these restraint methods, otherthan the current routine procedures practiced by the parachuting community.

Although not directly addressed by this test series, the potential for head and neck injures may be minimized for each of these methods by the limited flail distance inherent to the "caterpillar" seating arrangement. Thus, restraining the parachutist by the means demonstrated in these tests appears to provide an obvious improvement in safety, when compared with the documented accident scenarios with the customary lap belt restraints unattachedto the parachute harness.

The 5D method of restraint attachment appears to be the best candidate for operational implementation, among the ones tested. Routing of the restraint belt through the parachute harness is straightforward with this method, and it should work well on virtually any normal parachute. The 6D method of restraint attachment, which clips onto a ring sewn into the harness, has the advantage of being very simple and quick to use. However, implementation of method 6D would necessitate all parachutes not already incorporating a ring be modified to add a load bearing ring attachment at the intersection of the backstrap and main lift web. Although modifying parachutes to add the ring would obviously entail some time and expense, it may prove to be worthwhile, since this method minimizes the possibility of misuse. It may also enhance egress.

Some additional operational procedures that may improve the effectiveness of the methods describedin this project include:

a) The person most forward in the cabin should be leaning against a bulkhead or other substantial support to limit flailing and head impact.

b) Each parachutist's restraint should be anchored to the floor aft of his/her pelvis (relative the aircraft's orientation) at a point on the floor near the middle of the thigh. The restraint should be taut to reduce forward motion and the loads transmitted to the person behind.

c) The proper brace for impact position would be to lean toward the front of the an-craft onto the person or bulkhead behind them.

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