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STRUCTURES NOTE 469

DISENGAGEMENT OF SAFETY HARNESS BUCKLES —CT4

by

S. R. SARRAILHE and G. A. THOMAS

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DISENGAGEMENT OF SAFETY HARNESS BUCKLES —CT4

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S. R. SARRAILHE and G. A. THOMAS

SUMMARY

During the crash of a CT4 Airtrainer in August, 1979 both safety harness buckles disengaged.

The crash was very severe but the harnesses did not show signs of overloading.

After a series of tests it was concluded that the buckles disengaged because of misalignment of the loads onto the buckle.

This misalignment may not be represented in the standard test procedures and they may give a false sense of security. New tests are proposed, but further work would be desirable to establish design and test criteria.

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ABSTRACT

During the crash of a CT4 Airtrainer in August, 1979 both safety harness buckles disengaged.

The crash was very severe but the harnesses did not show signs of overloading.

After a series of tests it was concluded that the buckles disengaged because of misalignment of the loads onto the buckle.

This misalignment may not be represented in the standard test procedures and they may give a false sense of security. New tests are proposed, but further work would be desirable to establish design and test criteria.

CONTENTS

1. INTRODUCTION

Both "Aerolex" quick release buckles (QRB) fitted in the safety harnesses of Airtrainer CT4 A19-028 disengaged at some time during a crash at Oakey, Queensland, in August, 1979, and both occupants were ejected through the windscreen. The crash was very severe and was probably not survivable.

There was evidence that the harnesses had started to take load but there were no obvious signs of overload in the restraint system. The harnesses and some anchorage fittings were sent to A.R.L. for examination and tests were conducted on four similar harnesses to determine:

1. the basic strength of the harness and whether the disengagement was likely to have been caused by overload.
2. The probable maximum load and cause of the disengagement, if the buckles had released without being overloaded.

2. EXAMINATION OF THE INSTALLATION AND HARNESS

2.1 The Installation

The shoulder strap guides had failed and the plastic edging of the guides had melted into the straps. The top of the back rest of the seat had been bent downwards presumably by the shoulder straps.

The seat base and a sheet aluminium seat spacer which had been fitted between the seat and cushion, had been compressed towards the wing spar.

The lap strap anchorage on one side of the fuselage had been damaged when one rivet of a pair attaching an anchor nut had sheared.

2.2 The Harness

The backs of both buckles were dished as shown on Figure 1*a*. The deflection was greatest at the sides adjacent to the lap strap tongues as shown in Figure 1*b*. This figure also shows the flat back of a new buckle. The slots for the tongues were enlarged and some of the rivets which connect the front and back together were elongated. The distortion of the back suggested that the outer ends of the lap strap tongues had been pulled backwards and had prized the front and back of the buckle apart.

The only other stress marking was slight crushing in the latch pin holes in the buckle tongues. These marks were only apparent when viewed under a microscope and are shown in a magnified (x8) photo later in this report.

3. CONSTRUCTION OF THE QUICK RELEASE BUCKLE

The construction is shown diagrammatically in Figure 2. Tension from the straps is transmitted across the buckle by "tongues", "latch pins" and a "load plate" as shown in Figure 3. The "tongues" are held onto the "latch pins" by the front plate, the sides of the case and shoulders on the studs as shown in Figure 4.

Tension across the buckle will tend to deflect the "latch pins" and "load plate" and in the event of an overload the resulting slope could cause the tongues to slide off the latch pins as illustrated in Figure 5. If the tongue starts to slide off the latch pin the bearing area is reduced and the bearing stress increased. If this reaches a critical value the edge of the hole or pin will shear off or crush. (This apparently occurred in one of the tests detailed later).

If the ends of the tongues are pulled backwards they will tend to prize the buckle apart as shown on Figure 6. As the sides of the case are forced back the load plate will also be pushed back against spring pressure and this will withdraw the latch pins from the tongues. The buckle is drawn to scale in Figure 6, with the width of the slot 6·4 mm as measured on the buckle from the crashed aircraft. The maximum deflection would have been greater than the permanent distortion of the buckle case and even if the pin withdrawal was insufficient to allow free disengagement, partial disengagement would greatly increase the tendency for the parts to deflect and slip apart as suggested in Figure 5.

4. EXPERIMENTAL INVESTIGATION

Normal test procedures for harnesses (and seat belts) allow for the tension from the straps to be "in line" with the plane of the buckle.

The recommended procedure for proof testing the Teleflex harness (with the Aerolex buckle) arranges all the straps and the buckle in one plane as shown in Figure 7. A certification test for the buckle (reproduced in the appendix) refers to loading the belt and buckle on a "tummy block" but no details of the block are given and only lap straps were used.

Typical test procedures as given by the American National Aircraft Standard NAS 802 state:

"the curved portion of the test form may provide a cut out to accommodate the belt buckle".

This standard also says that:

"the whole assembly (is) to be in axial alignment" and

"all precautions shall be taken to prevent eccentric loading".

The initial tests carried out by A.R.L. to determine the strength of the harness were carried out with a body block or an anthropometric dummy but the tensions from the straps were "in line" with the plane of the buckle. The tests are detailed in Section 4.1 and were described in A.R.L. Laboratory Report 310879. In each case the harness withstood more than 20 kN (corresponding to 25 g). Straps broke in two tests. In one test the buckle disengaged but the test did not reproduce the damage to the aircraft buckles. Much deeper crushing marks were evident on the buckle tongue than in the aircraft parts, on the other hand, the test did not cause as much "dishing" in the back of the buckle.

To reproduce this "dishing" new tests were devised in which the lap straps were arranged to "pull back" on the buckle. These tests are detailed in Section 4.2 (subsections 4.2.1, 4.2.2, and 4.2.3) and were described in A.R.L. Laboratory Report 231079. These tests all produced disengagement of the buckle at low loads, and reproduced the crash damage more closely than the "in line" tests.

Further information about the magnitude of the load in the harness was provided by testing the lap belt anchorages from the crashed aircraft and evidence of the downwards load on the seat was obtained by compressing an aluminium alloy "seat spacer" like the one which had been flattened against the seat pan and mainspar in the accident.

To check the effect of the "pull back" test on other types of buckle, a buckle and the associated components made by the G.Q. Parachute Company, and salvaged from the harness of an RAAF F111C was tested. This buckle is also designed to join a crotch strap, two lap straps and two shoulder straps and has a rotary release but is more robust, heavier and more expensive than the normal CT4 buckle.

4.1 The "In line" Tests

Two harnesses were tested on an articulated body block as shown in Figure 8*a*. The lap straps, shoulder straps and crotch straps were anchored to the load frame so that the slopes and lengths of the straps were approximately the same as in the aircraft. The lap part of the body block was shaped to prevent contact between the block and the buckle. Load was applied to the body block in the horizontal direction at a position which gave representative division of load between the shoulder straps and the lap strap.

In the test shown in Figure 8*a* the torso is seen to have "slumped" forwards. This slumping depends on the stretch of the straps, initial fit and tightening of the shoulder strap webbing on the inertia reel. Damage to the top of the back rest in the crash suggests that the occupants slumped forwards and this could have an important bearing on the loading of the buckle as described in Section 4.2.

The body block moved forward as the lap strap stretched and so the crotch strap was not loaded.

A third harness was fitted on an anthropometric dummy and loaded statically as shown in Figure 8*b* The crotch strap could not be fitted with this loading system.

In two tests (one with the body block) the lap strap webbing failed at loads of about 20 kN, but in the remaining test the buckle disengaged. This occurred at a load of 23 kN and it is probable that the tongues slipped off the latch pins in the manner suggested in Figure 5. There was slight "dishing" of the buckle as shown in Figure 9*a*, but it was much less than occurred in the aircraft Figure 9*b*. Similarly enlargement of the slots in the sides of the buckle was less as shown in Figures 10*a* and 10*b*.

The crushing damage to the buckle tongue as it slipped off the latch pin in the test, shown in Figure 11*a*, was more severe than that in the most heavily marked parts from the aircraft, Figure 11*b*. This indicates that at the instant of disengagement the test buckle was carrying a much higher load than the aircraft buckle.

4.2 The "Pull-back" Tests

The "dishing" of the buckles in the crash suggested that the ends of the buckles had been pulled backwards so that the tongues prized the buckle apart. To react this pull a forwards force must have acted elsewhere on the buckles. No direct evidence could be found but possible modes are:

(a) the body could have applied a direct but distributed load to the back of the buckle;

(b) the shoulder straps and crotch straps could have applied tension to the buckle in a forwards direction while the lap straps were pulling backwards;

(c) the buckle could be prized apart by a twisting action in the tongues.

In explanation of mode (b) it is noted that the shoulder strap tension would act forwards and upwards, over the slumped body (as shown in Fig. 8*a*) and, as the crotch strap is attached to the front of the seat, tension in this would also act in a forwards and downwards direction. The two body block tests did not produce tension in the crotch strap but it is considered that the tension in this strap would depend on the initial adjustment of the straps and the direction of the load vector on the body. In the tests the load was horizontal but in the crash it must have varied from forwards-and-downwards, when the seat spacer was crushed, to forwards-and-upwards, when the occupants were ejected through the windscreen. It is thought that this forwards and upwards vector may have been the critical one.

The effects could act in combination but tests were made to represent each of the three modes separately.

Each test resulted in disengagement at a low load.

4.2.1 "Pull-back" Test A

This test was to simulate direct pressure on the back of the buckle.

The buckle, lap strap and shortened shoulder straps were set up on a loading rig as shown in Figure 12. The lap straps were pulled in a direction 30° to the plane of the buckle and the back of the buckle was supported on a hard felt pad 25 mm wide and 12 mm thick. Compression of the pad and deflection of the buckle during the test reduced the pull back angle but the assembly was photographed at intervals so that the angle could be measured.

Deflection of the back of the case was evident when the load had reached 4 kN. This was accompanied by enlargement of the slots and partial disengagement of the latch pins. The buckle disengaged when the load reached 5·4 kN. The strap angle was then 26°, resolution of the forces indicates that the force on the back of the buckle was 2·4 kN.

The dishing of the back of the buckle and enlargement of the slots are shown in Figures 9c and 10c and the measured widths are shown on Table 1. The distortion of the buckle is seen to be almost identical to that in the aircraft components.

TABLE 1

Width of slot for lap strap tongues

Buckle	Width mm	Remarks
New	3·75	Not Shown
After "In-line" Test	4·80	Figure 10*a*
From Aircraft	6·35	Figure 10*b*
After "Pull-back" Test A	6·55	Figure 10*c*

The crushing of the edges of the holes in the buckle tongues is shown in Figure 11c and it is seen that the damage is comparable to that in the aircraft components. This suggests that the tensions in the straps when the buckle released in the test were about the same as those in the aircraft. (Note the holes in the aircraft tongues had a slightly greater depth of countersink.)

4.2.2 "Pull-back" Test B

This test was to simulate forwards loading onto the buckle from the shoulder and crotch straps.

The arrangement is shown in Figure 13. The lap strap caused dishing of the back of the buckle while the tongues of the shoulder and crotch strap pressed against the front plate. This deflected until the load was carried by the release handle and transmitted into the case by tension in the spindle (construction shown on Fig. 2). When the load reached 3 kN the retaining ring sheared off the spindle. The buckle was prized open and the straps disengaged.

The 3 kN load would represent the difference between the forwards and rearward load vectors at the buckle rather than a net body block force and corresponds to the force of 2·4 kN on the buckle in the "Pull-back" test A.

Separation of the retaining ring shows that the tension on the spindle was greater in test B than in the crash although the backs of the buckles from the crashed aircraft show deformation which could be associated with tension in the spindle.

4.2.3 "Pull-back" Test C

This test was to simulate twisting of the buckle tongue.

The loading arrangement is shown in Figure 14. The lap strap was fitted to a body block, which was recessed behind the buckle, and a load of 6 kN was applied to hold the strap tight. Load was then applied progressively to the shoulder strap so that the buckle was twisted by the lap strap tongues. As the load approached 360 N partial withdrawal of the latch pins was evident but then the buckle appeared to "stick". Sticking in this way can be variable and unpredictable so to break the "friction" the crotch strap was jerked by hand, this resulted in separation of the assembly.

The test was qualitative rather than quantitative because the buckle had been used in earlier tests, although it had not previously disengaged, and the jerk force is unknown but the forces were very low in relation to the rated strength of the harness (about 2%).

4.3 Anchorage Test

The outer lap strap anchorages each consist of a double lug bolted and riveted to the fuselage side structure. The strap end fitting is fastened by a 6 mm bolt in double shear and is held centrally between the lugs by distance pieces and washers. The bolt is retained by an anchor nut riveted to the outer lug and, to allow some tolerance in the alignment of the nut, the hole in the lug is oversize to the bolt. Consequently load from the bolt to the nut/lug combination is carried firstly by the nut and rivets. If the rivets are overloaded and shear, the nut can move until the bolt bears on the bore of the hole in the lug and a new load path is established. In the crash the rivets sheared in the port anchorage assembly but did not shear in the starboard assembly. This suggests that the strap forces were about equal to the strength of the rivets, although asymmetry of loads on the aircraft could have produced higher loads in the outer strap on the port side than in the outer strap on the other side of the cockpit.

In order to determine the load which would shear the rivets, the undamaged starboard anchorage assembly was mounted in a testing machine, on suitable dummy structure, and was loaded by a lap strap in a representative direction. The anchor nut rivet failed when the applied load reached 4 kN. The anchorage was dismantled and no other damage was found. It was reassembled and load was increased to 6 kN and re-examined. This load produced visible crushing of the bore of the hole in the lug.

As no crushing could be found in the anchorages after the crash it is considered that the loading in the port anchorage was more than 4 kN but less than 6 kN and the loading in the starboard anchorage was less than 4 kN, say the average loading was about 4 kN.

4.4 Tests on the Seat Spacer

Downwards loading was applied to the seat spacer and it compressed to the extent found in the aircraft when the load reached 14 kN (about 20 g on the torso).

The vertical force in the crash must have been as great as this but could have been greater. The seat and spacer were flattened onto the almost incompressible spar so the maximum load cannot be estimated.

4.5 Tests on the Buckle from an F111C

The quick release buckle from an F111C was tested with the procedure of "Pull-back" test A and it withstood loading corresponding to 25 g with no significant damage.

5. DISCUSSION

Conventional tests did not reproduce the damage or failure modes which occurred to the buckles in the crash of the CT4 aircraft at Oakey.

Deliberate misalignment of the loads applied to the buckle, by the straps, resulted in disengagement of the assembly with damage which was almost identical to that in the accident. If it is assumed that the test represented the crash loading and that 30% of the total load was carried by the shoulder straps, the load on the assembly when the buckle released would have been about 8 kN corresponding to 10 g.

Tests on the anchorage indicated a total load of about 11 kN or 14 g (assuming the same load distribution.) Together the results suggest that the aircraft harnesses withstood 10–14 g before disengaging.

The precise mechanism by which the "out-of-alignment" loads were applied and reacted was not discovered and it is probable that strap configuration adjustment and the direction of the load vector on the occupant would all influence the chance of disengagement. If this is the case the harness may be satisfactory in some circumstances but fail in others, even though the magnitude of the load may be similar.

It must also be noted that the crash of A19-028 was very severe and unusual load vector directions may have been present.

The buckles from the crash show that misalignment can occur (even if it does not always occur) and buckles and harness components should be able to withstand misalignment of the loads. Further investigation of accidents would be desirable to decide the amount of misalignment which should be considered. Certification testing should include checks with a specified amount of misalignment but until research indicates a better value the test procedure of "Pull-back" test A is recommended.

Design and test criteria should be monitored continually because if they do not represent the critical conditions adequately they may be misleading, particularly when the systems are refined, e.g.

1. Adding a crotch strap may improve restraint if the buckle is secure but may place additional loading on the buckle.
2. Design for minimum weight requires tailoring the strength to the design criteria. If these only represent ideal conditions the strength under real conditions may be inadequate.

6. CONCLUSIONS

1. The Aerolex buckle and harness was able to withstand forces corresponding to 25 g on the occupant provided that the tensions from the straps were "in line" with the plane of the buckle.
2. The buckles disengaged in the crash of Aircraft A19-028 because the tensions in the straps were "out of line" with the plane of the buckle, and the "tongues" prized the buckle apart.
3. Laboratory tests to simulate "out of line" strap tensions resulted in buckle disengagement at forces corresponding to 10–14 g on the occupant and damage similar to that found in the aircraft components.
4. The conditions which resulted in "out of line" loading may depend on a number of factors including restraint geometry and the direction of the crash force vector. It follows that a harness may be satisfactory in tests and in some accidents but can still fail because of "out of line" loads in another.
5. Current test requirements avoid "out of line" loading but the crash shows that "out of line" loading can occur and should be allowed for in acceptance tests.
6. Further investigation is required to find the extent of misalignment that is likely to occur. It is suggested that test procedure A described in this report (Section 4.2), is a suitable method for certification testing.
7. The more robust "GQ" buckle as fitted in the RAAF F111C aircraft withstood the "out of line" test procedure "A" at forces corresponding to more than 25 g on the occupant with no significant damage.

APPENDIX

Copy of Test Certificate

TEST REPORT No. AL/T.76

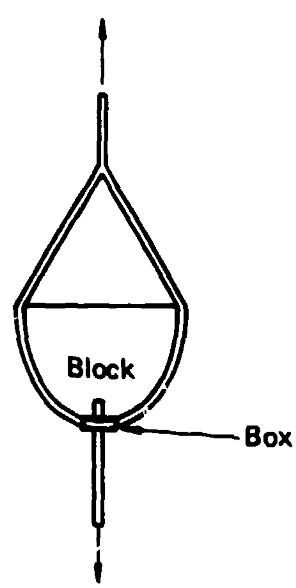
From:	To:
Aerolex Limited Bridge Road Camberley Surrey	Date: 11th October, 1960
M.O.A. Contract Number —	Sub-Contract Order No.: —

Drawing Number	Drawing Issue	Serial Number
891/Sht.2RH.& LH	(C)	—

Description	Batch Number
Harley Release Box-4-point connection	—

Quantity Received	Quantity approved	Quantity Rejected
1	1	—

The following test was effected to establish strength factor in relationship to Webbing Harness.



Lap strap with release box was placed around tummy block as sketch, and a 4000 lb. load applied in direction of arrows. No visible distortion or damage to box was apparent.

....

Chief Inspector

Received 12 Sept. 1979

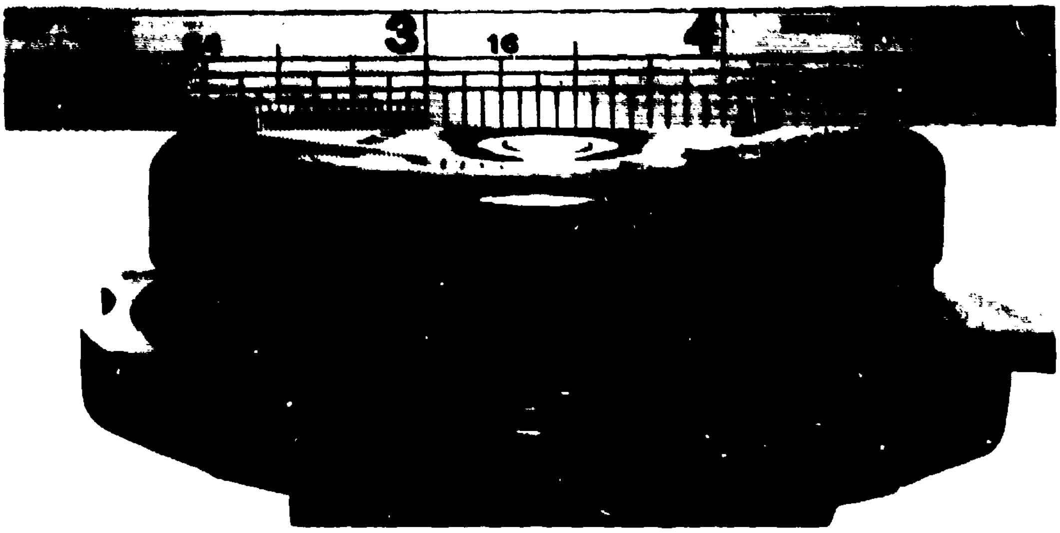


FIG. 1(a) A BUCKLE FROM THE CRUSHED AIRCRAFT SHOWING DISHING OF THE BACK AND LOOSENING OF A RIVET.

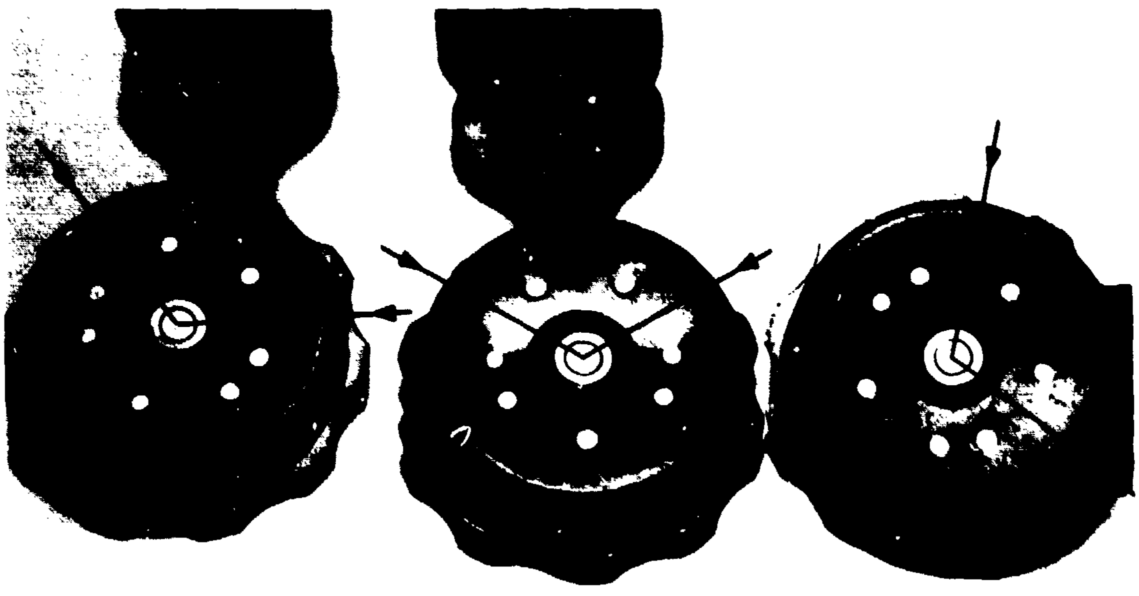


FIG. 1(b) THE BACKS OF A NEW BUCKLE AND THE BUCKLES FROM THE CRASHED AIRCRAFT SHOWING 'DISHING'. POSITIONS FOR THE LAP STRAP TONGUES ARE ARROWED.

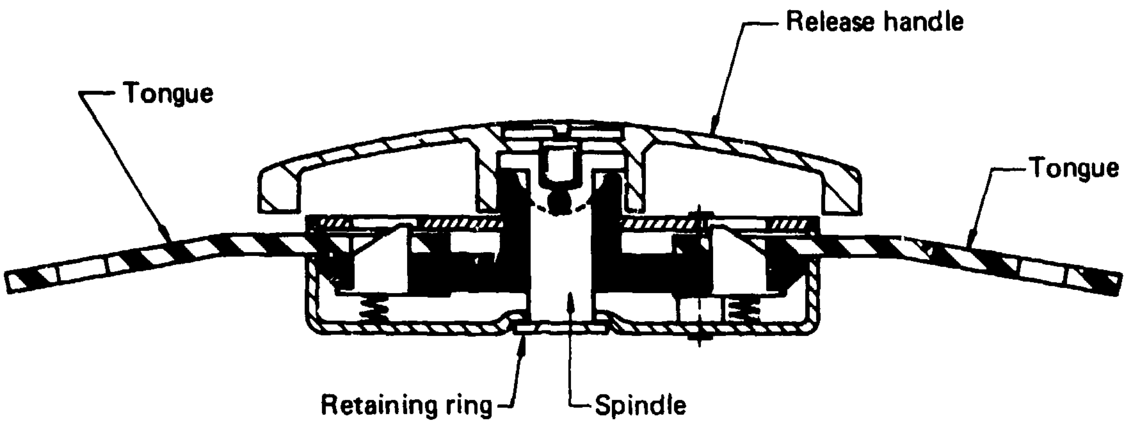


FIG. 2 CONSTRUCTION OF THE BUCKLE.

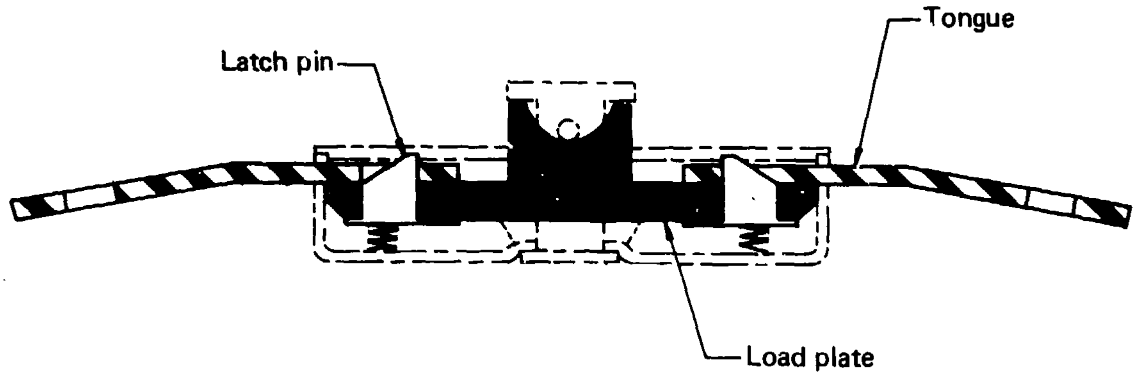


FIG. 3 TRANSMISSION OF TENSION ACROSS THE BUCKLE.

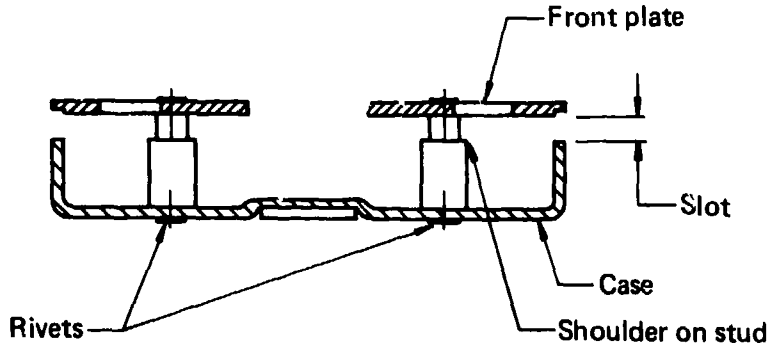


FIG. 4 'SLOTS' FOR LOCATION OF THE TONGUES.

FIG. 5 PRESUMED DEFLECTION UNDER DIRECT OVERLOAD (EXAGGERATED).

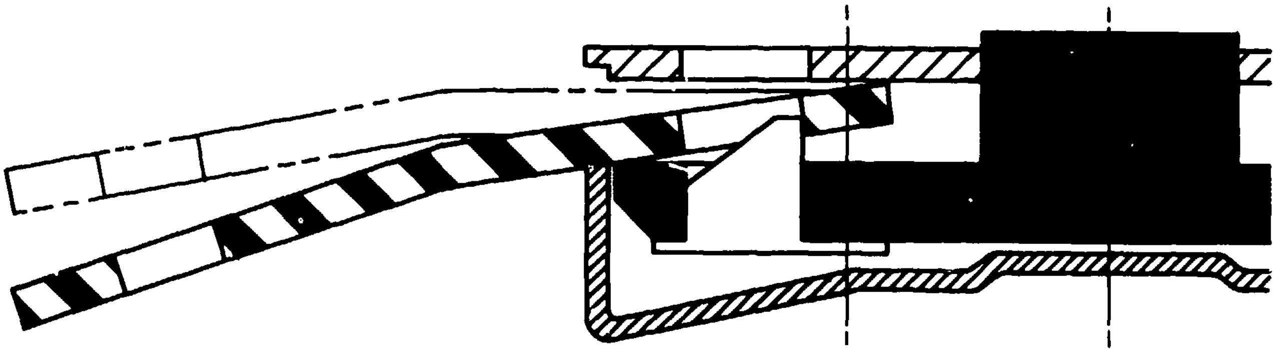
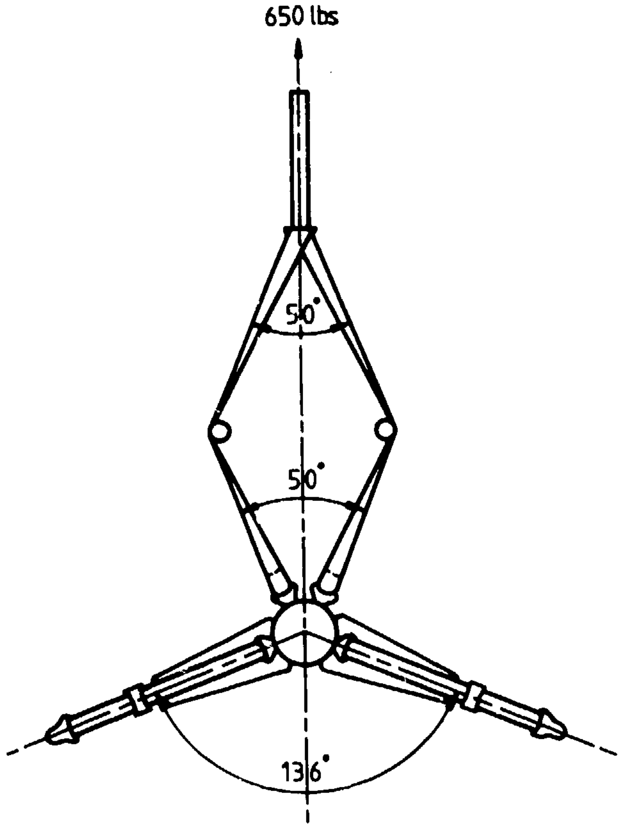


FIG. 6 PARTIAL DISENGAGEMENT OF THE LATCH WHEN THE TONGUES PRIZE THE BUCKLE APART. SCALE DRAWING WITH SLOTS ENLARGED TO 6.4 mm.



Proof loading diagram

FIG. 7 MANUFACTURER'S PROOF LOADING TEST.

8(a) Static test
with a body block

8(b) Static test
with an anthropometric
dummy

FIG. 8 STATIC TESTS.

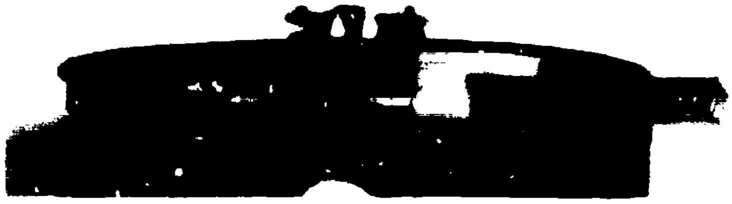
9(a) Buckle after static 'In-line' test

9(b) Buckles from crashed aircraft

9(c) Buckles from 'Pull-back' test 'A'

FIG. 9 'DISHING' OF THE BACKS OF THE BUCKLES. DISTORTION IN THE POSITION OF THE LAP BELT TONGUES IS SHOWN BY WHITE CLAY AND A BLADE STRAIGHT EDGE.

10(a) Buckle from 'In-line' test



10(b) Buckle from crashed aircraft

10(c) Buckle from 'Pull-back' test 'A'

FIG. 10 SLOTS IN THE SIDE OF THE BUCKLE. ENLARGEMENT SHOWN BY WHITE MODELLING CLAY.

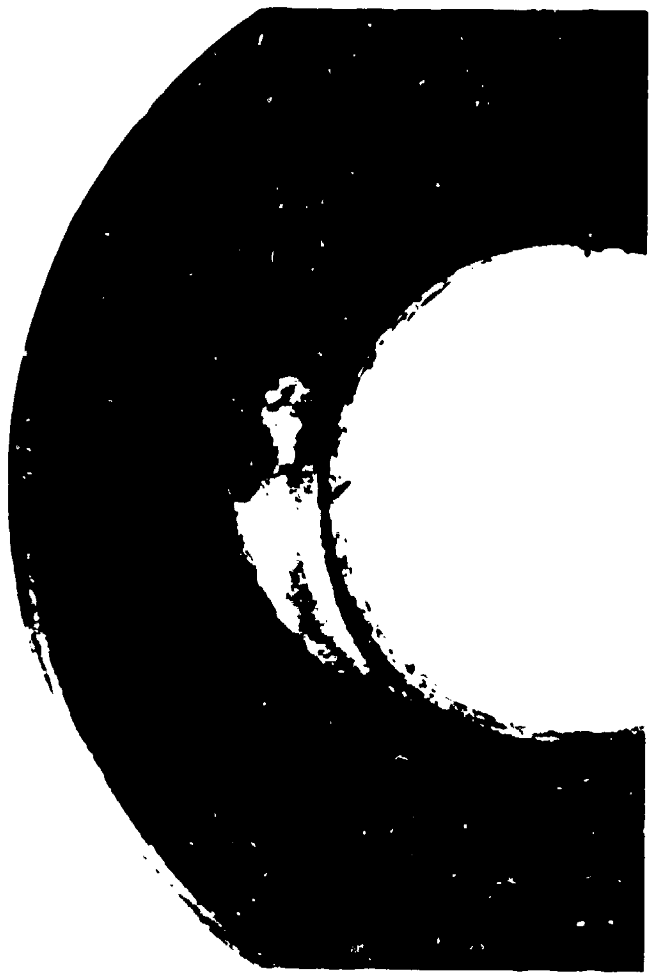
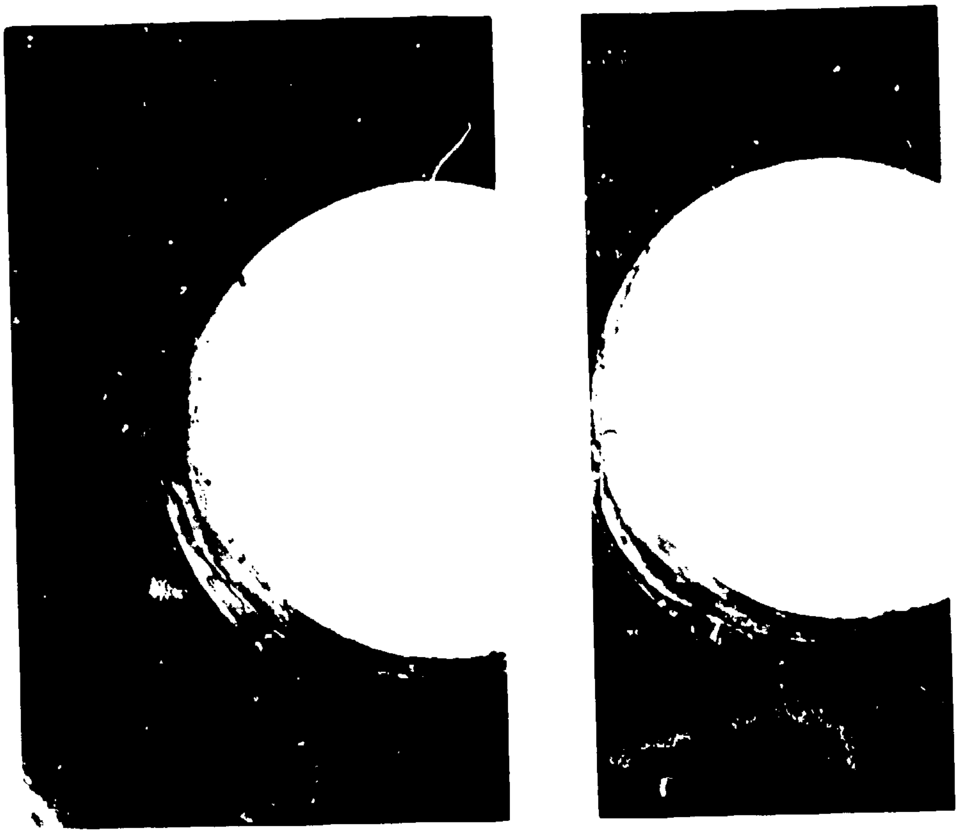
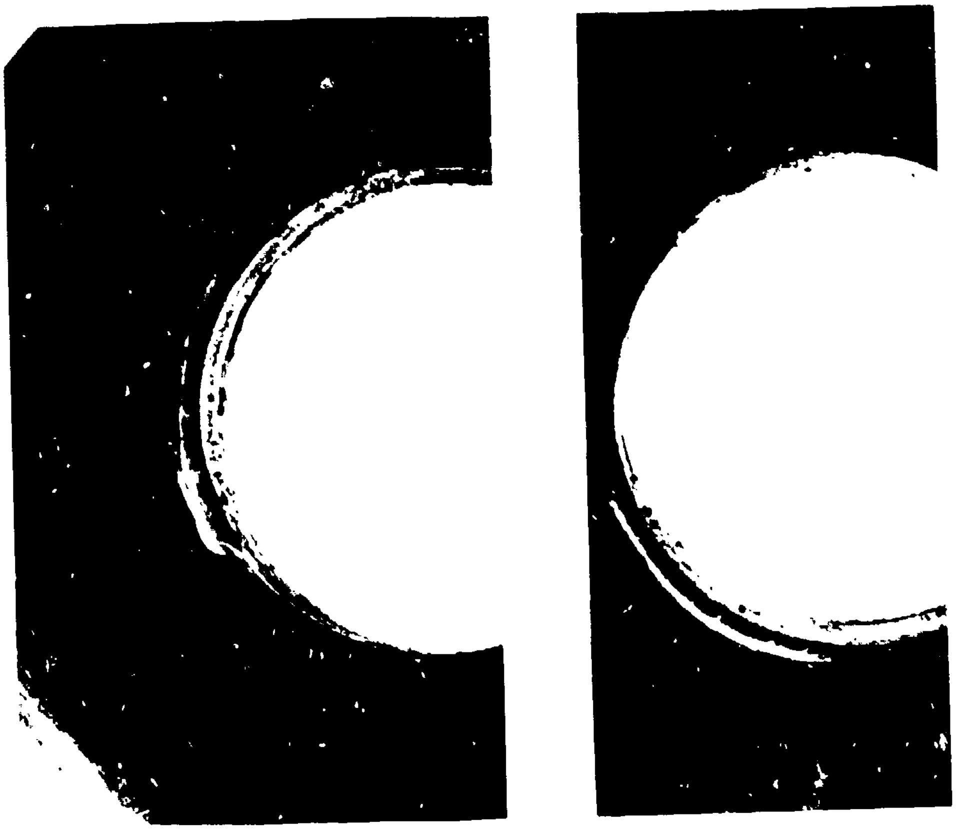


FIG. 11(a) CRUSHING AT THE HOLE IN THE LAP STRAP TONGUE FROM THE 'IN–LINE' TEST.



11(b) Left lap strap tongue from Port (left) and Starboard (right) harness of aircraft.



11(c) Tongues from the 'Pull-back' test 'A'

FIG. 11 CRUSHING AT THE HOLES IN THE LAP STRAP TONGUES.

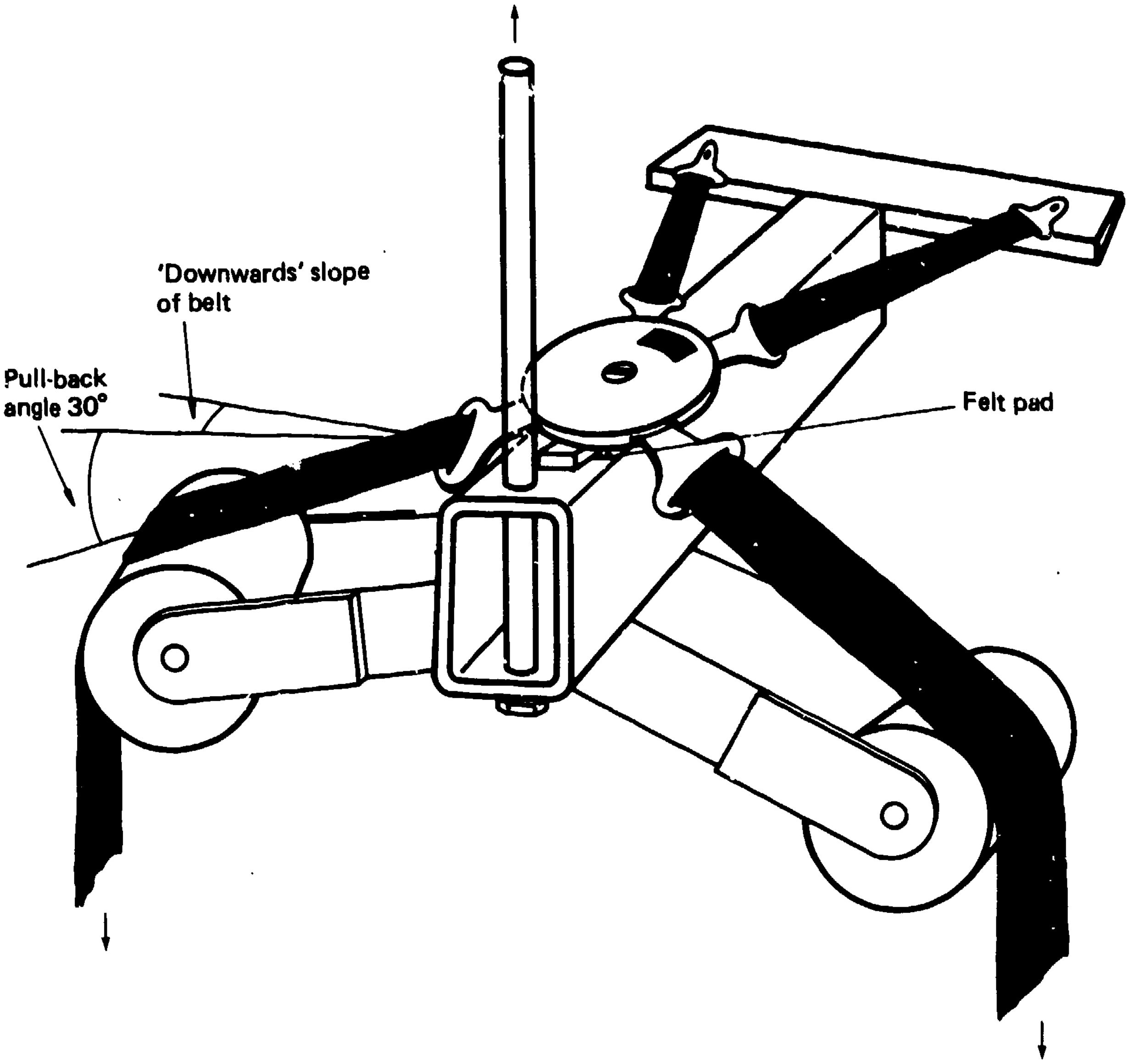


FIG. 12 'PULL–BACK' TEST 'A'.

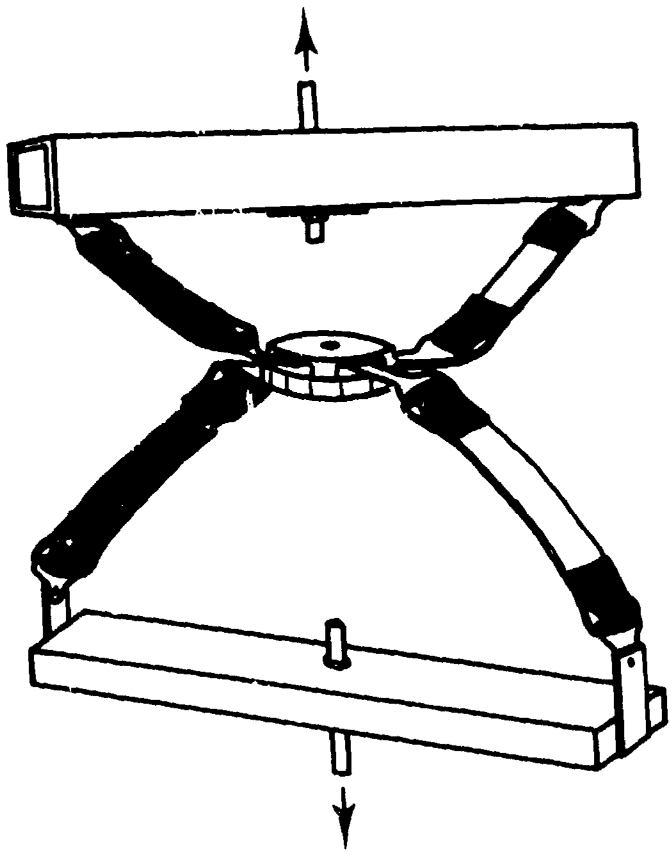


FIG. 13 'PULL-BACK'
TEST B

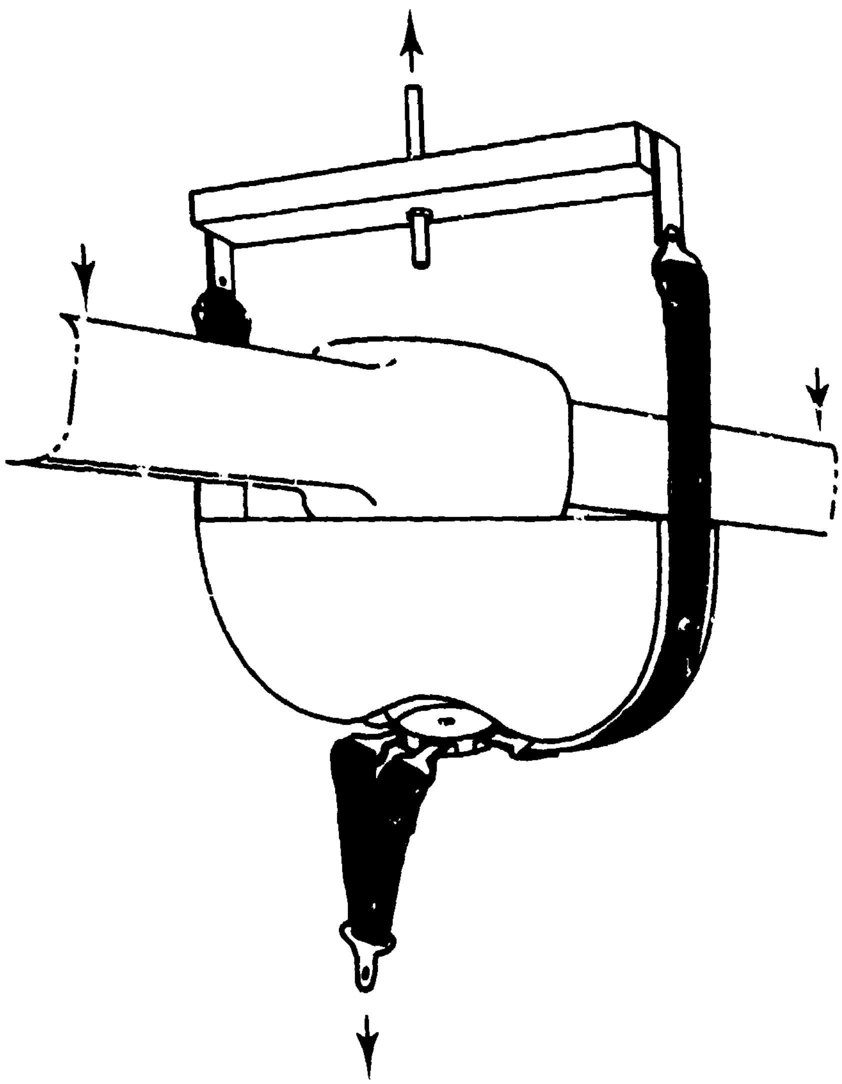


FIG. 14 'PULL-BACK'
TEST C

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