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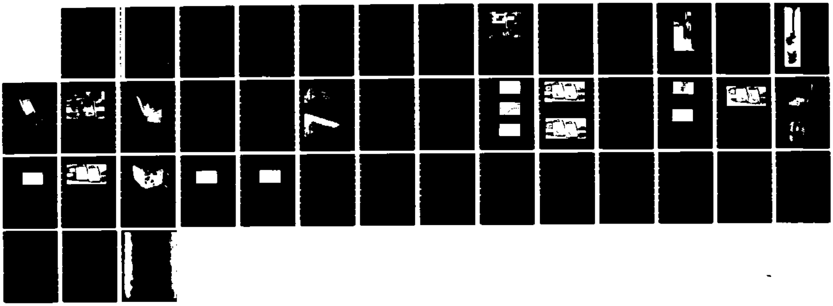

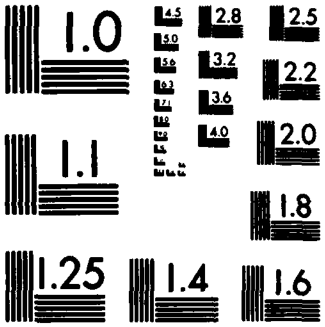

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MELBOURNE, VICTORIA

STRUCTURES NOTE 491

SIMULATED CRASH DECELERATIONS IN A LIGHT AIRCRAFT CABIN

by

S. R. Sarrailhe.

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STRUCTURES NOTE 491

SIMULATED CRASH DECELERATIONS IN A LIGHT AIRCRAFT CABIN

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Summary

A light aircraft cabin containing a seat and anthropometric dummy was subjected to a vertical deceleration to simulate a minor crash. Several alternative seats were used, all were typical of those in light aircraft.

The tests showed that with most seats a moderate rate of descent (5 m/s) could produce potentially injurious forces in the spine, but one seat limited the force to a safe value.

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1. Introduction

When an aircraft lands both the horizontal and vertical components of velocity must be reduced to zero. The horizontal deceleration may be spread over a long ground run but the vertical deceleration must be achieved by deflection of the landing gear and aircraft structure. In a common type of survivable crash the aircraft may impact generally flat ground, at a moderate angle but with an excessive rate of descent so that the landing gear is overloaded and may be broken (or it may be retracted). Then most of the deceleration must be achieved by structural collapse. The stopping distance for the occupant, in a downwards direction is limited by the usually small amount that the seat and under floor structure can collapse. And this can result in large deceleration forces occurring in the spine of the occupant.

The height of the seat is usually a substantial proportion of the distance between the occupant and the bottom of the aircraft and so its compression characteristics can have an important effect on the forces transmitted to the occupant.

In this type of crash the longitudinal forces, developed during the ground slide, are a consequence of the vertical forces so the downwards component of deceleration is likely to be dominant. These views are confirmed by most simulations of aircraft crashes.

Recent tests by NASA involving four high-wing, light-aircraft[1] showed that in a simulation of a crash landing with a descent rate of 6·4 m/s the pelvis decelerations in the downwards and longitudinal directions were similar even though the landing gear was effective in absorbing a large fraction of the landing impact, and the dummies were not dislodged from normal positions. Under more severe conditions, which produced extensive collapse of the cabin and so would have been only marginally survivable, the downwards acceleration was two to three times greater than the longitudinal component. Previous series of NASA tests on low-wing twin-engine aircraft,[2,3] and a comparison of a test crash with an actual accident[4] all show vertical loading was as great or greater than the longitudinal loading. The injury consequences are likely to be serious because the spine of a seated occupant is vulnerable to compressive loads.

Current civil aviation requirements such as FAR 23[5] appear to under-rate the importance of vertical forces and the need for energy absorption, and the downwards design strength is usually much less than the design longitudinal strength.

It may be noted that the significance of this imbalance may have been masked by the ineffective support provided by the simple lap-belt. The benefit of longitudinal strength has only been available since the introduction of safety belts with upper torso restraint.

The Crash Survival Design Guide,[6] recent military standards[7,8] and a proposed but not implemented civil standard cited by Snyder,[9] all recommend greater strength and capability to absorb energy. Certain recent helicopters and light aircraft incorporate some energy absorption and both tests and computer simulations have been made, but to date incorporation of the principle has been tentative and the FAA recently rejected calls for improvements in the standards.

To provide a benchmark on the performance of simple, conventional seats, several different types were subjected to vertical deceleration tests.

The tests were carried out in the cabin of a typical, high-wing light-aircraft so that any flexibility in the floor would be represented.

The cabin, carrying the test seat with an anthropometric dummy, was allowed to fall through a distance of 1·6 metres and was stopped in one tenth of this distance. The average deceleration was thus about 10g. The peak was about 14g. The test velocity, approximately 5 m/s, was several times greater than would be expected in a normal landing, but is less than the design value used for some robust types of aircraft such as naval aircraft intended for deck landing.

The cabin and seats were salvaged from a number of light aircraft that were wrecked by a cyclone at Darwin in 1975. Other tests on these aircraft have been described previously.[10]

The tests were carried out as part of the crash safety program supported by the Department of Aviation.

2. CURRENT SEAT DESIGN CRITERIA

A typical specification for civil aircraft seats[11] requires the seat to be able to withstand 9g applied in a forward direction but only 6 or 7g downwards, this loading is mainly to ensure strength in flight. A 'fitting factor' of 1·33 is applicable in some parts and some standards note that energy-absorption is desirable.

Severe design requirements are given in Mil-S-58095[7] which states that the seat should attenuate body deceleration to tolerable values when the cabin is subjected to a pulse with a peak of 48g and velocity change of 15 m/s and an energy absorbing stroke of at least 300 mm is recommended. Tolerable acceleration is given as 23g, but if the yielding force is not adjustable to suit the mass of the occupant a value corresponding to 14·5g on the 50th percentile occupant is recommended.

A more recent specification, Mil-S-81771,[8] is superficially similar and requires energy absorption in a similar pulse, but allows the designer to select the operating force to suit the available stroke. Certification testing is carried out with a heavy 'body' (105kg). By setting the test conditions for a very severe impact and very heavy 'occupant' without a limit on the transmitted deceleration, the specification is likely to encourage a high yield force which would produce excessive spinal loading for most occupants in most crashes.

3. TEST EQUIPMENT

The cabin was decelerated after falling 1·6 metres, by a shock absorber connected to the cabin by eight seat belt webbing straps.

The shock absorber was mounted on a gantry approximately four metres high as shown in Fig. 1. Four of the webbing straps were attached to the wing mountings, the others were looped under the cabin. During the deceleration the straps stretched about 100 mm, but they returned to their original length after the test.

The shock absorber dissipated energy by bending two steel rods, 6·4 mm in diameter, as they were pulled over rollers. The construction of the absorber is shown in Fig. 2. Each test extended the unit about 60 mm, but four tests could be carried out before the rods were fully extended. The rods were then replaced. The force required to extend the unit could be adjusted by varying the thickness of the spacer plates in the shock absorber, but all the tests described used the maximum force setting of 29 kN. The variation of the decelerating force with time, or displacement, was approximately trapezoidal, but the interaction between the dummy and the cabin resulted in a cabin deceleration pulse with peaks and troughs above and below the nominal 10g deceleration. This is detailed in 'Results' section 9.

The cabin was lifted to its drop position by an additional webbing strap. This was attached to an overhead hoist by a bomb release. The shock absorber and bomb release were both directly above the centre of gravity of the cabin to minimize the tendancy of the cabin to pitch or roll, but in addition the attitude was maintained by a continuous cable which was attached to the front and back of the cabin and ran over pulleys on the gantry. The arrester straps were attached to the sides of the fuselage to prevent it from rolling.

The test seat was fitted on the floor rails in the cabin and the dummy was restrained by the aircraft seat belt.

4. INSTRUMENTATION AND RECORDING

The impact accelerations were measured by quartz accelerometers mounted on the cabin floor and in the 'pelvis' of the dummy. The floor accelerometer was mounted on a 25 mm thick steel plate (50 mm wide) bonded to the floor beams. The downwards deflection of the dummy

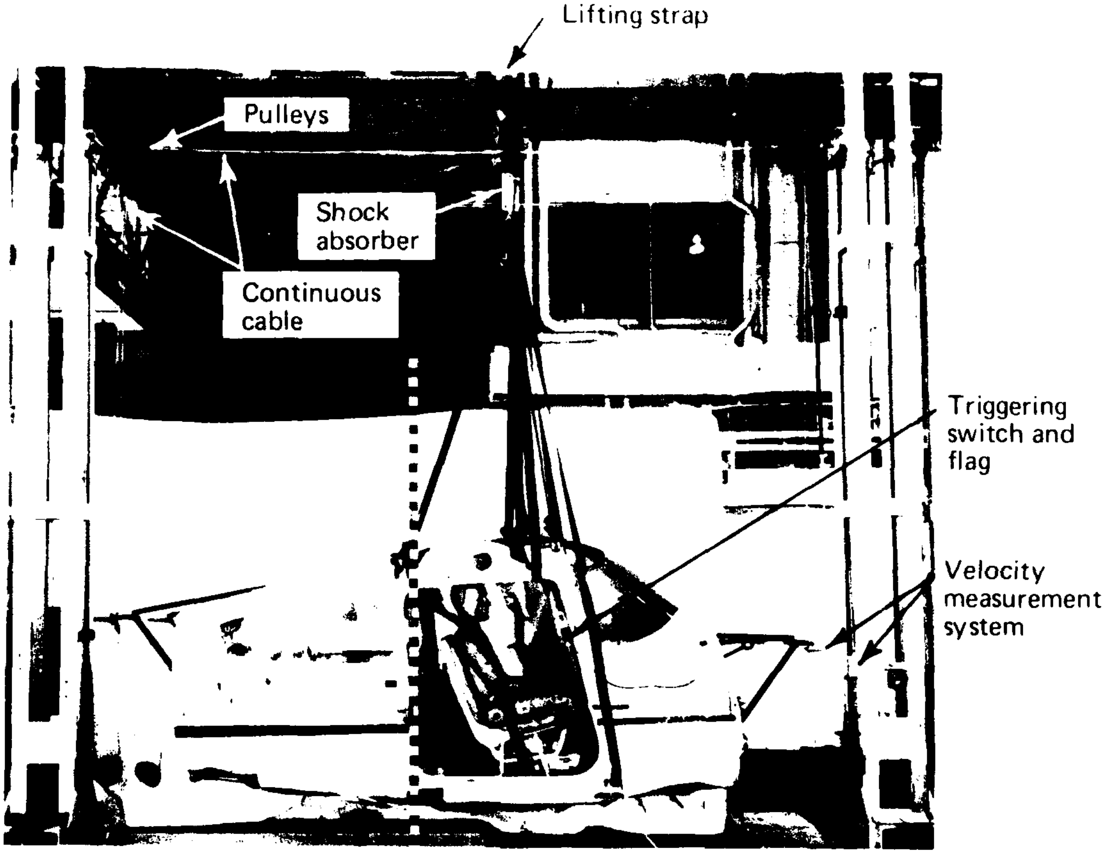


FIG. 1 AIRCRAFT CABIN DROP TEST RIG.

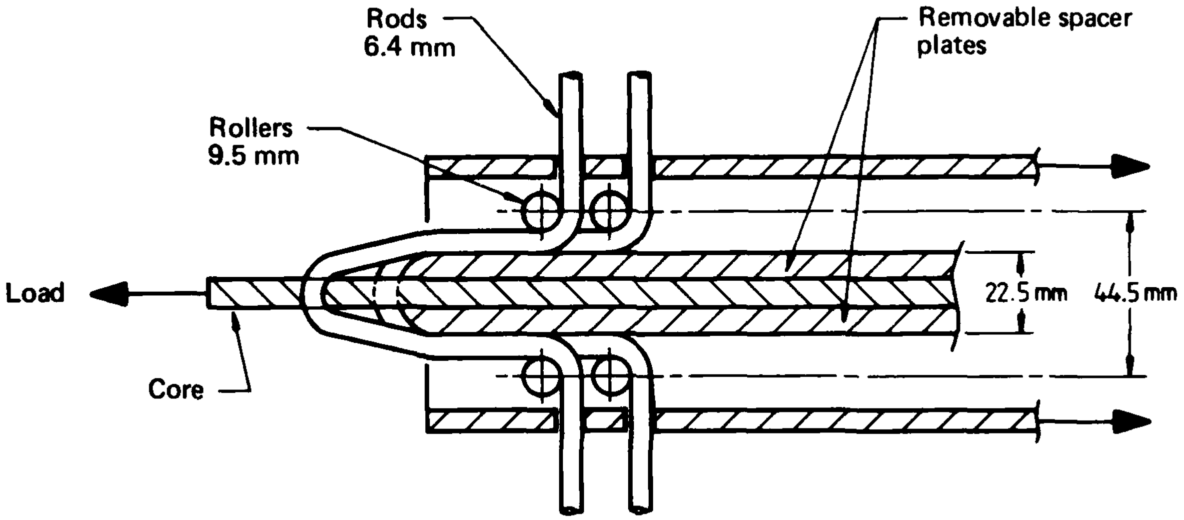


FIG. 2 CONSTRUCTION OF THE SHOCK ABSORBER
(for 29 Kn.)

pelvis (i.e. seat compression) was measured in tests from No. 12 onwards. Accelerations and pelvis movement were displayed on a four channel storage oscilloscope, and filters were incorporated in the accelerometer system to attenuate vibration effects. Satisfactory traces were obtained when the filters were set to block frequencies above 100 Hz. The oscilloscope was triggered by a switch on the cabin, activated as the arresting straps tightened. The tests were filmed at 400 frames per second and the oscilloscope trigger mechanism was visible in the film. Triggering also flashed a signal onto the edge of the film.

The impact velocity, drop height and stopping distance were measured by sliders which were moved along vertical wires by an arm attached to the front of the cabin. Velocity was calculated from signals generated as the slider passed two photo electric sensors. The slide wire components are evident in Fig. 3.

5. THE TEST DUMMY

A detailed 50th percentile anthropometric dummy (Alderson VIP 50) was used in the commissioning tests but it was observed that the 'buttocks' were wider than the seat frame as shown in Fig. 4*a*. Most seats had a peripheral frame with springs or webbing straps stretched across the frame and as the dummy was expected to penetrate deeply into the frame it was considered essential that the steel and rubber dummy should not have greater resistance than the flesh-and-blood counterpart. The relatively fragile structure of a human pelvis is shown in Fig. 5. A 5th percentile dummy was available and whilst less sophisticated the buttock width was considered more suitable as shown in Fig. 4*b*.

This dummy has articulated 'arms' and 'legs' and semi-flexible 'spine' and 'neck'. The movement of the limbs during impact may indicate kinematics, but it also makes assessment of the impact force from the impact acceleration difficult because the effective mass is unknown.

To allow this force to be calculated the dummy 'torso' was replaced by a rigid mass bolted to the pelvis in some tests. These are referred to as 'rigid-back' tests. The rigid connection to the 'pelvis' also ensured that the accelerometer axis could be determined from the photographs. The mass of the rigid torso could be 35 kg to give a total of 63 kg corresponding approximately to the 5th percentile (57 kg), or 49 kg to give a total of 77 kg corresponding to the 50th percentile. The mass of the lower legs and feet was 9 kg.

6. THE SEATS

6.1 Seat A

This type of seat was provided originally for the [illegible]
used for all the tests. It is shown with seat upholst[illegible]
frame was constructed from round steel tube and th[illegible]
canvas sheet bonded to the frame a foam cushion [illegible]
position on the floor rails by a single pin on th[illegible]

6.2 Seat B

This type, shown in Fig. 7 was provided for the [illegible]
of aircraft as Seat A and fits the same floor r[illegible]
made from rectangular section aluminium [illegible]
springs similar to those on Seat A but they are [illegible]

6.3 Seat C

This seat, Fig. 8, was provided for the pilot and [illegible]
aircraft. Like Seat A the frame was made from round [illegible]
supported by a lattice of natural fibre webbing. The [illegible]
after wrapping around the frame. The seat was uphol[illegible]
and fabric cover. The seat was designed for a floor rail [illegible]
in the cabin by using adaptors. It was locked in position by p[illegible]

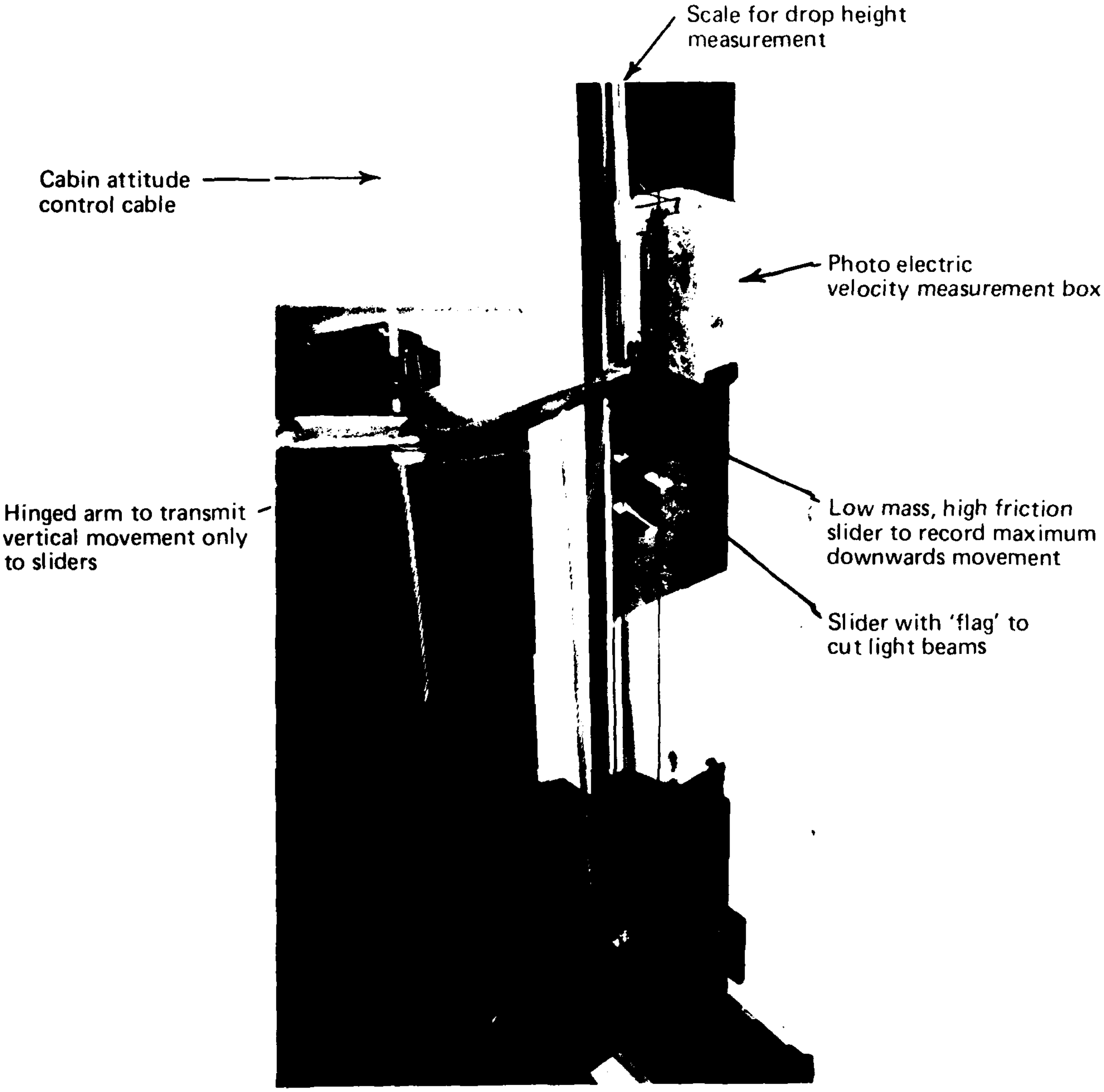
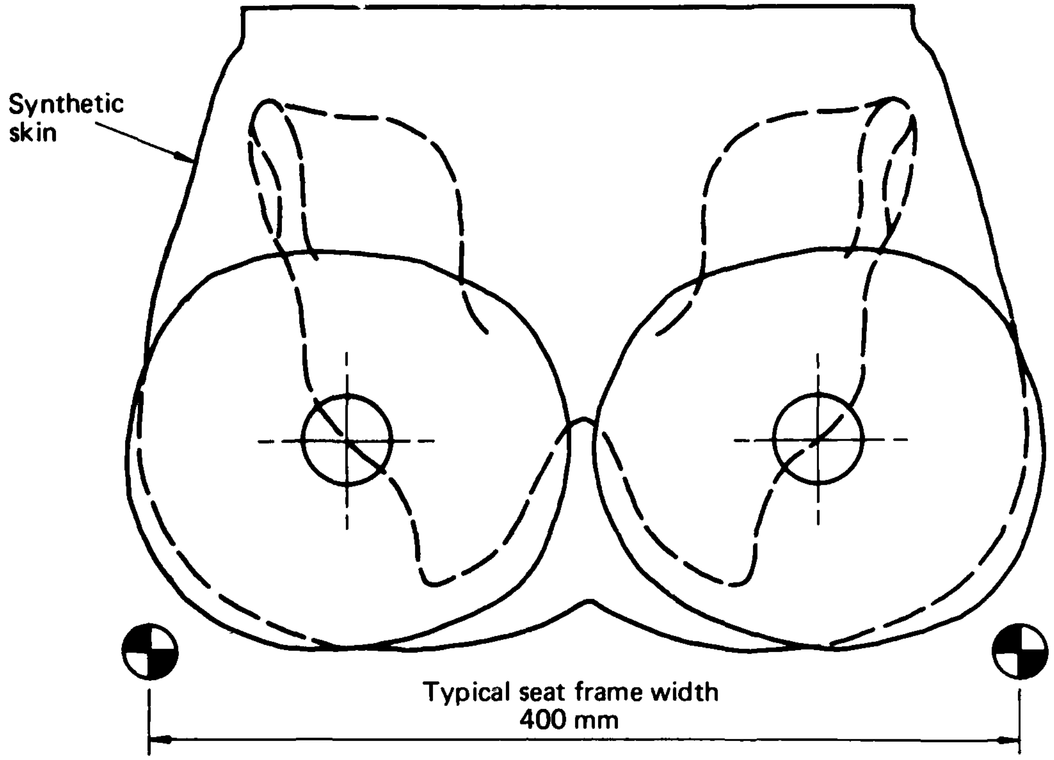
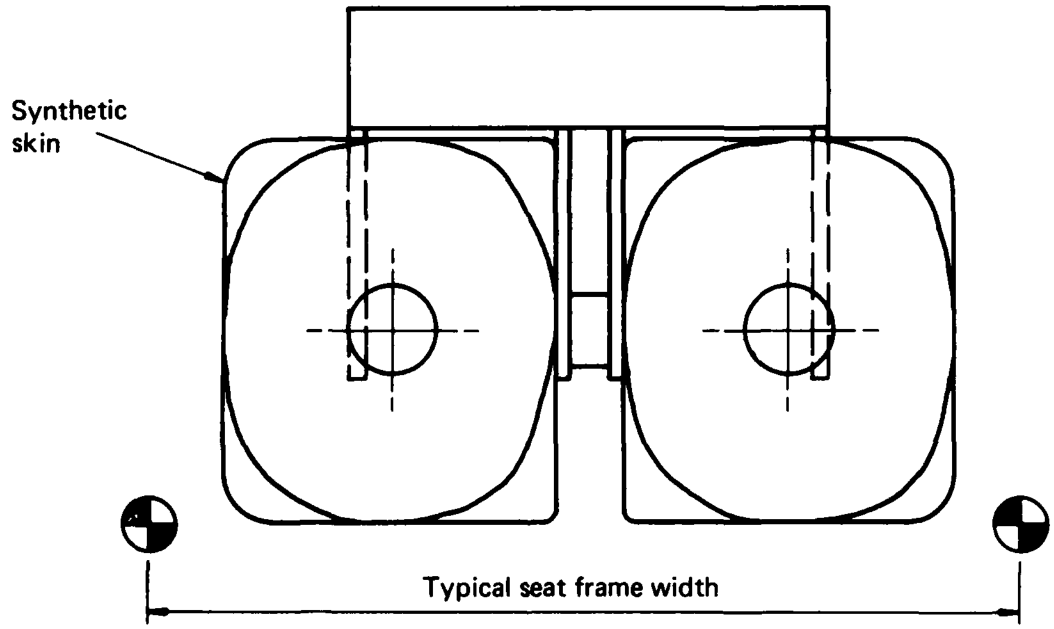


FIG. 3 SLIDE WIRE ARRANGEMENT FOR VELOCITY MEASUREMENT



(a) 50th percentile



(b) 5th percentile

FIG. 4 CROSS-SECTION OF THIGHS AND PELVIS OF 50TH PERCENTILE AND 5TH PERCENTILE MALE DUMMIES AND TYPICAL SEAT WIDTH.

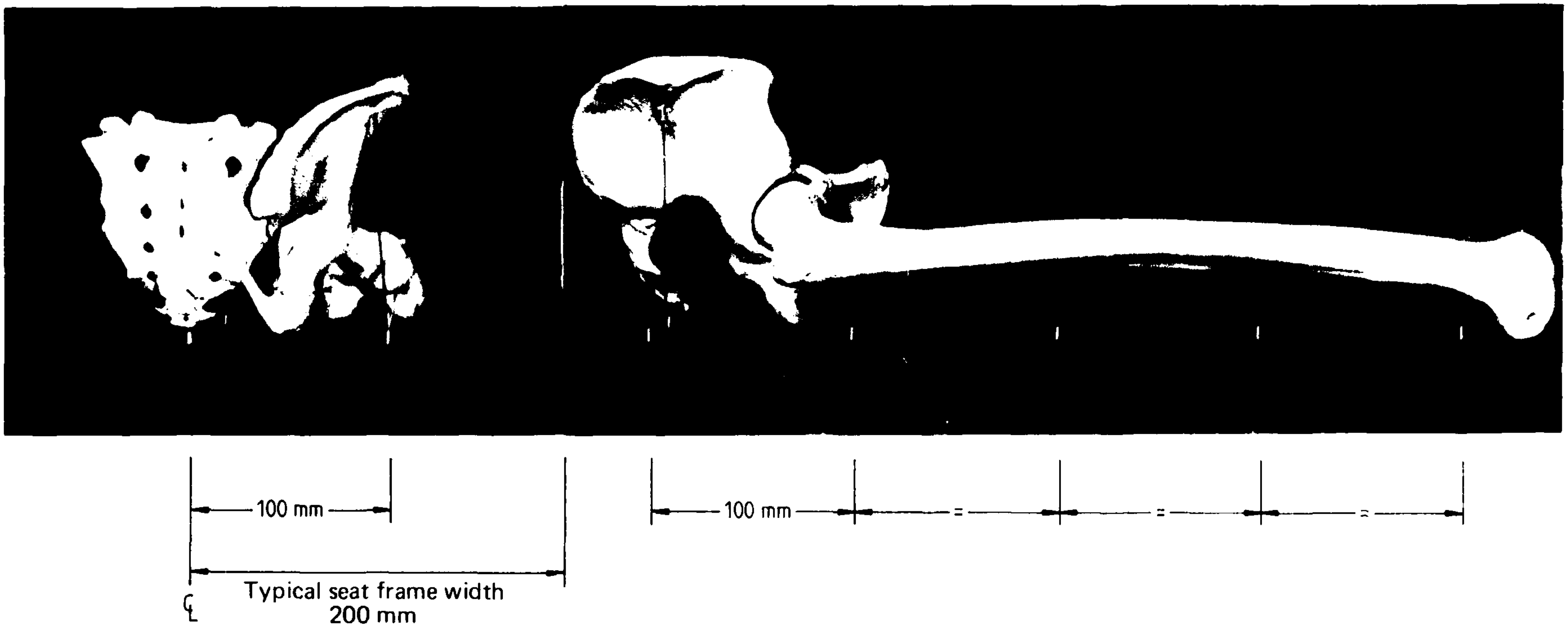


FIG. 5 PELVIS AND FEMUR OF A SMALL HUMAN FEMALE

(Seat 'A' after testing)
Springs normally covered by canvas, a foam cushion and fabric.

FIG. 6 – SEAT CONSTRUCTION

FIG. 7 SEAT 'B' IN CABIN WITH 5TH PERCENTILE DUMMY.

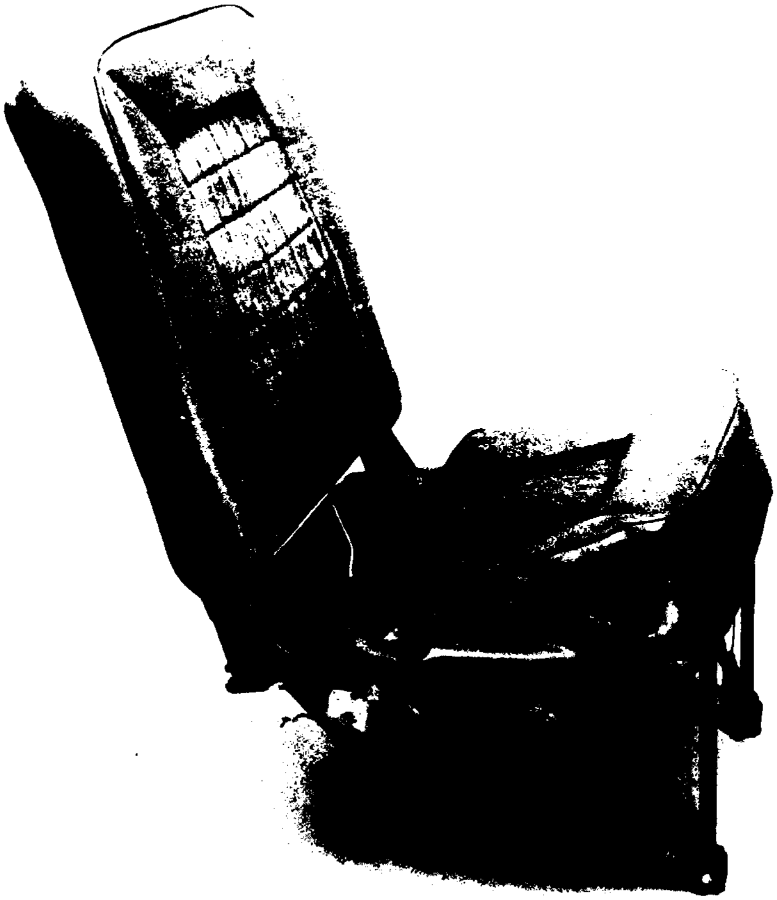


FIG. 8 SEAT 'C' AFTER TESTING

6.4 Seat D

This was an experimental, energy absorbing derivative of Seat C and had the webbing replaced by a series of transverse wires. Each wire was arranged to make a simple energy absorber as shown in Fig. 9. When the critical tension of 1·5 kN was exceeded the wires pulled over the spindle. End to end symmetry within the sleeve balanced the loads on the spindle and rotation of the spindle minimized friction. The sleeve controlled the bend radius and was located by the spindle.

6.5 Seat E

Seat E was provided in the rear of the test cabin to accommodate two passengers and since it is fitted over a raised part of the floor has only stub legs as shown in Fig. 10*a*. The occupant is only supported a few centimetres above the floor as shown in Fig. 10*b*.

Lap belts are attached to the seat frame.

In the tests the seat was mounted in the front seat position to maintain the correct centre of gravity of the cabin assembly.

6.6 Seat F

This was a cushion of energy absorbing foam with a density of 60 kg/m^3 and a thickness of 75 mm. It was placed directly on the floor, and the floor anchored lap belt was used to restrain the dummy.

7. TESTING PROCEDURE

Before each test the dummy was positioned as far back as possible on the seat and strapped in firmly with the aircraft restraint system. In some of the early tests it was found that if the dummy lent on the back rest, the high vertical inertia forces and backwards slope of back rest resulted in large backwards movements. It was considered that in a crash there would usually be sufficient forwards inertia force to preclude this motion and so in some tests—as noted later—the dummy was supported in an erect position by a strap braced from the cabin fire wall.

The velocity measuring device and the datum for drop height and stopping distance measurement were set at the resting height of the cabin and the cabin raised to its drop height. The trigger and slide-wire markers were set and with a suitable 'count-down' the camera was started and the cabin released.

After impact the deflections and traces were recorded and the cabin inspected, the dummy and seat were removed and examined.

8. INTERPRETATION OF DUMMY ACCELERATION

The spine of a seated human can withstand a compressive force corresponding to a steady acceleration of about 20g[6] in the direction of the spine. If the body is slumped forward the strength of the spine is reduced because load is concentrated at the front edges of the vertebrae. Firm support with some arching in the lumbar region may increase the strength. Humans vary, both in the strength of the skeleton and the mass which must be supported, and therefore a precise tolerance figure is not possible. In addition the duration of the pulse, its shape and any 'spikes' superimposed on the pulse are important.

To check the safety of ejection seats some specifications[12] require a sample to be tested with a dummy to represent the occupant and the seat acceleration pulse is measured. This pulse is interpreted by calculating the response of a damped mass/spring system. This system represents the mass of the occupants torso and the compressive stiffness of his spine. The maximum compression of the spine/spring, expressed as the 'Dynamic Response Index', DRI, is evaluated and compared with the allowable value DRI 18. (This corresponds to the condition under a steady acceleration of 18g).

Although the situation with a heavy ejection seat is not the same as that with the light cabin seats, the Dynamic Response Index was evaluated from the pulse recorded in the pelvis of the dummy for most tests. This and the DRI method are discussed further in the Appendix.

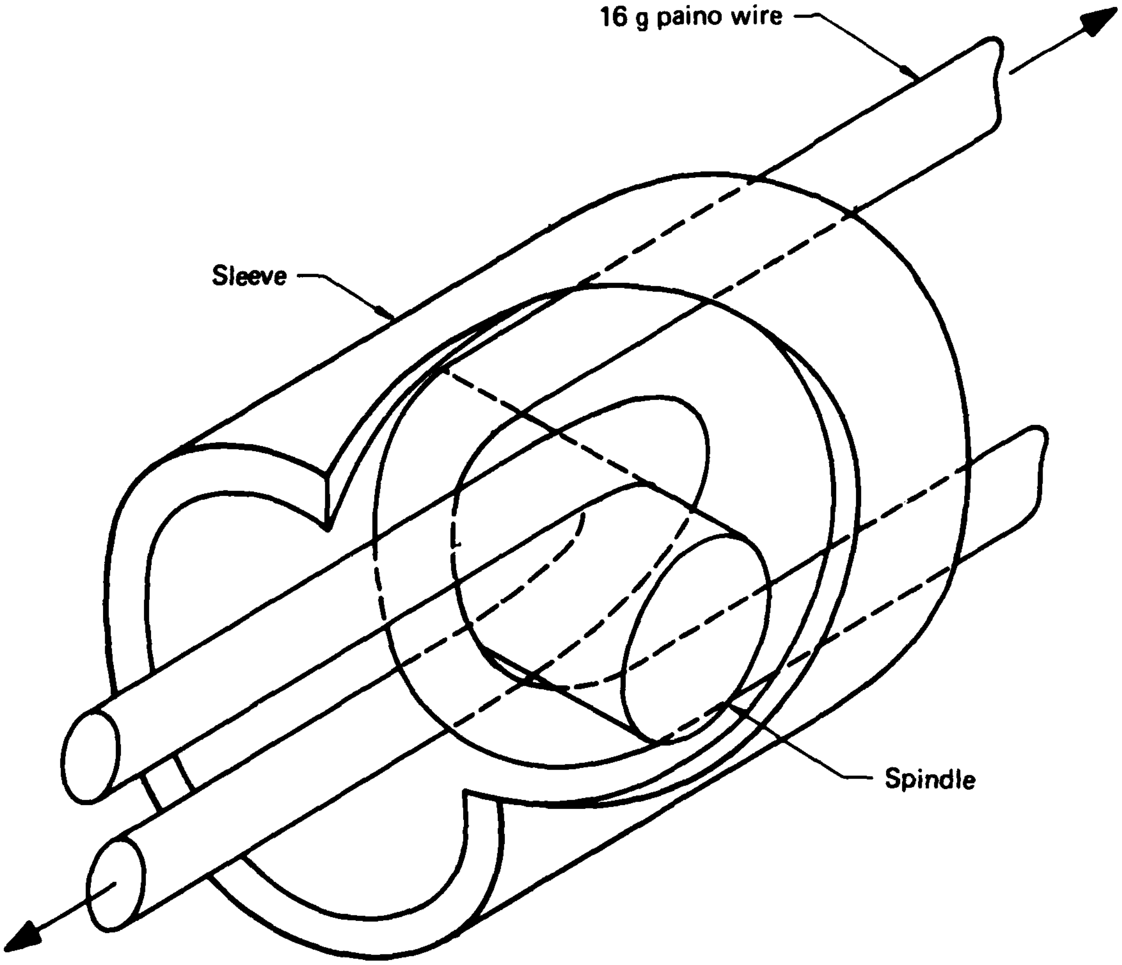
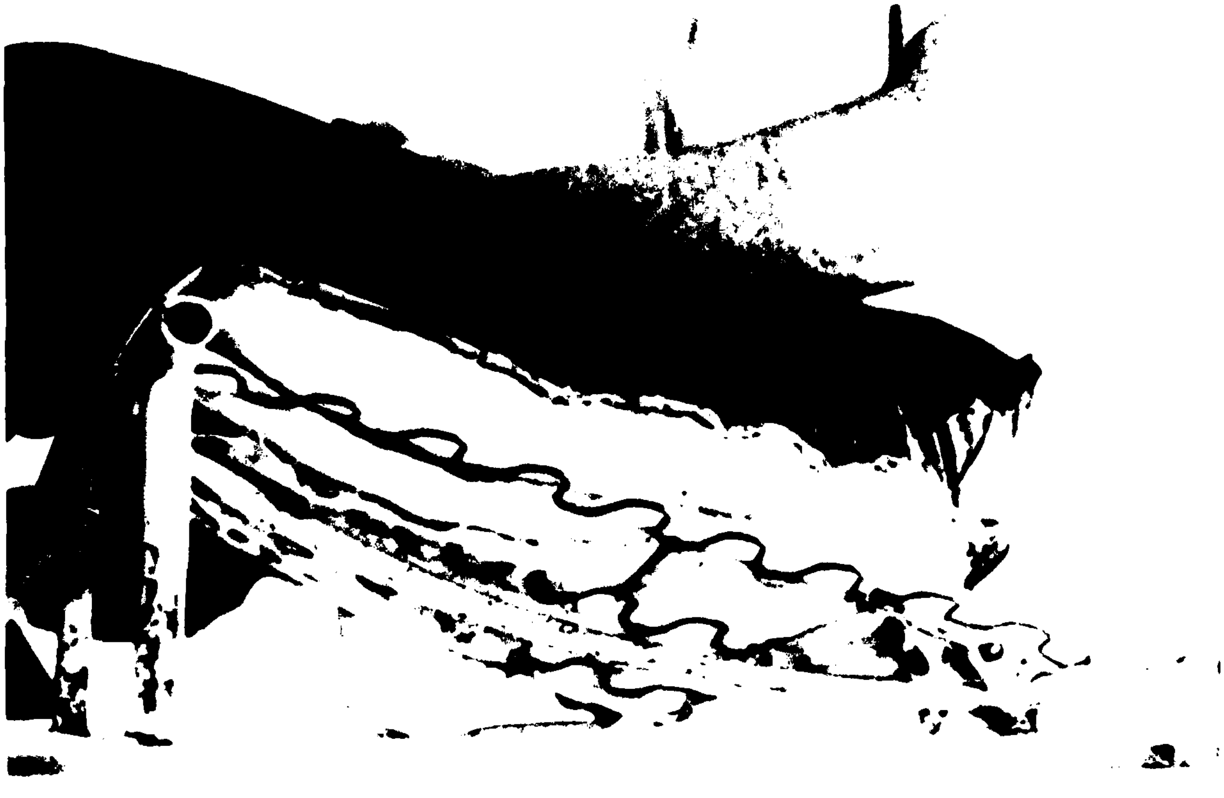


FIG. 9 CONSTRUCTION OF WIRE ENERGY ABSORBER
(Sleeve cut away to show cross-over of wire)

(a) Unloaded seat



(b) Seat loaded by occupant

FIG. 10 SEAT 'E'
(One side is cut away to show construction)

9. RESULTS

The velocity of the cabin just prior to the deceleration in all of the tests was between 5·15 and 5·25 m/s but the cabin rebounded and this added approximately 1 m/s to the total velocity change.

A record of cabin and dummy decelerations and seat compression is shown in Fig. 11*a*. It is seen that cabin deceleration increased progressively for the first 20–25 ms as the webbing straps were stretched. The deceleration then 'levelled-out' as the shock absorber started to extend but fluctuated above and below the mean of 10g because of the interaction of the dummy and cabin. After about 60 ms, the deceleration decreased indicating that the cabin had been brought to rest and that the taut straps were contracting and accelerating the cabin upwards ('upward acceleration' is indistinguishable from 'deceleration' in the traces). The nominal pulse, corresponding to the force applied to the cabin, is shown in Fig. 11*b*. The cabin deceleration fluctuated above and below this because early in the pulse (say at A, Fig. 11*a*) the decelerating force from the strap tension, approximately 29 kN, acted only on the cabin mass (230 kg) resulting in a high deceleration of 14g. Later the dummy's deceleration reached its peak value of 21g (at point B) and the resulting force from the dummy, 16 kN, acting downwards onto the seat, in opposition to the strap tension, reduced the decelerating force from 29 to 13 kN and the cabin deceleration to 6g (point C).

The traces, Fig. 11*a*, also show that the maximum dummy deceleration was developed later than the maximum cabin deceleration. This was because the dummy deceleration force was only produced as the seat was compressed. It follows that a large part of the cabin deceleration was completed before the dummy deceleration was fully established. Therefore, a large proportion of the dummy deceleration and energy absorption had to be provided by the seat. This is, of course, a typical response of a flexible system, but in the drop tests the delay in the build-up of the dummy deceleration was exaggerated because the dummy was lifted above its normal static position while the cabin fell freely. This 'slack' increased the time taken to re-compress the cushion (or seat) and achieve effective deceleration forces. The spurious delay caused by the lifting of the dummy is roughly equivalent to a more abrupt deceleration.

In summary it is safer to regard the pulse as an abrupt deceleration, with a peak in the range 14–30 g, and a velocity change of approximately 6 m/s, than to relate response directly to the measured cabin deceleration.

This behaviour must be common to many types of dynamic test in which the test specimen is disturbed from its normal static equilibrium shortly before impact, unless the dummy is held in its 'static' compression by very stiff supports. Despite efforts to hold the dummy in the cabin it usually lifted by about 20 mm as shown by the 'Seat Compression' trace in Fig. 11*a*.

10. SEAT BEHAVIOUR

10.1 Seat A

Two examples of this type of seat were tested, one, which had been overloaded in static tests and repaired was used in tests 6 and 8 (a list is given in Table 1) the other had been used in normal service and was used in tests 9 and 10. The seats were inspected after each test and if necessary the springs were reset. The standard 5th percentile dummy was used in tests 6 and 9, but the rigid back dummy was used in the other two tests. It was weighted to 64 kg (5th percentile) in test 8, and 77 kg (50th percentile) in test 10. Deceleration traces for tests 6, 8 and 10 are shown in Fig. 12 but the trace for test 9 was incomplete.

The maximum decelerations in the dummies were between 18 and 20g and it is seen that the results were very similar even though there were differences in the dummies.

Pictures from the high-speed film of test 9, Fig. 13, show the cabin at the start of the deceleration pulse and at about the time of maximum seat deflection. The backrest fold mechanism was damaged and seat springs were stretched by the test loading.

In the tests with the rigid back dummies the 'torso' was supported in a vertical position. The assembly is shown at the start of the deceleration pulse of test 10, and when the deflection of the seat was a maximum in Fig. 14. This test resulted in the greatest deflection of Seat A. Post-test inspection showed distortion of the springs and sufficient deflection to bend the diagonal strut as shown in Fig. 6.

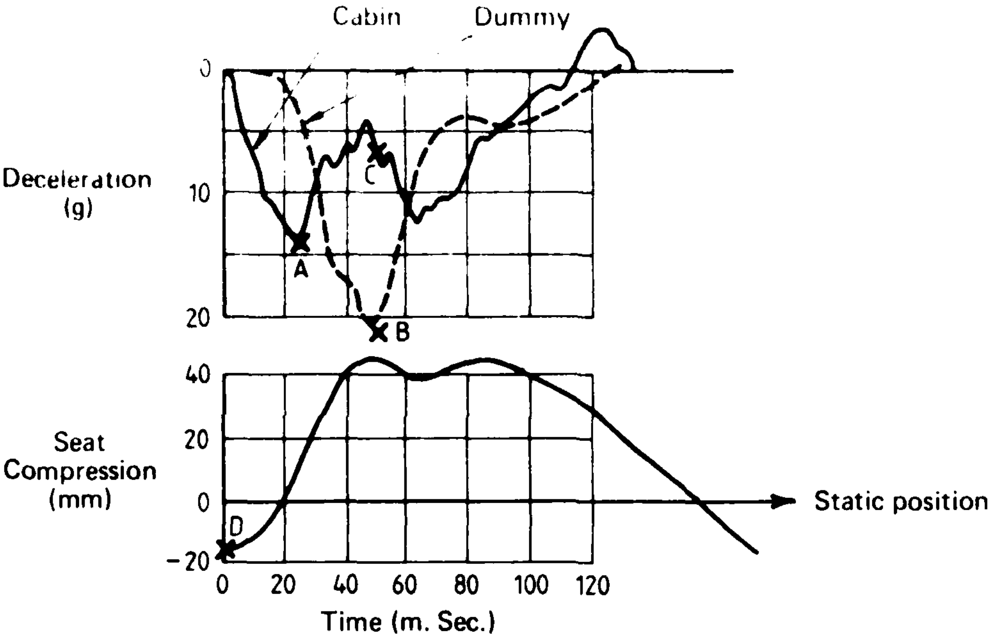


FIG. 11a TYPICAL TEST RECORD. (TEST NO. 16)
Dummy sitting on cushion on floor.

(Traces copied directly from oscilloscope
photo but separated for clarity.)

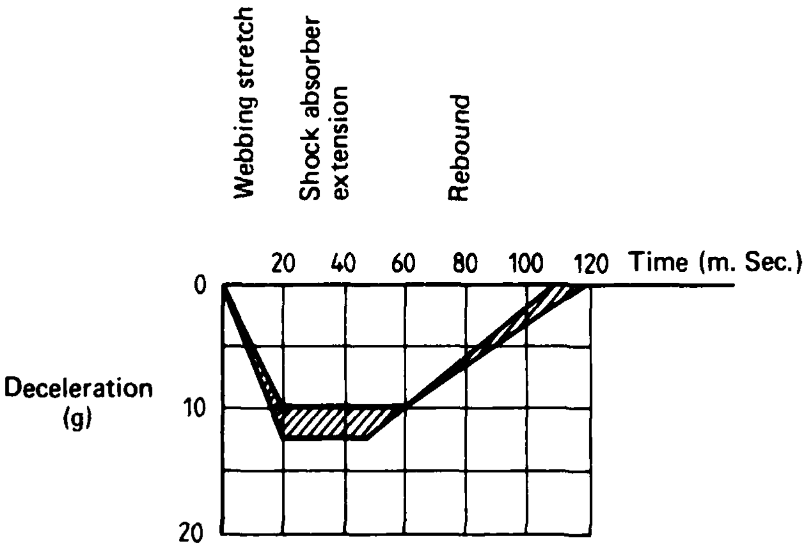
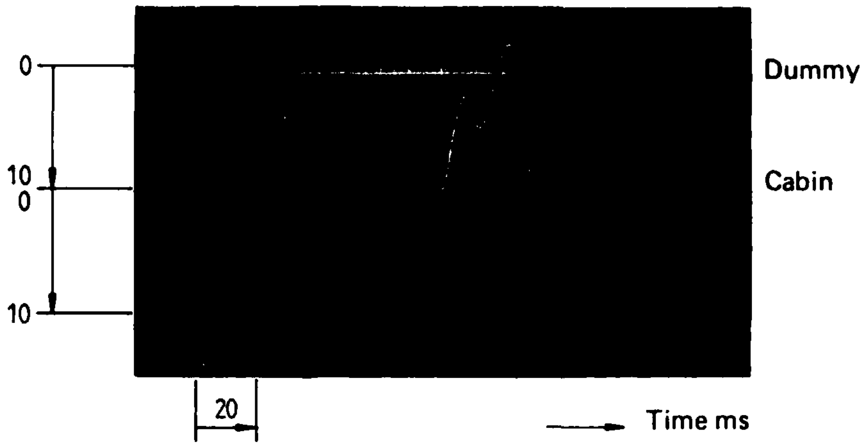
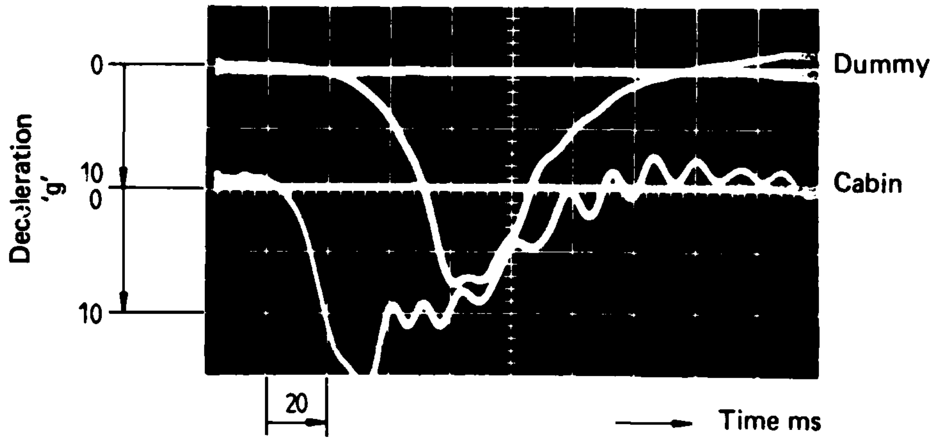


FIG. 11b NOMINAL DECELERATION PULSE

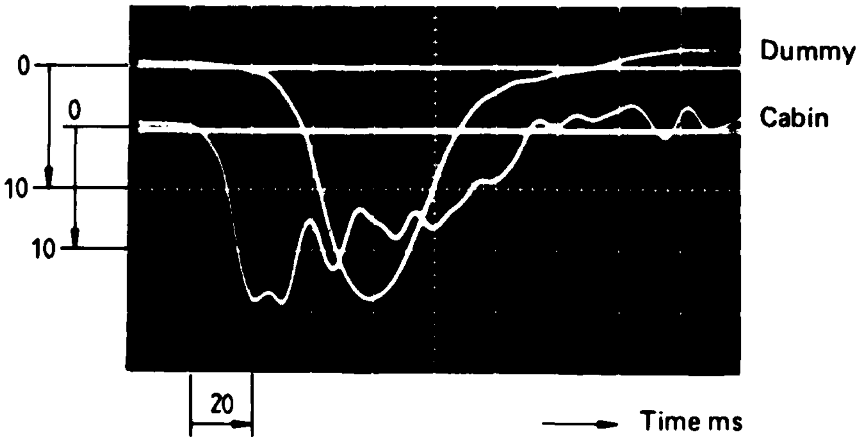
FIG. 11 CABIN AND DUMMY DECELERATION



Test 6 5th percentile dummy



Test 8 Rigid back, 5th percentile



Test 10 Rigid back, 50th percentile
DRI 22.4

1 division = 5g.mg 20 ms

FIG. 12 SEAT A. DECELERATION TRACES

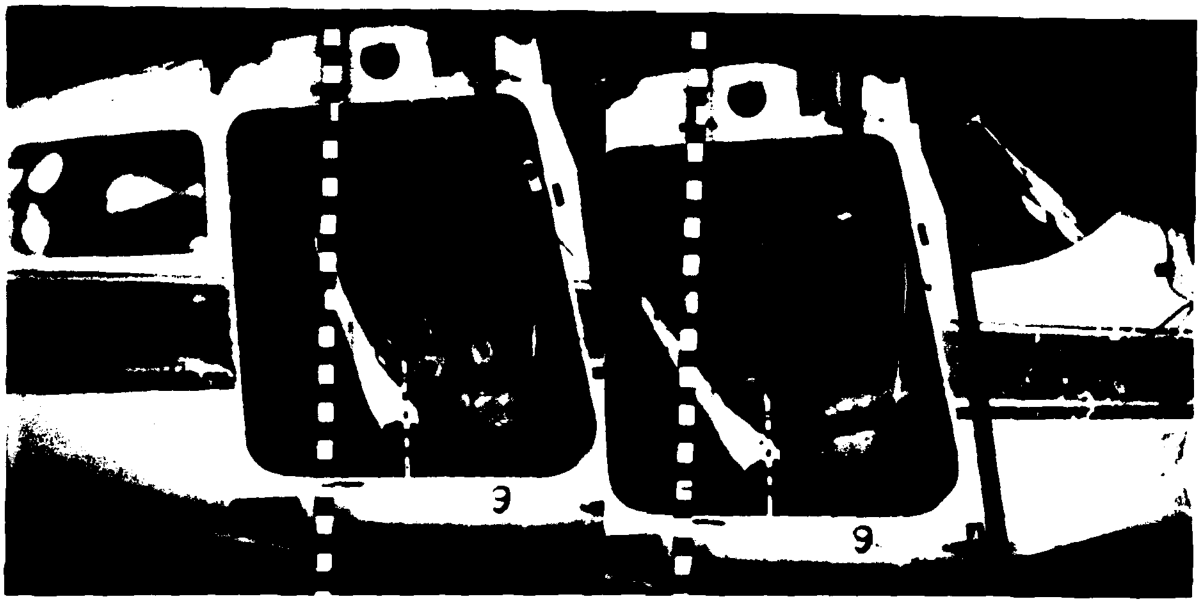


FIG. 13 SEAT 'A' DURING TEST No. 9
(Standard dummy)

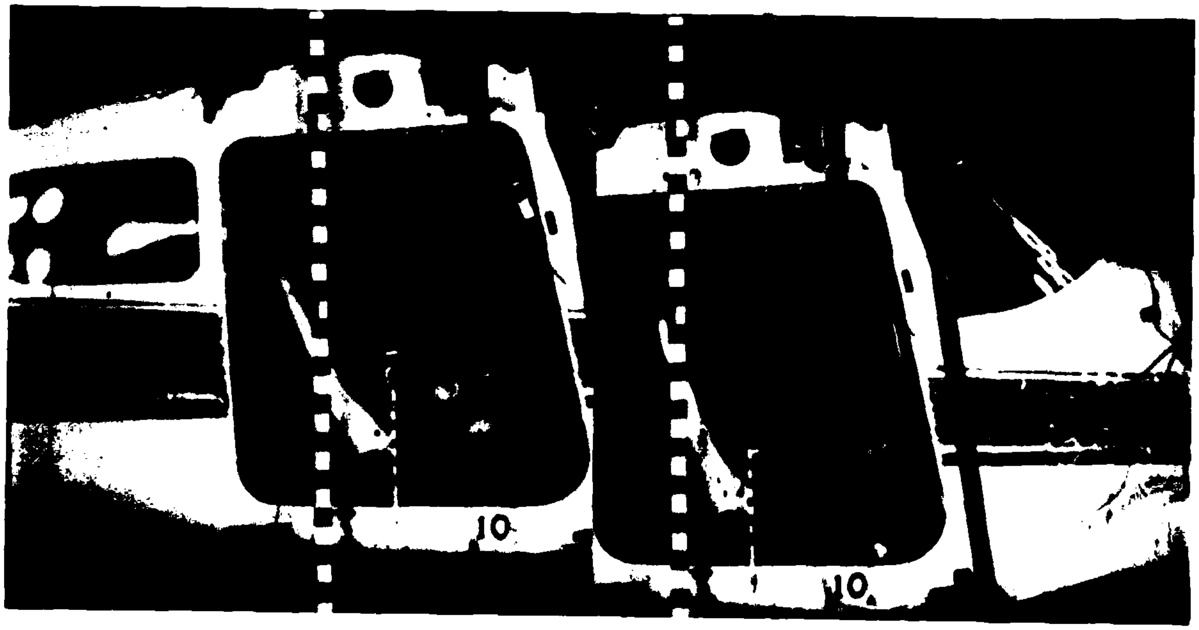


FIG. 14 SEAT 'A' TEST No. 10
(Rigid back dummy)

The DRI for test 10 was 22·4.

This value, and the peak values of the cabin and dummy deceleration are listed in Table 1.

10.2 Seat B

This seat was tested twice, first with the 5th percentile dummy (test 14) and later with the rigid back dummy weighted to 50th percentile mass (77 kg) (test 15).

Traces of the decelerations and dummy displacement are shown in Fig. 15.

The peak deceleration was about 20g in each test. The deflection with the smaller dummy was only 80 mm and did not cause visible damage to the seat. The assembly is shown at the start of the deceleration and near maximum deflection on Fig. 16. The heavier dummy depressed the cushion by nearly 180 mm and the bottom of the upholstery contacted the seat frame and left several threads on the structure as shown on Figs 17*a* and 17*b*.

The deceleration was less than with the lighter dummy initially but increased rapidly as the seat bottomed.

The DRI with the heavier dummy was 24.

10.3 Seat C

This seat was tested only with the rigid back dummy at 50th percentile mass (test 12). The deceleration and displacement traces, Fig. 18, show a maximum dummy deceleration of 13g followed by a period when deceleration varied between 8 and 12g and deflection increased from 80 to 120 mm.

The DRI was 17·3.

The dummy was pressed deeply into the seat as shown on Fig. 19 and the staples fastening the webbing straps pulled through, freeing the straps as shown in Fig. 20.

Based on dummy mass and deceleration the force on the seat must have been about 10 kN corresponding to the maximum load that could be reacted during static tests on a similar seat.[10] During this static test the webbing straps failed.

10.4 Seat D

The energy absorbing seat was intended to limit the dummy deceleration to about 18g, consequently the peak deceleration (18g) and DRI of 23 were about the average for the conventional seats, but the shape of the dummy deceleration trace Fig. 21 and examination of the wires showed that the system had started to yield. Some of the wire energy absorbers had extended by about 60 mm and they were clearly capable of absorbing much more energy.

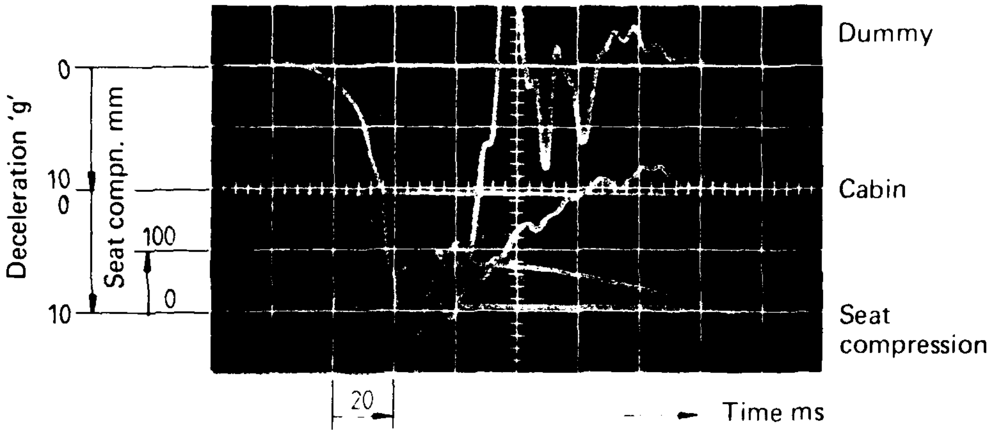
10.5 Seat E

The springs of Seat E compressed and allowed the dummy to impact the floor producing a very high deceleration as shown in Fig. 22. The maximum was off the scale but the effect on the cabin deceleration suggests that the dummy deceleration reached about 45g, on this basis the DRI would be 33.

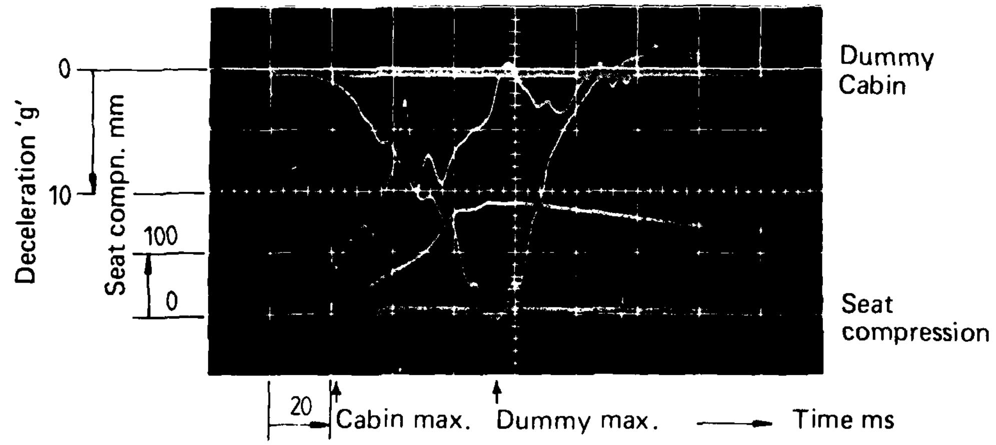
The lap belt was nearly horizontal and so did not hold the dummy down firmly on the seat, this resulted in the dummy rising more than usual during the free fall and the delay in the deceleration was correspondingly increased as can be seen in Fig. 22.

10.6 Seat F

The cushion was only 75 mm thick and consequently the available distance for compression was small. The seat compression trace, Fig. 11*a*, shows that maximum deflection beyond the 'static' position was about 45 mm and the peak dummy deceleration was 22g.



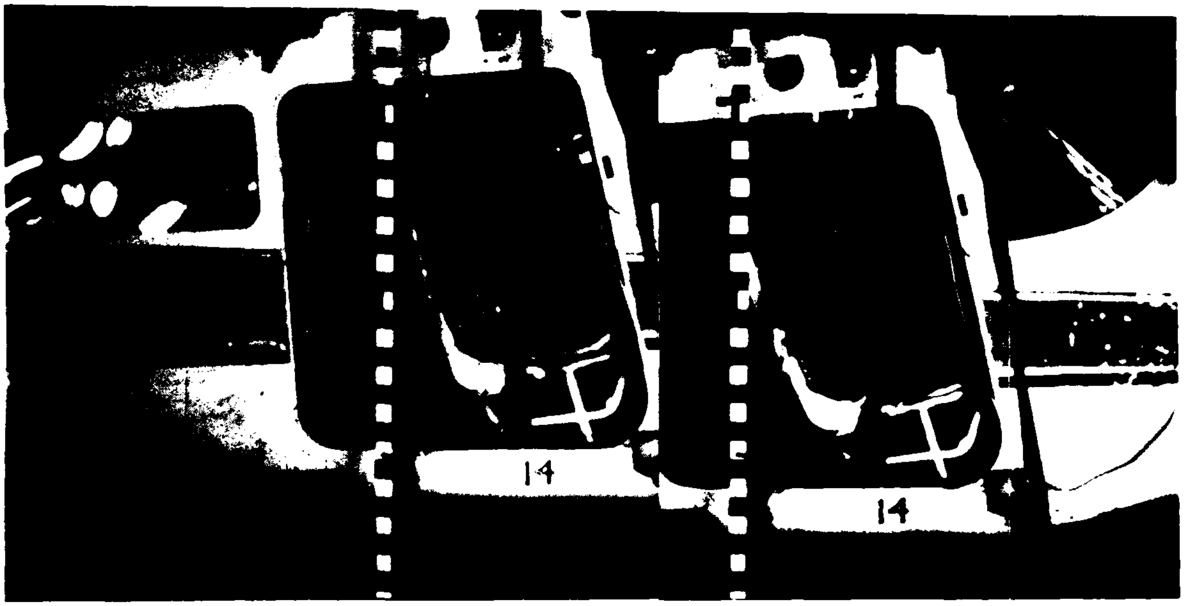
Test 14



Test 15 DRI = 24

Scale 5 g, 100 mm, 20 ms = 1 division
Note compression scale smaller than in Fig. 11

FIG. 15 SEAT 'B'. DECELERATION TRACES



Start of pulse Maximum deflection

FIG. 16 SEAT 'B'. TEST NO. 14

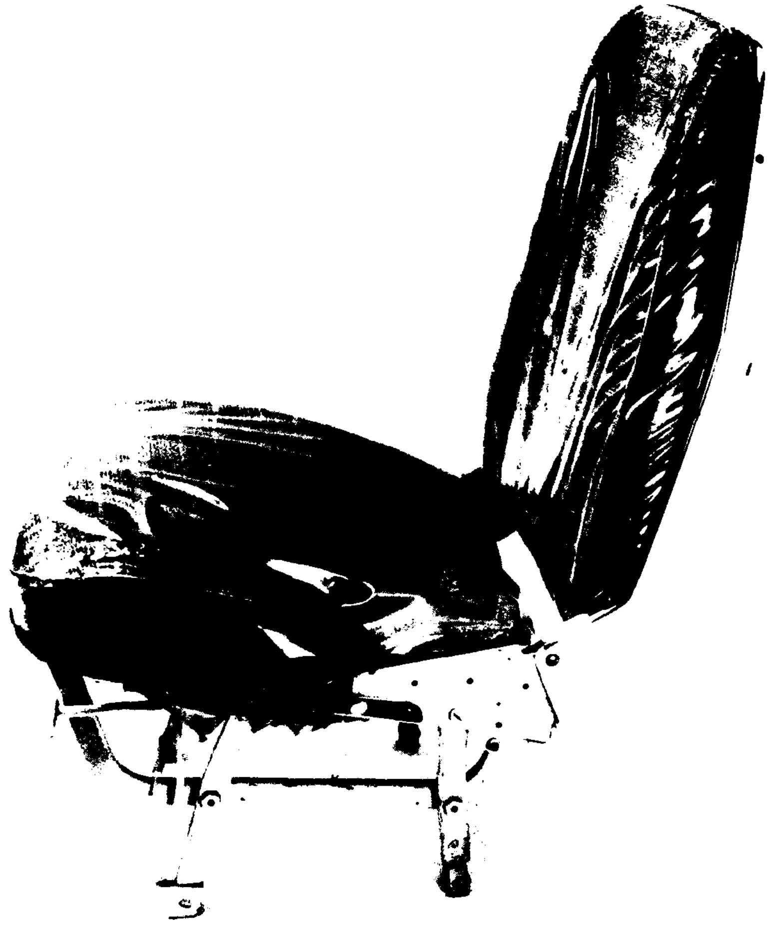
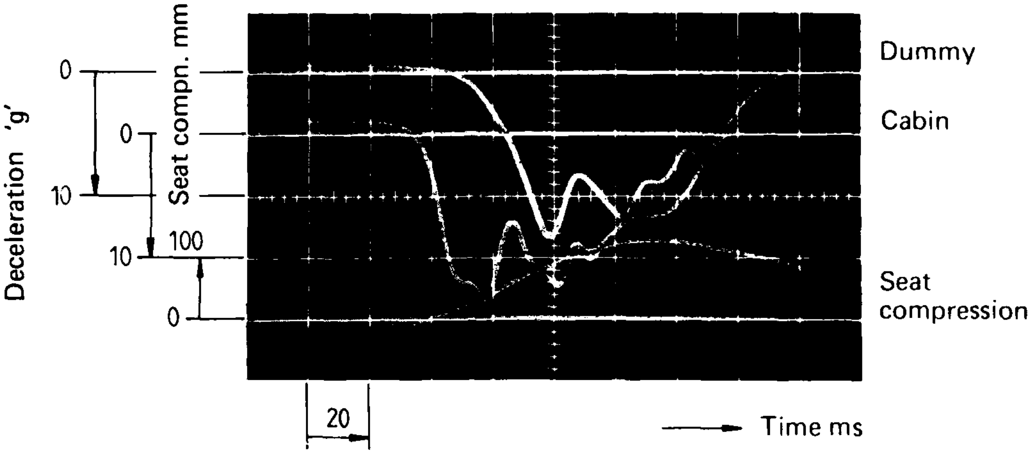


FIG. 17a SEAT 'B' AFTER TEST 15.

(Arrow showing fibre from upholstery adhering to seat frame.)

FIG. 17b SEAT 'B' AFTER TEST 15.



1 division = 5 g, 100 mm, 20 ms

FIG. 18 SEAT 'C' DECELERATION TRACES
TEST 12 DRI = 17.3

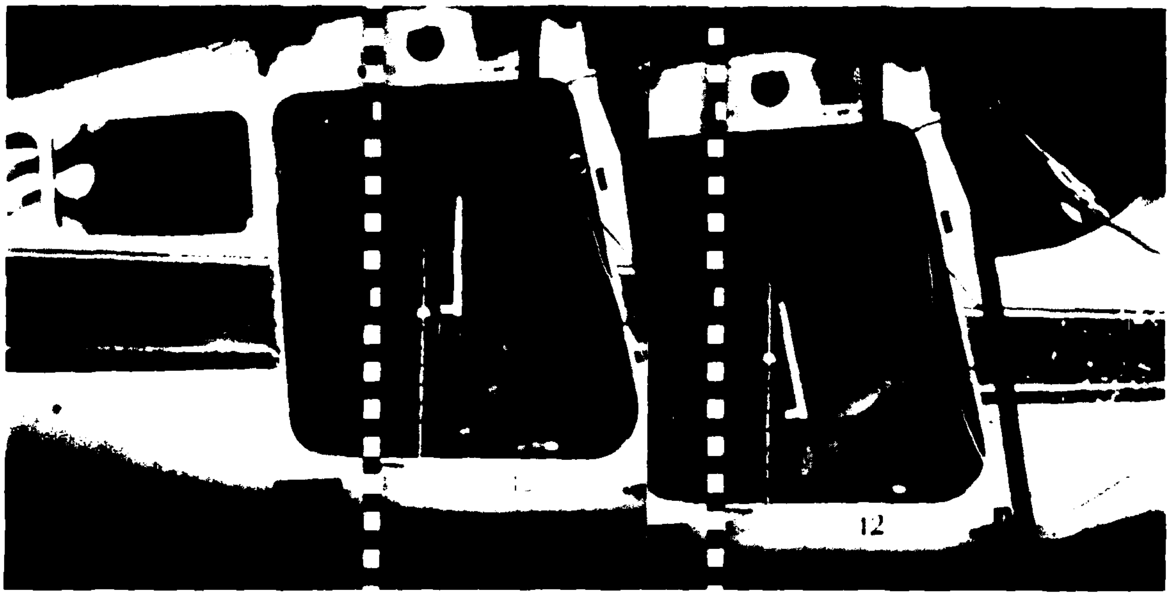


FIG. 19 SEAT 'C'. TEST NO. 12

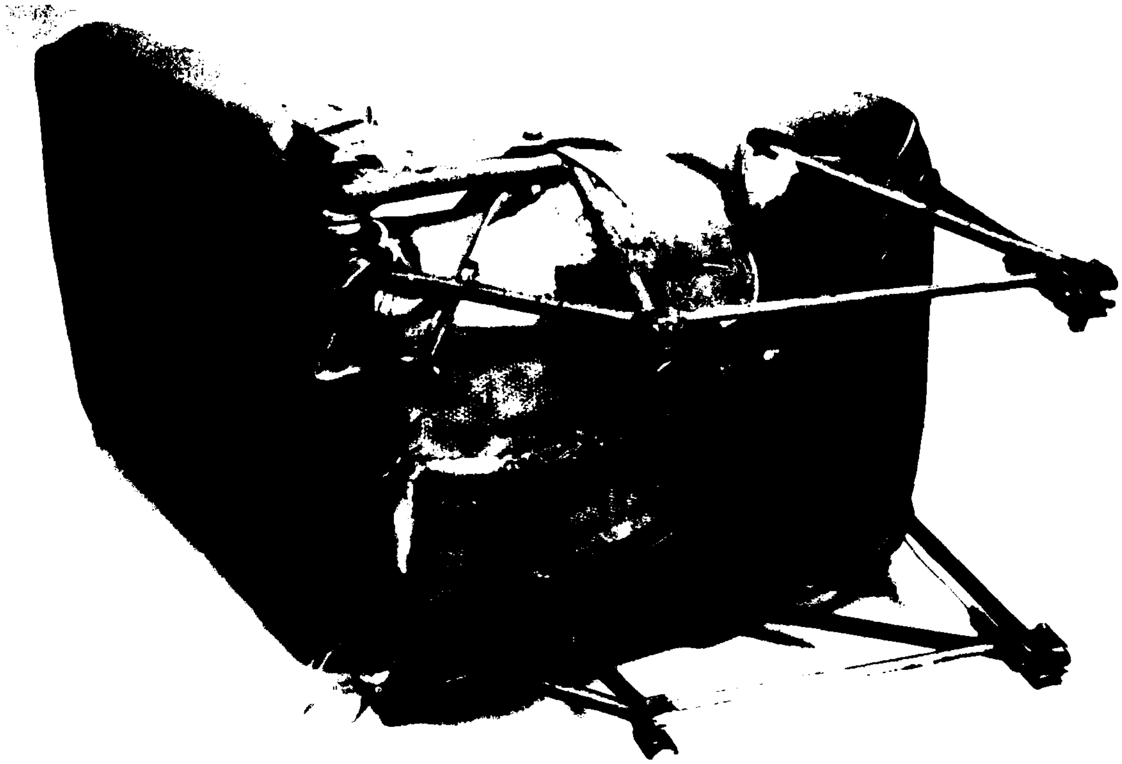
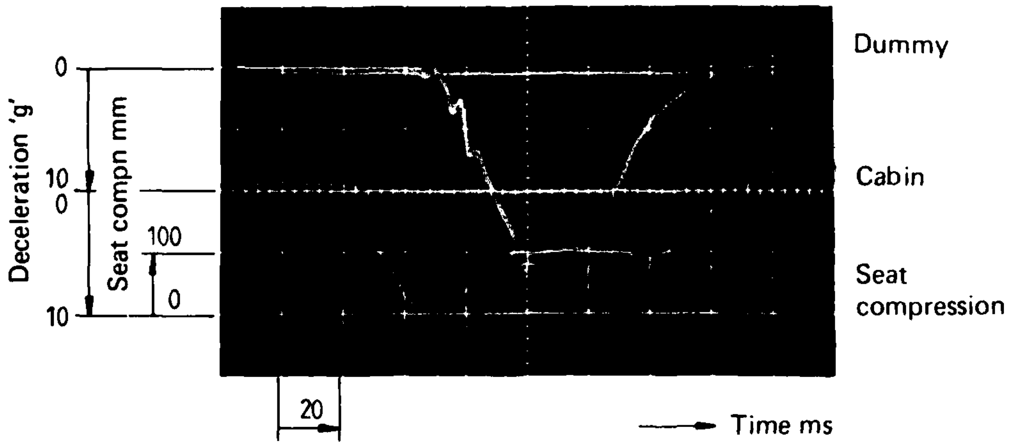
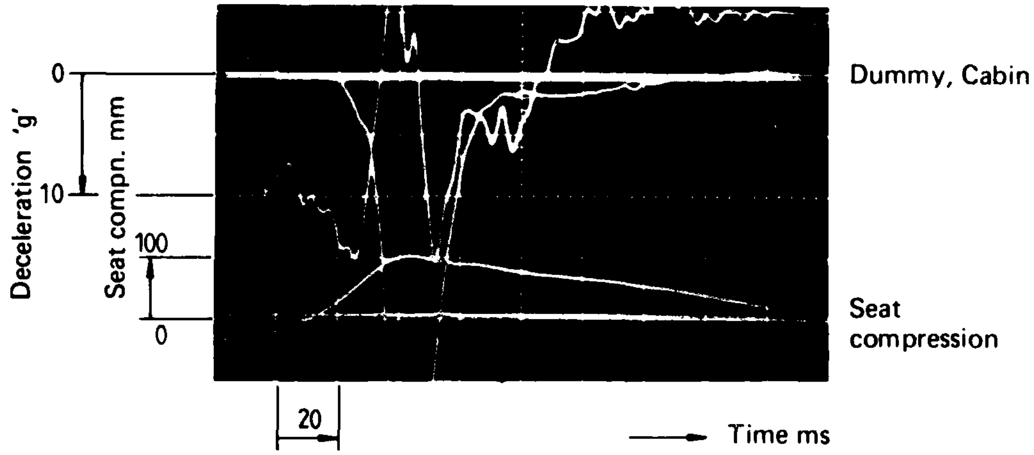


FIG. 20 SEAT 'C' AFTER TESTING



1 division = 5 g, 100 mm, 20 ms

FIG. 21 SEAT 'D' DECELERATION TRACES
TEST 13 DR1 = 23



1 division = 5 g, 100 mm 20 ms.

FIG. 22 SEAT 'E' DECELERATION TRACES
TEST 17 DR1 = 33

10.7 Tabulation of results

TABLE 1

Peak decelerations and Dynamic Response Index (All Tests with rigid torso dummy)

	Seat					
	A	B	C	D	E	F
Test No.	10	15	12	13	17	16
Peak Cabin deceleration g	14	16	13	15	15	14
Peak Dummy deceleration g	19	20	13	18	45	22
D.R.I.	22·4	24	17·3	23	33	—

The DRI calculated for a typical cabin deceleration (test 10) was 17.

11. CONCLUSIONS

The test series provided information about the behaviour of the seats and also about testing procedures as follows:

11.1 Conclusions Regarding the Test Procedure

1. The base of test dummy should be as narrow as the load bearing part of a seated human, to ensure that the seat and seat cushion receive representative loading.

2. The articulated dummies developed for car crash testing are not suitable for vertical impact tests, because they do not usually represent spinal compressive stiffness, and the large number of connected masses prevents the evaluation of seat forces from the deceleration measured in the dummy.

3. The 'spinal' stiffness of the dummy could affect the behaviour of the seat and should be represented in the test dummy.

4. A simple and more representative test dummy could embody the spinal stiffness and damping characteristic used in the mathematical model for the Dynamic Response Index. The 'torso' would be rigid and supported by a damped spring on a rigid base. The seat forces could be deduced from accelerometer measurements in the torso and base and the DRI (or potential injury level) would be indicated directly by the compression of the spine/spring.

5. Drop tests can produce impact conditions which are more severe than indicated by the 'cabin' deceleration pulse. This is because the seat springs may expand during the period of free full and lift the dummy above its normal position and introduce slack into the system.

6. Test systems which accelerate the seat and dummy before impact are likely to displace the dummy just before impact as described above (5).

7. It follows that unless the seat and dummy are in equilibrium before impact, the dummy must be held firmly to keep the seat springs etc., compressed to their normal static position. This would be facilitated by the rigid torso and base arrangement suggested above.

11.2 Conclusions Regarding the Seats

1. One seat (C) deformed and attenuated the deceleration to a safe value (13g corresponding to DRI 17). This shows that the impact could be non-injurious. The webbing straps in this seat failed and the performance would have been more reliable if the straps had extended without actual failure.

2. With three types of seat (A, B and E) the deceleration in the dummy (14g, 26g and 45g) and the Dynamic Response Index (DRI) (22, 24 and 33) exceeded the 'safe' values and injury would have been probable for an occupant.

12. ACKNOWLEDGEMENTS

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APPENDIX

Dynamic Response Index (D.R.I.)

The limit of human tolerance to impact acceleration cannot be adequately defined as a single value, measured as an input acceleration at the seat, because the body is a complex, deformable system. A sudden upwards acceleration of the seat will not result in the instantaneous development of a reacting force, but will start a compressive process which will subsequently produce a response force.

The magnitude of this response force and hence the potential for causing injury will depend on the duration and shape of the acceleration pulse as well as the peak value. To take account of these effects some ejection seat specifications, e.g. **Mil-S-9479B**, require the evaluation of the response of a mass spring system, representing the body, to the acceleration pulse measured in the seat during the proving trials of the ejection system.

Using the iterative process the maximum compression of the 'spring', representing the spine, is calculated. The coefficients in the equations given in the standard define the body stiffness etc. and the measure of spring compression, called the Dynamic Response Index, resulting from the test pulse must not exceed 18. This corresponds to the condition of a steady acceleration of 18g.

The method assumes that the seat acceleration, measured in the test with a dummy, represents the pulse that would occur with a human occupant. This is a reasonable assumption with a heavy ejection seat but is less satisfactory with a light seat because the behaviour of the seat, however measured, will be effected by the characteristics of the dummy. It would clearly be desirable to use a dummy with human-like response and as the DRI mathematical model is used for interpretation of results it is proposed that the test dummy should incorporate the DRI characteristics. To be consistent with the established DRI model the dummy would be simple, with a single torso mass supported on a spring and a damper. The DRI equation assumes damping proportional to rate of compression but an approximately equivalent hydraulic damping could be selected. A base would have to be provided representing hip and thigh mass. In use the DRI would be indicated directly by the spring force or compression.

Arms, legs and head should not be fitted as they would conflict with the DRI concept. It may be noted that the dummies developed for automotive tests do not generally represent the DRI spinal compression characteristics. Multi degree of freedom mathematical models are available, but if theory and test are to be correlated it is desirable for the test and mathematical occupant surrogates to be compatible.

Determination of DRI

The equations for finding DRI, given in Mil-S-9479B are:

$$\frac{d^2\delta}{dt^2} + 23\cdot7\frac{d\delta}{dt} + 2798\,\delta = \frac{d^2z}{dt^2}$$

$$\mathrm{DRI} = \frac{2798\delta}{g} = 86\cdot9\delta$$

δ — compression of the spine/spring in feet.

23·7 — a 'damping' coefficient

2798 — a 'stiffness' coefficient

$\frac{d^2z}{dt^2}$ — the acceleration of the seat, upwards in ft/sec^2

t — Time sec.

g — acceleration due to gravity 32·2 ft/sec^2.

The standard states that DRI must not exceed 18, i.e. the spinal compression must not exceed the equivalent of a steady acceleration of 18g.

Hence it follows that for a torso mass M lb:

the spring stiffness is $86{\cdot}9\ M$ lbf/ft, and

the maximum compression must not exceed $18/86{\cdot}9$ ft $= 2{\cdot}5''$ (63 mm),

the damping is $23{\cdot}7\ M/32{\cdot}2$

$= 0{\cdot}74\ M$ lb/ft/sec.

Note: Imperial units are shown because they are used in the Standard.

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16. Abstract

A light aircraft cabin containing a seat and anthropometric dummy was subjected to a vertical deceleration to simulate a minor crash. Several alternative seats were used, all typical of those in light aircraft.

The tests showed that with most seats a moderate rate of descent (5 m/s) could produce potentially injurious forces in the spine, but one seat limited the forces to a safe value.

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