

# Improvements in Seat Belt Restraint Systems

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One of the prime requirements for survival in a crash is protection of the occupant from the effects of deceleration. The seat belt restraint has shown its effectiveness, but upper torso restraint is necessary, and the geometry must be arranged so that loads are applied to the strong parts of the body. The crash severity that can be accepted will depend on the allowable restraint loads.

The allowable restraint loads are limited either by the tolerance of the body or by the strength of the restraint and its attachments – the tie down. A well restrained human can withstand 30–40 g but civil aircraft restraints are generally only designed to a strength of 9 g on the occupant with safety factors which make an effective 12 g. Clearly the strength of the restraint is likely to be the limiting factor. Protection could be improved by increasing the strength of the restraint and military aircraft and agricultural aircraft are designed to higher strengths. However, whilst the loads developed in the restraint clearly depend on the crash deceleration, they also depend on the stretching properties of the restraints. These can be modified by incorporating energy absorbers which allow the restraint to yield. This can permit greater crash decelerations without increasing the restraint loads.

To obtain experimental evidence on the behaviour of yielding and standard systems, examples of both were tested on a crash simulator.

## Test Method

The tests were carried out on the Hyge Crash Simulator at the General Motors Holden's vehicle safety test centre. This device simulates the crash deceleration by a backwards acceleration of a sled carrying a seated and restrained dummy, see Fig. 1. The dummy represented an average man (fiftieth percentile, mass 77 kg). The test seat design was based on a light aircraft seat, reinforced to withstand repeated loadings. The legs were replaced by a parallelogram linkage to allow measurement of the horizontal load by a load transducer and also to allow the seat to move forwards under the control of an energy absorber in the yielding experiments.

The restraint was an automotive type lap sash combination belt. The lap straps were anchored to the seat and the sash strap anchored to the test frame. For the yielding experiments, a second energy absorber was interposed between the test frame and the end of the sash strap. As in common with Australian vehicle seat belts the outer lap strap, that is the lap strap on the same side as the sash anchorage, and

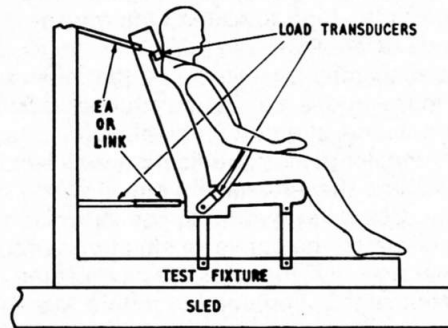


Fig. 1. Test assembly.

the sash were a continuous length of webbing joined by the buckle to the inner lap strap; the inner strap therefore reacted tension in the other two straps. Load transducers were fitted on each strap near their anchorage. The belts were fitted to the dummy with the buckle well down on the hip and with slack standardized as the equivalent of 25 mm of free movement of the body forwards.

The energy absorbers were simple mechanical devices consisting of two steel strips each folded to an U shape and fitted in a case as shown in Fig. 2. One end of each strip was attached to the case and the restraint strap or seat was attached to the other ends. The case was anchored to the test frame which represented the aircraft structure.

When the tension from the strap or seat reached the design yield value the bending moments produced at the fold overcame the bending resistance of the strips and the unit extended. As the unit extended, the fold 'rolled' along the case and the continuous bending and straightening resulted in a uniform resistance. Energy was dissipated by the plastic deformation at the bend. The sled acceleration was measured

and all data were recorded continuously throughout the acceleration pulse. Sled and dummy motion were filmed by high speed cine cameras and the film could be matched to the load records by synchronized timing marks. The test acceleration pulses were approximately sinusoidal. The standard and yielding systems were each tested twice with pulses having a peak acceleration of 120 m/s<sup>2</sup> and velocity change of 9 m/s, acceleration 180 m/s<sup>2</sup> velocity 11 m/s and acceleration 240 m/s<sup>2</sup> and velocity 13 m/s. The yielding system was also tested at 300 m/s<sup>2</sup>–15 m/s the equivalent vehicle stopping distance was approximately 450 mm in each case.

## Standard System

A typical acceleration pulse and the resultant strap loads with the standard system are shown on Fig. 3. This shows the build up of loads was slow compared with the build up of sled acceleration. Strap loading did not commence until the slack was taken up and then only increased slowly as the webbing stretched, the dummy settled in the seat and the belt took up its load bearing geometry.

To allow a comparison between the sled acceleration and the inertia loading on the dummy, the overall dummy acceleration was evaluated from its mass and the total force exerted on it by the straps (see Fig. 4). At the time when sled and dummy accelerations are equal it is seen that the velocity change of the sled, indicated by the area under the curve, is greater than that of the dummy. The dummy therefore achieved a velocity relative to the sled. Subsequently they must be brought to a common velocity and so energy must be absorbed by the restraint system, the greater the delay the greater will be the amount of energy to be absorbed. For a webbing system to absorb more energy and starting from this loaded condition, it must stretch further and the load must increase, consequently the peak dummy acceleration is likely to be greater than that of the sled. In these tests it was about 50% greater, and this is typical for a conventional restraint system. Fig. 5 shows the peak loads plotted against input pulse severity. As the sled acceleration pulse was increased from 120 m/s<sup>2</sup> and 9 m/s to 240 m/s<sup>2</sup>

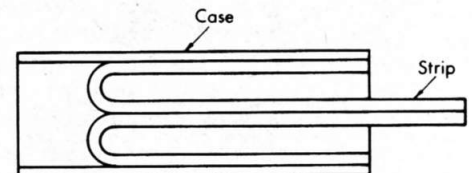


Fig. 2. The energy absorber

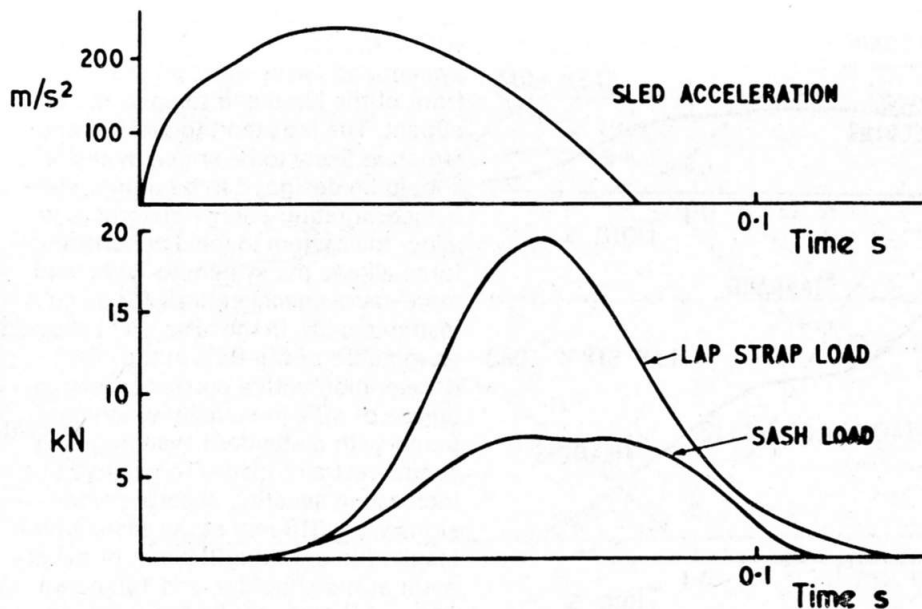


Fig. 3. Sled acceleration pulse and restraint strap loads (lap strap load = sum of inner and outer strap loads).

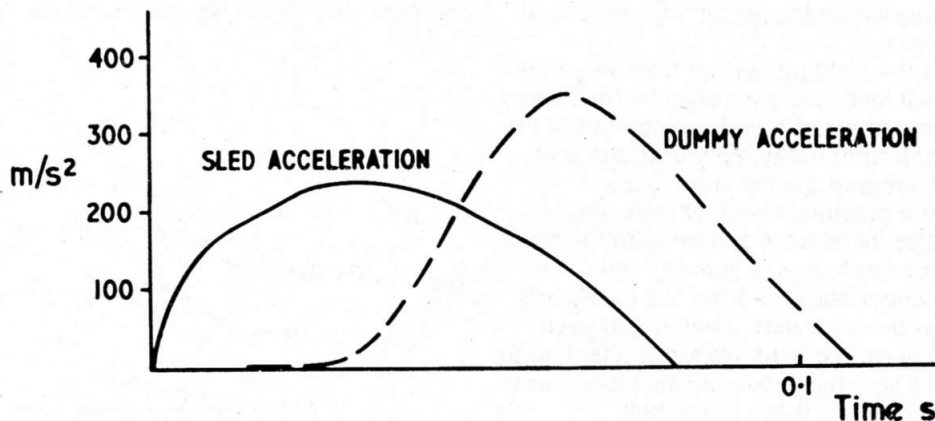


Fig. 4. Sled and deduced dummy acceleration.

and 13 m/s the sash load increased from 5 to 7 kN and the combined lap strap load increased from 11 to 19 kN. The total strap load increased from 16 to 26 kN. At the latter value the inner lap strap of one belt broke, but as the load exceeded the specified static strength the failure was not unexpected. The total seat load, which included lap strap and seat inertia loads, increased from 13.6 to 31 kN, but as the increase was not progressive the test points have not been connected by a line. The seat loading is discussed later.

#### Yielding Restraints

The energy absorbers were designed to become operative at the loads produced with sled accelerations between 120 and 180 m/s<sup>2</sup>, the sash unit yielding at 5 kN and the seat unit at approximately 16 kN.

Fig. 6 compares strap loads in the yielding and standard system at 240 m/s showing a reduction of 30% in the

sash load and 20% in the lap load with the yielding system.

These reductions in load were achieved by yield in the restraint so the dummy movement relative to its initial seated position was greater than with the standard system; however, as shown on Fig. 7, movement with the standard system was substantial and with yield the movement was only increased by about 20%. The profiles show the most forward position of the torso. The legs and arms continued to move forwards and upwards and the head forwards and downwards. In designing the cockpit interior space must be provided for head and torso movements and areas likely to be impacted by arms or legs should be padded to minimize injury.

The movement of reference points on the hip and shoulder are shown on the horizontal axis of Fig. 8. The corresponding sash and lap belt loads are plotted to produce load deflection diagrams.

It is seen that the increase in deflection with yield (C-F) is less than the energy absorber extension DE. It can also be seen that the energy absorbed by the two systems indicated by areas ABC and ADEF are approximately equal. Comparison between these force deflection curves and webbing elongation properties suggested that approximately 100 mm of extension at low load must have been caused by compression of the dummy and geometry changes resulting from compression of the seat.

Variation in peak loads with severity is shown on Fig. 9. At 120 m/s<sup>2</sup> the loads with the standard and yielding systems were similar but with the yielding system the sash load was maintained at 5 kN throughout the severity range 120 m/s<sup>2</sup> to 300 m/s<sup>2</sup> and lap strap loads were maintained at approximately 14 kN up to 300 m/s<sup>2</sup>. The total load in the straps was maintained at 19 kN up to 300 m/s<sup>2</sup>. This corresponds to the load at 160-180 m/s<sup>2</sup> with the standard system, so an increase of 65-85% in the input acceleration was achieved without increase in the total load. The corresponding velocity change was increased by 40%.

Dummy movement and energy absorber extension are plotted against severity on Fig. 10, and it is seen that to maintain uniform restraint load up to 300 m/s<sup>2</sup> the sash energy absorber extended 310 mm and to maintain loads over the range 160-300 m/s<sup>2</sup>. The shoulder movement increased 210 mm (220 to 430 mm) and hip movement increased 140 mm (210 to 350 mm). It is also seen that with either yielding or standard system extension increased progressively with severity and that for a given severity the increase in movement with yield is less than the energy absorber extension.

#### Seat Load

Seat loads for the standard and yielding systems at 240 m/s<sup>2</sup> are shown on Fig. 11. It is seen that with the yielding

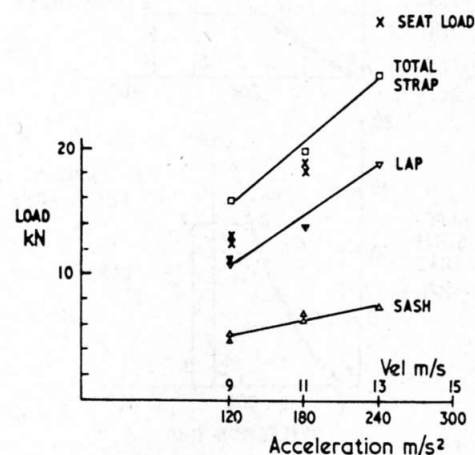


Fig. 5. Variation of load with pulse severity.

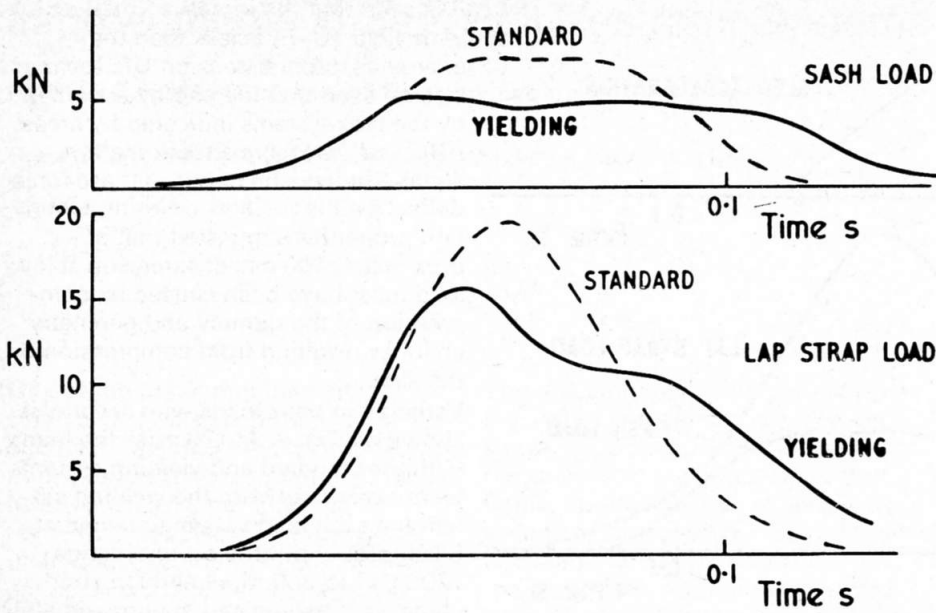


Fig. 6. Strap loads, yielding and standard systems at 240 m/s<sup>2</sup>.

system the load was about half that with the standard system. The seat load comprised seat inertia, strap load and direct dummy to seat load. This last load was probably fairly small until the belt had stretched sufficiently for the base of the dummy to approach the front crossmember of

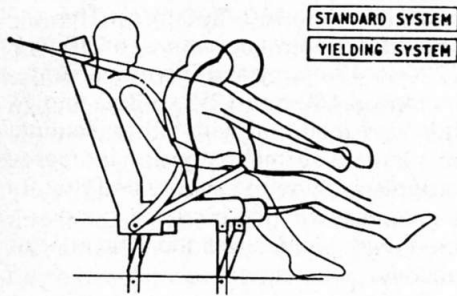


Fig. 7. Dummy movements 240 m/s<sup>2</sup>.

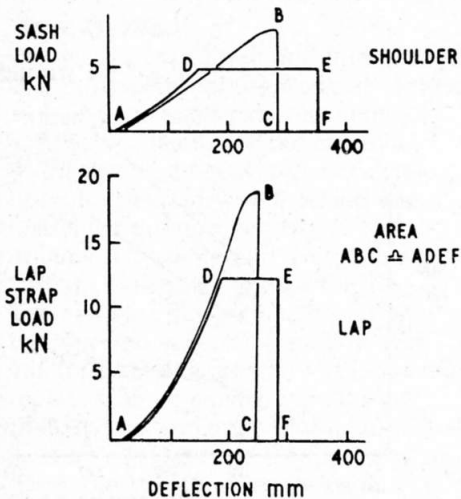


Fig. 8. Load displacement curves at 240 m/s<sup>2</sup>.

the seat and apply an impulsive loading.

In the yielding system tests the total seat load was controlled by the energy absorber and therefore increase in the load from the dummy onto the seat decreased the lap strap load.

In a previous series of tests, the lap strap belts were anchored to the floor. The lap belt was consequently at a steeper angle and the induced loads on the seat were greater, and even though the belts were not attached to the seat the maximum seat loads were as great as those in the belt. These results were obtained on the General Motors car crash simulator and the deceleration pulse produced was more appropriate to the stopping distance available in a car than an aircraft. An aircraft crash is likely to involve a greater stopping distance and consequently result in a lower vehicle deceleration although velocity changes may well be higher. This would result in a different response to that measured in the tests, but theoretical investigations show that the improvement in allowable severity that could be achieved by yield in the restraint would still be considerable.

### Conclusions

Initial slack and stretch in the restraint together with deflections of the seat delay the decelerations of an occupant in a crash deceleration so that a large proportion of the occupant's kinetic energy must be absorbed by the restraint.

The tests showed that:—

1. With a standard system, the maximum deceleration of the occupant (dummy) was about 50% greater than the crash deceleration (sled acceleration).

2. Considerable body movements occur within the cabin even with a standard system and space must be provided in front of the head and torso of the occupant. The legs tend to kick up and structure likely to be struck by the legs should be designed to be uninjurious.

3. Incorporating energy absorbers to allow the system to yield at constant force allows the system to withstand more severe decelerations for given restraint loads. In the tests, yield allowed an increase of 65–85% in the crash deceleration with a corresponding increase of 40% in velocity when compared with a standard system giving similar restraint loads. To achieve this increase in severity, absorber extensions were 310 mm at the sash, which resulted in an extra 210 mm of movement at the shoulder, and 140 mm at the seat which resulted in a similar increase in movement at the hip.

4. The tests also showed that large loads could be induced by the lap straps onto the seat. These depend on the geometry of the lap strap but even

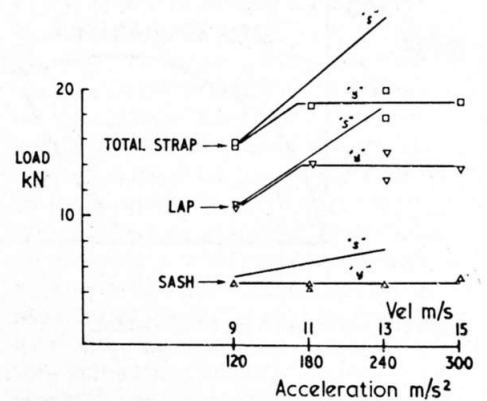


Fig. 9. Variation of load with pulse severity, standard system (s) and yielding system (y).

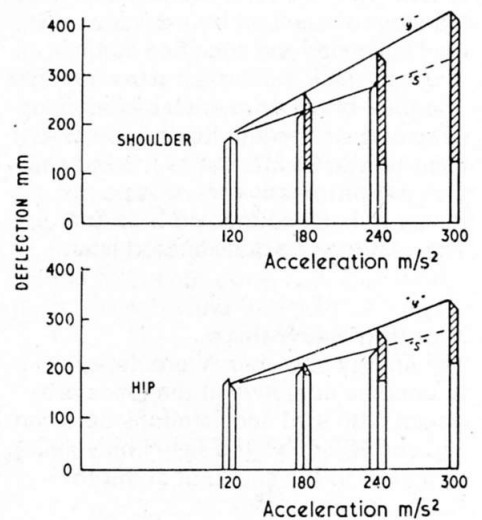


Fig. 10. Variation of maximum dummy movements with pulse severity, standard system (s) and yielding system (y).

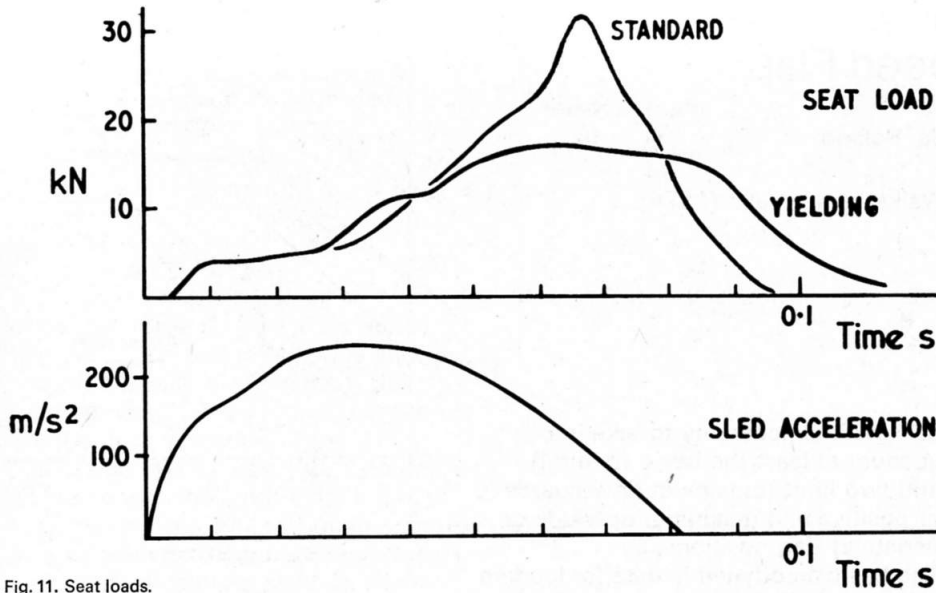


Fig. 11. Seat loads.

when the straps are not connected to the seat the induced loads may be as great as the belt loads. Failure of the seat under these induced loads could destroy the restraint effectiveness.

**Acknowledgements**

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**References**

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