DEVELOPMENT OF A HEAD IMPACT COMPATIBLE PARTITION WALL

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Abstract

Head impact on walls under emergency landing conditions is a major problem in the design of aircraft cabin interiors.

For objects like walls which are installed in front of seats at a distance of less than 35 inches to the seat reference point it has to be shown by tests that the injury criteria of FAR 25.562 are fulfilled.

A partition wall has been developed which can be installed at a distance of less than 35 inches to the seat reference point (Fig 1). The paper discusses parameters which are of influence on the deceleration curve of the head and the injury criteria.

Based on measured head movement curves head impact tests with a specially designed pendulum have been run on a prototype of the partition wall, using the headform of a PART 572 dummy.

All the regions which might lead to the most critical HIC values have been tested at an impact velocity of 51 km/h. The tests led to very good results within head injury criteria at relatively low deformations of the wall and with a very efficient energy absorption. The specific weight of the energy absorbing panels is about 5 kg/m².

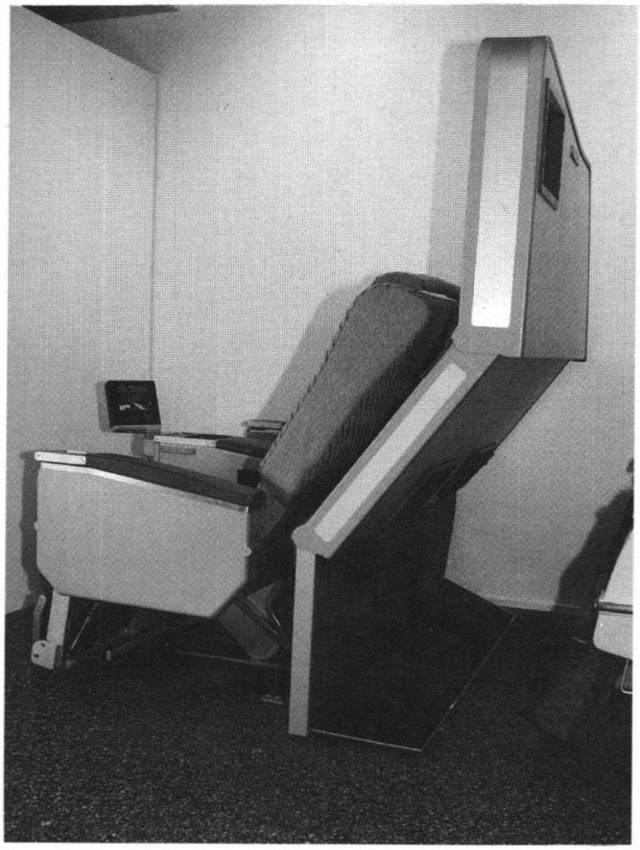

Fig 1 Partition wall built by Bucher Leichtbau, Switzerland.

Introduction

Improving crash impact protection for occupants of civil aircraft is an important objective in aircraft development.

Therefore since 1988 new dynamic test standards for seats are in use (FAR 25.562).$^{(1)}$ One of the two dynamic tests to be run with seats decelerates with a defined pulse in mainly longitudinal direction and simulates horizontal impact with a ground level obstruction. In this test head impact may occur with structural parts or with equipment within the occupant's head strike envelope. These seat tests are run with Hybrid II 50th percentile male anthropometric test dummies.

In aircraft cabin interiors seats may be placed behind vertical walls of galleys, lavatories, wardrobes or, as in this case, class dividers. Fig 2 shows the situation of a passenger behind a partition wall, the head path and the velocity measured in dynamic seat tests according to AS 8049.$^{(2)}$ Gowdy V. et al. investigated the head impact kinematics for passengers.$^{(3)}$

Applicable regulations for certification of interior walls in the case of head impact

FAR 25.562 defines the emergency landing dynamic conditions under which seats and restraint system are tested using a PART 572 anthropometric test dummy. If the head of the test dummy is exposed to impact during the test, the Head Injury Criterion HIC is used to judge severeness.

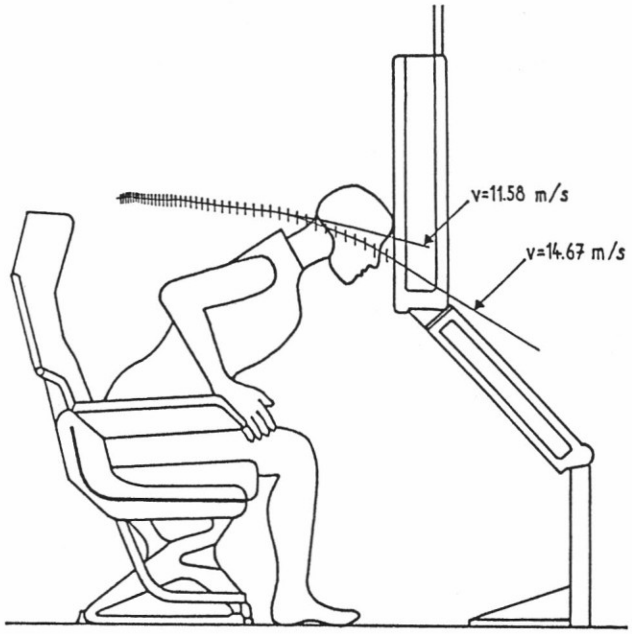

Fig 2 Head path and velocity in emergency landing conditions (without wall) and typical position of a partition wall.

A HIC value of 1000 shall not be exceeded.

The HIC is based on acceleration data measured in three directions by accelerometers which are installed in the head of the dummy. The level of HIC is defined by

$$\mathrm{HIC} = \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)\, dt \right]^{2,5} \right\}_{\mathrm{max.}} \leq 1000$$

where t_1 = initial integration time
t_2 = final integration time (sec)
$a(t)$ = total head acceleration in units of gravity

Evaluating the HIC from measured head acceleration curves the time interval $t_2 - t_1$ has to be chosen such, that HIC becomes a maximum.

In SAE Aerospace Standard AS 8049, a "Performance Standard for Seats in Civil Rotorcraft and Transport Airlines", it is stated that documented head strike path and documented head velocity along the path "can be used by the interior designer to ensure either that head impact with the interior will not take place or that, should any unavoidable head impacts occur, they can be evaluated using HIC."

Until now it is not expressed clearly whether a component test using a headform impactor (a dummy head with a pendulum or another type of striking device) would be accepted to determine HIC during impact on an interior cabin wall corresponding to the measured head strike path.

Today full scale tests are required for certification. They require a complete setting up of the partition wall and the involved seats on a test sled.

Corresponding to the worst load case one or more seats have to be equipped with a Part 572 anthropometric test dummy. Test conditions as for example the deceleration test pulse are defined in SAE AS 8049.

Evaluation of HIC with component tests

Unfortunately in full scale tests only one location of head impact can be evaluated per test. Probability is low that the location tested is really the impact location resulting in the highest HIC.

Component tests require less effort and lead to more systematic results than expensive full scale crash tests. Once the impact regions are known by running full scale seat tests (or eventually by mathematical computer simulation) impact locations

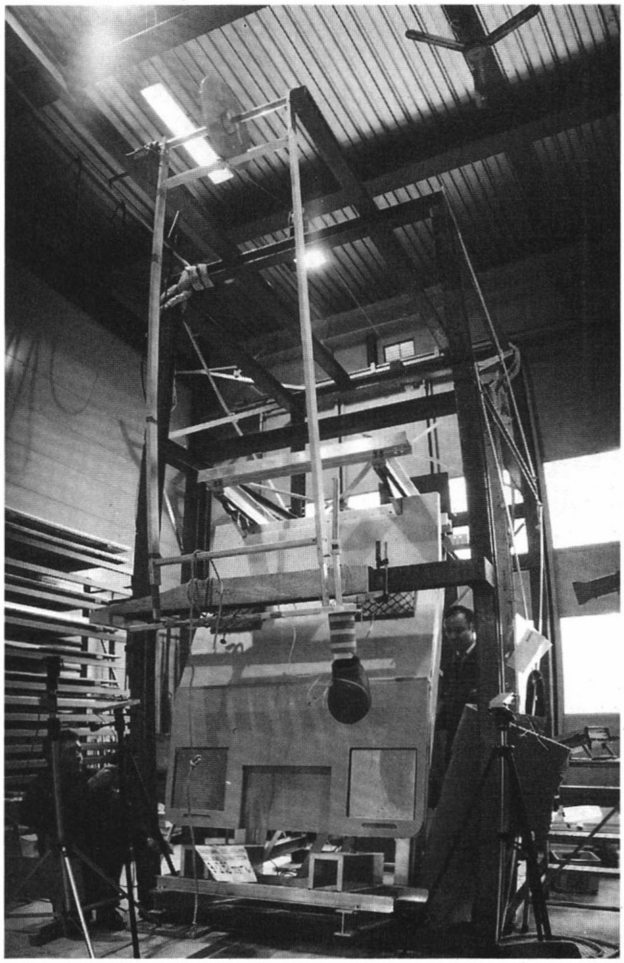

Fig 3 Test installation for component tests with a headform attached to a pendulum.

are more precisely struck in component tests with a headform pendulum than in full scale crash tests.

Therefore it may be worthwhile to work out and to propose a certification procedure for head impact on cabin interior walls mainly based on pendulum tests with an instrumented Part 572 dummy head used as impactor.

In the test configuration of Fig 3 the dummy head is connected to the shaft of the pendulum by a device which discontinues shear force and bending moment transfer between head and shaft just before impact of the head takes place (Fig 4).

The accelerations measured with an anthropometric headform in a component test will always be equal to or higher than those measured in the head of an anthropomorphic dummy in a full scale test. The reason is that an additional mass like the mass of the head and the upper part of the body involved in an impact at a given deformation force will always lead to lower deceleration values according to Newton's law of motion.This is in agreement with the results of impact tests with headforms of different weight obtained by Sakurai M. et al.[(4)] Head impact test methods are discussed by Glaeser K.[(5)]

A simple HIC design criterion for the engineer

Designing for compliance with the Head Injury Criterion HIC which is based on the weighting of an acceleration time history in an impact is very different from design corresponding to static load cases.

In order to determine the shape and the dimensions of structural parts assumptions on the applied loads must be made.

Therefore the question arises how large a dynamic load on the impacted structure may be to be consistent with the Head Injury Criterion.

A first approximation would be to assume a constant force corresponding to a constant deceleration if applied only to the headform of the dummy and determine the constant value of the deceleration a_0 which leads to a HIC of 1000.

At an impact velocity of v_0 = 15 m/sec which is in the order of the largest head velocities observed in fullscale dynamic seat tests (corresponding to AS 8049) the time interval until the head will stop is:

$$t_2 - t_1 = \frac{v_0}{a_0}$$

and with a_0 in units of gravity:

$$t_2 - t_1 = \frac{v_0}{9{,}81\ a_0}$$

Fig 4 Just before impact, the steel cable which prestresses the neck is completely loosened, the discs between head and pendulum therefore disconnect. Head impact velocity is 15 m/sec.

the HIC-formula can be simplified to:

$$HIC = (t_2 - t_1) \cdot a_0^{\ 2,5} = \frac{v_0}{9{,}81} \cdot a_0^{\ 1,5}$$

and:

$$a_0 = \left[\frac{9{,}81 \cdot HIC}{v_0}\right]^{\frac{2}{3}}$$

With HIC = 1000, v_0 = 15 m/sec solved for a_0 follows:

$$\underline{a_0 = 75{,}3\ g}$$

A constant deceleration can be regarded as quite efficient in stopping an impacting part on short distance.

With a mean acceleration of a = 75.3 g and an impact velocity of 15 m/sec a stopping distance of $s = v^2 / 2a$ results:

$$s = \frac{v^2}{2a} = 0{,}152\ m$$

This means that the structure impacted by a head will have to deform six inches at a constant deceleration rate of 75.3 g in order to only just perform the criterion $HIC_{max.} \leq 1000$.

Neglecting the rotation the head can be idealized into a particle with a mass of about 5 kg. Newton's law of motion can then be written as:

$$\sum F = m \cdot a$$

where $\sum F$ = vector sum of forces acting on the particle
m = mass of the head (about 5 kg)
a = deceleration during impact

Based on the considerations on deceleration curves and the Head Injury Criterion HIC it can be stated that the acceleration a should not exceed 80 g for more than a few milliseconds.

Therefore $m \cdot a = 5\ \mathrm{kg} \cdot 80\ \mathrm{g} \geqslant 4000\ \mathrm{N}$

The upper value for the force applied to the head ΣF must be therefore about 4000 N.

The estimated values for the force and the deformation are a good starting point for the designer: Keep the plastic deformation load as constant as possible and below 4000 N (= 80 g times 5 kg). Provide a deformation way of about six inches.

The forces contributing to ΣF are on the one hand inertia forces due to the acceleration of the zone of the wall which is impacted by the head, on the other hand forces corresponding to the stiffness of the impacted structure under relatively large plastic deformations.

The impact velocities are too low to influence the static stress strain curves of the materials used in the design of the wall. The buckling resistance under impact loads however may be substantially higher than under static loading due to the inertia loads of the structure in lateral bending.

A constant deceleration is not the best shape for low HIC. Instead a high deceleration at the beginning of the impact is more efficient in reducing the stopping distance. Therefore at a given deformation an acceleration curve which starts with a high value and decreases continuously to zero until the impact deceleration comes to an end will result in a lower HIC, as can be seen in Fig 5.

However the order of magnitude of deformation at a given HIC is not substantially chanced. For design purposes it therefore seems easier to work with a constant deceleration; there is no need to be too afraid of a very short high deceleration peak at the beginning of the impact.

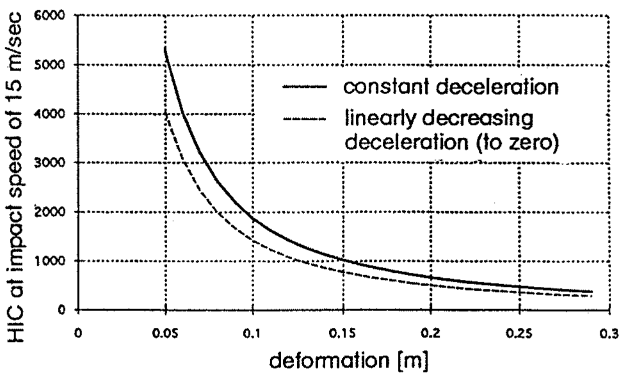

Fig 5 Structural deformability and Head Injury Criterion, impact velocity is 15 m/sec.

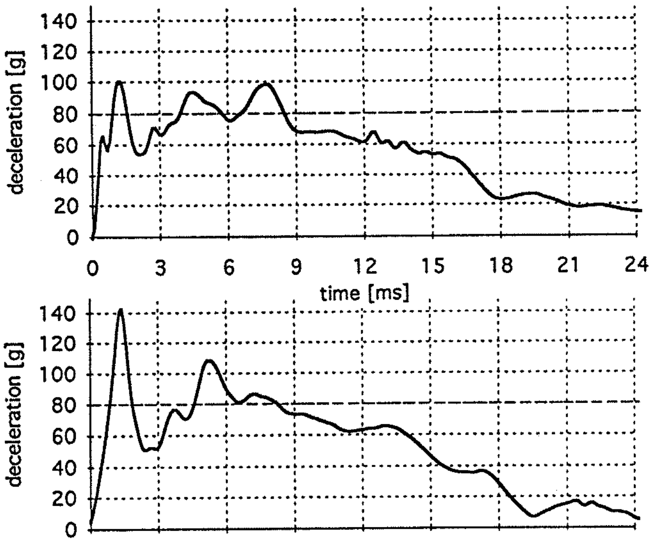

Fig 6 Head impact in the center part of the partition wall. The different initial peak depends mainly on the different initial inertia load of the accelerated impact location of the panel. The differences of the HIC values are small: 680 for the small and 690 for the high peak.

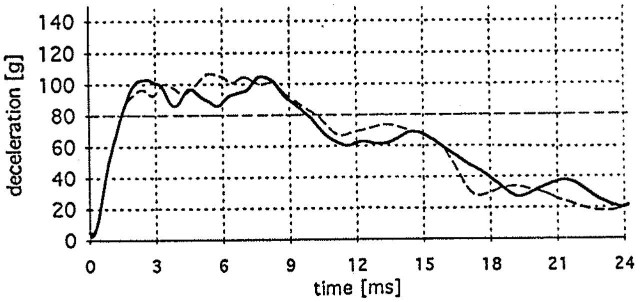

Fig 7 Head impact on the partition wall a few centimeters away from a monitor (weight: 3.5 kg). Full line: HIC = 903. Broken line: HIC = 1015 (impact 12 mm nearer to the monitor). Small changes in the deceleration curves may cause large differences in the HIC values.

A different deceleration peak at the beginning of impact has only a small influence on the HIC (as shown in Fig 6). On the other hand small differences in the deceleration curves over a longer time period may result in large differences of the HIC, see Fig 7.

Design of a wall which is crash-worthy in head impacts at 15 m/sec

The similar design problem of head impact on hoods of automobiles has been discussed by Kaeser R. et al.(6) A head impact proof hood for automobiles has been presented by Gaegauf M. et al.(7)

The previously assumed impact load of about 4000 N is acting on an area of approximately 150 cm^2 and should not vary too much during a deformation of six inches. At the moment no foam material is known which offers an appropriate force deformation characteristic and complies with the flammability and toxity regulations.

Conventional sandwich panels are very stiff and therefore offer no chance to comply with the Head Injury Criterion.

Handling loads must be kept in mind. They ask for a surface which is not sensitive to locally applied forces and they ask for an appropriate dynamic stiffness. The required low mass under the mentioned conditions can be obtained with a sandwich plate with thin aluminium facings combined with a flexible core material.

It must be provided that the impacted sandwich panel does not locally deform like a membrane - after large deformations under a low force level the stiffness would augment rapidly due to large membrane strains. With appropriate local stiffening of the sandwich panel, the pattern and the amount of local deformations can be influenced as well as the load deformation characteristic.

The dynamic stiffnesses at the different impacted regions should not differ significantly. Head impact at locations where supports are behind the panel shall lead to deceleration curves which respect as well the HIC ≤ 1000-Criteria as an impact in the middle of the panel or an impact at locations where a stiffener is located behind the panel. Therefore supports must be designed such that they deform together with the involved panel region under loads below 4000 N. Fig 8 shows schematically the structural design elements of the wall.

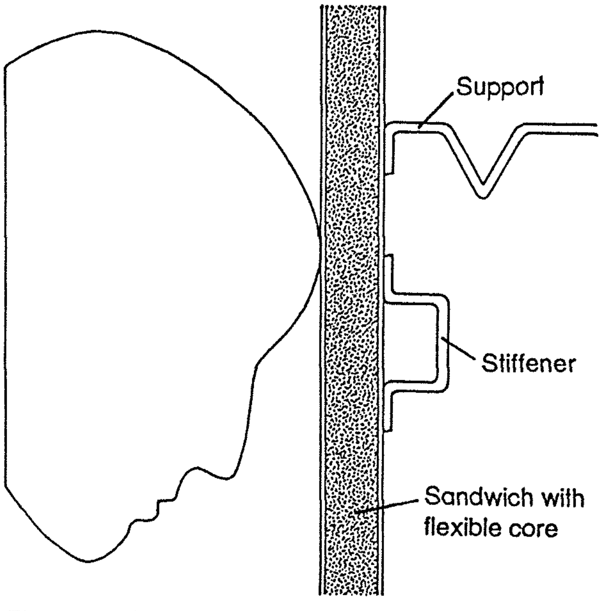

Fig 8 Design elements of a panel adapted to head impact.

High masses like monitors integrated in the panel must be kept away a few inches from head impact regions. Acceleration of these masses by the impacted panel region leads to head accelerations which can easily exceed HIC≤1000.

Experimental verification of the wall design

Head impact tests were carried out with a pendulum hitting different points in those regions of the partition wall, which might be impacted during emergency landing and during the corresponding dynamic test (FAR 25.562). All the potential impact regions, which might be estimated as the worst cases of head impact have been tested.

Points chosen for impact tests were:
- in the center of the wall (large inertia loads of the wall)
- on the border of the wall at different heights (influence of the side border and of structural parts behind the wall)
- overlap of the impacted upper panel over the middle panel
- near supports behind the wall
- near opening of the monitor (high inertia loads due to the mass of the monitor)

Impact angles were 22° and 47.5° to the normal on the wall surface, corresponding to the evaluated worst position cases. Impact velocities have been chosen between 14.5 and 15.4 m/sec.

The complete partition wall was mounted upside down in a test rig on supports corresponding to the fixation in the airplane. The position and the angle of the test rig could be easily adapted to meet the chosen impact locations and head impact angles with the impact pendulum (Fig 3).

The impact pendulum consisted of a lightweight frame pendulum with a PART 572 dummy head mounted on the lower end. The head could be mounted in different positions to meet impact locations on the right and on the left of the test wall.

As impact velocity had to be high (more than 50 km/h) the pendulum was additionally accelerated by an external load which was introduced by a wire near the upper end of the pendulum. The action of the external load was stopped just before the resulting impact velocity was reached. A laser based light barrier then measured the velocity of the headform.

As mentioned earlier the highest deceleration and HIC values result when the head alone hits the wall.

Supplementary mass reduces decelerations and HIC. Therefore shear force and bending moment transmission between head and pendulum have to be interrupted when head impact takes place.

The head was connected to the impact pendulum by means of shear transferring discs which were prestressed by a cable. This cable was completely loosened just before impact of the head on the wall to prevent transmission of shear force and bending moment between head and pendulum (Fig 4 and Fig 9). The pendulum was stopped separately.

Head accelerations were measured by a Piezotron miniature triaxial accelerometer. Data acquisition and processing was done with an industrial 386 LapTop. The acceleration in the acceleration-time curves is the resulting acceleration from triaxial measurement.

The HIC values were determined on the base of the measured accelerations in the tests. They range from 342 (on the corner of the wall) to 928 (border with a sliding flap behind it). Hitting the net pocket led to a HIC of 1045.

Fig 9 and Fig 10 show typical patterns of damage of the wall.

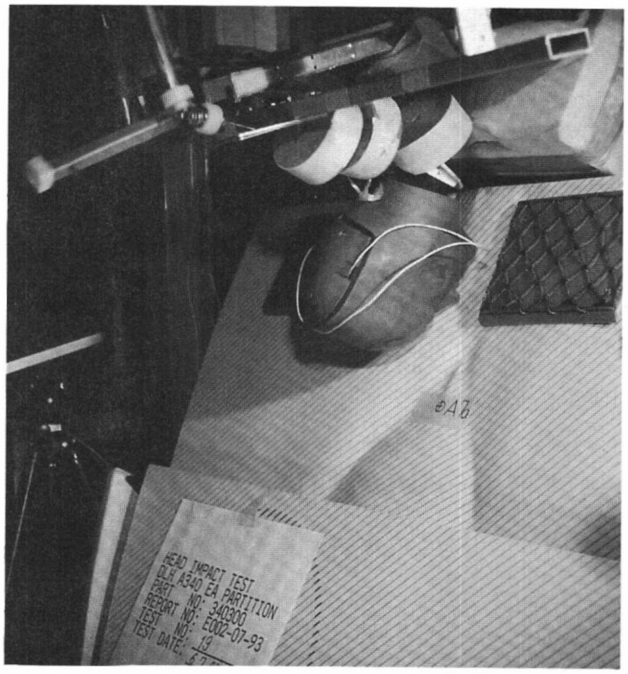

Fig 9a A few milliseconds after head impact in the center of the middle panel. After impact the head glides down the wall (in the picture = up due to reverse position of the wall). Impact velocity 15 m/sec.

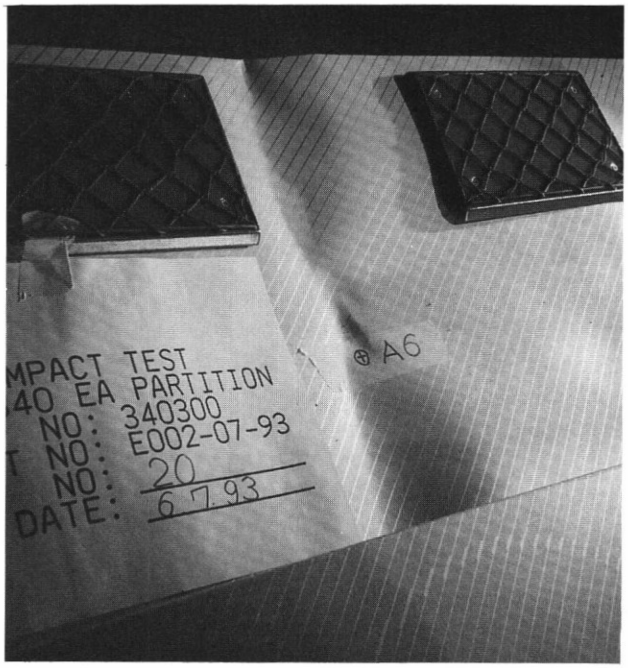

Fig 10a Damage after head impact in the center of the middle panel. Impact angle 47° to the normal on the panel. Impact velocity 15 m/sec.

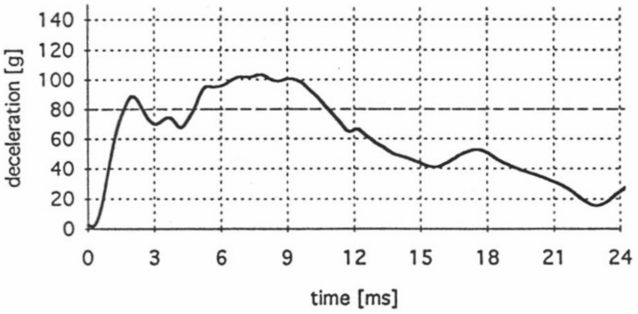

Fig 9b Corresponding deceleration curve HIC = 790. Impact location 185 mm more to the right than in Fig 10.

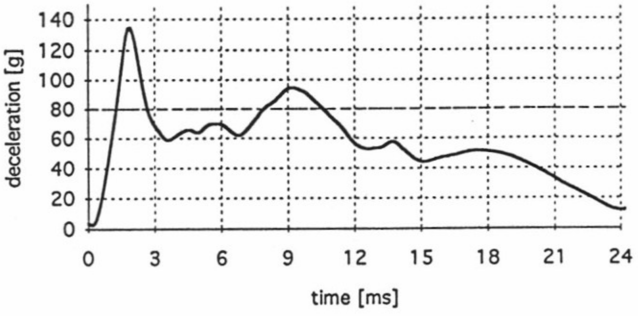

Fig 10b Corresponding deceleration curve of the head. HIC = 672.

Conclusions

Cabin interior walls which are crash-worthy in head impacts at 15 m/sec are available today.

A deformability of about six inches is required to satisfy the Head Injury Criterion.

A certification procedure for head impact based on component tests should be worked out.

References

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(3) Gowdy V., DeWeese R.: "Evaluation of Head Impact Kinematics for Passengers seated behind Interior Walls", DOT/FAA/AM-92/20.

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