SAFETY OF SEATS IN MINIBUSES - PROPOSAL FOR A DYNAMIC TEST

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ABSTRACT

The paper discusses the safety of minibus seats in the light of the current European Safety Directives, general safety requirements regarding structural behaviour and occupant protection, accident investigation, full scale tests on minibuses and vans and numerical simulation studies. The evidence strongly supports the view that the current static testing of the seat belt anchorages ought to be extended to dynamic complete seat tests with instrumented dummies, for which a test acceleration corridor and safety requirements have been proposed.

INTRODUCTION

A 'minibus' (usually referred to as an 'M2' vehicle) represents a small public service vehicle that carries more than 8 seated passengers (normally without standees) and the upper bound is referred to either a maximum number of 16 passengers, or to a maximum gross vehicle mass (GVM) of 5000 kg. Almost all modern European minibuses are produced as van conversions, where the front end with engine, transmission, steering, wheels and (usually) the complete floor pan are kept. The van body structure is either basically unchanged, or replaced by a variety of purpose-built new bodies. A very large majority of minibuses have the GVM less than 3,500 kg. In comparison with cars, the minibus transport is statistically rather safer, but accidents do happen attracting much media attention and public concern.

The safety of minibus seats is currently affected in the European Union by the Safety Directives, whose latest revisions 96/36/EC, 96/37/EC and 96/38/EC were largely based upon the results of the research programme summarised in Ref. [1]. Seatbelts will be gradually phased-in from October 1997, 1999 and 2001, with 3-point belts compulsory in minibuses with the GVM less than 3,500 kg, while lap-belts are allowed in heavier vehicles. Safety belts are usually mounted on the seats and the current Requirements are defined only in terms of the *static* forward pull loads. The seat may be rigidly mounted on the test rig (for seat Approval) or on a representative segment of the vehicle body (for the system, i.e. seat and installation Approval).

The car (M1) seats and headrests must be tested (without anthropometric dummies) under a series of static and dynamic loads. The large coach (M3) seats are tested under reverse acceleration between 8g and 12g and with Δv = 30 km/h, loaded with 50%ile male instrumented dummies whose injury criteria are limited to : HAC (head)=500, ThAC (thorax) = 30g and FAC (femur) = 10 kN (8 kN for not more than 20 ms).

The objective of the current research was to establish whether a new, dynamic safety test method of the minibus seats may be appropriate and, if so :

(a) what test acceleration pulse should be used to reproduce loading in 'typical' real accidents ;
(b) what other test conditions and requirements would be most suitable.

ACCIDENT RESEARCH

VSRC examined for many years the crash performance of vans and minibuses in the UK (a total of 265 cases) on behalf of the Ford Motor Company. The study included inspection of the crashed vehicles, collection of occupant injury data, accident reconstruction and assessment of the sources of injury.

The *objects struck* were : lighter collision partners - passenger cars (49%), heavy (and stiff) goods vehicles (20%), light goods vehicles of similar mass (5%) and a wide variety of on- and off-road obstacles, such as trees, posts, etc. Most (50 %) of the accidents took place on 'A-roads' (primary arterial routes), 37 % in local traffic, 10 % on 'B'-roads and 4% on high speed motorways.

The *impact severity* was measured by the equivalent energy speed (EES). This was based on measurements of the *vehicle structural* damage, subsequently processed by the program CRASH3. The main cluster of cases spreads between 10 and 80 km/h (Figure 1.), with the median (50th percentile) speed of 35 km/h and the 90th percentile of 65 km/h. Most accidents happened between 20 and 50 km/h.

The frequency of the *front end overlaps* with the collision partner is shown in Figure 2. The distribution of

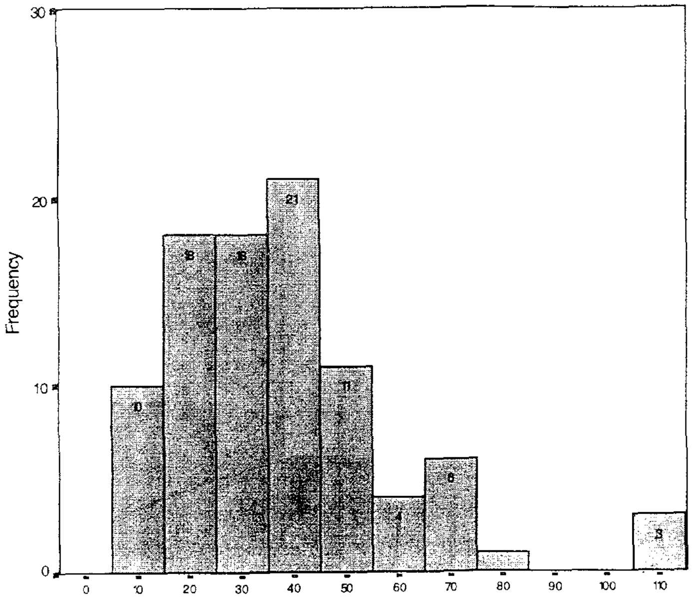


Figure 1. Equivalent Test Speed at impact (km/h)

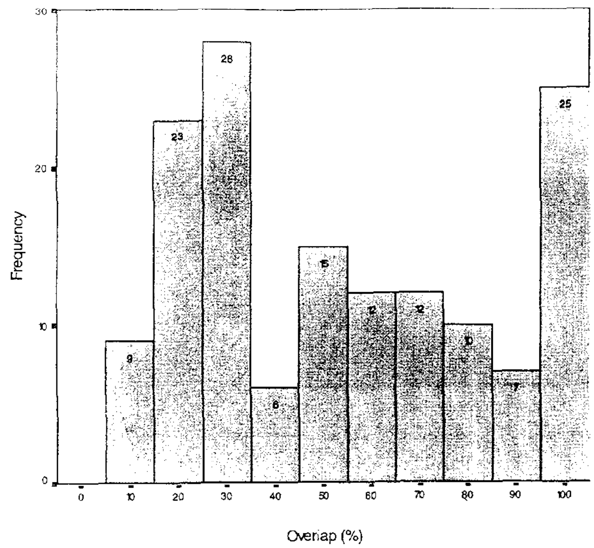


Figure 2. Front end overlap with collision partner

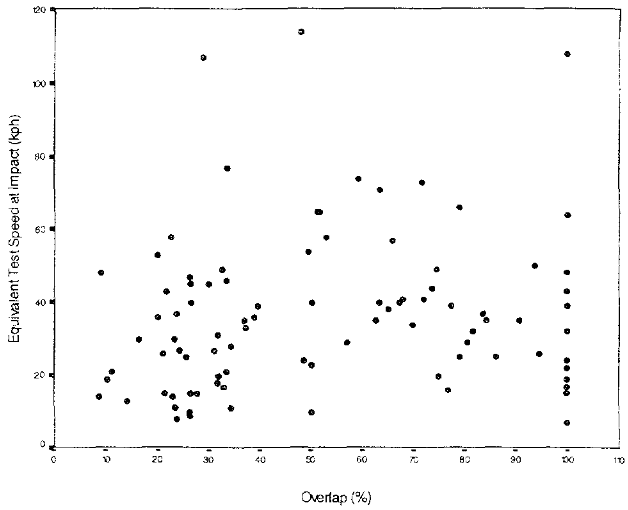
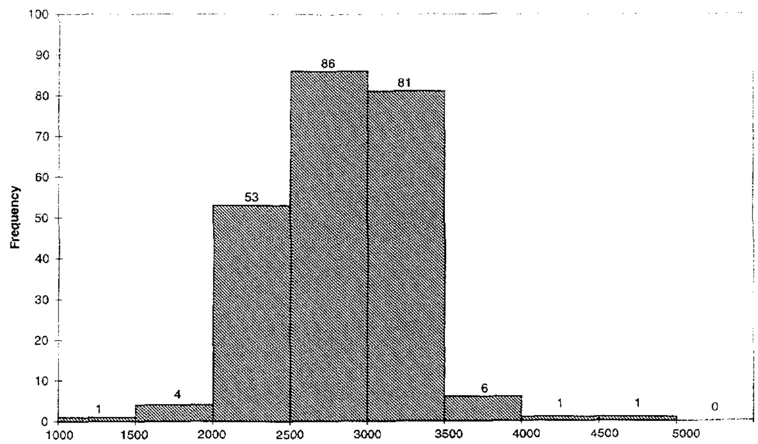
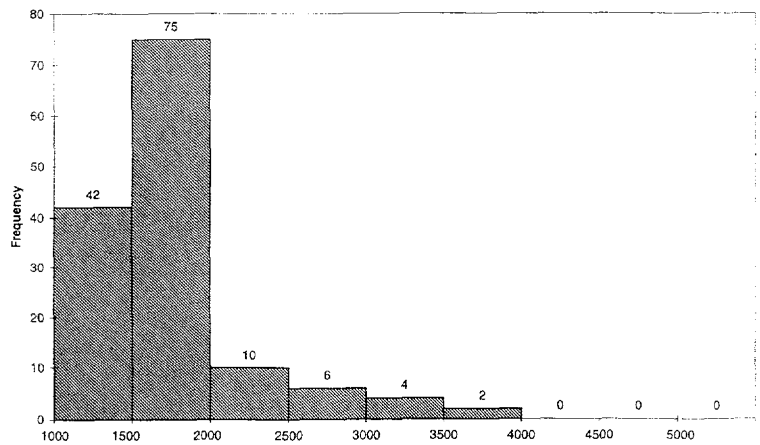


Figure 3. Overlap vs. Equivalent Test Speed



(a) Gross vehicle mass (kg)



(b) Mass at impact (kg)

Figure 4. Vehicle Mass distribution from accident data

the *location of the contacts zone* was : the left, right and central third - 12 %, 21% and 5 % respectively, left and right two thirds 12% and 16 % and all three thirds 34 % (possibly with less than 100% overlap). The EES and front end overlap were broadly independent (Figure 3), with a relatively even spread of impact speeds over the full spectrum of highly offset (10% overlap) to full frontal impacts.

The *gross vehicle mass* of most minibuses and vans was 2500 kg to 3500 kg (Figure 4a), with the actual *mass at impact of 1500 kg to 2500 kg* (Figure 4b). Hence it was concluded that van conversions with GVM less than 3500 kg ought to be regarded as reference for the possible future amendments of the EEC safety Directives for all minibuses.

The 25 vehicles from the frontal impacts sample had eight or more passenger seats, out of which 18 contained information on the seating positions and injuries to the vehicle occupants. Selected typical accident scenarios (front and rear impacts, collision with other vehicles with different offsets, crash against a tree, etc.), were studied including the circumstances within the passenger compartment (forward /side facing seats, etc.) and the injuries to occupants. Over half of the vehicles in this sample had occupants who were at most slightly injured (57%), but more than half were travelling on class A roads or motorways, or on roads with a speed limit of 60 or 70 mph.

Most back passengers had no seat belts to use and they generally moved into or over the seat in front. A relatively small proportion of these passengers received isolated bone fractures of the hand, arm, leg, nose or chest, but no fractures of the skull were recorded, nor any damage to the internal organs (brain, heart, lungs, liver, etc.). It is likely that the use of three-point seat belts would have prevented the occurrence of almost all these injuries. Two cases presented involved restrained drivers whose injuries were almost certainly aggravated, if not caused, by occupant impact from behind. The need for seats to protect both the restrained and the rear unrestrained occupants becomes increasingly important as the fitment and use of seat belts in minibuses increases.

The worst case involved a high speed front impact followed by fire of a minibus with side facing bench seats in which 10 young teenagers died on site.

In the vast majority of (frontal) minibus impacts, the front region of the passenger compartment - dashboard, steering wheel, windscreen and so on - does not intrude into the vicinity of the back seats. Provided a satisfactory restraint system is fitted to these seats, the back passengers therefore have the opportunity to survive exceedingly severe impacts, as has been documented many times in passenger cars. The primary requirement is that the restraint system does not fail, including no separation of the seat and belt anchorages from the floorpan. Such separation turns the passengers into flying objects, to the detriment of themselves and their fellow occupants, despite having secured their seat belts before the impact. In modern passenger cars, the restraint failure in the back seats is very rare, hence safe seat belts and anchorages in minibuses aim to provide protection similar to that of the back seat passengers in cars.

It is not necessary to optimise the whole seat design (structural and injury criteria) for the most severe impacts that cause the most serious and costly injuries, but are relatively rare. A seat optimised only for the most severe impacts with *combined* loading, from the belted occupant(s) in the seat and unbelted sitting behind, might present harder and stiffer surfaces to the unrestrained or lap-belted passenger than is desirable over the *whole range* of accident circumstances. The overall cost of head and lower limb injuries, in particular, may thus not come down towards the best achievable level. The general seat design (i.e. including the injury criteria) should therefore be optimised for the 'intermediate' crash severity of real-world impacts - high enough for a significant risk of injury to back seat passengers, but low enough for the effective countermeasures, particularly including the combined loading.

The 'intermediate' crash severity test acceleration pulse can be based on a 48 to 55 km/h (30-35 mph) rigid barrier front impact complete minibus test, with an overlap (offset) of approximately 50%. This speed range would stand at around the 85th percentile level for the cases in the VSRC database and has already been widely adopted as a reference speed for crash testing. In view of the wide spread of overlaps observed in real crashes, a mid-range value of 50% may be regarded as representative.

It would, however, be desirable that the *structural* strength of the seat and seat belt anchorages is extended to sustain a higher load than that associated with optimisation for the 'general', i.e. injury-criteria inclusive, seat design. It is, for example, known that even with sub-optimal seat performance, restrained passengers in the front seat of cars (with belts holding while attached to the car body) endure the impact from behind of unrestrained rear passengers. An acceleration pulse based on a full scale minibus crash against a rigid barrier at 55 km/h (35 mph) with full overlap, would represent a moderate requirement for the structural integrity of the seat and seat belt anchorages. With the seat and belt anchorages capable of sustaining combined loading under these conditions, it is likely that a restrained occupant not struck from behind by an unrestrained occupant would be protected in most of the accidents documented in the VSRC archives. This may not apply to all occupants in seats under combined loading, since there were accidents at even higher speeds and full overlap. Still, the higher impact speeds need not always generate higher maximum decelerations, as may be strongly influenced by the vehicle mass at impact, whether occupants are belted and on the properties of the collision partner. However, there is a difficulty in comparing the recommended test condition to impacts at greater speed (higher severity acceleration pulse) but less overlap (lower severity acceleration pulse). The matter is further complicated by the fact that the mass of the same vehicle may vary depending on payload and whether and how the passengers are belted.

EVIDENCE FROM THE FULL SCALE MINIBUS / VAN CRASH TESTS AND SIMULATIONS

A study was made of the deceleration pulses measured during the full scale minibus and van crash tests under different conditions. To start with, a method was needed to transform the highly oscillating full scale test deceleration pulse (Figure 5-a), with a high scatter amongst vehicles, into an equivalent, 'smooth' one for repeatable, standardised laboratory sled testing. This was achieved by first fitting a polynomial function to the full scale *velocity* pulse (Figure 5-b), usually obtained by integration of the acceleration signal, or from the high speed film analysis. The first derivative of the polynomial is then plotted (Figure 5-c) to obtain the smooth accelera-tion signal for the laboratory test. The method was justified by the fact that the maximum seat / belt loading and dummy injury results are primarily influenced by the *relative speed at contact between the dummy and seat*, rather than the peak vehicle acceleration which usually happens while the occupants are still freely moving.

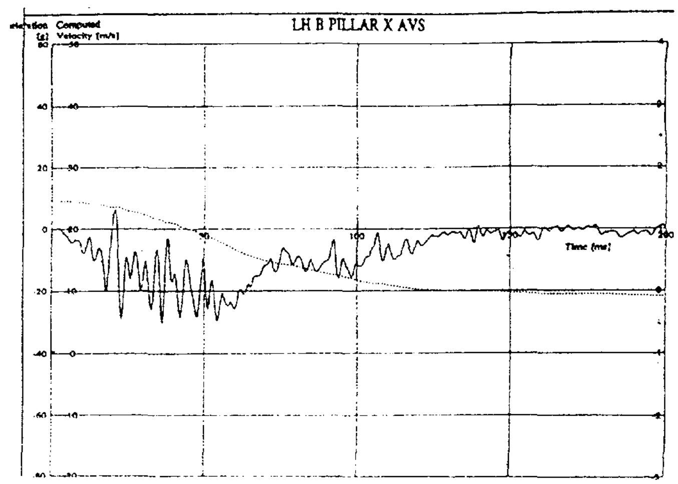
Background full scale frontal crash tests on typical light European vans and minibuses of different make provided 8 deceleration pulses obtained at different masses (1633 kg to 3500 kg), impact speeds (48.6 km/h to 64 km/h) and offsets (40% to 100%) into rigid barrier and stationary minibuses (Table 1. - tests 1 to 4 and 6 to 9).

Two *foreground full scale tests on minibuses* were designed to complement the background evidence in terms of deceleration pulses and demonstrate the safety phenomena related to the non-forward facing seats. Both tests exceeded by far the front impact legislative requirements for the light vans (GVM less than 1500 kg) with driver mass only and impact speed of 48 km/h (30 mph).

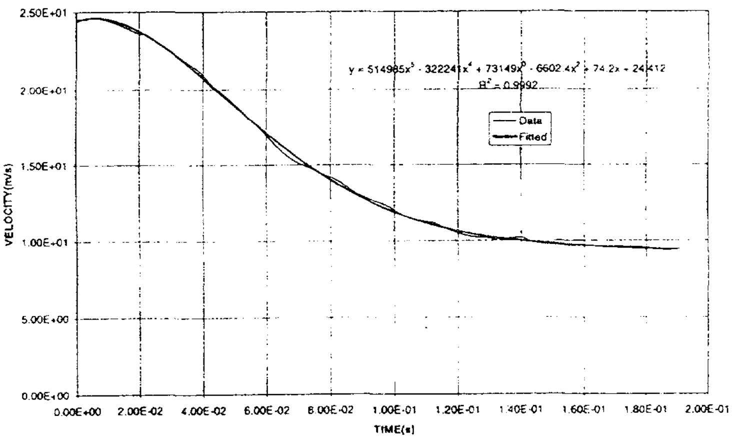
The first test (Figure 6-a and Test 5 in Table 1) was done on a typical European minibus with seating capacity of 15 including the driver, fully laden with sand bags belted in seats (total vehicle mass 3300 kg) and run at approximately 57.7 km/h (36 mph) into a rigid barrier. The 'seat-test equivalent' pulse is shown in Figure 6-b. All seats and anchorages (approved to M1 level) held well.

The second test (Figure 7-a and tests 10/11 in Table 1.) involved a similar vehicle, laden with six anthropometric dummies in side, forward and rear-facing seats (total mass 2609 kg), running into the back of the first test specimen (still fully laden) at 88.5 km/h (55.3 mph). The 'seat-test equivalent' acceleration pulse for the bullet vehicle is shown in Figure 7-b.

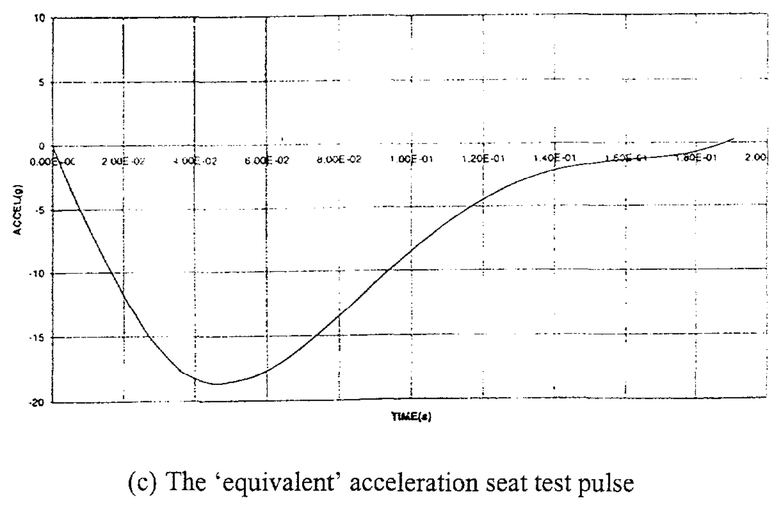
The *full scale test simulations* contributed useful additional evidence on the effect of vehicle mass and obstacle on the deceleration pulse. The background



(a) Crash acceleration and velocity time histories



(b) The true and fitted vehicle velocity curves



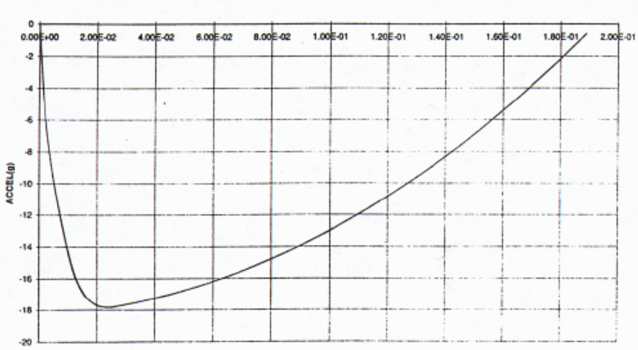
(c) The 'equivalent' acceleration seat test pulse

Figure 5. Derivation of the equivalent seat test pulse

Table 1.
Summary of the full scale crash test data

Test No.	Vehicle Mass (kg)	Impact Speed (km/hr)	Impact Scenario	Max. Equivalent Acceleration (g)	Time at Accelmax (ms)	Duration of Accel. (ms)	Comment
1	3500.0 (Target)	64.0	50% frontal impact into front of minibus	6.8	58	170	Target vehicle data inc. 2 dummies + 1180kg
2	3493.0	50.0	50% frontal impact with barrier	11.6	70	200	1850kg ballast
3	1989.0	56.2	50% frontal impact with barrier	22.1	45	140	inc. 3 dummies + ballast
4	1633.2	51.1	40% frontal impact with barrier	17.9	48	140	inc. 2 dummies + test instrumentation
5	3300.0	57.7	100% frontal impact with barrier	17.8	25	190	**Foreground test**
6	2209.0	56.0	100% frontal impact with barrier	24.3	32	120	inc. 3 dummies + 300kg ballast
7	2194.5	48.6	100% frontal impact with barrier	27.1	36	105	inc. 3 dummies + test instrumentation
8	2001.0	48.9	100% frontal impact with barrier	28.0	33	95	
9	1959.0	57.2	100% frontal impact with barrier	28.7	25	105	inc. 3 dummies + test instrumentation
10	2609.0 (Bullet) 3300.0 (Target)	88.5	100% frontal impact into back of minibus	18.7	45	150	**Foreground test** Bullet vehicle data
11	2609.0 (Bullet) 3300.0 (Target)	88.5	100% rear impact from minibus	14.8	14	180	**Foreground test** Target vehicle data

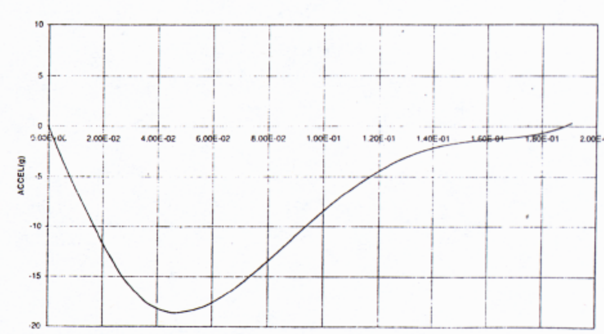
(a) Extract from the high speed film



(b) The 'equivalent' seat test pulse

Figure 6. Full frontal rigid barrier test at 57.7 km/h

(a) Extract from the high speed film



(b) The 'equivalent' seat test pulse

Figure 7. Vehicle-to-vehicle crash test 88.5 km/h

detailed finite element model of a typical light van (mass 2600 kg) was validated under the 56.9 km/h full frontal and 50% offset frontal impacts into an oblique barrier (Figure 8-a,b). The new parametric variations involved the full frontal 56 km/h (35 mph) impact of a vehicle with mass of 3500 kg, once into a rigid and then into a mobile deformable barrier (Figure 8-c,d).

The above full scale tests and computer simulations confirmed the effects of vehicle mass, obstacle characteristics, front end overlap and impact speed, with trends of higher and shorter acceleration pulses in lighter vehicles, stiffer barrier and higher overlaps.

The 'intermediate' severity crash tests, described as 50 % offset into the rigid barrier, produced the maximum equivalent HyGe sled accelerations: 11.6g (3500 kg), 22.1g (1990 kg) and 17.9 g (1630 kg), while the simulation model gave 29g (2600 kg). The timing of those maxima were mainly in the region of 40 to 50 ms.

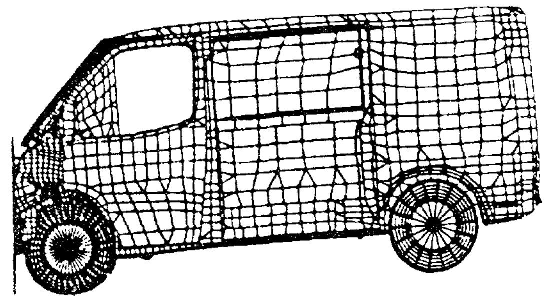
The 'more severe' crash tests described as 100 % overlap into the rigid barrier, produced the maximum equivalent HyGe sled-type accelerations : 17.8 g (3300 kg), 24.3g (2210 kg) and 27.1 g (2195 kg), 28 g (2000 kg) and 28.7 g (1960 kg), while the simulation model gave 29g (2600 kg). The timing of those maxima were in the region of 25 to 35 ms.

Impacts against other minibuses produced the equivalent acceleration maxima of 6.8 g (50 % offset front impact into a 3500 kg minibus) and 18.7 g (very severe impact at 88.5 km/h of a 2610 kg bullet vehicle into the rear of a 3300 kg target with 100 % overlap).

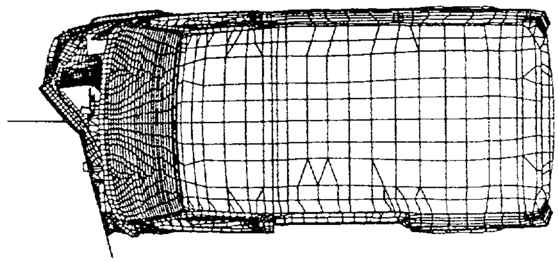
PROPOSAL FOR THE NEW DYNAMIC TESTS FOR APPROVAL OF THE MINIBUS (M2) SEATS

The research background summarised above served as basis to propose the following new dynamic tests for minibus (M2) seats :

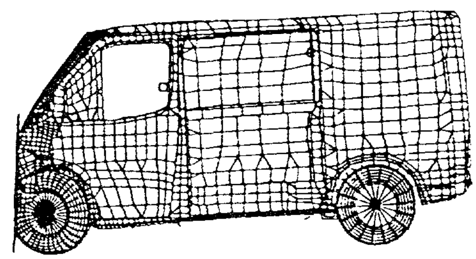
1. The test reference ought to be developed on the basis of minibuses with gross vehicle mass (GVM)less than 3,500 kg. As regards minibuses with GVM more than 3500 kg (up to 5000 kg):
   (a) their *mass at impact* is likely to be lower than or close to 3500 kg ;
   (b) they are often converted for transport of people in wheel chairs, for which the deceleration pulse (currently under discussion) is converging towards 20 g maximum at $\Delta v = 48$ km/h ;
   (c) it is commercially better (higher numbers - lower price) to have only two seat types - M2 and M3, rather than three - 'light' and 'heavy 'M2 and M3.
2. The M2 vehicle seats ought to be tested in isolation (seat Approval), or mounted on a representative segment of the vehicle body (system Approval).



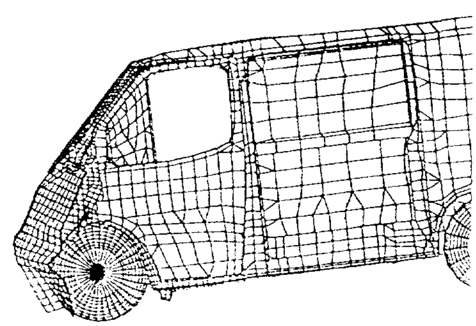
(a) Full frontal, rigid barrier, 56.9 km/h, m = 2600 kg (background information - courtesy : Ford)



(b) Oblique rigid, 50 % offset, 56.9 km/h, m = 2600 kg (background information - courtesy : Ford)



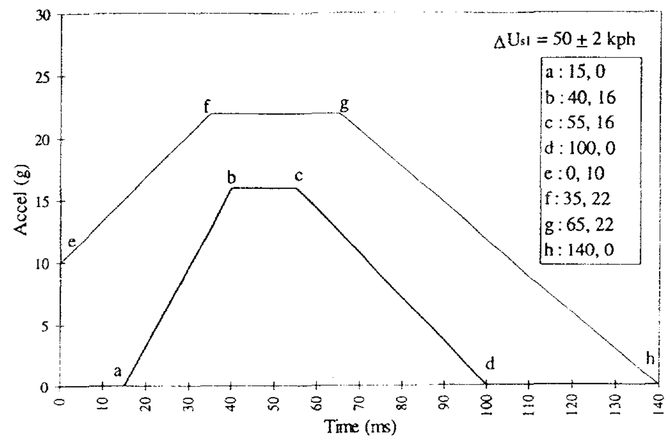
(c) Full frontal, rigid barrier, 56 km/h, m = 3500 kg



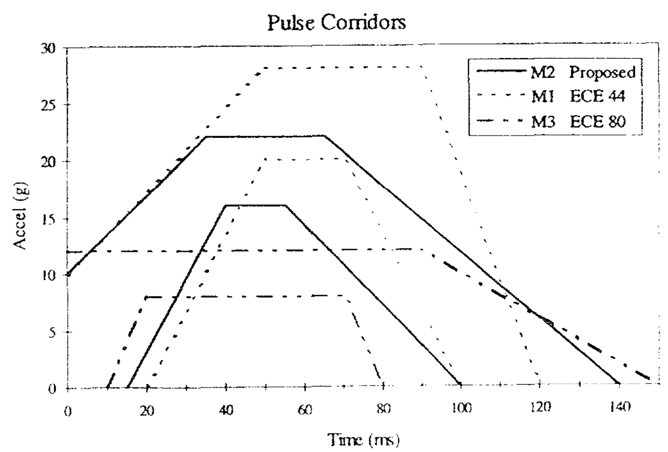
(d) Full frontal, deformable barrier, 56 km/h, m = 3500 kg

Figure 8. Numerical simulation scenarios

3. The *'intermediate' test pulse corridor* is shown in Figure9-a, with co-ordinates of characteristic points. The velocity change is between 48 and 52 km/h (30 and 32.5 mph), corresponding to the maximum HyGe sled speed in the reverse direction, or to the forward impact speed in deceleration tests. For comparison, the new M2 test pulse is overlaid in Figure 9-b with the corridors: ECE44 for child restraints in M1 cars and ECE80 for seats in M3 large coaches. The seat would have to meet both the injury and structural criteria under the test scenarios below.



(a) The proposed test corridor for minibus (M2) seats



(b) The M2 test proposal vs. the M1 and M3 corridors

Figure 9. The proposed test corridor for M2 seats

4. *Test scenarios* :
   (a) *Single loading by the belted occupant(s)*, with belt types specified in the EC Directives ;
   (b) *Single loading of an empty seat* i.e.:
      b1 : empty seat loaded by unbelted occupant(s) sitting behind,
      b2 : if applicable, empty seat loaded by lap-belted occupant(s) behind (for GVM>3500kg);
   (c) *Combined loading* produced by the belted occupant(s) in the seat (belt types as specified in the EC Directives) and :
      c1 : unbelted occupant(s) sitting behind,
      c2 : if applicable, lap-belted occupant(s) behind.

   The occupants would be simulated by the 50 %ile Hybrid III dummies including the neck injury transducers, although the Hybrid II dummy would also be allowed for a limited period (see 5(b) below).
5. The proposed *injury criteria* for all unbelted and lap-belted dummies interacting with seat in front under single and combined loading scenarios :
   (a) while appreciating the car- and minibus-related differences in the relative position of the occupant body and its immediate environment, still apply the best researched injury criteria for the front impact of the (M1) cars (Directive 96/79/EC), i.e. :
      a1: *head* HAC ≤ 1000 and acceleration shall not exceed 80 g for more than 3 ms ;
      a2: *thorax* - either use the new compression criterion - ThCC ≤ 50 mm and viscous criterion V*C ≤ 1.0 m/s, or apply the already specified ThAC ≤ 30 g for M3 coaches;
      a3: *femur*- either use the new FAC or FFC ≤ 9.07 kN and ≤ 7.58 kN for > 10 ms, with linear interpolation between 9.07 kN (duration zero) and 7.58 kN at duration 10 ms ; or apply the already specified FAC ≤ 10 kN (8 kN for less than 20 ms) for M3 coaches ;
   (b) *Neck injury criteria* neck (NIC), as in the front impact safety Directive for cars, i.e. :
      b1 : *Tension criterion* described, in the coordinate system : duration of loading over given tension (ms) vs. axial tensile neck force (kN), by the border line connecting points: (0, 3.3), (35, 2.9) and (≥ 60 , 1.1) ;
      b2 : *Shear criterion* described, in the coordinate system : duration of loading over given shear force (ms) vs. AFT neck shear force (kN), by the border line connecting points: (0,3.1), (25 to 35, 1.5) and (≥ 45, 1.1) ;
      b3: *Bending moment* about the lateral 'y' axis forcing the chin away from the chest *(extension)* ≤ 57 Nm.

      As in the Directive 96/79/EC, the neck criteria would be recorded during Approval tests, but shall not be pass/fail values to grant Approval until a specified date. Thereafter, the above figures would count unless or until alternative values are adopted.

6. *Structural integrity* criteria would specify that the seatbelts must remain attached to the seat, the seat must remain attached to the vehicle structure and that there should be no sharp edges in the occupant body contact regions.
7. *Seat anchorage test for combined loading under the higher, 28g pulse* is not proposed in either dynamic or static form for the following reasons (supported by other evidence to be reported elsewhere):
   (a) the seat anchorage loads were higher under the combined loading during the proposed 'intermediate' severity test for minibus seats than under the single loading at the 28g pulse,
   (b) simultaneous occurrence of the very severe accidents *and* combined seat loading are perceived to be so rare that the additional costs to the industry are difficult to justify.

   If such extreme conditions were to be included in the future Regulations, then additional work ought to investigate the feasibility, procedures and requirements for a cheaper *static* test.

RECOMMENDATIONS

The proposal above reflects the author's views in the relevant, but 'purely technical' terms. Whether this or a similar submission may be adopted for the future Safety Regulations for minibus seats ought to be also considered from the point of view of their technical and *commercial* feasibility and the overall cost benefits to the society. A further study covering these aspects would be desirable.

Not being specifically prepared, many of the current minibus seats may not meet the proposed criteria. It could therefore be useful to demonstrate the *technical* and *commercial* feasibility of such seats *prior* to Legislation. Based on the past experience, Cranfield Impact Centre is confident that both would be shown as effectively as with the *Universal Coach Safety Seat* [2] that *followed* Project [1]. This seat was conventional in all the production, size, weight and cost aspects, yet met and exceeded the new EC requirements, including the combined loading (with protection of unbelted and lap-belted rear occupants) and the neck criteria even with some 95th and 5th %ile dummies. The new M2 pulse is higher, but so is the critical HAC, and the most difficult case of protecting lap-belted occupants may be dropped.

As a longer term interest, the inherent problem with the 'narrow' scope test conditions in all modern Safety Regulations lies with the versatility of the accident impact conditions and the human body sizes, injury tolerance levels, etc. A system may be designed to solely meet a specific safety requirement, even at the expense of making it less safe in the overall sense. While appreciating and fulfilling the specific objectives of the current Project, the authors recommend that some Regulation-related future effort also addresses the wide variety of accident scenarios and human injury tolerances observed.

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