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A Dynamic Test Method for a Car's Interior Side Impact Performance

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Abstract

This paper gives a general description of a dynamic test method for development of a car's interior towards improved side impact performance. It also describes an application and some advantages of the test method.

The background and needs for this method are to:

- enable development of the interior of a car before the body is available in a new car concept.
- reduce the number of full-scale tests.
- reduce development time.
- reduce the needs of expensive test equipment.

In short, the method is based on a small moving barrier which carries the trim panels mounted on a door and side structure/bullet-substitute. Any available side impact dummy can be used in the method. The dummy is placed in the seat, which is positioned on the ground, via a special frame. To run the test, the moving barrier is accelerated up to a chosen "dummy impact velocity" before it impacts on the dummy and seat.

Preliminary findings show the test method to have good conformity with a full-scale test, both in dummy response and the behaviour of the interior components. Apart from the possibility of easily evaluating the advantages of improved design of regarding the trim panels, seat and padding, the method can be used to determine the effects of different bullets and structural performance.

Introduction / background

The increased interest in side collisions around the world has meant that the need for evaluation methods at different levels has also increased. There are a number of different ways to evaluate a car's performance in side collisions.

These can be divided up into four groups;
* Full-scale tests
* Component and sub-system tests
* Computer simulation
* Analysis of accidents in the field.

The most common is the full-scale test, but this has become more and more costly, particularly when it refers to, for example, evaluation of a minor change to the interior.

This paper concerns the group, components and sub-system test methods.

There are two main purposes for evaluating the side impact performance:
* Verification of legal requirements. This is relatively "simple", with only a few parameters which need to be measured.
* Development of own goals and authority's requirements. The costs and problems during this "engineering phase" are much greater since it requires the interpretation of large amounts of test data and analysis of performance, and where improvements need to be made.

The performance of a car during side collisions is often divided up into structural performance and an interior performance. The structural performance shall first and foremost make sure that the speed against the occupant is limited, by ensuring that penetration into the side of the car occurs in a peaceful manner and that the depth of penetration is kept small. The interior section shall limit the forces from the side of the car against the occupant during the course of the crash. This can occur by using a balanced impedance in the doors and seats. See figure 1.

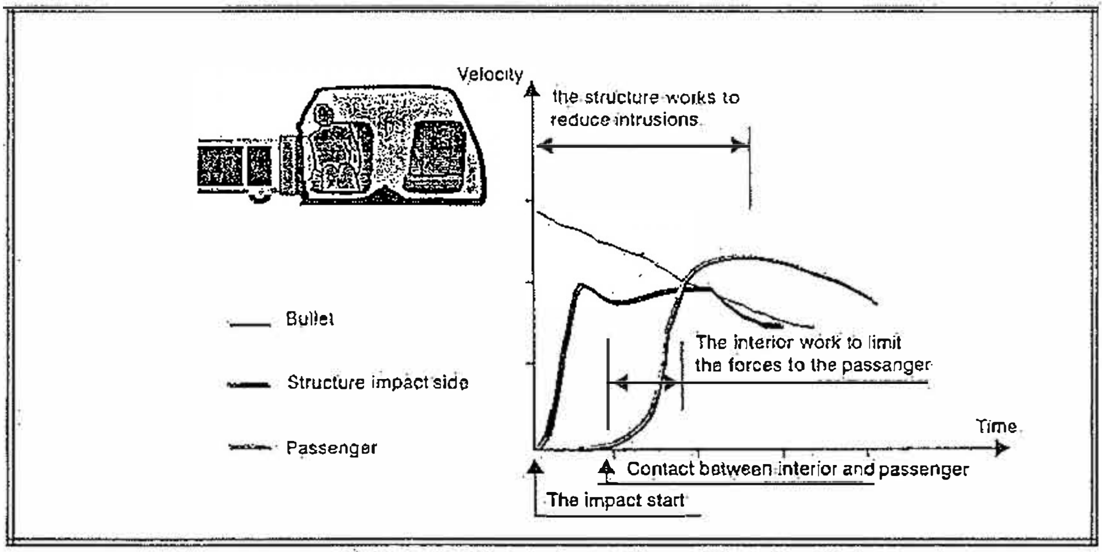

Figure 1. Basic side impact dynamics in full-scale test.

The background to the development of this test method was that Volvo needed an effective and simple method to get a better check on the stiffness of the interior. The method should primarily be used in a project where the goal of the car's structural performance was reached, but the interior still needed a certain amount of development work. The primary reasons for the choice of the method described in this paper were that the most important mechanisms of the full scale test should be retained. In addition the method should permit as quick and simple evaluations as possible.

Description of the test method

The test method was given the name DYNSUB test method (=DYNamic SUB-system test method), which will be used from now on in this paper. See Fig. 2.

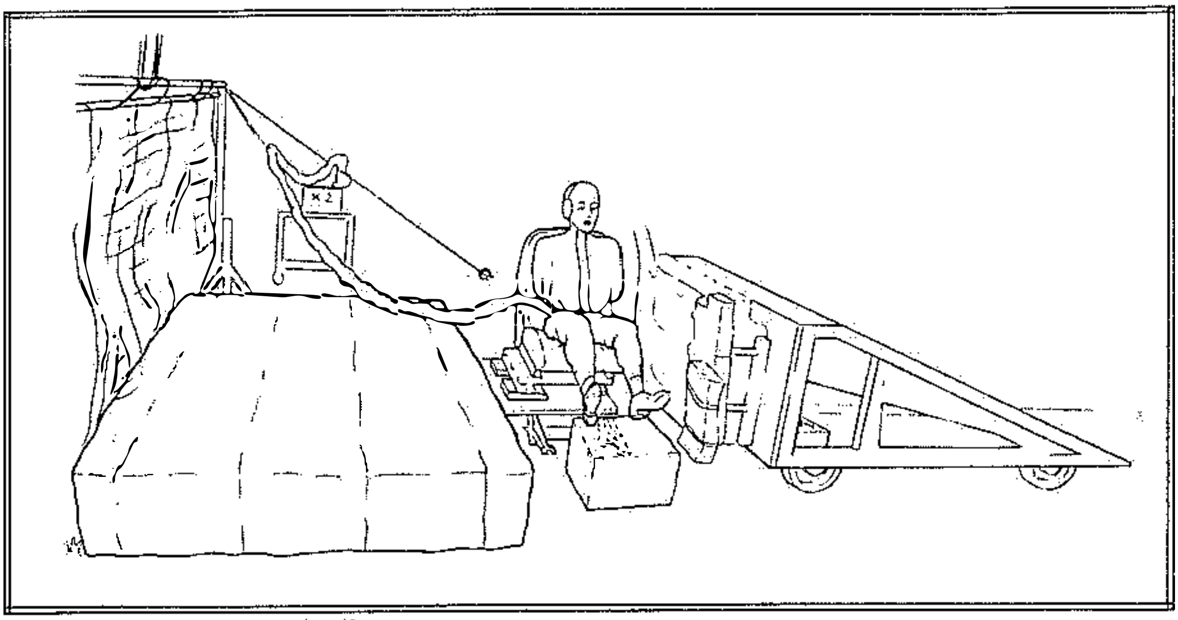

Figure 2. The DYNSUB test method set-up.

In principle, the DYNSUB test method was developed and designed to produce the velocity to which the front seat passenger is subjected by a pre-determined combination of crash type and structural performance. In addition, the following important parameters were simulated:

Seat movement, lateral and vertical.
Dynamic stiffness of the door which has been deformed from the outside.
Correct movement between the seat and the door.

The test equipment was based upon three main elements:

* A small moving barrier carrying the trim panels mounted on a door and side structure/bullet substitute.
* A special frame with the seat is positioned on the ground.
* A safety net and a large mattress which takes care of the movement of the dummy after the door impact.

The small moving barrier

The barrier was equipped with a flat front plate with the measurements 1600 mm by 700 mm. The complete barrier weighed approx 650 kg. The following items were fitted to the front plate:

The door substitute. This was made up of a plastic casting of an inner door plate filled with a very hard foam (Araldite 35 kg/m^3) in order to simulate the door when deformed from the outside. The door substitute was not fitted with a glass window, since experience has shown that this does not affect the dummy response, especially not that of the chest or pelvis. The door was placed vertically. Since the door's vertical profile is very important regarding how the occupant is struck, it must be adapted so that it corresponds to that which is simulated in the full-scale test (1).
Simulation of a partly deformed CCMC barrier. This was made up of a 150 mm thick PUR foam block (40 kg/m^3) and was placed between the front plate and the plastic casting's flat rear side. Adjustment of the door substitute's stiffness was done using computer simulation and static pressure on the substitute.
A car body structure section, containing A-pillar, B-pillar and bottom rail. This section was chosen from an earlier frontally crashed car, and surrounded the door in the same way as in a car. It was firmly fixed to the barrier's front plate.
The door panel, which was the test object, was fitted on the door substitute. See Fig. 3.

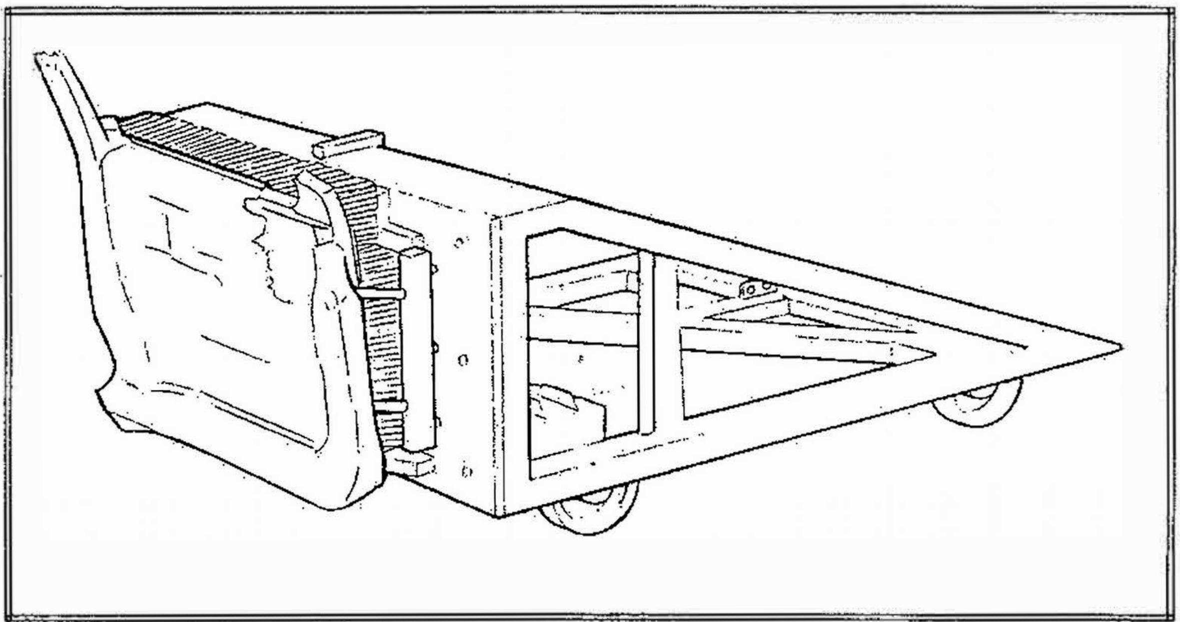

Figure 3. The DYNSUB test method barrier.

The seat frame

The seats which were used were real car seats. These were fitted on a special fixture which was placed directly on the floor of the test hall.
The fixture was made up of two sections:

An upper section which replaced the seat's normal slide rails. This was to achieve an even surface under the seat.
A lower section with the purpose of giving the seat a real pattern of movement during the test. This was achieved by wedges on which the upper section rested and was guided. This way the seat received a downward movement on the impact side and upward movement on the far side. In addition, the four "legs" consisting of car jacks made it easy to adjust the height and angle of the seat.

No seat belt system has been used in the DYNSUB test method, since the belt system does not allow for this to be fitted in a simple manner. Earlier investigations have shown that belts do not affect the dummy's chest and pelvis responses in side collisions (2).

Two aluminum, honeycomb blocks were fitted to the impact side seat cushion, one front and one back. Their purpose was to produce a correct relative movement between the seat and door (method parameter 4)., and to give the seat the correct lateral speed. The blocks each had a thickness of 100 mm and a stiffness of 6 kN. Both the thickness and the stiffness of the blocks required adjusting during the fine tuning of the method.
See Fig. 4

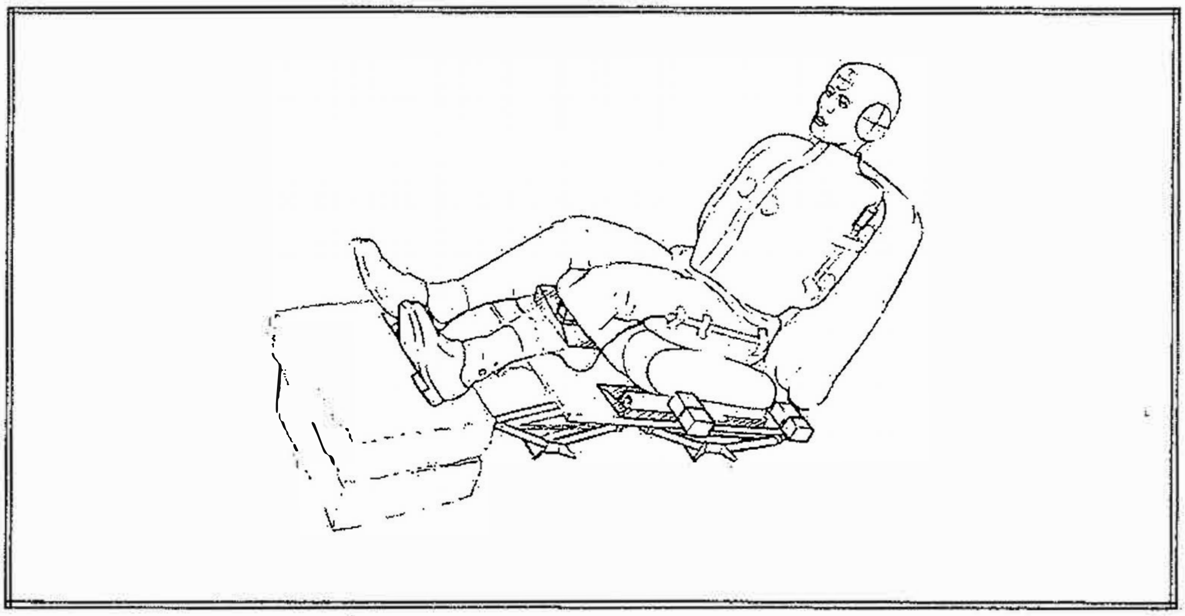

Figure 4. The seat frame.

The retension arrangement

A vertical safety net was placed across the the direction of the dummies' movement for the purpose of eliminating damage which can occur on the dummy and its cables after the course of the test. A large mattress was spread out on the floor in front of the net for the same purpose.
A brake cable was fitted right at the back of "the small barrier".
The length of the cable was adjusted so that the barrier was braked 500 mm after it had come into contact with the dummy/seat. With this arrangement the brake distance was approximately 2 metres.

This design of test equipment was the result of a number of modifications, mainly on "the seat frame" which in the beginning gave an incorrect movement.

Excitation

To run the test, the moving barrier is accelerated up to a velocity approximately 1 m/s above the chosen test velocity. The velocity of the barrier during the course of the test is, on the whole, decreasing, but during the time for the contact against the dummy it is relatively constant, see figure 5.

In order to create a correct simulation of a full-scale test, in this case car-to-car side collision, the profile of the structure's penetration velocity must be re-created in a similar manner (3).

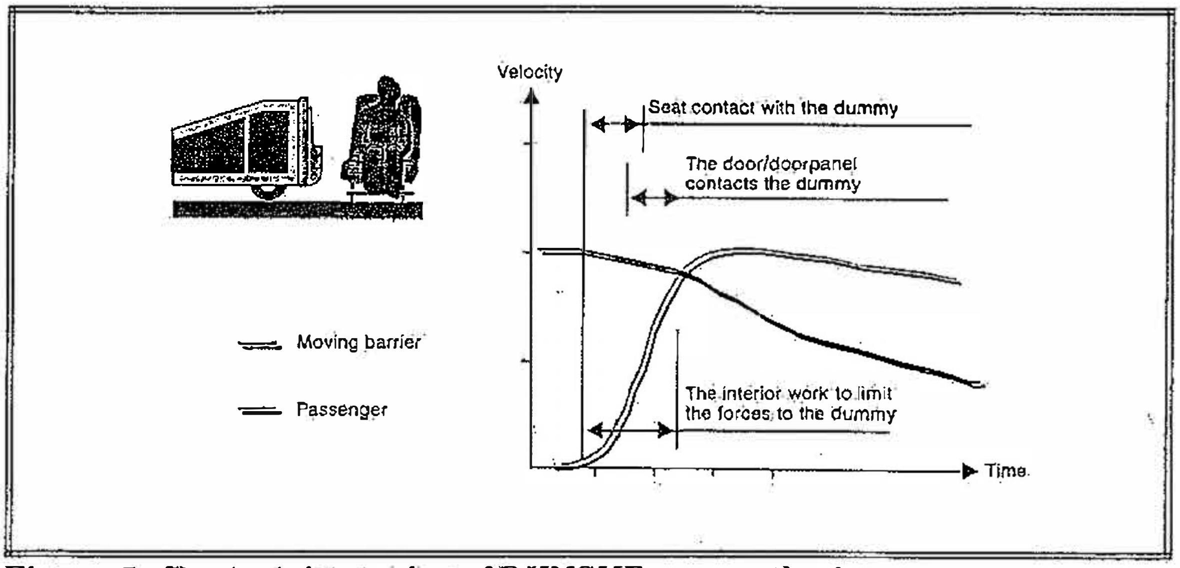

Figure 5. Typical dynamics of DYNSUB test method.

Measurements / Analyses

The DYNSUB method has primarily used the US-SID dummy. Modifications have been done since there are no possibilities for reading of force distribution in the pelvis in the original design. The pelvis was divided into two parts with a vertical incision, see figure 6. These are connected with three load cells, named as follows:

Iliac wing rear
Iliac wing front
Sacrum

The modifications were not done in any strict scientific way but nevertheless turned out to be of great use in the analysis in the future tests.

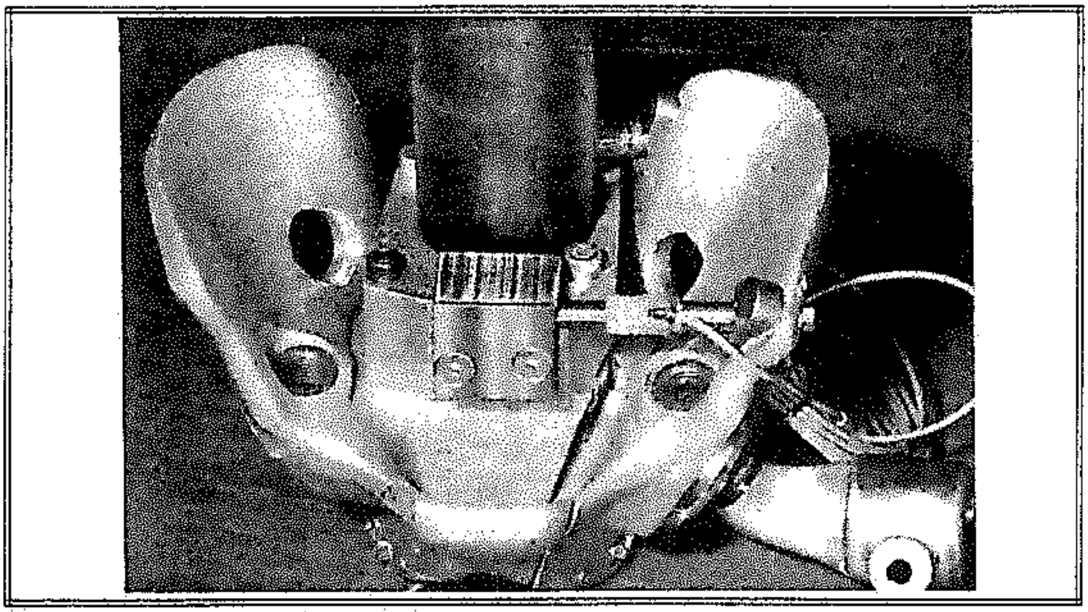

Figure 6. Modified US-SID pelvis.

In order to ensure that the method is comparable to the full-scale test more parameters than just the injury criteria must be taken into consideration. The parameters were divided into two groups:

Method parameters

Result parameters

Method parameters

The method parameters which have been considered are the following:

1 Test velocities

1.1 The Mean Contact Velocity, MCV, at chest height. This is defined as the penetrated side's (B-pillar) average speed during 20 ms from the time of contact between the door panel and chest. 20 ms is the normal time for the dummy's impact cycle (3).

1.2 The Mean Contact Velocity, MCV, at pelvis height. This is defined in a similar way as 1.1, but based on the impact point of the hip.

2 Seat movement

2.1 The seat cushion's lateral movement as a factor of time, from the time point "0 ms" until the maximum criteria in the dummy occur.

2.2 The seat cushion's vertical movement as a factor of time on the impact side, from the time point "0 ms" until the maximum criteria in the dummy occur.

3 Dynamic stiffness of the door substitute
  3.1 Stiffness of the chest impact area.
  3.2 Stiffness of the pelvis impact area.
4 The seat and door's relative movements
  4.1 The seat cushion's lateral movement relative to the B-pillar.
  4.2 The seat backrest's lateral movement relative to the B-pillar.
5 Dummy impact pattern against the door panel. A simple technique is used to register this. Stickers placed on the dummy fastened on the door panel during impact. See figure 7.
  5.1 The impact pattern for the chest, a deviation of + 20 mm horizontally and vertically from the pattern measured before the test, in order that the test be regarded as OK.
  5.2 The impact pattern for the pelvis, with the same tolerance as for the chest.

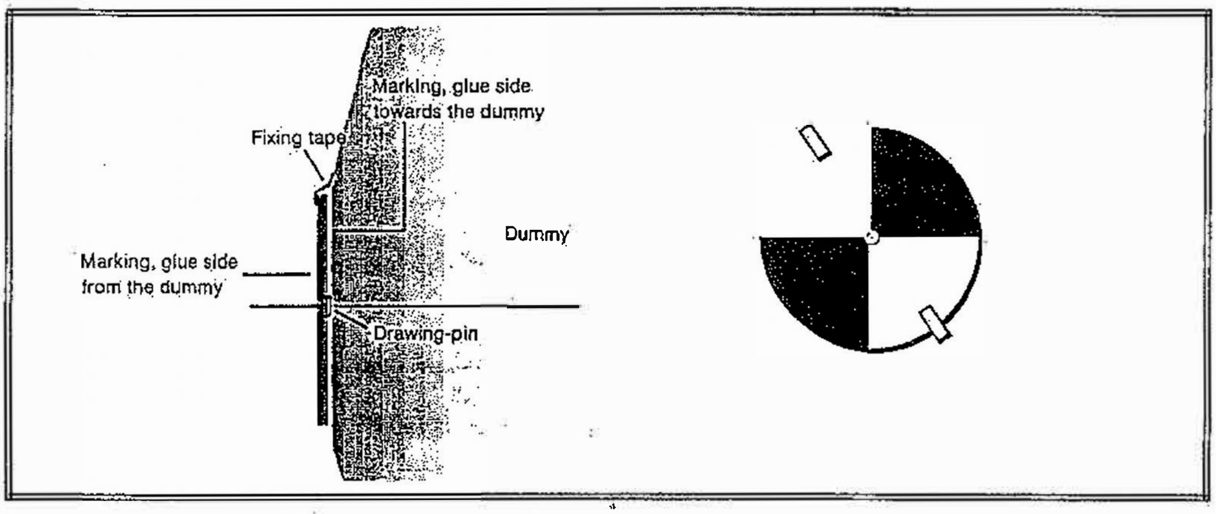

Figure 7.Marking the pattern of impact

Result parameters

The choice of result parameters depends upon the type of dummy used. In order to analyse the results the following parameters are used as a base:

1 Chest response
  1.1 TTI-value calculated from upper rib.
  1.2 TTI-value calculated from lower rib.
  1.3 Left upper rib maximum.
  1.4 Left lower rib maximum.
  1.5 Upper spinal maximum.
  1.6 Lower spinal maximum.

2 Pelvis response
   2.1 Lateral acceleration maximum.
   2.2 Total force maximum.
   2.3 Iliac wing rear force maximum.
   2.4 Iliac wing front force maximum.
   2.5 Sacrum force maximum.
3 Time of events
   3.1 Contact between trim panel and chest
   3.2 Contact between trim panel and pelvis
   3.3 Left upper rib maximum.
   3.4 Left lower rib maximum.
   3.5 Upper spinal maximum.
   3.6 Lower spinal maximum.
   3.7 Pelvis lateral acceleration maximum.
   3.8 Pelvis total force maximum.

In addition to a comparison of parameters, an extensive study was also carried out into the shapes of the curves for the dummy response in order to understand the dynamics.

Development of the method

The primary aim for the development of the DYNSUB test method was to make it possible in an effective, simple and quick way to solve some specific problems regarding the interior energy absorption. It should also be able to be utilised for future needs and form a base for further development of component and sub-system test methods.

An important condition during development of the method was that it should have simple and uncomplicated rigging. Wherever possible the method should use the existing in-house full-scale track. In the past, and at present, our sled test facility has been heavily overloaded with other tests.

Reference tests

The method development was based on a "reference test". The reference test was a full-scale test according to a test method used by Volvo. The full-scale method can be decribed as a modified CCMC method (4). See footnote *) A US-SID dummy was placed in the driver's position. See figure 8.

*) Since the introduction of the DYNSUB test method, the NHTSA has published their updated version of FMVSS 214, which differs from Volvo's test method in several aspects. The measuring results presented in this paper cannot be interpreted as if they were measured according to FMVSS 214's test procedure.

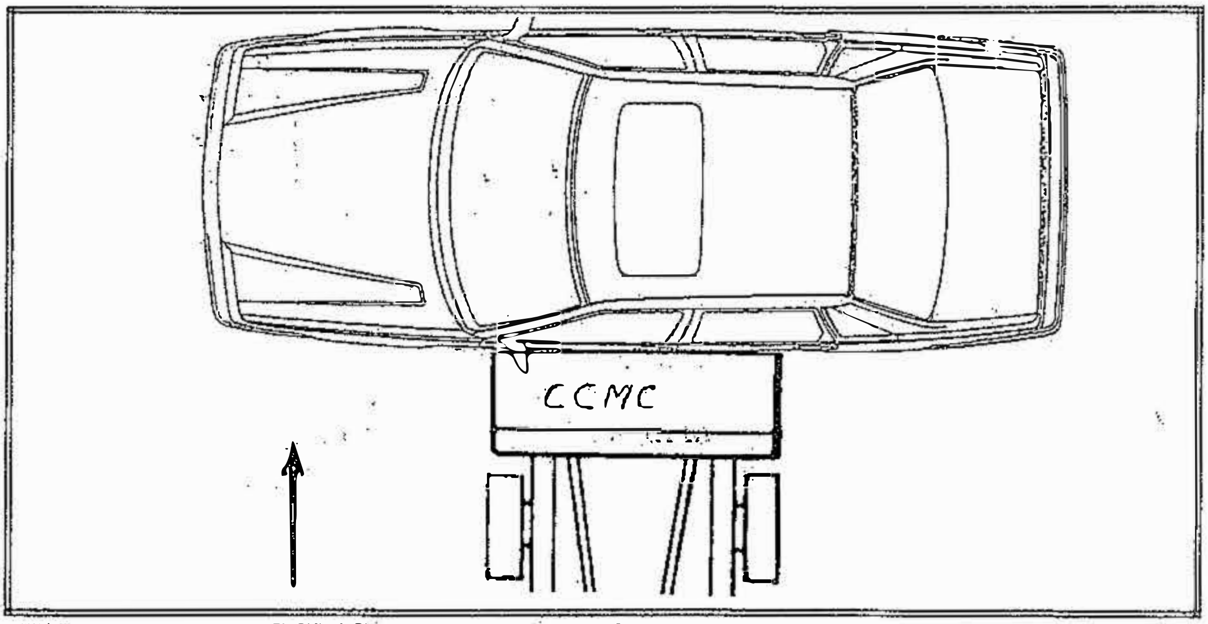

Figure 8. The CCMC test configuration.

The results from the reference test were as follows:

Structural performance was satisfactory.

Penetration speed (measured on the B-pillar during contact of the interior with the occupant) was 10.5 m/s at chest height and 9.8 m/s at pelvis height.

The level of penetration speed in the time was relatively constant, there was a slight increase in speed during the contact.

Penetration of the cabin was approx. 300 mm.

The interior performance of the car was unsatisfactory, since the dummy values were high.

Using supporting information from computer simulations it was judged that there was a potential to lower the criteria in the dummy by using a better balanced impedance for the interior, with retained structural performance.

The interior sections of interest were:

The door panel
- The design (relative position of the surfaces)
- The deformation properties
- Attachment to the door
- The stiffness

Components within the door panel.
Components which cannot be deformed were found within the impact area around the occupant. This counteracted a full utilization of the available deformation stretch in the door panel.
The structure of the seats.
The backrest frame of the seat came into contact with the dummy's spine, which was indicated by both cuts in the seat foam and a very rapid increase in the acceleration of the spine during the moment when seat contact began.
In addition there were suspicions that the seat's frame made contact with the pelvis in an unsatisfactory manner. It was, however, impossible to prove this based on the results from these tests.

In addition to the criteria measurements in the dummy, a number of other measurements and observations were carried out during the course of the crash. Included in these items were: acceleration and film measurements of the penetration of the B-pillar and side door, contact times for dummy/interior, door deformation and film measurements of the movement of the seat.

Trimming of the DYNSUB test method

It is crucial that the results are verified in some way against an accepted evaluation procedure, in this case full-scale tests, in order to validate the results of a component test method or a sub-system test method. Approximately 5 tests were needed to be run in order to trim the method. Two examples of the trimming series are given below.

R1 Reference test as described earlier.
T1 Tuning test 1. Test objects the same as in reference test.
The movement of the seat did not comply fully with that in the reference test.
T2 Tuning test 2. Test objects the same as in reference test and test T1.
The movement of the seat complied with that in the reference test.
See tables 1 and 2.

Table 1
Conditions for trimming

Method parameters	R1 Ref. test	T1 Tuning test	T2 Tuning test
1 VELOCITIES 1.1 MCV Chest	10.5 m/s	9.5 m/s	10.3 m/s
1.2 MCV Pelvis	9.8 m/s	9.2 m/s	10.0 m/s
2 SEAT MOVEMENT 2.1 Lateral	180 mm	150 mm	190 mm
2.2 Vertical	30 mm downwards	15 mm upwards	30 mm downwards
3 DOOR STIFFNESS 3.1 The chest impact area	- -	400 kN/m	400 kN/m
3.2 The pelvis impact area	- -	650 kN/m	650 kN/m
4 SEAT REL. DOOR 4.1 Seat lateral	90 mm	80 mm	100 mm
4.2 Seat backrest lateral	110 mm	95 mm	120 mm

Table 2
Results of trimming

Result parameters	R1 Ref. test	T1 Tuning test	T2 Tuning test
1 CHEST RESPONSE 1.1 TTI upper rib	103 G	93 G	94 G
1.2 TTI lower rib	117 G	89 G	104 G
1.3 Left upper rib	79 G	98 G	71 G
1.4 Left lower rib	107 G	88 G	91 G
1.5 Upper spinal	98 G	105 G	83 G
1.6 Lower spinal	127 G	89 G	116 G
2 PELVIS RESPONSE 2.1 Lateral acceleration	133 G	91 G	122 G
3 TIME OF EVENTS 3.1 Trim/chest contact	18 ms	15 ms	12 ms
3.2 Trim/pelvis contact	21 ms	18 ms	15 ms
3.3 Upper rib max	32 ms	27 ms	21 ms
3.4 Lower rib max	30 ms	27 ms	23 ms
3.5 Upper spinal max	39 ms	37 ms	38 ms
3.6 Lower spinal max	33 ms	30 ms	26 ms
3.7 Pelvis lat. max	36 ms	26 ms	25 ms

Analysis trimming

The trimming consisted primarily of adjustment of the seat's vertical and lateral movement in relation to the door.

The test speed in test T1 was almost 1 m/s too low, and in addition the vertical movement of the seat was upwards. This produced a relatively lower response in the dummy throughout the course of the test. The seat affected the pelvis more noticeably than in the reference test which amongst other things can be seen in the acceleration level of approx. 25 G when the door panel starts to come into contact with the pelvis.

In principle the trimming test T2 produced the same response in the dummy as the reference test. This shows the accuracy of the method in relation to the full-scale test.

Using the method

The DYNSUB test method has been used to study a large number of modifications, etc. This paper shows sections of two test series connected to the reference test.

* Evaluation of the effect of the seat on the occupant.
* Evaluation of door panel modifications

Evaluation of the effect of the seat on the occupant

Strong suspicions existed in the reference test that the effect of the seat contributed to increase the maximum loading on the occupant. In these tests the door section on the barrier's front plate was dismantled. This was done to isolate the effect of the seat's influence by significantly delaying the impact from the door. Instead, a 70 mm thick foam block was fitted on the barrier's front plate in order to protect the dummy from injuries when the course of the seat's influence was over. In this series the MCV was calculated from the moment when the seat moves 20 mm laterally, over a period of 20 ms.

A1 The seat had the same status as in the reference test, but an "incorrect" vertical seat movement, upwards instead of downwards.

A2 The seat had modifications on the backrest frame. This consisted of the backrest frame's hard sections being moved backwards 25 mm relative to the dummy's seating position. The seating position was retained by increasing the thickness of the foam in the backrest.
The seat movement was the same as in test "A1" "incorrect".

A3 The seat had the same modifications as in test "A2". The seat movement in this test complied with that in the reference test.

See tables 3 and 4.

Table 3
Conditions for test series A

Method parameters	A1	A2	A3
1 VELOCITIES 1.1 MCV Chest	10.0 m/s	9.8 m/s	9.8 m/s
1.2 MCV Pelvis	10.0 m/s	9.8 m/s	9.8 m/s
2 SEAT MOVEMENT 2.1 Lateral	200 mm	230 mm	240 mm
2.2 Vertical	20 mm upwards	20 mm upwards	30 mm downwards
3 DOOR STIFFNESS 3.1 The chest impact area	No door in test	No door in test	No door in test
3.2 The pelvis impact area	- " -	- " -	- " -
4 SEAT REL. DOOR 4.1 Seat lateral	100 mm	110 mm	105 mm
4.2 Seat backrest lateral	120 mm	125 mm	115 mm

Table 4
Results of test series A

Result parameters	A1	A2	A3
1 CHEST RESPONSE 1.1 TTI upper rib, *	54 G	31 G	Approx. 14 G
1.2 TTI lower rib, *	58 G	38 G	18 G
1.3 Left upper rib, *	46 G	23 G	Approx. 10 G
1.4 Left lower rib, *	53 G	36 G	20 G
1.5 Upper spinal, *	49 G	21 G	Approx. 5 G
1.6 Lower spinal, *	62 G	39 G	17 G
2 PELVIS RESPONSE 2.1 Lateral acceleration, *	87 G	90 G	62 G
3 TIME OF EVENTS 3.1 Trim/chest contact	34 ms	34 ms	32 ms
3.2 Trim/pelvis contact	33 ms	34 ms	31 ms
3.3 Upper rib max	33 ms	31 ms	35 ms
3.4 Lower rib max	35 ms	31 ms	35 ms
3.5 Upper spinal max	31 ms	32 ms	32 ms
3.6 Lower spinal max	31 ms	34 ms	33 ms
3.7 Pelvis lat. max	26 ms	26 ms	27 ms

(*) Before "3.1" and "3.2" respectively.

Analysis of test series A

The analysis of "series A" shows that the seat can have a very significant effect on the occupant in a side collision, primarily in the pelvis and the spine.

Regarding the pelvis, it was shown that the effect was primarily governed by the vertical movement of the seat during this lateral movement. The seat's effect became considerably less with a "reference-like seat movement", but still apparent.

In order to evaluate the contribution of the seat in the reference test, the pelvis acceleration level in test A3 should be read at the moment when the seat's lateral movement relative to the pelvis complies with the movement in the reference test during maximum pelvis acceleration.

This means that the effect of the seat in the reference test can be estimated as approx. 20 G. If, instead, the vertical seat movement had been rising, then the effect of the seat on the pelvis acceleration would have been approx. 40 G. The total effect of the seat on the pelvis criteria depends on the time relationship for other contacts with the pelvis, primarily the contact with the door panel. Early seat impact should probably in most cases be positive, whilst a late impact risks producing a parallel force to the dominating contact from the door panel. It should be emphasized that in all the tests, the design of the seat did not produce any "hooking", but the seat contact which occurred was caused by friction forces.

The dummy's spine is significantly affected by the seat of the design in the reference test. The seat's vertical movement is also significant here, but not to the same extent as for the pelvis.
By introducing a very limited modification, the maximum possible effect of the seat on the spine could in principle be halved.

Evaluation of door panel modifications

These tests were run with modified seats according to the description above ("test A3"), together with "real" seat movement according to "test A3". The test method for test series B was complete with the same construction as during trimming.

B1 In this test a hard component within the panel was dismantled and the stiffness of the panel in the chest area was adjusted.
B2 In addition to the measures according to test "B1" the panel in the pelvis area was adjusted regarding the panel surface's position and stiffness.
B3 Same as test "B2" but with a slightly different stiffness in the panel.
See tables 5 and 6.

Table 5
Conditions for test series B

Method parameters	B1	B2	B3
1 VELOCITIES 1.1 MCV Chest	10.5 m/s	10.2 m/s	10.6 m/s
1.2 MCV Pelvis	10.2 m/s	9.9 m/s	10.3 m/s
2 SEAT MOVEMENT 2.1 Lateral	210 mm	190 mm	215 mm
2.2 Vertical	35 mm downwards	30 mm downwards	25 mm downwards
3 DOOR STIFFNESS 3.1 The chest impact area	400 kN/m	400 kN/m	400 kN/m
3.2 The pelvis impact area	650 kN/m	650 kN/m	650 kN/m
4 SEAT REL. DOOR 4.1 Seat lateral	100 mm	100 mm	105 mm
4.2 Seat backrest lateral	125 mm	125 mm	125 mm

Table 6
Results of test series B

Result parameters	B1	B2	B3
1 CHEST RESPONSE			
1.1 TTI upper rib	91 G	93 G	106 G
1.2 TTI lower rib	96 G	91 G	113 G
1.3 Left upper rib	82 G	80 G	88 G
1.4 Left lower rib	93 G	75 G	102 G
1.5 Upper spinal,	81 G	93 G	74 G
1.6 Lower spinal	100 G	107 G	123 G
2 PELVIS RESPONSE			
2.1 Lateral acceleration	130 G	91 G	107 G
2.2 Total force	14.4 kN	10.6 kN	11.2 kN
2.3 Iliac wing rear	3.5 kN	4.8 kN	5.0 kN
2.4 Iliac wing front	4.2 kN	4.3 kN	3.6 kN
2.5 Sacrum	6.8 kN	2.6 kN	3.7 kN
3 EVENTS			
3.1 Trim/chest contact	11 ms	10 ms	10 ms
3.2 Trim/pelvis contact	13 ms	13 ms	13 ms
3.3 Upper rib max	26 ms	19 ms	20 ms
3.4 Lower rib max	24 ms	21 ms	23 ms
3.5 Upper spinal max	35 ms	33 ms	34 ms
3.6 Lower spinal max	27 ms	25 ms	25 ms
3.7 Pelvis lat. max	26 ms	23 ms	23 ms
3.8 Pelvis force max	26 ms	25 ms	24 ms

Analysis test series B

In test B1 the lower spinal acceleration was reduced by approx. 15 G, and thereby also TTI. This occurs in spite of a somewhat high test speed. The pelvis response remained at the same level as in the reference test. The force measurement in the pelvis showed that the greatest portion of the forces was led into the lower section of the pelvis via the hip-joint.

The maximum response on the pelvis was reduced dramatically in test B2, by approximately 35 G. At the same time the force dispersion in the pelvis became more even. The chest response remained at the same level as in test B1.

In test B3 the test speed was 0.4 m/s higher than in test B2. This resulted in that the response from the dummy increased, primarily in the left lower rib, in the lower spine and the pelvis.

Verification of measures in full-scale test

A full-scale test was run in order to further confirm the tested effects of the interior modifications in the DYNSUB test method and to verify the test method.

The verification test was carried out in the same way as the reference test, i.e. a Volvo-modified CCMC full-scale test.

Simultaneously, the verification test had been carried out on a number of modifications to the car body structure. Some of these were shown to have an unexpected, significant effect on the performance of the car's structure. Both the profile and the level of the speed of penetration differed significantly from the reference test.

The following are shown for comparison:

V1 Verification test
R1 Reference test
B3 The DYNSUB test whose conditions best comply with those in the verification test.

See tables 7 and 8.

Table 7
Conditions for verification

Method parameters	V1 Ver. test	R1 Ver. test	B3
1 VELOCITIES 1.1 MCV Chest	9.0 m/s	10.5 m/s	10.6 m/s
1.2 MCV Pelvis	10.5 m/s	9.8 m/s	10.3 m/s
2 SEAT MOVEMENT 2.1 Lateral	200 mm	180 mm	215 mm
2.2 Vertical	35 mm downwards	30 mm downwards	30 mm downwards
3 DOOR STIFFNESS 3.1 The chest impact area	--	--	400 kN/m
3.2 The pelvis impact area	--	--	650 kN/m
4 SEAT REL. DOOR 4.1 Seat lateral	105 mm	90 mm	105 mm
4.2 Seat backrest lateral	110 mm	110 mm	125 mm

Table 8
Results of verification

Result parameters	V1 Ver. test	R1 Ref. test	B3
1 CHEST RESPONSE 1.1 TTI upper rib	69 G	103 G	106 G
1.2 TTI lower rib	81 G	117 G	113 G
1.3 Left upper rib	50 G	79 G	88 G
1.4 Left lower rib	74 G	107 G	102 G
1.5 Upper spinal	92 G	98 G	74 G
1.6 Lower spinal	88 G	127 G	123 G
2 PELVIS RESPONSE 2.1 Lateral acceleration	135 G	133 G	107 G
2.2 Total force	16.0 kN	NA	11.2 kN
2.3 Iliac wing rear	5.2 kN	NA	5.0 kN
2.4 Iliac wing front	5.4 kN	NA	3.6 kN
2.5 Sacrum	5.7 kN	NA	3.7 kN
3 EVENTS 3.1 Trim/chest contact	18 ms	18 ms	10 ms
3.2 Trim/pelvis contact	20 ms	21 ms	13 ms
3.3 Upper rib max	31 ms	32 ms	20 ms
3.4 Lower rib max	34 ms	30 ms	23 ms
3.5 Upper spinal max	45 ms	39 ms	34 ms
3.6 Lower spinal max	38 ms	33 ms	25 ms
3.7 Pelvis lat. max	39 ms	36 ms	23 ms
3.8 Pelvis force max	39 ms	NA	24 ms

Analysis of verification

The verification test confirmed that the improvments which were strived for could be attained in a full-scale test as well.

The changed structural performance does, however, cause a dramatic change in the dummy criteria. A structural analysis was carried out with the aim of surveying the various effects of the structure modifications on the changed structure performance. This analysis meant that with the removal of the "negative" modifications, the structural performance for a front seat occupant should be:

Chest height: 9.5 m/s, MCV
Pelvis height: 10.0 m/s, MCV

Earlier computer simulations have shown that there is a definite correlation between MCV Mean Contact Velocity and the dummy criteria TTI and Amax-Pelvis. Based on these simulations and experience gained from the DYNSUB testing, an estimation of the dummy criteria was carried out for the structurally analysed car body design.

Using the newly developed DYNSUB test method, the car's side collision performance has been improved in a simple and relatively quick way.

The new total estimation gave the following results, when compared with the reference test. Most of the improvements could be attributed to the modifications which have been developed with the DYNSUB test method. See table 9.

Table 9
Improvement via the DYNSUB test method

Dummy response	R1 Ref. test car	V1 Ver.test car	Car corrected for V1 structural changes
TTI (G)	117	81	90 (−23%)
Amax Pelvis (G)	133	135	105 (−21%)

Advantages with the method

The simplicity of the method has made it possible for two engineers and a mechanic to carry out two tests per day. The method has produced sufficient information to permit a decision regarding car design changes.

The method has the potential to be developed and become a very usable development tool, particularly when co-ordinated in the development work with computer simulations, similar to the method used in CTP tests (5).

Adapting the method for various needs

The described DYNSUB test method can be used in several different situations. Using the described method of usage as a base, the various needs can be divided up into two groups:

* Changes in car design
* Changes in test method/evaluation method

The changes in design can have several causes, among other things:

A The need to improve the interior performance (due to high dummy response values) in an existing car design, as in the described case.

B Design or other property-dependent causes. These changes require checking in a simple and quick manner.

C Development of new car models. It can save a lot of time and money if the interior performance can be established during early concept development, when access to complete cars is severely limited.

D Development of new protection systems, for example side collision airbag.

The changes in test method/evaluation method can, for example, be made up of some of the following examples:

A Variation of speed severity with the view to evaluating interior performance for various crash speeds. This should be done to avoid optimization for only one speed.

B Change of bullet. Different bullets produce different deformation of the door. This in turn affects its stiffness from the inside, which the occupant experiences. The door stiffness can be the part which dimensions the contact forces against the occupant for many car designs with a relatively ineffective interior.

C Change of dummy.

D Change of criteria.

If the structural performance is unknown for a "new" crash speed or if it is a question of a new car body design, it must be estimated. This can probably be done using complete car simulation or by interpolation/extrapolation of known crash speed/structure performance relationship.

The important door stiffnessis difficult to simulate. The method described earlier is only suitable for bullets with a flat front (for example CCMC), where the door receives a relatively even crumpling. For bullets with a marked bumper (e.g. NHTSA), another form of substitute is better.The way in which the door substitute should be geometrically designed can be determined by taking a basic view of an already crashed door, or alternatively by carrying out a "dry crash" on the drawing table/computer. It should be noted that a crashed door is often not nearly as tightly packed after a test as it was during the course of the test. This makes it unsuitable to use a crashed as well as an uncrashed (undeformed) door such as the door substitute in the DYNSUB test method. A suitable principle design for the door substitute for a "bumper bullet" is to fit a deformed bumper section onto the front plate of the DYNSUB test method barrier. Additional "undeformable" components such as for example, lift motor, lock unit, door member, etc should also be fitted to the front plate. A door inner plate (as complete as possible) is then fitted over these.

Conclusion and summary

The increased interest in side collisions around the world has meant that the need for evaluation methods at various levels has increased. The DYNSUB test method, through its simplicity, fulfills an important function by in many cases replacing expensive full-scale tests and by being a link between full-scale tests and computer simulation.

The DYNSUB test method reflects the most important mechanisms from the full-scale tests. This gives a good platform for further developing of the method for the large and varying needs which can be anticipated in the future.

Computer simulations have shown that the DYNSUB test method complies very well with full-scale tests.

The method has produced sufficient information to bring about decisions regarding car design changes.

In order to really have the benefit ofthe DYNSUB test method it is valuable to coordinate the tests with computer simulations.

The DYNSUB test method is far from being a fully-developed method and in the future, at Volvo, it will be made both more usable and more effective.

References

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(2) N. Shimoda, Effects of Belt Restraint Systems on Occupant Protection Performance in Side Impact Crashes. Twelfth International Technical Conference on Experimental Safety Vehicles, Göteborg 1989.

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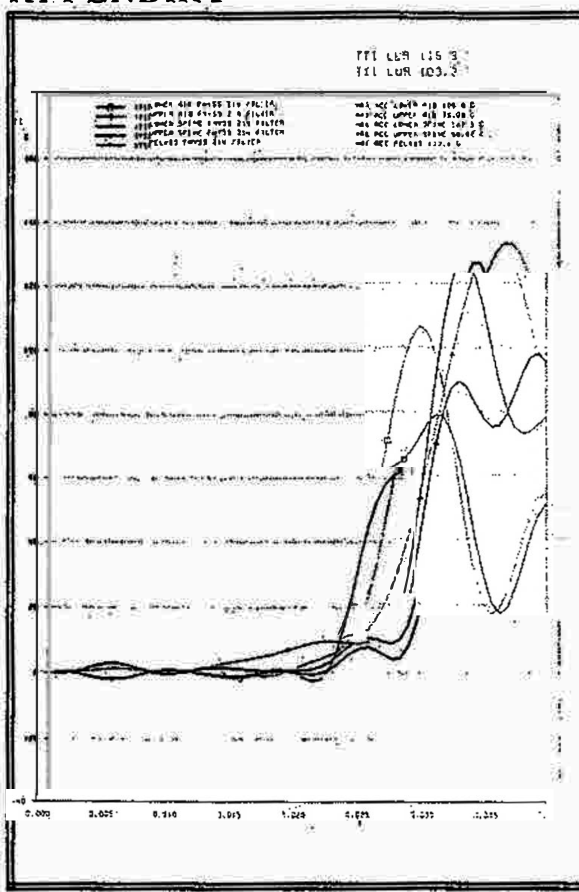
(4) M. Nilsson, Volvo Side Impact Testing. Tenth International Technical Conference on Experimental Safety Vehicles, Oxford 1985.

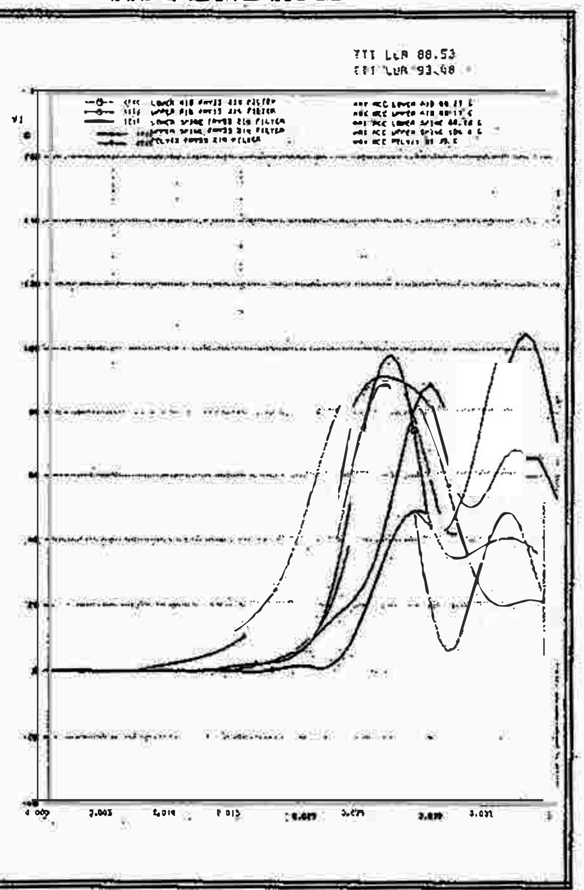
(5) B. Richter, The Composite Test Procedure (CTP) - State of the art. Twelfth International Technical Conference on Experimental Safety Vehicles, Göteborg 1989.

APPENDIX I



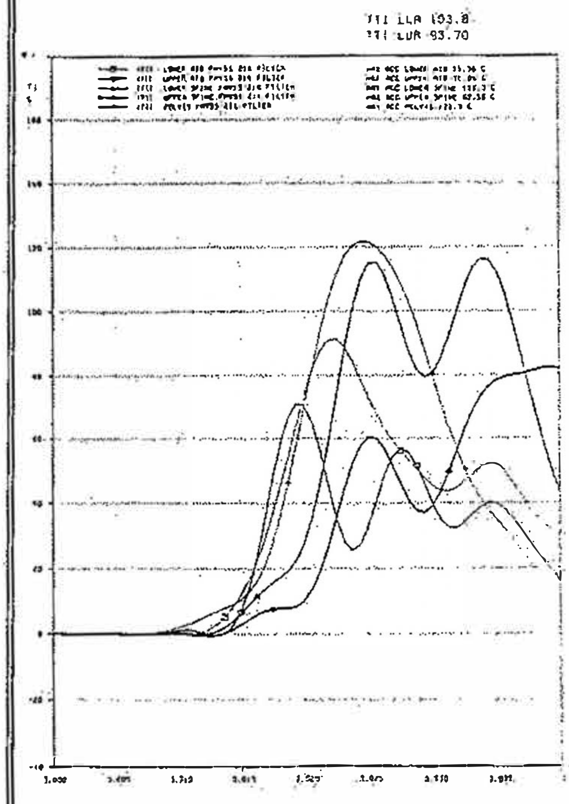
Dummy response ref. test

APPENDIX II



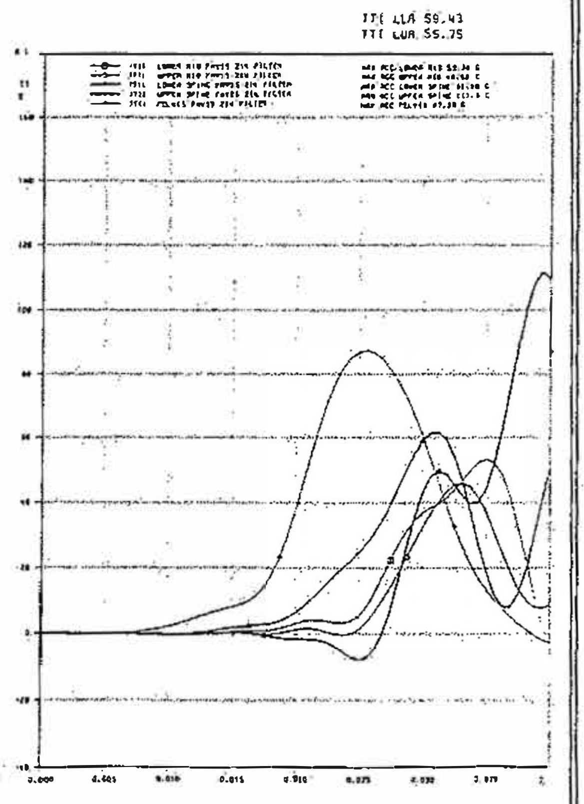
Dummy response T1

APPENDIX III



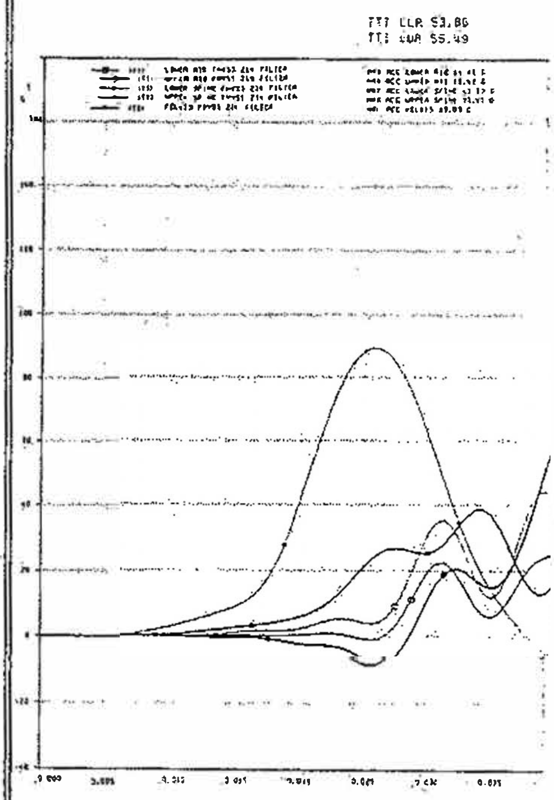
Dummy response T2

APPENDIX IV



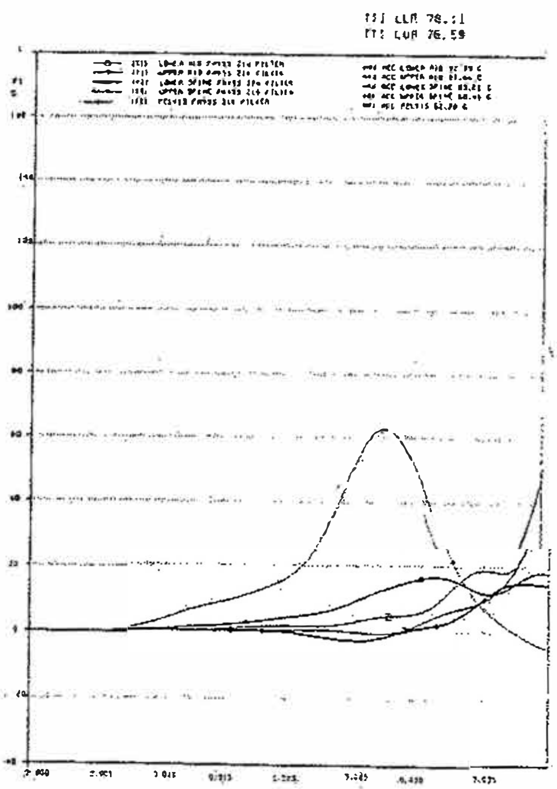
Dummy response A1

APPENDIX V



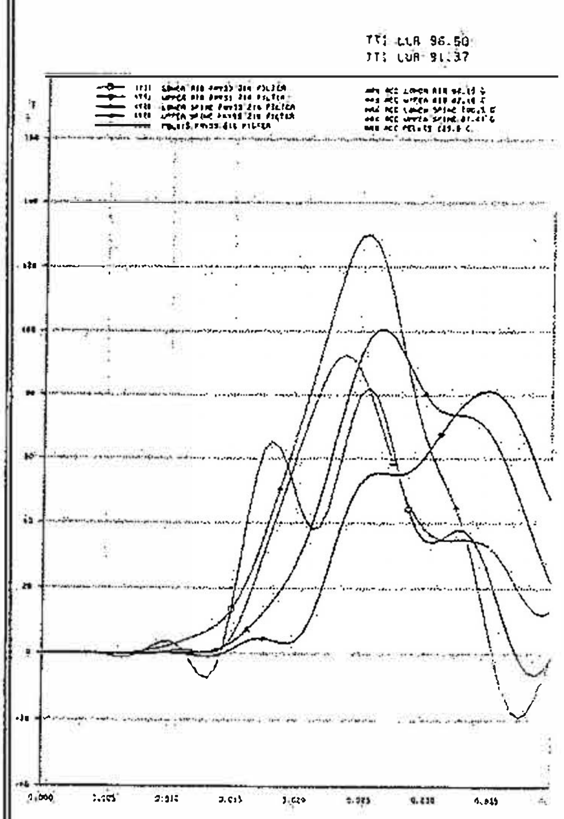
Dummy response A2

APPENDIX VI



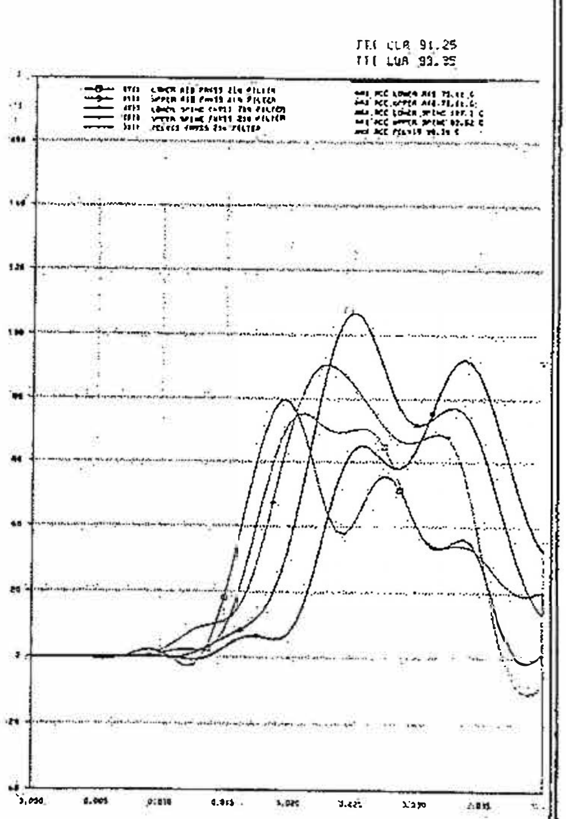
Dummy response A3

APPENDIX VII



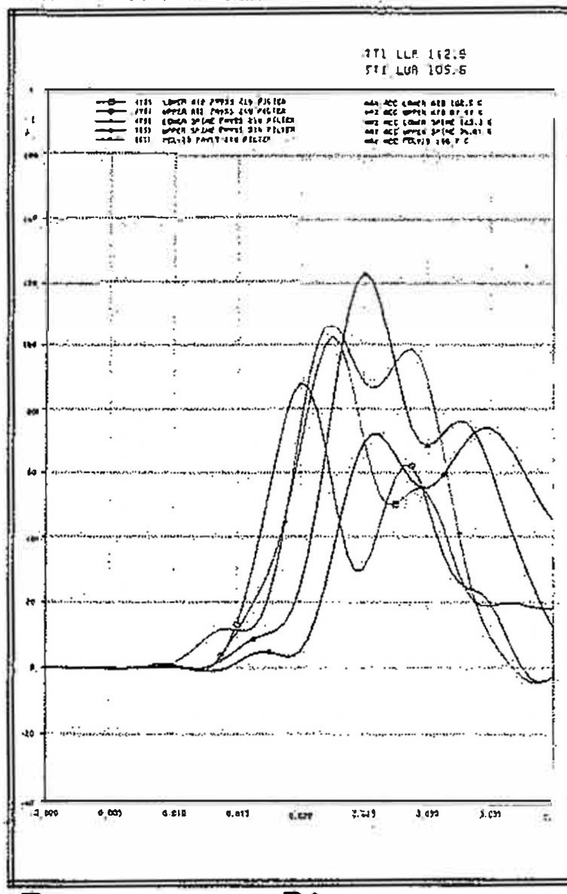
Dummy response B1

APPENDIX VIII



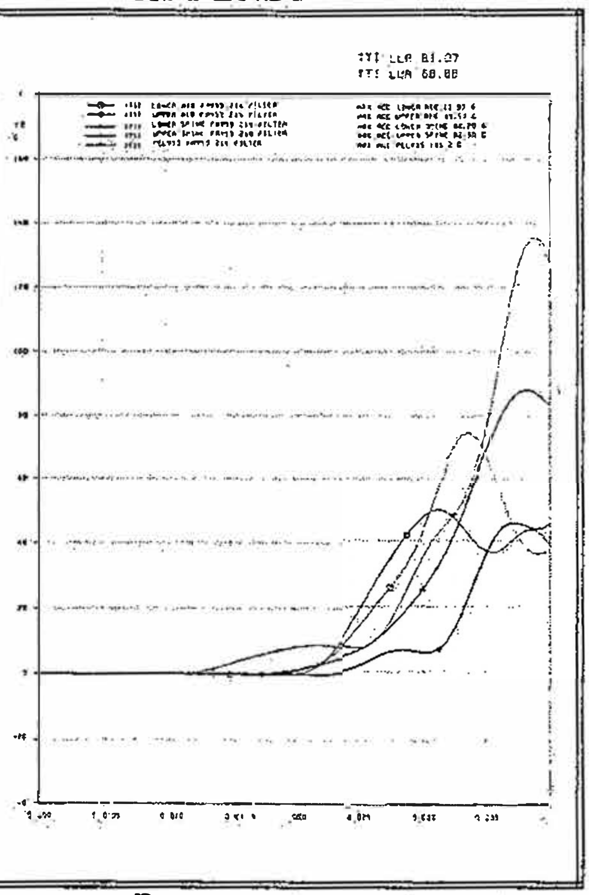
Dummy response B2

APPENDIX IX



Dummy response B3

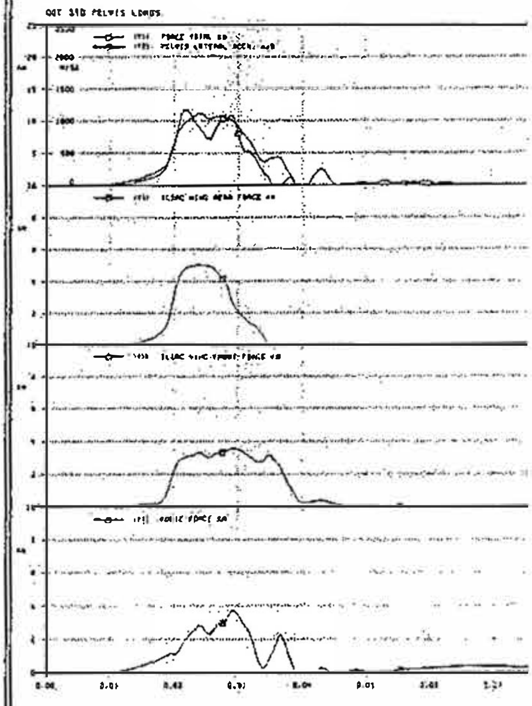
APPENDIX X

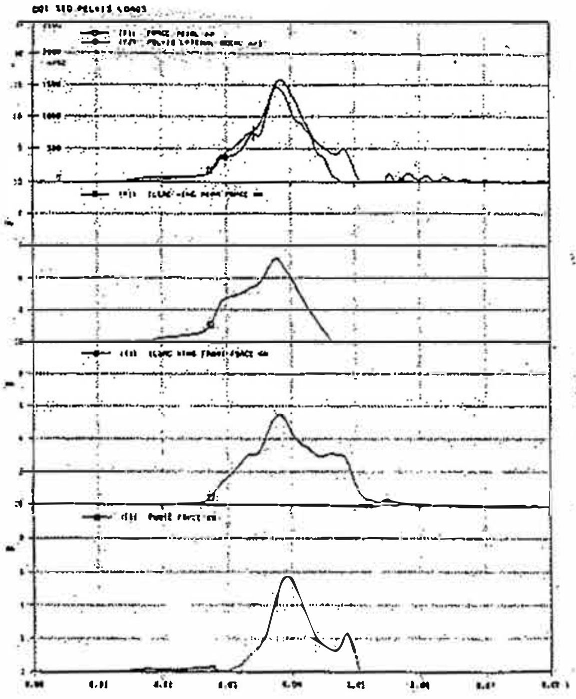


Dummy response ver. test

APPENDIX XI

APPENDIX XII





Pelvis forces B3

Pelvis forces ver. test