COMPARATIVE PERFORMANCE TESTING OF PASSENGER CARS RELATIVE TO FMVSS 214 AND THE EU 96/EC/27 SIDE IMPACT REGULATIONS: PHASE I

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ABSTRACT

Based on a long recognized need, the National Highway Traffic Safety Administration (NHTSA) has begun to reexamine the potential for international harmonization of side impact requirements. To this end NHTSA, as directed by the U. S. Congress, has recently submitted a report to the Congress on the agency plans for achieving harmonization of the U. S. and European side impact regulations. The first phase of this plan involves crash testing vehicles compliant to FMVSS 214 to the European Union side impact directive 96/27/EC. This paper presents the results to date of this research. The level of safety performance of the vehicles based on the injury measures of the European and U.S. side impact regulations is assessed.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) has long recognized the need for international harmonization of side impact requirements and the potential of added safety benefits resulting from such harmonization. Although the U.S. and EU side impact regulations ideally address the same safety problem, they differ in test procedures, barriers, dummies, and injury criteria. Recently, the U.S. Congress directed NHTSA to study the differences between the U.S. and proposed European side impact regulations and to develop a plan for achieving harmonization of these regulations. Also, manufacturers believe that these differences lead to different vehicle designs, thus posing undue financial burdens in terms of dual development, testing, manufacturing and distribution of vehicles in various markets.

NHTSA submitted a side impact harmonization plan to the U.S. Congress in April of 1997 [1]. The first phase of the plan is an attempt at assessing whether the safety performance of vehicles is functionally equivalent relative to the European regulation (EU Directive 96/27/EC) and the Federal Motor Vehicle Safety Standard (FMVSS) 214. The Functional Equivalence Assessment Process (Appendix A) was developed by the U. S. and Australia in coordination with foreign governments, industry and consumer groups. NHTSA has recently published a final rule institutionalizing the process [39]. The final rule sets forth the process that the agency will use in comparing U.S. and foreign vehicle safety standards and in determining appropriate rulemaking response, if any. The rule reaffirms NHTSA's policy of actively identifying and adopting those foreign vehicle safety standards that require significantly higher levels of safety performance than the counterpart U. S. standards. The rule also outlines the agency's policy in the case where the comparison indicates that the foreign standard's safety benefits are approximately equal to those of a counterpart U. S. standard.

To begin gathering the data necessary to make the functional equivalence assessment, NHTSA initiated a research program by testing eight U.S. production FMVSS 214 compliant vehicles to the EU Directive 96/27/EC requirement. This paper focuses on the results of the testing in terms of the level of safety performance of the vehicles for both the U.S. and EU regulations.

Current U.S. and European Side Impact Standards

The U.S. regulation on side impact is FMVSS 214; Side Impact Protection [2] addressing thoracic and pelvic fatalities and injuries in vehicle-to-vehicle crashes. The dynamic requirement, or crash test portion of this standard was added in October of 1990. It was phased-in beginning with 1994 model year (MY) cars such that all cars by the 1997 MY had to meet the requirements. Starting with the 1999 MY, trucks, buses, and multipurpose passenger vehicles under 2,721 kg (6000 lbs) must meet the dynamic part of this standard [3].

The European Union (EU) side impact regulation, EU Directive 96/27/EC was approved in October of 1996. It applies to new and redesigned M1 and N1 vehicle types beginning with the 1999 MY. M1 vehicles are those with a capacity of nine or less occupants and would include passenger cars, multipurpose passenger vehicles, and mini buses. N1 vehicles are those with the capacity of carrying up to 3.5 metric tons, e.g. vans and chassis cabs. Vehicles with R-point of lowest seat >700 mm are excluded. All M1 and N1 vehicles starting in the 2004 MY must meet this regulation.

The test procedures of both regulations are similar in that a stationary test vehicle is struck with a moving deformable barrier (MDB). These dynamic test procedures focus on the measurement of anthropomorphic test dummy responses to compute injury criteria. However, the two regulations use different test procedures, barriers, dummies, and injury criteria. Figures 1 and 2 show a schematic of the test setup for the U.S. and EU regulations. Table 1 compares the relevant crash test parameters such as impact direction, impact velocity and barrier face dimensions.

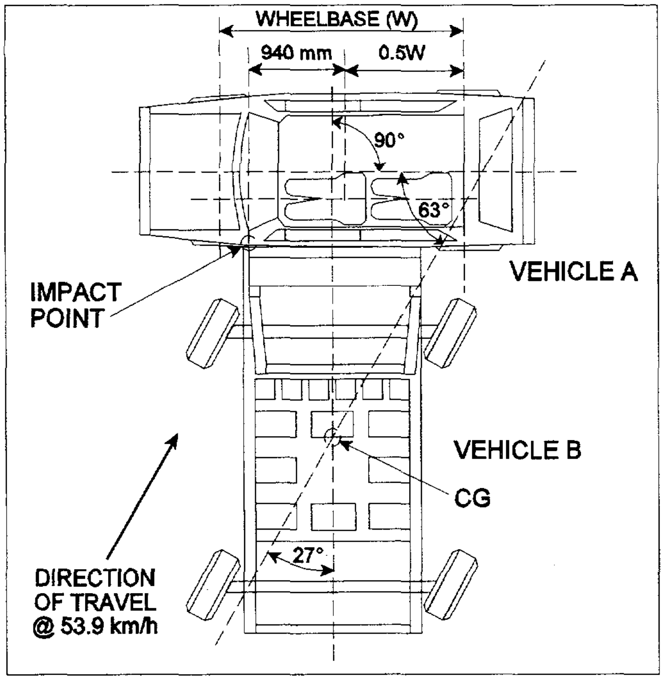


Figure 1. FMVSS 214 Side Impact Test Configuration.

The FMVSS 214 dynamic test simulates the 90 degree impact of a striking vehicle traveling 48.3 km/h into a target vehicle traveling 24.2 km/h. This is achieved by a moving deformable barrier with all wheels rotated 27 degrees (crab angle) from the longitudinal axis, impacting a stationary test vehicle with a 54 km/h closing speed. For a typical passenger car, the left edge of the FMVSS 214 MDB (214MDB) is 940 mm forward of the mid point of the struck vehicle wheel base.

In the EU 96/27/EC dynamic test, the European MDB (EUMDB) impacts the target vehicle at 50 km/h and 90 degrees with no crab angle. This differs from FMVSS 214 in that no attempt is made at simulating the movement of the target vehicle. The lateral striking position is aligned with the occupant seating position rather than the vehicle wheelbase. The EU MDB is centered about the R-point or seating reference point defined as the H-pt for lowest and rearmost driving seat position.

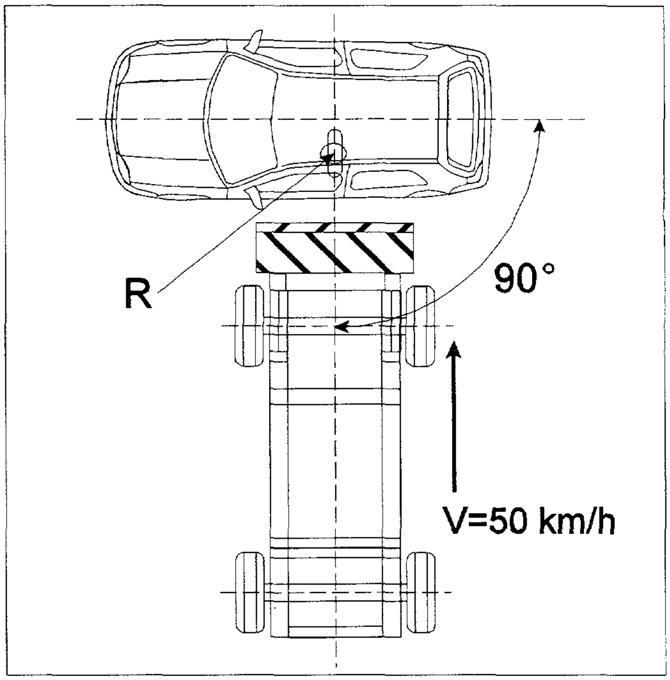


Figure 2. EU 96/27/EC Side Impact Test Configuration.

Table 1.
Crash Test Parameter Comparison

	EU 96/27/EC	FMVSS 214
MDB Mass	950 kg	1367 kg
Velocity Vector	50 kph/90°	54 kph/63°
Impact Point	Centered on R-point*	940 mm from wheelbase center
Barrier Face Ground Height	300 mm	280 mm Bumper 330 mm
Face Width	1500 mm	1676 mm
Barrier Material	Performance Defined	Aluminum Honeycomb

*same as seating reference point

FMVSS 214 and EU 96/27/EC Movable Barriers - The dimensions and material characteristics of the 214MDB face are shown in Figure 3. The aluminum honeycomb of the barrier face is specified by design. The bottom edge of the MDB is 280 mm from the ground. The protruding portion of the barrier simulating a bumper is 330 mm from the ground. The 214MDB has a total mass of 1367 kg initially derived from the weights of passenger cars and lights trucks in the U.S. fleet with a adjustment made assuming a downward trend in vehicle mass due to fuel economy needs [4, pg IIIA-6]. The dimensions of the EUMDB face are given in Figure 4. The European barrier face is segmented into six blocks with force deflection performance characteristics specified in the EU regulation. The lower blocks are stiffer than the top blocks and the center blocks are stiffer than the outboard elements. The EUMDB face is about 20% smaller than the 214MDB in terms of face area. It is also much softer than the 214MDB face on the blocks closest to the sides. The bottom edge is the most forward part of the European MDB and is 300 mm from the ground. The European barrier has a mass of 950 kg , 40% less then the mass for the U.S. barrier.

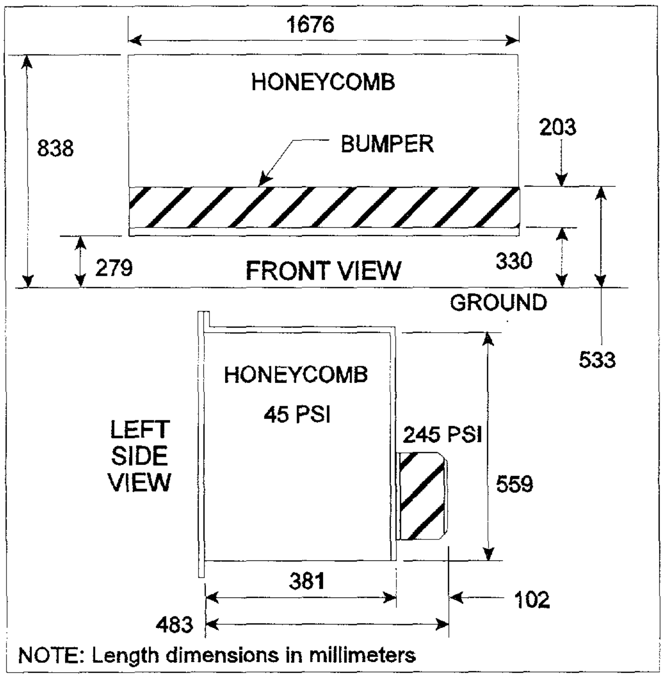


Figure 3. FMVSS 214 Side Impact Deformable Barrier Face.

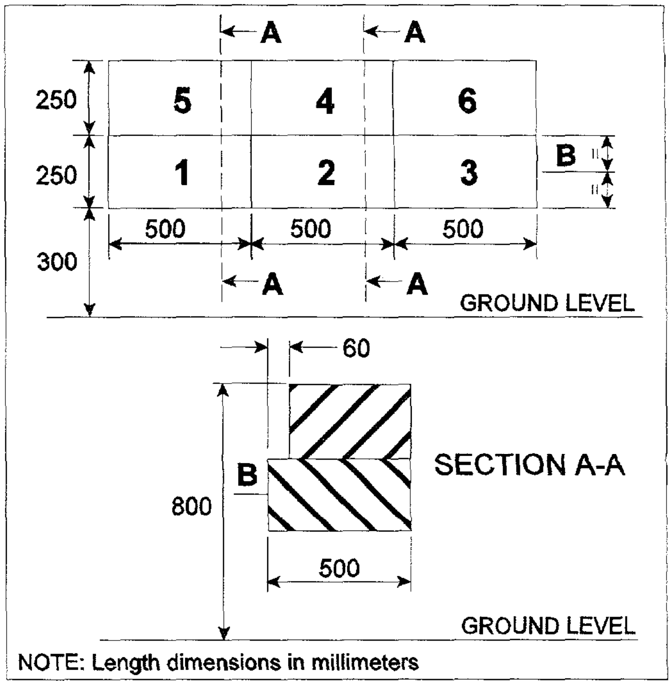


Figure 4. EU 96/27/EC Side Impact Deformable Barrier Face.

FMVSS 214 and EU 96/27/EC Dummies and Injury Criteria - In both regulations, successful test performance is determined by dummy injury criteria. However, the regulation differ in both the test dummy and injury criteria. Figure 5 is a schematic of the two side impact dummies, the U.S. side impact dummy (SID) used in FMVSS 214 and the EU dummy EUROSID-1 used in Directive 96/27/EC.

Although both dummies ideally represent a 50^{th} percentile side impact anthropomorphic device, they are based on different designs and have different measurement capabilities. In particular, Eurosid-1 has an articulating half arm, while the response of the arm is folded into the design of the thorax in SID. FMVSS 214 requires that a SID be placed in both the front and rear seats of the test vehicle. The EU Directive requires that only one EUROSID-1 be placed in the front seat. The injury criteria for each regulation, given in Table 2, relate to the measurement capabilities of the dummy used.

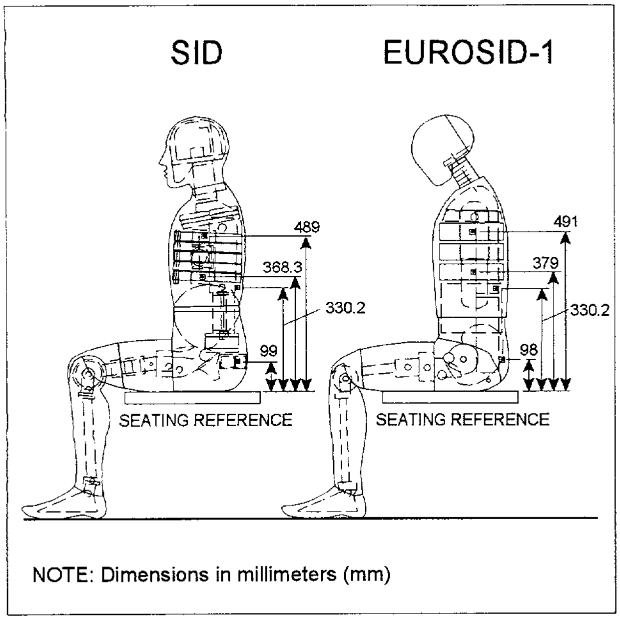


Figure 5 Schematic of Side Impact Dummies of FMVSS 214 and EU 96/27/EC

Table 2.
Test Dummy Injury Criteria

EUROSID-1	U.S. SID
HIC - 1000	
Rib Deflection ≤ 42 mm	TTI ≤ 85 or 90 G
V*C ≤ 1 m/s	
Abdominal Force ≤ 2.5 KN	
Pubic Symphysis Force ≤ 6 KN	Pelvic Accel. ≤ 130 G

SID was designed to measure only the acceleration of the ribs, spine and pelvis to compute thoracic and pelvic injury criteria [20]. The rib and spine accelerations are combined into a single metric called the Thoracic Trauma Index (TTI(d)) which has an 85g limit for 4-door vehicles and a 90g limit for 2-door vehicles. The pelvic acceleration has a 130g limit.

EUROSID-1 has additional measurement capabilities than SID, including force and displacement as well as acceleration based readings [5]. The EU regulation places limits on five dummy criteria to determine vehicle performance. The head protection criteria (HPC) is derived from head acceleration over a head contact time duration and must remain below 1000. A rib deflection criterion (RDC) allows a maximum of 42 mm of deflection in the thorax. A soft tissue viscous criterion (V*C), computed from combined rib deflection and velocity, is to be reported with a proposed limit of 1 m/s. It is worth noting that for the first two years in which EU 96/27/EC becomes effective, V*C values are to reported but not used as a pass/fail criterion . A review of the EU directive is planned in the year 2000 during which the status of V*C as a required injury criteria will be decided. The abdominal peak force (APF) is limited to 2.5 KN. Finally, the pubic symphysis peak force (PSPF), which is in the pelvic region, must be less than 6 kN.

VEHICLE MATRIX

Table 3 lists the U.S. production vehicles that were tested to the EU 96/27/EC requirements. The vehicles were identical in design to vehicles tested to FMVSS 214 in the NHTSA compliance test program. The matrix included four 4-door and four 2-door passenger cars.

Table 3.
FMVSS 214/ EU 96/27/EC Test Matrix

Vehicle		FMVSS 214 test	Side NCAP	Prod-uction
1996 Ford Taurus*	4-Dr	1996	Yes	539K
1995 Volvo 850	SW	1995	No	63K
1997 Nissan Sentra	4-Dr	1996	Yes	72K
1997 Hyundai Sonata	4-Dr	1996	Yes	15K
1997 Ford Mustang	2-Dr	1996	No	170K
1997 Lexus SC300	2-Dr	1995	No	13K
1995 Geo Metro	2-Dr	1996	No	58K
1997 Mitsubishi Eclipse	2-Dr	1996	No	111K

*The EU test for the 1996 Taurus was performed by Ford Motor Company.

The selection criteria for the vehicles in order of importance were the following:

1. FMVSS 214 test results were used to provide a range of performance from marginal to good performers within the set of 4-Dr vehicles and correspondingly within the set of 2-Dr vehicles.
2. Vehicles to be tested in the side impact New Car Assessment Program (NCAP) were included as much as possible in order to provide an additional comparative data set at a higher performance level for the current test program and for possible future ECE 95 testing at a higher performance level.
3. Vehicles built or sold by all U. S. manufacturers or their subsidiaries would be represented, and similarly, to the extent possible, for those built or sold by foreign manufacturers.
4. The highest production vehicles would be represented.

EU 96/27/EC TESTS SETUP

With the exception of placing a Eurosid-1 dummy in the rear outboard position, the procedures of the EU 96/27/EC Directive were followed in performing the European side impact tests of the U.S. production vehicles. In addition, experts from TNO, Netherlands, provided training on the latest dummy seating practices. They also provided guidance on common EU 96/2/7EC test set up practices, especially in areas where the EU directive is not specific. Although the seat track position for the front dummy is not specified in the EU Directive, the Eurosid-1 in the driver position was seated in the mid-track position to provide the best comparison with FMVSS 214. In addition, comparison checks of the test vehicle options, test weight and attitude, and dummy H-points and lateral clearances between the FMVSS 214 and EU test setups were performed. This was done to ensure minimum differences in the vehicles, dummy positioning, and test setups for the comparison testing.

The Plascore layered honeycomb construction barrier face, was used for the EU Movable Deformable Barrier (EUMDB) elements. The choice of barrier face was based on a recent evaluation of barrier faces performed through the International Standards Organizations (ISO) working group on Car Collision Test Procedures [6]. The evaluation compared the characteristics of the Cellbond/TRL, Plascore, and AFL/UTAC EUMBD faces and indicated that the Plascore face best fits the force performance corridors specified by EU 96/27/EC. It has been established by various researchers that different EUMDB face designs lead to significantly different vehicle performance results, for both the occupant responses and vehicle intrusion profiles [7,8]. As such, the recently developed honeycomb face from Plascore was chosen to ensure the best currently available fit to EUMDB performance requirements.

In both the 2-Dr Mustang and Eclispe, there was no room to fit a rear Eurosid-1 dummy in the EU tests. In the FMVSS 214 compliance tests, there was no room to fit a rear SID only in the Eclipse. It is worth noting that the Eurosid-1 dummy has a slightly higher seated height specified at 904 ± 7 mm versus 899 ±10 mm for the SID. On the other hand the SID has a wider hip width specified at 373 ±18 mm versus 355 ±5 mm for the Eurosid-1.

<u>**Eurosid-1 Calibration Issues**</u> - Problems in certification of Eurosid-1 lumbar spine parts were encountered in the set up for the EU vehicle testing. As such, a round robin calibration of three new lumbar spines was performed at three U.S. sites. The results are listed in Appendix A. The base angle output requirements were only met about 50% of the time for two of the parts although the lumbar pendulum pulse requirements were typically met. The differences in base angle outputs were small and consistent suggesting that the new parts were similar in construction but the calibration corridors may be too narrow. The results were presented to TNO and ISO/TC22/SC12/WG5 working group, Anthropomorphic Test Devices, in June of 1997. TNO has initiated a round robin research activity to address this lumbar spine calibration issue.

COMPARISON OF OCCUPANT RESPONSES

The first level of comparison of results was based on the normalized injury criteria of each regulation. Tables 4. and 5. list the computed injury criteria for the FMVSS 214 and EU 96/27/EC tests of the eight vehicles for both the driver and rear dummies. In general, the basis of the comparisons made below was to normalize the computed injury values by the limit of the criteria specified by each regulation. For example, the TTI(d) was normalized by 85 for the 4-Dr vehicles and by 90 for the 2-Dr vehicles, and RDC was normalized by 42 mm. Overall, the results indicate a higher severity for the driver dummy in the EU tests for the RDC thoracic criterion when compared to the TTI(d) in the FMVSS 214 tests. No trend is seen for V*C versus TTI(d). The results also indicate possibly a higher severity for the driver dummy in the 4-Dr vehicles for PelvicG in the FMVSS 214 tests when compared to the PSPF pelvic criterion in the EU tests. This apparent trend is reversed for the driver dummy in the 2-Dr vehicles where a lower severity is indicated for PelvicG when compared to PSPF.

Table 4.
FMVSS 214 and EU 96/27/EC Results (Driver)

	TTI(d)	Pelvic (g)	RDC	Flat Tops	V*C	PSPF (kN)	APF (kN)	HPC	Tstart	Tend	HIC36
	85/90	130	42 mm		1.00	6.0	2.5	1000	(ms)	(ms)	
1997 Ford Mustang 2-Dr	56	65	39.8	yes	0.69	4.827	2.295	33.4	58.9	62.1	85.3
1997 Lexus SC300 2-Dr	63	78	28.1	nd	0.26	2.437	1.409	24.9	63.5	118.3	44.1
1995 Geo Metro 2-DR	80	84	**43.9**	yes	0.65	4.158	1.518	nc			97.1
1997 Mitsubishi Eclipse 2-Dr	82	86	**48.6**	yes	**1.04**	4.097	1.429	nc			94.9
1995 Volvo 850 SW	49	58	29.9	yes	0.38	1.686	0.719	nc			23.5
1996 Ford Taurus 4-Dr	50	61	40.0	yes	0.94	2.196	1.131	67	116.1	145.65	90.8
1997 Nissan Sentra 4-Dr	67	94	**49.0**	yes	**1.32**	4.531	1.029	231.9	42.2	48	389
1997 Hyundai Sonata 4-Dr	70	102	29.7	yes	0.60	3.490	1.369	nc			177.6

* Numbers in bold are in excess of the criterion.
nc= no contact
nd= not determined

Table 5.
FMVSS 214 and EU 96/27/EC Test Results (Rear Passenger)

	TTI(d)	Pelvic (g)	RDC	V*C	PSPF (kN)	APF (kN)	HPC	Tstart	Tend	HIC36
	85/90	130	42 mm	1.00	6.0	2.5	1000	(ms)	(ms)	
1997 Lexus SC300 2-Dr	39	50	10.4	0.04	2.419	0.207	nc			308.6
1995 Geo Metro 2-Dr	69	100	33.5	0.23	3.725	0.110	365.4	38.2	96.7	365.4
1997 Nissan Sentra 4-Dr	51	74	11.4	0.04	5.036	0.576	234.9	61.6	141.6	252
1995 Volvo 850 SW	51	49	6.7	0.01	3.098	0.742	234	58.3	195.4	234
1996 Ford Taurus 4-Dr	57	65	23.6	0.14	1.171	0.594	nc			160.1
1997 Hyundai Sonata 4-Dr	60	102	17.5	0.09	0.673	0.317	nd			188.6

The results also indicate a much lower severity in the EU tests for the rear passenger dummy when both EU thoracic criteria are compared to TTI(d) in the FMVSS 214 tests. No trend is apparent when PSPF was compared against PelvicG for the rear passenger dummy.

Thoracic Injury Criteria

With the caveat that the Eurosid-1 rib deflections which form the basis for computing RDC and V*C are questionable (Refer to section **"Flat-Top"Anomalies in Eurosid-1 Rib Deflection Responses** below), the following observations are made. For the 4-Dr vehicles, the Nissan Sentra driver dummy, exceeded the RDC and V*C criteria (See Figure 6). For the 2-Dr vehicles driver dummy, the Geo Metro exceeded RDC and the Mitsubishi Eclipse exceeded both RDC and V*C.

With the exception of the Sonata and the Lexus SC300, the normalized TTI(d) was on the average 26.8% lower than RDC for the driver dummy. For the Sonata and the Lexus, TTI(d) was 12% and 3% higher than RDC. As to V*C, the results were more of a mismatch, with normalized TTI(d) on the average 27.1% lower than V*C for the driver dummy for four of the vehicles and higher by 27.5% for the remaining four vehicles. There were no apparent trends in these differences for either the 2-Dr or 4-Dr sets of vehicles.

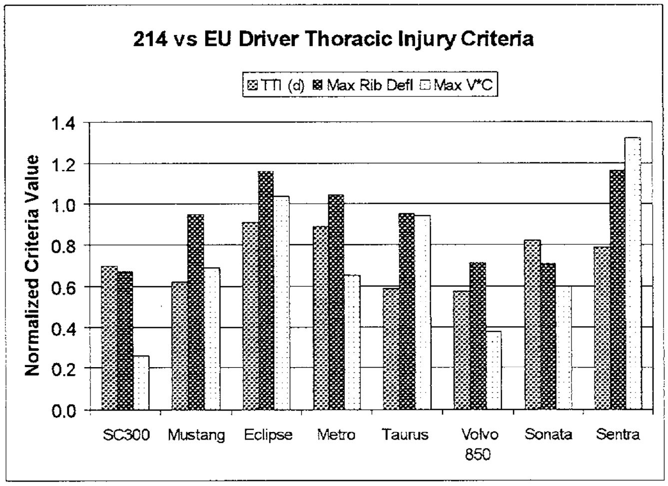


Figure 6.

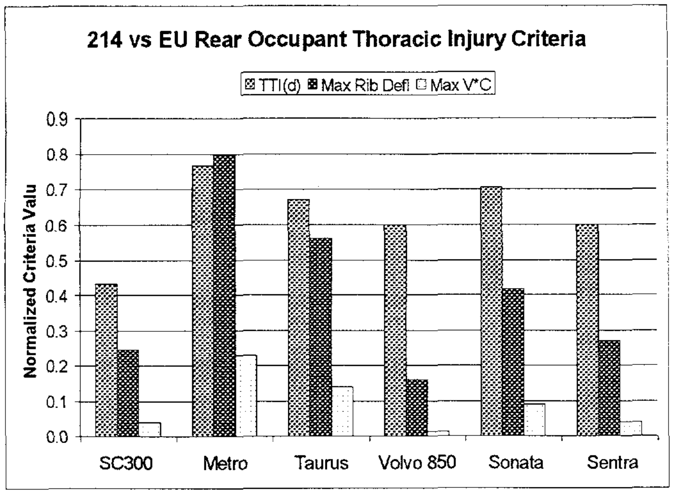


Figure 7.

The average normalized thoracic criteria for the 4-Dr vehicles and the 2-Dr vehicles are listed in Table 6. For the driver dummy, the average normalized TTI(d) and RDC are higher for the 2-Dr vehicles. In contrast the average normalized V*C is lower for the 2-Dr vehicles.

Table 6.
Average Normalized Thoracic Criteria

	4-Dr Vehicle Set		2-Dr Vehicle Set	
	driver dummy	rear dummy	driver dummy	rear dummy*
TTI(d)	69%	64%	78%	60%
RDC	88%	35%	96%	52%
V*C	81%	7%	66%	14%

*average results from only 2 vehicle tests

Pelvic Injury Criteria

For all the vehicles tested and for both front and rear dummy, none of vehicles exceeded the criteria for either regulation (See Figures 8. and 9.). For the driver dummy, the results were more of a mismatch when comparing the results for the two regulations. The normalized PelvicG in the FMVSS 214 tests was on the average 8% higher than PSPF in the EU tests for four of the vehicles and lower by 10% for the other four. When looking at the 4-Dr vehicles separately, PelvicG was on the average greater than PSPF by 16% for three of the four vehicles. The exception was the Sentra, in which PelvicG was less than PSPF by 3%. In contrast, for the 2-Dr vehicles, PelvicG was on the average 12% lower than PSPF for three of the four vehicles for the driver dummy. The exception was the SC300, in which PelvicG was larger than PSPF by 19%.

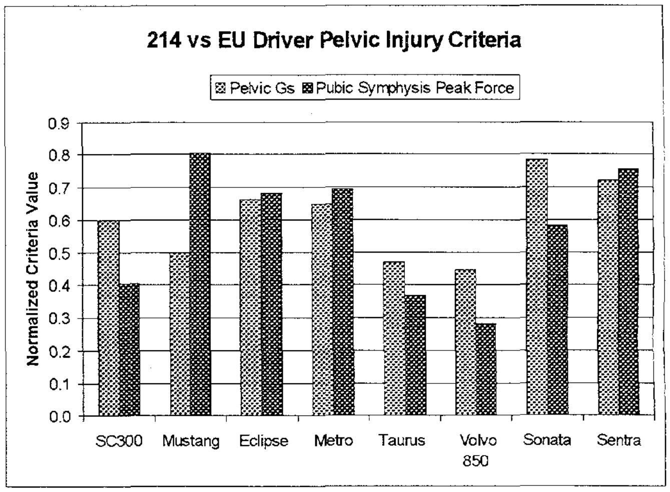


Figure 8.

For the rear passenger dummy, the normalized PelvicG was on the average 38% higher than PSPF for three of the vehicles and lower by 14% for the remaining three. There was no apparent trend in these differences for either the 2-Dr or 4-Dr sets of vehicles.

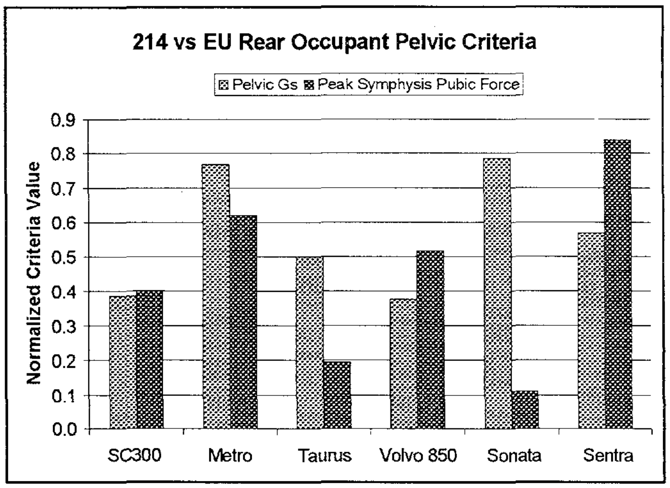


Figure 9.

Abdominal Injury Criterion

For the driver dummy in the EU tests, the Mustang normalized APF was 92% of the limit specified in the regulation and the Volvo APF was 29%. The normalized APF for the remaining six vehicles was clustered closer with an average of 53% of the limit.

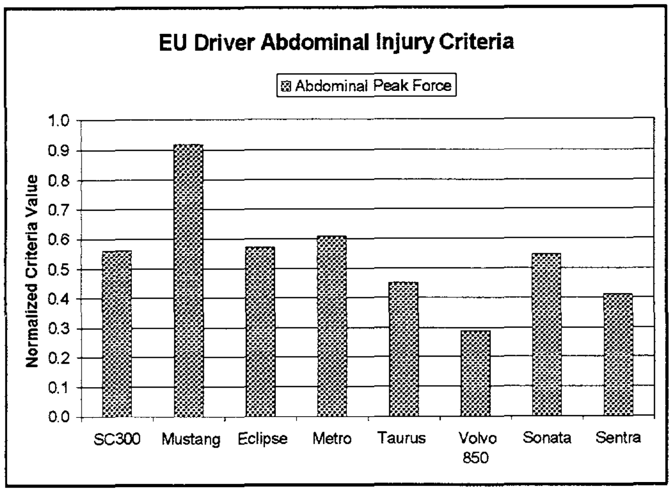
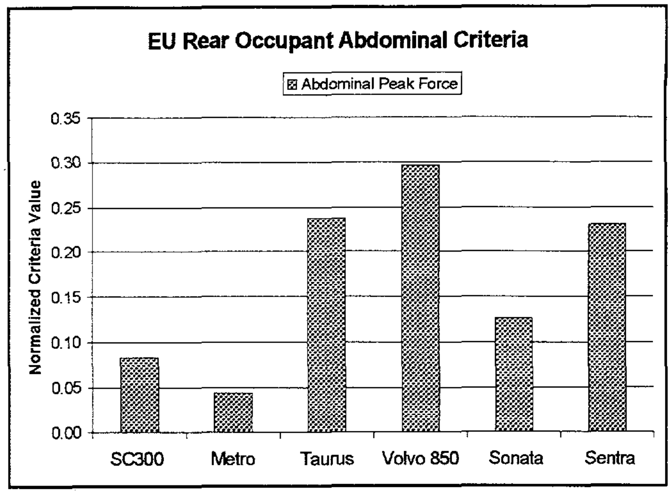


Figure 10.

Overall, the average APF for the driver dummy in 2-Dr vehicles was 67% of the limit. The average APF for the driver dummy for the 4-Dr vehicles was lower at 42 %. In contrast, for the rear dummy, the average APF was only 6.3% of the limit for the 2-Dr vehicles and 22.3% for the 4-Dr vehicles with no value exceeding 30% of the limit. The APF results are presented in Figures 10. and 11.

Head Injury Criterion

For the driver dummy in the EU tests, head contact occurred for four of the eights vehicles, with an average normalized HPC of only 8.9% of the limit specified in the regulation. For the rear dummy, contact occurred for three of the six vehicles with an average HPC of 27.8% of the limit. The normalized HPC and HIC36 values from the EU tests are presented in Figures 12. and 13. HPC is plotted only if head contact occurred.



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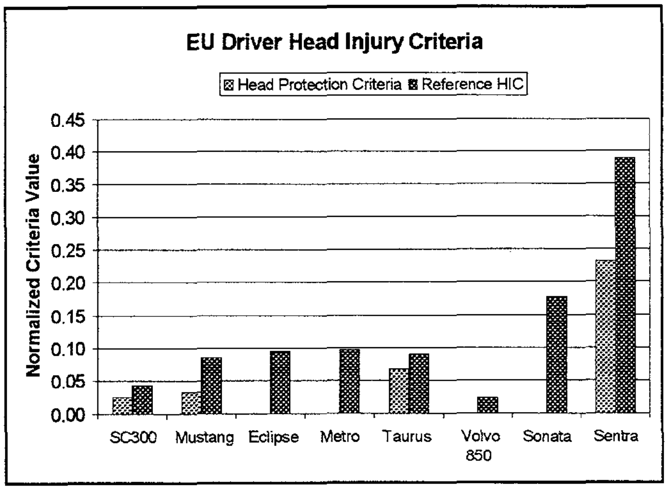


Figure 12.

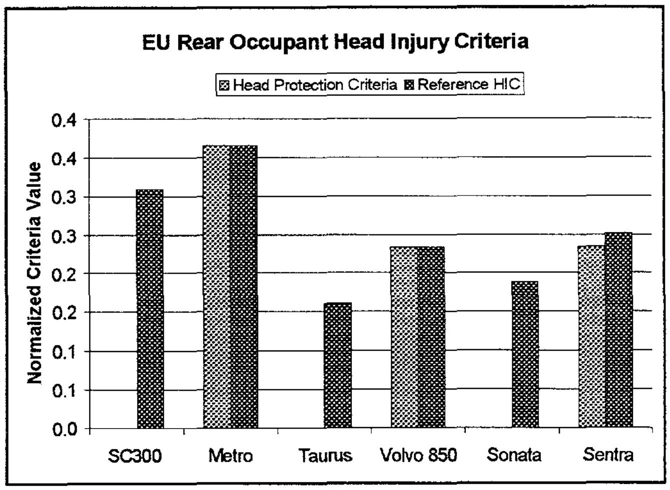


Figure 13.

"Flat-Top"Anomalies in Eurosid-1 Rib Deflection Responses

Figures 15. through 28. present an overlay of the raw (Class 1650) rib displacements for both the front and rear dummy for the vehicles tested. As shown in the figures, sustained peaks (plateaus of flat-tops) as long as 15 ms in at least one of the rib displacement curves are present for the driver Eurosid-1 for all the vehicles tested. These flat-tops are present for the rear dummy in three of the six vehicles. The displacement levels of these plateaus range anywhere from 15 to 50 mm and are below the full range of the rib potentiometers of the dummy.

Lau reported on this phenomenon in a series of Ford LTD crash tests [11]. Using a pneumatic impactor to impact the Eurosid-1, the sustained peaks in the rib displacement were produced but they could not be created with pendulum impact. (Integration of the rib and spine accelerations in the impactor impacts indicated that they were moving away from the impactor at similar speeds.) Henson et al. reported a similar rib deflection problem when testing Pontiac 6000's using the FMVSS 214 procedure with the Eurosid-1 [12]. This was believed to occur when impacts were more rearward than the lateral center of the ribs. The American Automobile Manufacturers Association (AAMA) has highlighted this anomalous rib behavior in their list of mechanical concerns relative to the Eurosid-1 dummy [13]. The AAMA has attributed this behavior to binding in the rib damping modules due to off-axis loading. Transport Canada has recently reproduced this flat-top behavior with the Eurosid-1 ribs with pendulum impacts at -15 degrees from the coronal plane, i.e. posterior or rearward of the center of the ribs [14]. In those tests, the pendulum face contacted the projecting back plate causing an alternative load path through the spine box, however the rib deflections were near their maximum.

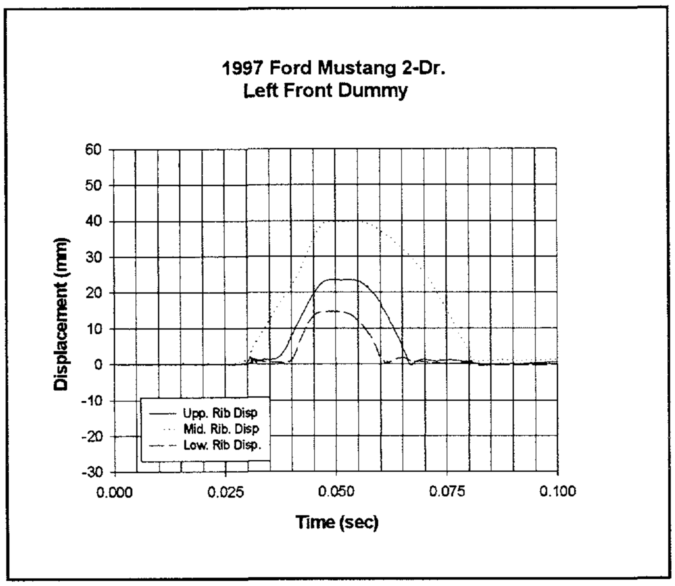


Figure 15.

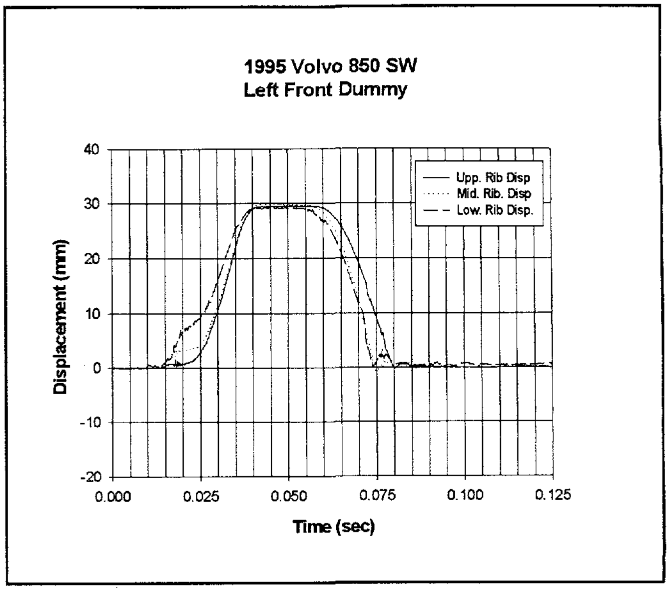


Figure 16.

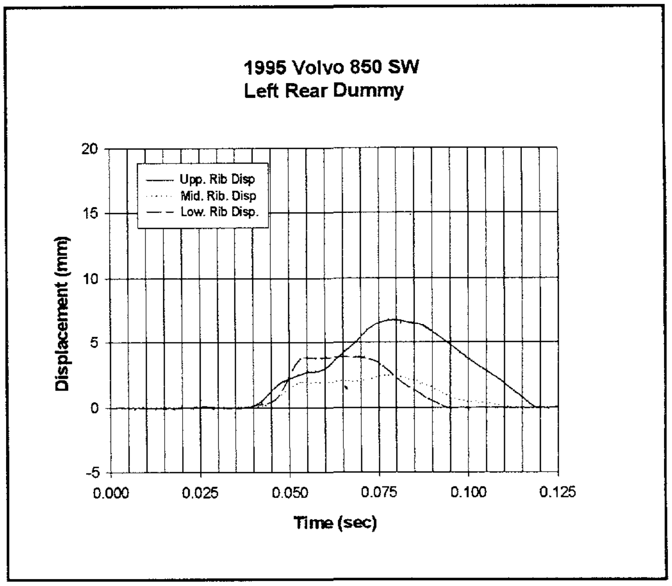


Figure 17.

Review of the high speed film from the series of eight test presented in this paper indicated that dummy rotation was visible in most of the tests. Contact with the intruding door was made more rearward than the lateral center of the ribs on some of the tests, while contact was forward of the center of the ribs in some of the tests suggesting off-axis loading conditions. This flat-top rib behavior of the Eurosid-1 was reproduced and further investigated with bumper pendulum impact tests outside the full vehicle test environment as outlined below.

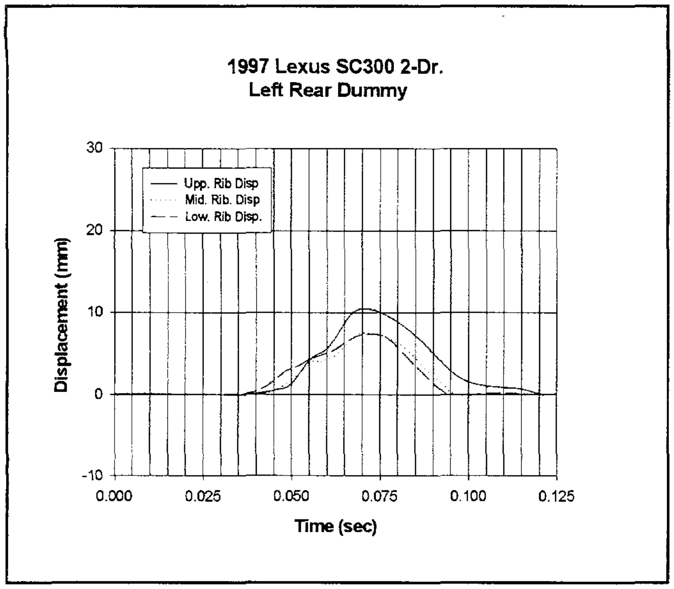
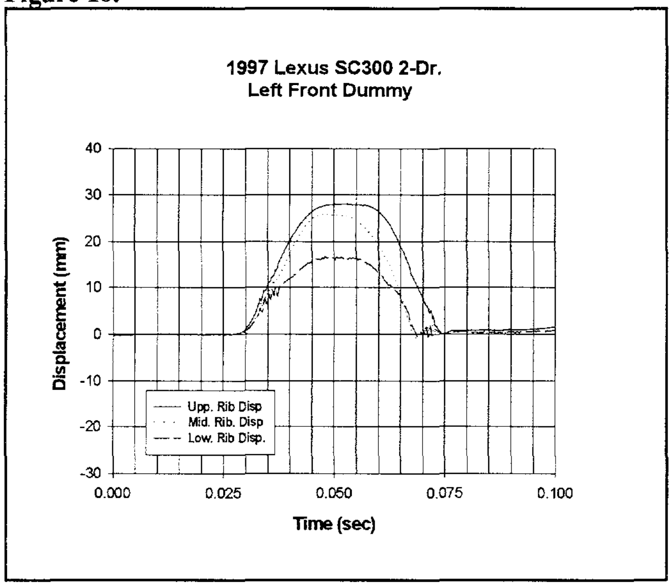


Figure 18.



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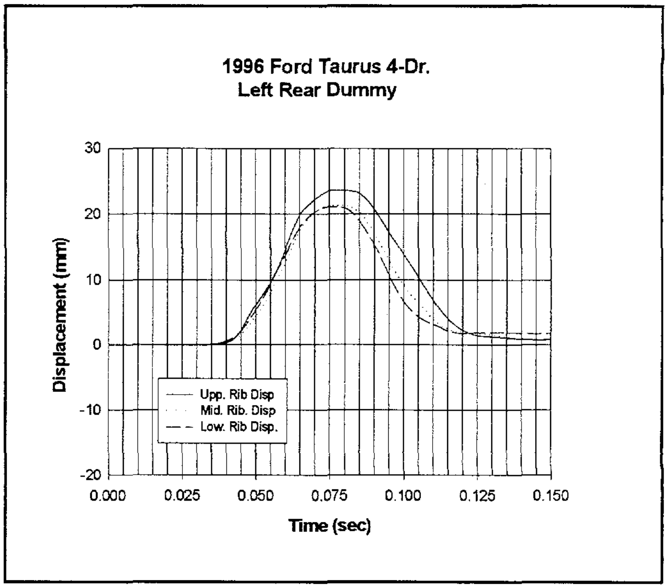

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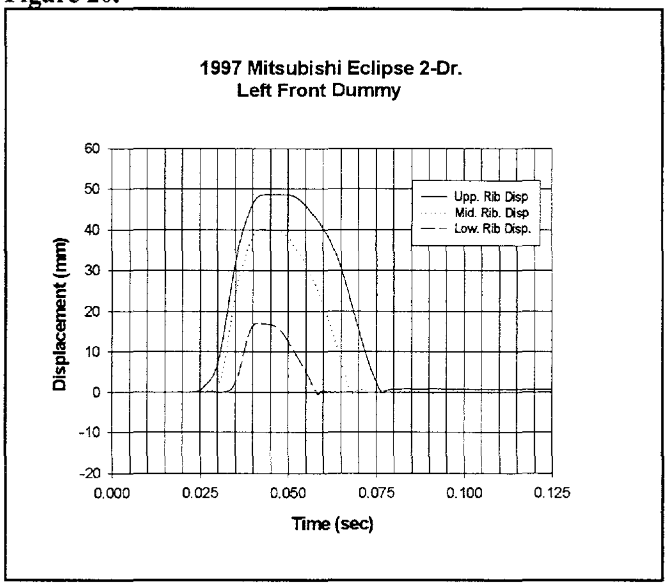

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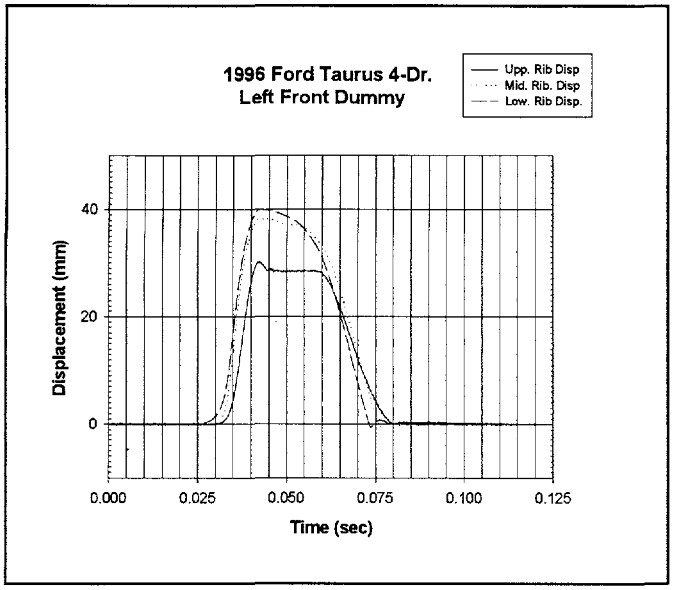

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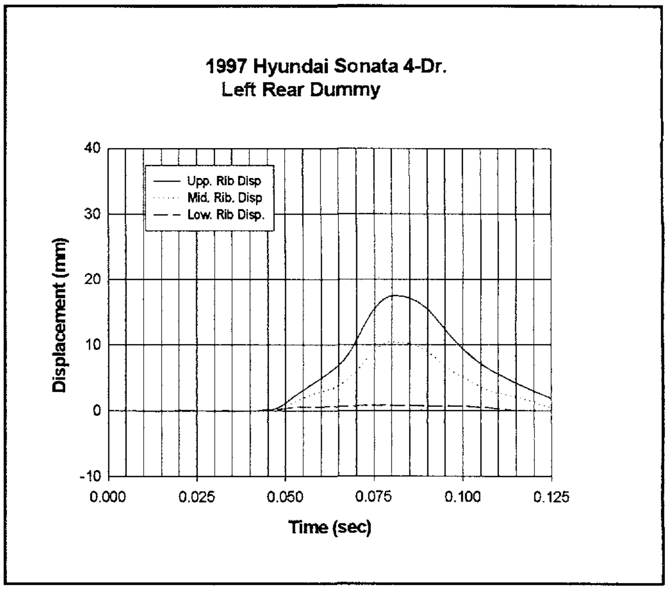

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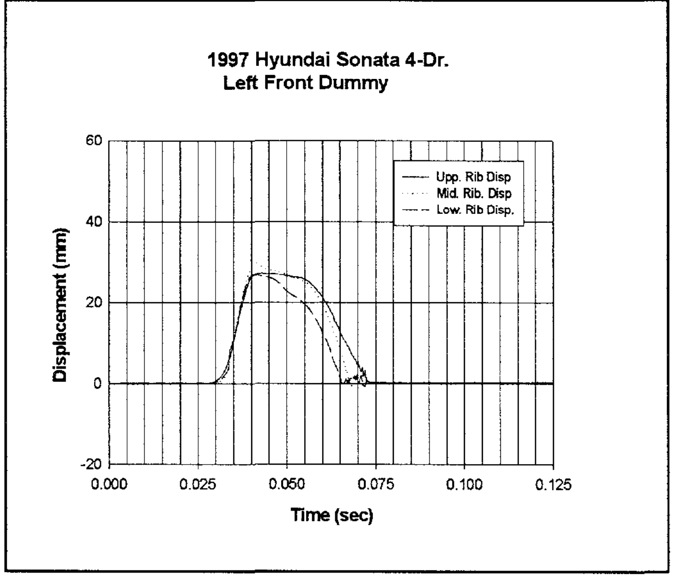

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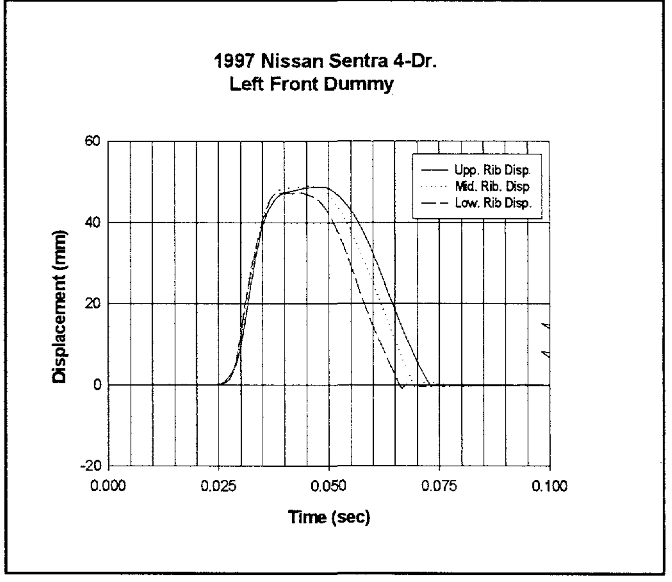

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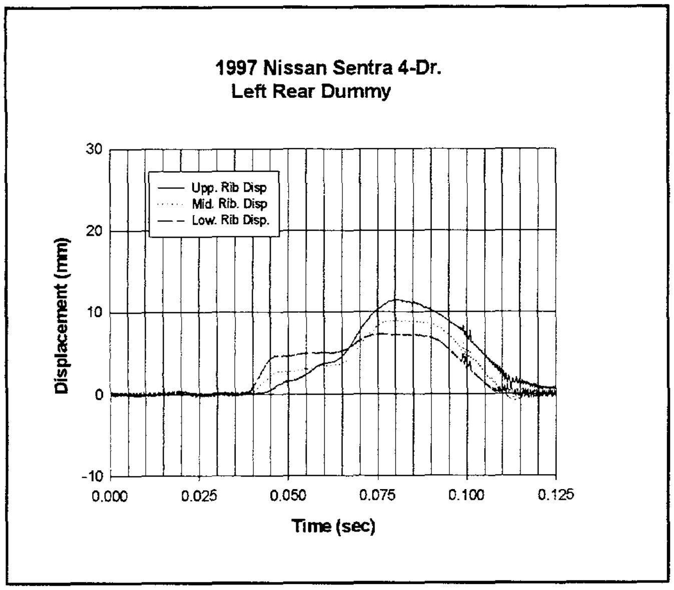

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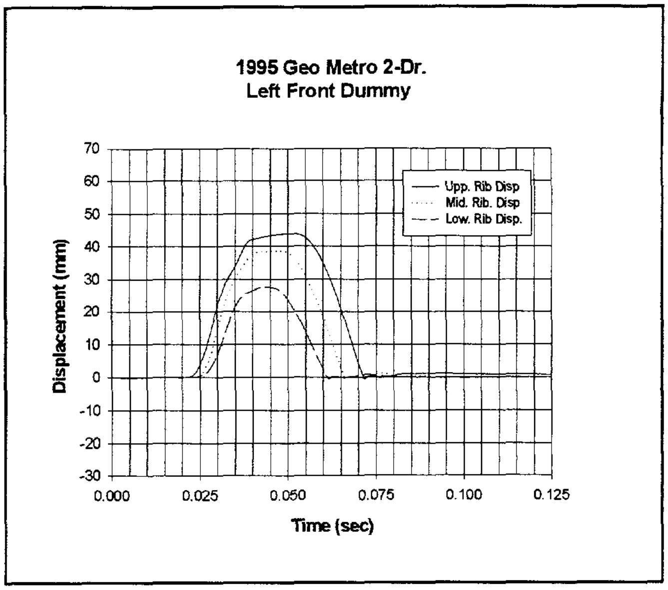

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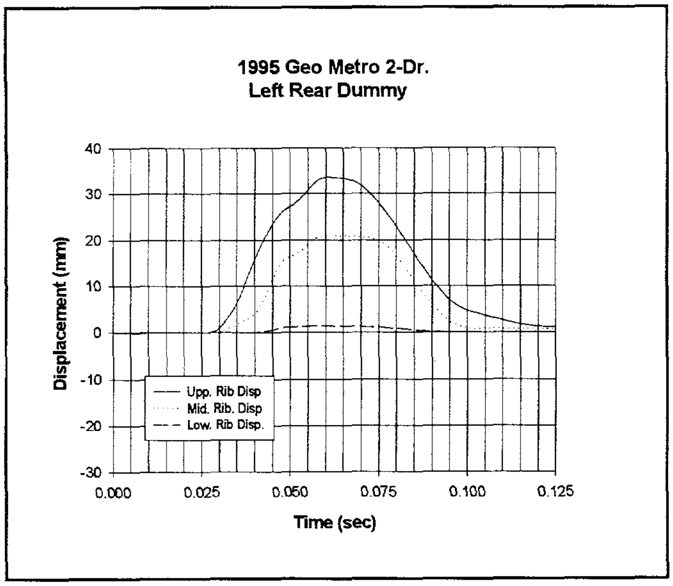

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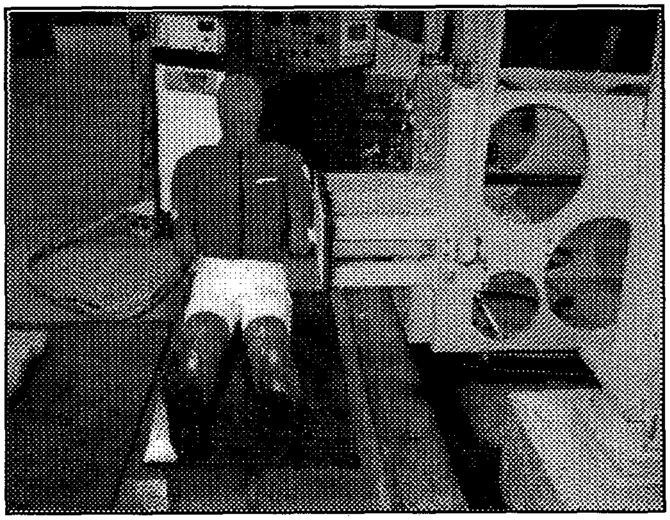


Figure 29. Eurosid-1 Bumper Pendulum Tests Setup.

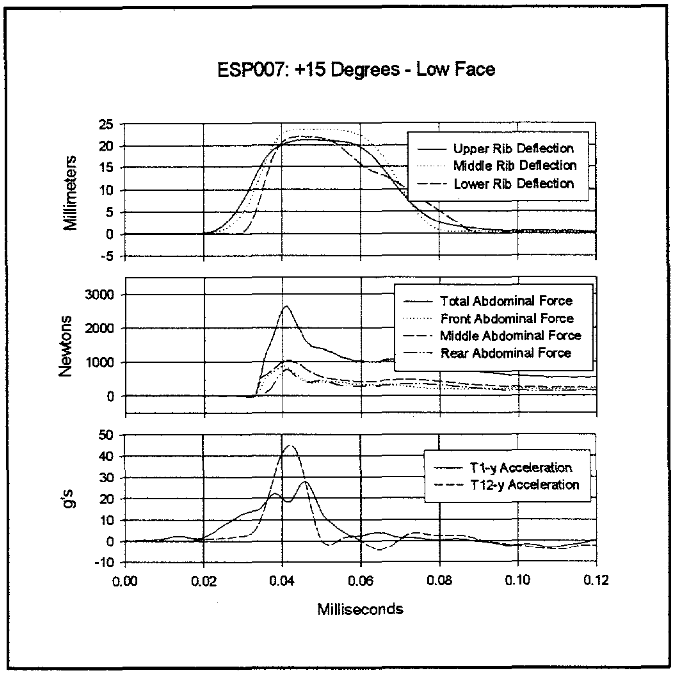
Eurosid-1 Bumper Pendulum Tests - To further investigate the flat-top behavior in the rib displacement responses, a series of bumper pendulum impact tests with the Eurosid-1 were performed. The general test setup is shown in Figure 29. The part 581 bumper pendulum which has a mass around 907.4 kg was used in all the tests. The bumper pendulum was rotated to a sufficient height and also given an initial velocity via springs to get a closing speed similar to the door contact speeds encountered in the series of EU full scale side impact tests. The test conditions are described in the following:

1. The impact speeds were around 18.2 km/hr.
2. The pendulum impact face was a steel plate with a 3/4" plywood cover, 610 mm wide measured from the seating surface at a height of 239 mm corresponding to the top of the molded pelvis of the Eurosid-1.
3. Based on the review of the full scale crash test films, two impact face heights were used: 239-503 mm (Low Face) & 239-558 mm (High Face) with the seating surface at z = 0. The low face extended from the pelvic/abdomen junction to approximately 1/3 down the arm (arm at 40 degrees) from the shoulder pivot bolt. The high face extended from the pelvic abdomen junction to the center of the shoulder attachment bolt.
4. The dummy was placed on the horizontal flat steel seating surface with legs extended.

5. Tests included +/-15 degrees, and 0 degrees left dummy side impacts (e.g. + 15 degrees is an anterior oblique impact and requires rotating the dummy by +15 degrees about the z-axis using a right-hand coordinate system with x positive in the posterior-anterior direction, and y positive lateral to the left.)

The 18.2 km/hr impact was on the low end of the range of 25-40 km/hr door contact speeds encountered in the EU full scale tests but, as can seen from the following figures, reasonable rib displacements ranges of 10 to 40 mm were achieved as compared to the values obtained in the full scale tests.

As shown in Figures 30. through 34., for both impactor face heights significant flat-top rib deflections responses were present in the +15 degree impact condition, while 0 degree impacts produced a lesser flat-top. The flat-top behavior did not occur for the tests at -15 degrees, neither with the Low Face nor with the High Face.



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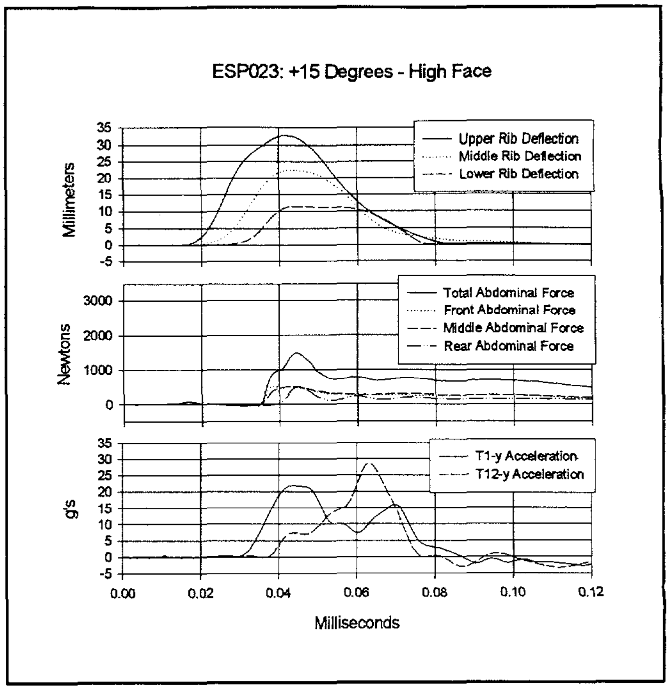

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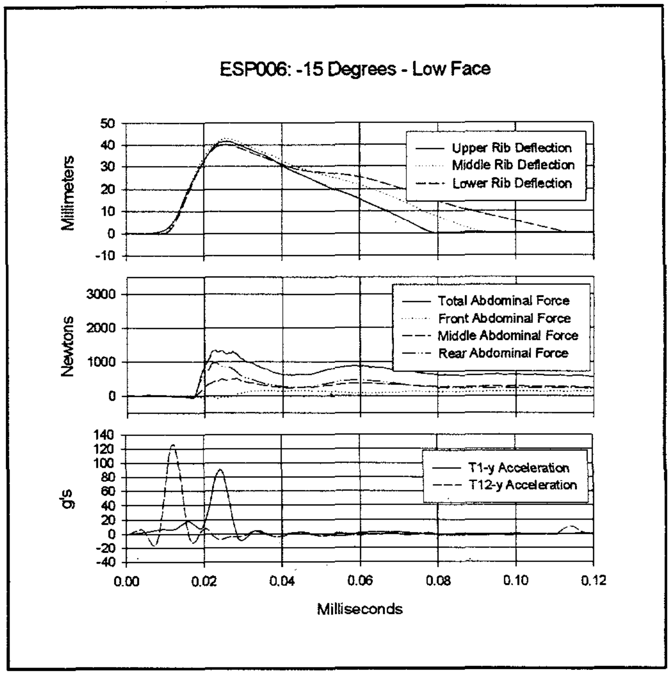

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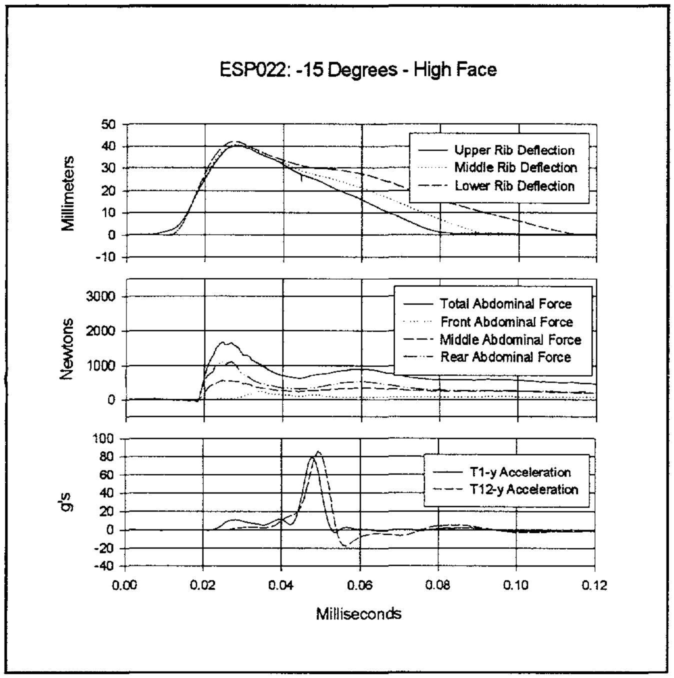


Figure 33.

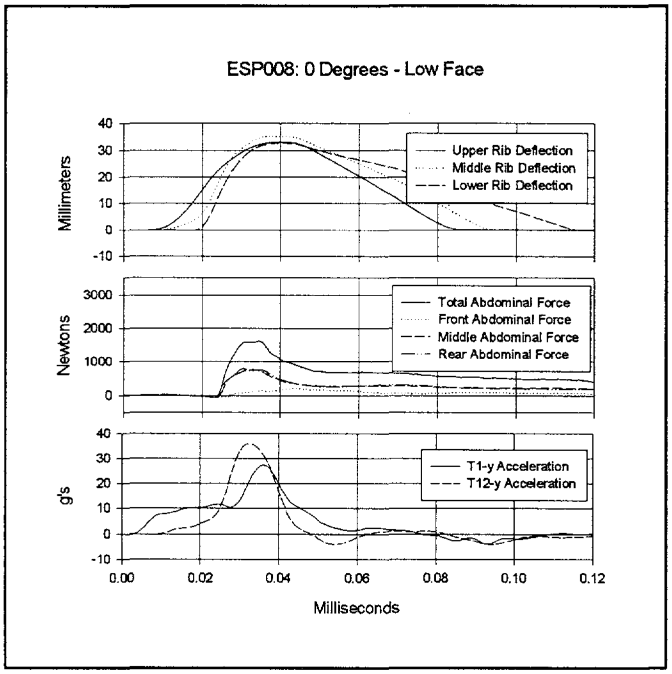


Figure 34.

Based upon this work and that of other researchers, the authors have developed the following hypotheses for the cause of rib flat-tops in the Eurosid-1:

1) Binding of the rib damper module: Henson et al. suggested that moment is transferred across the rib damper in the Eurosid-1 thorax during oblique impact [12]. Such a moment could cause excessive friction between the piston and cylinder wall of the damper, and cause it to bind.

2) Load Bridging: In this test condition, each of the elements of the torso (the shoulder complex, each of the thoracic ribs, abdomen, and possibly the back plate) share the total force transferred to the spine box to accelerate Eurosid-1 through the change of speed of the test. Load bridging can occur when an element's adjacent neighbors experience an increase in stiffness (due to a constitutive relationship in a material or structure, and/or a mechanical binding) and thus the element's deflection is governed by its neighbors. For example, should the upper and lower rib of the Eurosid-1 thorax bind due to some mechanical defect and thus increase their stiffness, the deflection of the middle rib should not exceed that of the upper and lower ribs. Load bridging may be present between a binding shoulder and the abdomen, or the shoulder and pelvis, or direct contact with the back plate, thereby limiting the deflection of the rib modules.

A series of tests was conducted at +15 and 0 degrees to determine the load sharing between the thorax and the abdomen. In these tests the load wall contacted the abdomen and thorax only, while the arm was rotated 180 degrees to point straight up, such that it was not contacted by the impactor. Figures 35. and 36. show the results from these tests, and flat-tops are observed in these conditions. These results show that after the flat-top rib responses, abdominal loads drop off significantly, and then rise again as the thorax begins its expansion. Newton's first law applied to deformable bodies loaded in parallel requires that a) the total load applied equal the sum of the loads carried by each of the bodies, and b) the load one body carries is directly proportional to its stiffness and mass (stress follows elastic modulus and density). Based on this law, we can then conclude from the data that the drop in force on the abdomen indicates an increase in force on the thorax. Thus we would conclude from this test that the flat-top is a result of binding within rib modules or quite possibly of the damper modules themselves. However, this may not be the only mechanism of rib binding in other test environments.

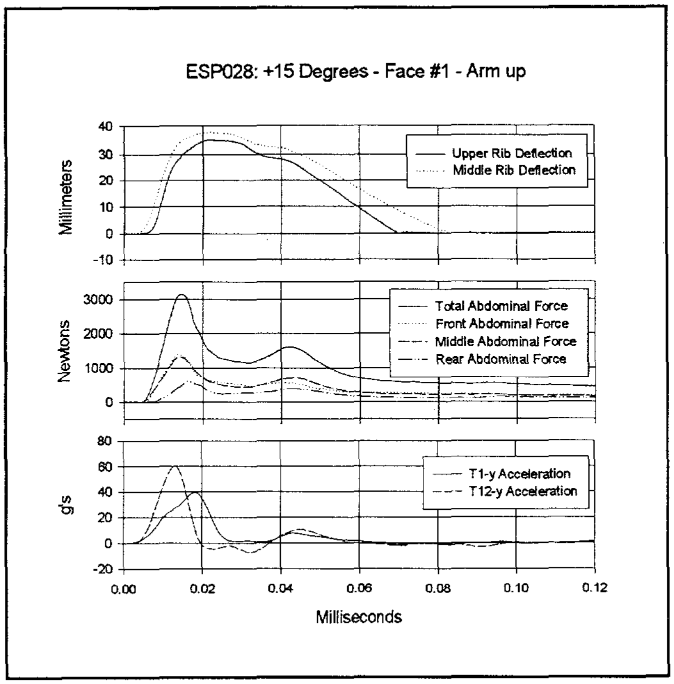


Figure 35.

Another series of tests with the Eurosid-1 was performed with the Eurosid-1 jacket removed at + 15 degrees, the results of which are shown in Figure 37. While these tests were originally designed to permit viewing of the thorax and shoulder during impact, the results indicate that there is a significant change in the dummy behavior between the jacket on and jacket off tests. In Figure 37., the results from three repeat tests at + 15 degrees, with the Eurosid-1 jacket removed in two of the tests, are presented . The results show that the flat-top behavior occurred in all of the three tests. These results indicate that the flat-top behavior is not only reproducible but is also repeatable under the given test conditions.

Other researchers have suggested that the impactor/door surface may come in contact with the back plate of the dummy, thereby off-loading the rib structure and causing a flat-top. Inspection of films from these series of bumper pendulum tests indicate that no impactor-to-back plate contact occurred. Moreover, contact with the back plate is only likely with a combination of oblique posterior loading and excessive rib deflection.

<u>Eurosid-1 Bumper Pendulum Tests with Upgrade Kit</u> -
TNO has recently developed a research kit tool upgrade to address some of the widely accepted mechanical dummy issues with the Eurosid-1 (Refer to section **<u>Eurosid-1 Mechanical Deficiencies</u>**) . The research upgrade kit for the Eurosid-1 addresses a number of minor issues. These include smoothing sharp edges on the projecting torso backplate, use of bumper washers to minimize impacts between the femur shaft and pubic load cell mounting hardware, beveling sharp edges on the clavicle link to prevent binding with the aluminum guide plates of the shoulder assembly, and use of plastic spacers in the lumbar spine and neck similar to those used in the SID. The modifications in this upgrade kit are minor in nature and would not seem tot address the major issues such as alleged binding of the damper in the rib cage, the influence of the kinematics of the shoulder structure on the rib cage deflection, and the deformability of the pelvis bone.

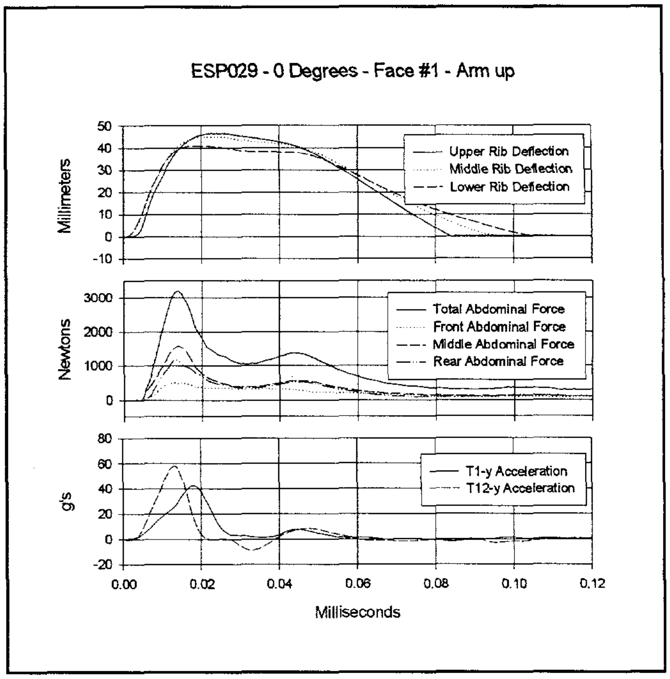


Figure 36.

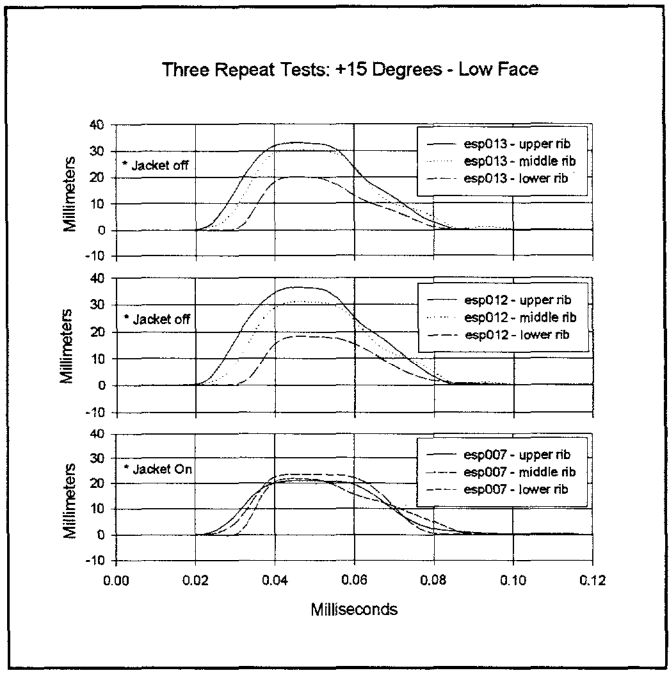


Figure 37.

In April 1998, the Eurosid-1 research upgrade kit was made available to NHTSA for evaluation. To date, a preliminary evaluation was performed through a series of bumper pendulum tests under test conditions similar to those described in the previous section. Tests were performed with the Low Face and were run at + 15 and 0 degrees. The purpose of performing repeat tests with the upgrade kit installed in the Eurosid-1 was to investigate if modifications in the kit address the flat-top anomalies in the rib potentiometer responses.

Figures 38. through 40. show the results from two repeat tests at + 15 degrees and one test at 0 degrees. As can be seen from the figures, the flat-tops are still observed in these conditions.

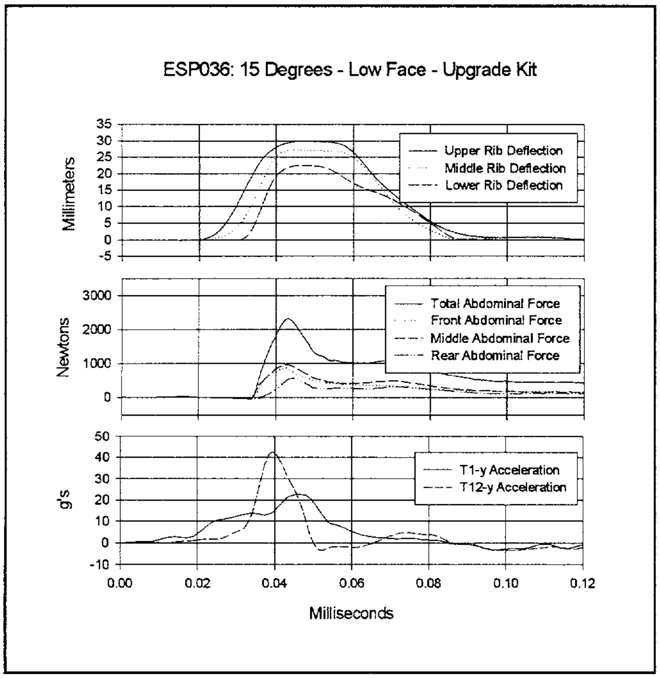
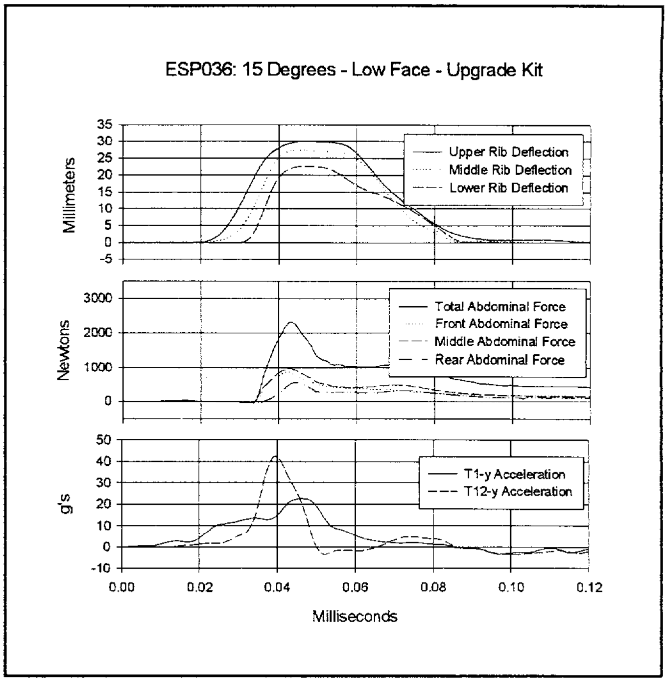


Figure 38.

<u>Conclusions Regarding Eurosid-1 Rib Responses "Flat-Top" Anomalies</u> -

Irrespective of the mechanism causing the anomalous behavior, the flat-top behavior in the rib potentiometer responses indicate that what should be the true peak rib deflections may not be occurring and thus the resulting rib deflections are in doubt. The V*C computation which is based on the rib deflection would also be suspect. In light of this, the RDC and V*C values for the EU 96/27/EC vehicle tests presented in this paper are questionable.



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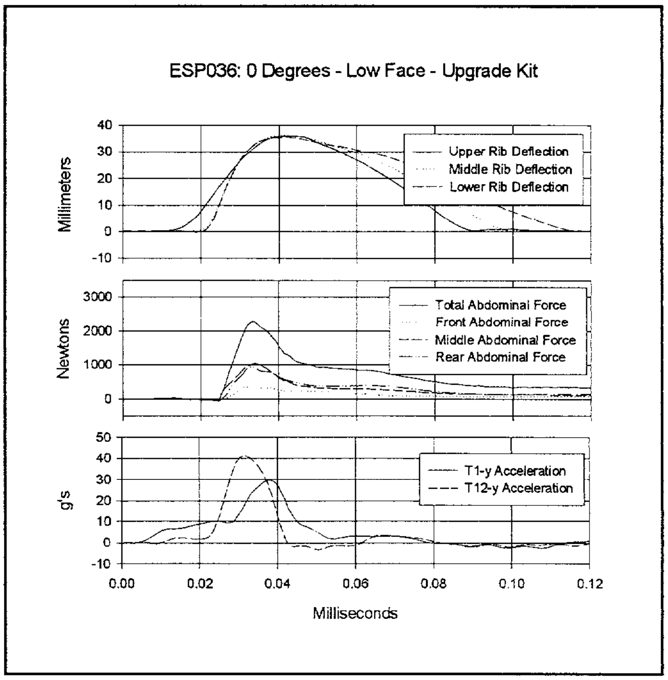


Figure 5.

COMPARISON OF VEHICLE RESPONSES

MDB Engagement - The EUMDB is 176 mm or 10.5 % narrower than the 214MDB and in the EU procedure it is centered on the driver seating reference point while the 214MDB is positioned more forward and is positioned relative to the center of the wheelbase. This resulted in no MDB to A-pillar engagement in the EU tests while the A-pillar was engaged in all of the FMVSS 214 tests. Also, the EUMDB right edge engaged the vehicle rearward of the 214MDB right edge for all of the vehicles tested. (See Table 7.). The vehicle contact areas for the EUMDB and 214MDB, drawn to scale, are shown for the Lexus SC300 and Volvo 850 in Figures 41. and Figures 42. as examples.

Table 7.
FMVSS 214 vs EU 96/27/EC MDB's to Vehicle Contact

Vehicle	Left edge difference* (mm)	Right edge difference* (mm)
Ford Taurus	N/A	N/A
Volvo 850 SW	253	77
Nissan Sentra	274	98
Hyundai Sonata	236	60
Ford Mustang	311	135
Lexus SC300	433	257
Geo Metro	337	161
Mitsubishi Eclipse	358	182

* 214MDB-EUMDB; positive is forward

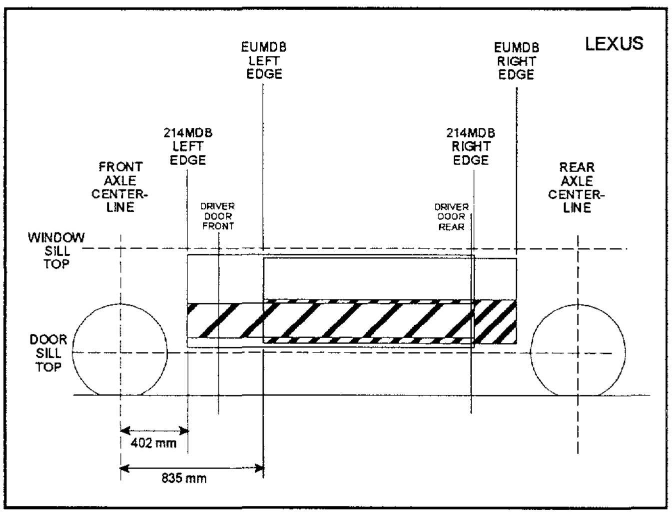


Figure 41. Lexus SC300: EUMDB and 214MDB Contact Areas.

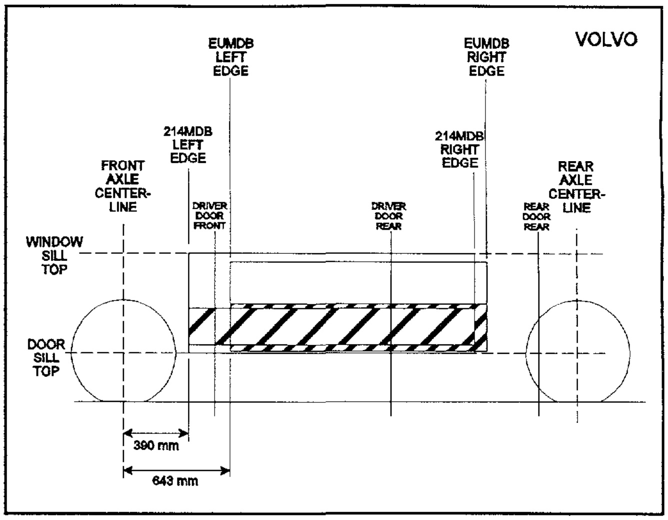


Figure 42. Volvo 850: EUMDB and 214MDB Contact Area.

Table 8.
Side Intrusion at Door Sill, Driver H-pt, & Mid Door

Vehicle	Door Sill Level max and average crush (mm)		Driver H-pt level max and average crush (mm)		Mid Door level max and average crush (mm)	
	FMVSS 214	EU 96/27/EC	FMVSS 214	EU 96/27/EC	FMVSS 214	EU 96/27/EC
Ford Taurus*	N/A	N/A	N/A	N/A	N/A	N/A
Volvo 850 SW	110 **70**	**150** 69	**284** **220**	264 178	**280** **227**	270 189
Nissan Sentra	166 **125**	**217** 120	310 270	**372** **287**	280 172	**377** **217**
Hyundai Sonata	147 91	**281** **164**	388 **326**	**443** 291	394 **332**	**435** 305
Ford Mustang	132 99	**266** **153**	254 **220**	**333** 211	234 171	**335** **197**
Lexus SC300	**157** **109**	130 100	320 **272**	**330** 216	**351** **239**	304 193
Geo Metro	**160** **112**	112 70	239 **227**	**249** 179	226 **161**	**262** 141
Mitsubishi Eclipse	178 **157**	**196** 107	304 **287**	**333** 265	296 **258**	**333** 248

* Crush profile data was not available for the Taurus EU test

Side Crush Profile Comparison - In order to facilitate comparison with the intrusion profile in the FMVSS 214 tests, pre and post test side crush measurements were collected for the EU tests as specified in the FMVSS 214 test procedure [15]. The maximum side crush at the door sill and mid door levels for the EU and FMVSS 214 tests are presented in Table 8. It is worth noting that relative magnitude for the maximum intrusion at these levels did not correlate with the thoracic and pelvic criteria values for the different vehicles neither for the FMVSS 214 nor for the EU tests. With the exception of the Volvo 850, the maximum static intrusion at the driver H-pt level for the EU tests was on the average 41 mm larger than for the FMVSS 214 tests. At the mid door level, with the exception of the Volvo 850 and Lexus SC300, the maximum static intrusion at the driver H-pt level for the EU tests was on the average 62 mm larger than for the FMVSS 214 tests.

The static crush profiles at the door sill and mid door levels are presented in Figures 43. through 56. In general, in the EU tests, the crush profile is more rounded with larger intrusion around the B-pillar and the rear section of the front door. In the FMVSS 214 tests, the crush profile is more rectangular in shape with the intrusion more evenly distributed along the area of MDB-to-vehicle engagement. This is attributed to the characteristics of the EUMDB and 214MDB and their positioning as described earlier.

At the sill level, with exception of the area around the B-pillar, intrusion was larger for the FMVSS 214 tests of the Metro, SC300, Sentra, and Eclispe. In contrast, the intrusion was significantly larger at the sill level for the EU tests of the Sonata and Mustang.

At the mid door level, also with the exception of the area around the B-pillar, intrusion was larger for the FMVSS 214 tests of the Metro, Sonata, and Eclispe. In contrast, the intrusion was significantly larger at the mid door level for the EU tests of the Sentra and Mustang, specifically around the B-pillar and rear section of front door areas. In fact, the B-pillar was split in half in the EU test of the Mustang.

The Lexus SC300 was the only vehicle which had more intrusion at both the sill and mid door levels for the FMVSS 214 test. For the Volvo 850, which is designed to meet both regulations, intrusion at both levels was comparable for the two regulations. It is worth noting that both the 850 and the SC300 were the best performers in the 4-Dr and 2-Dr vehicles sets relative to the requirements of both regulations.

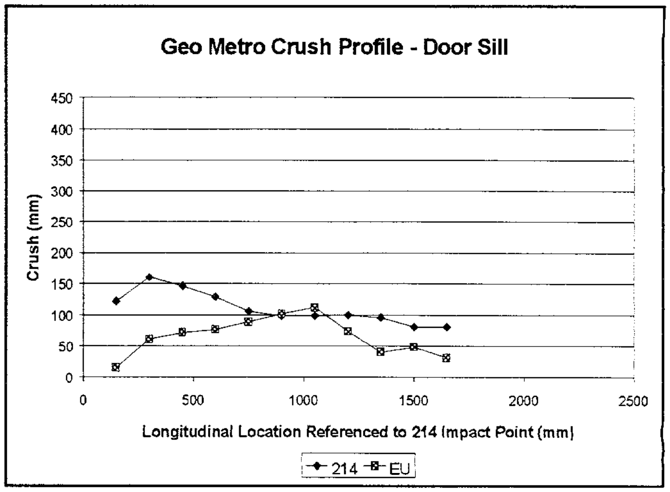
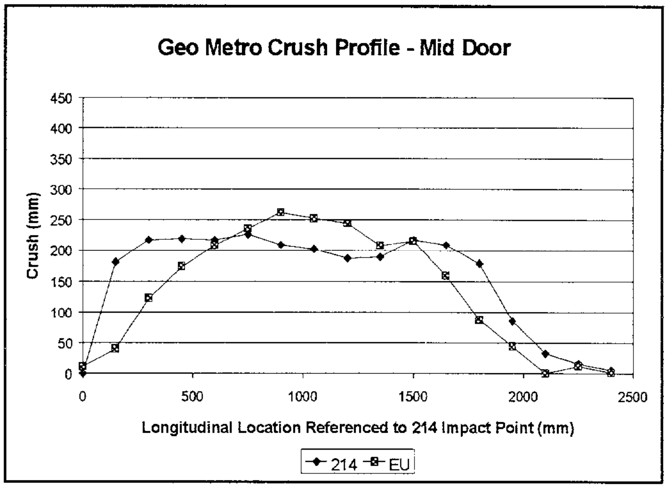


Figure 43.



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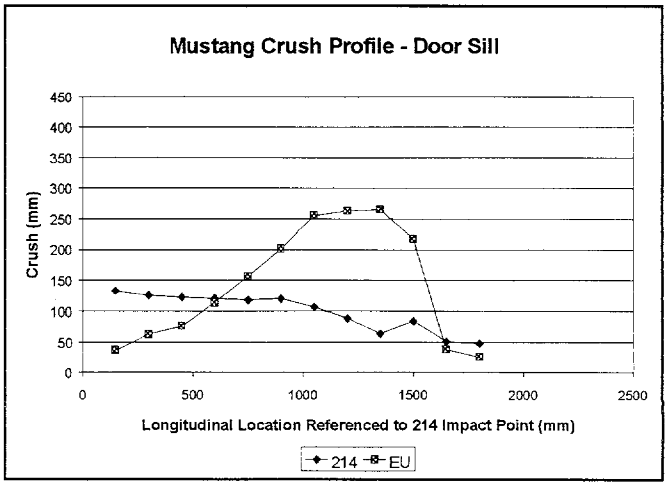

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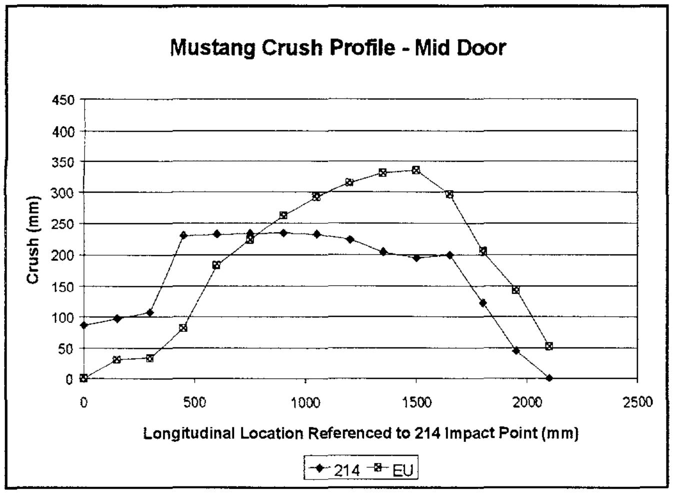

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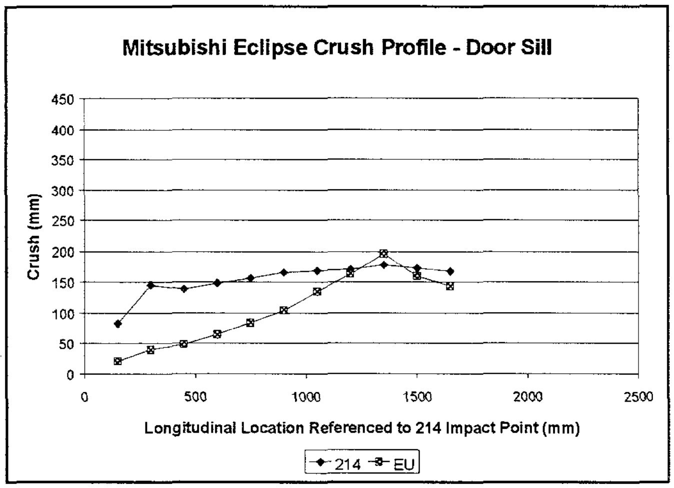

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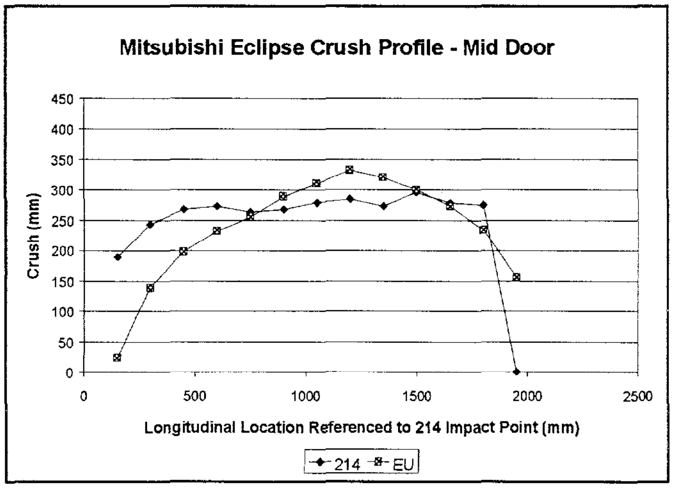

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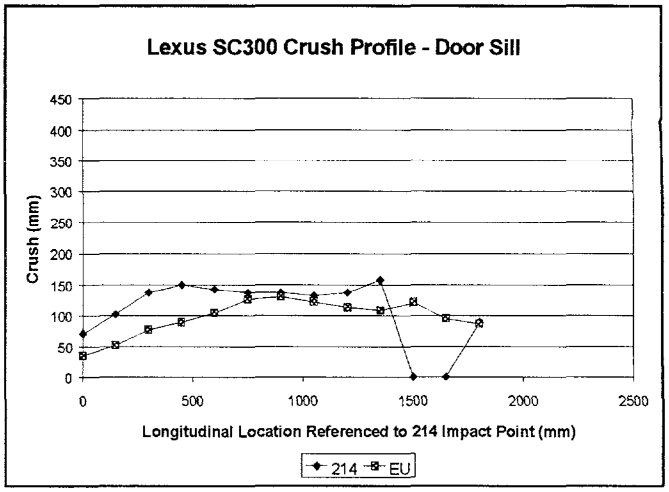

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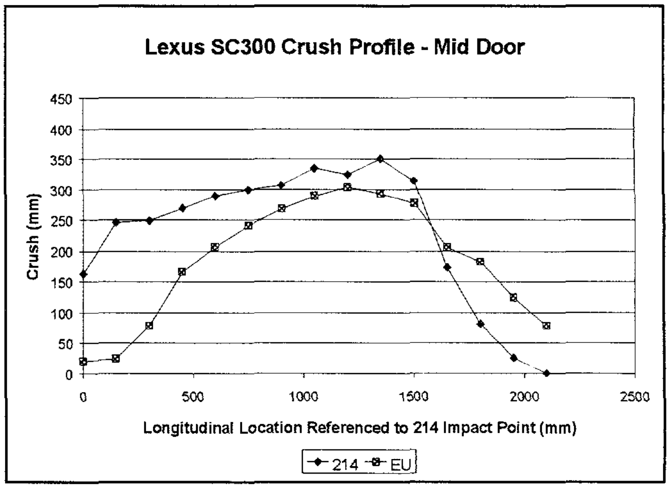

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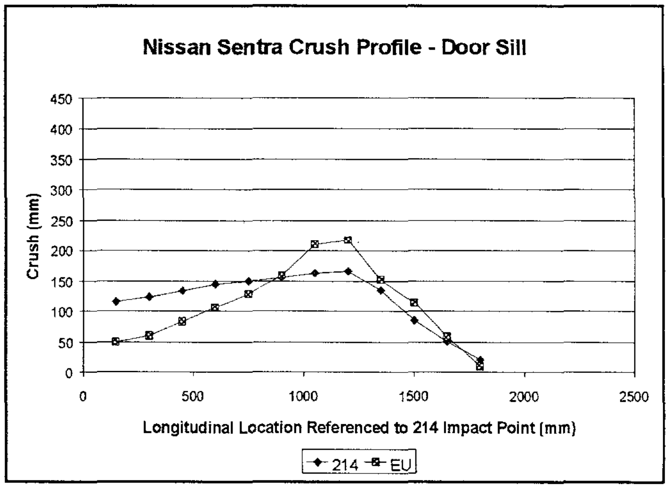

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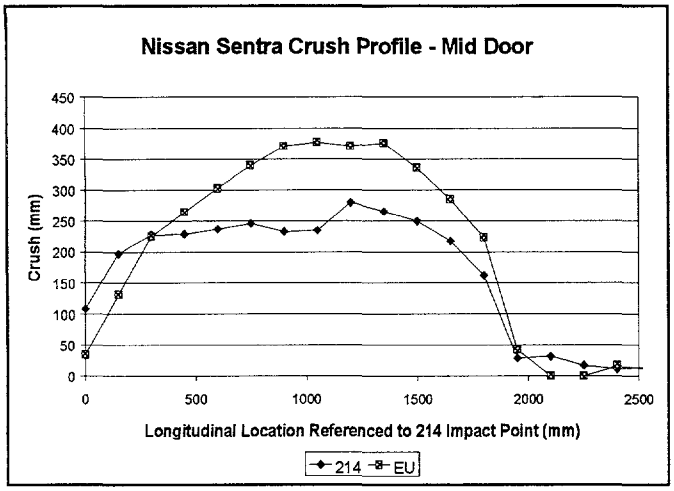

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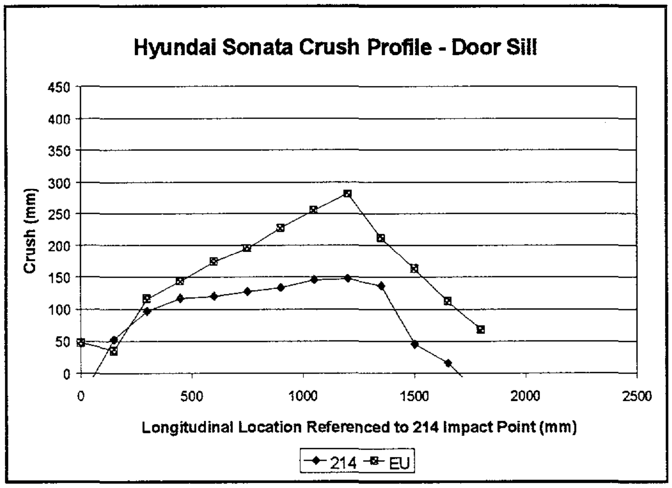

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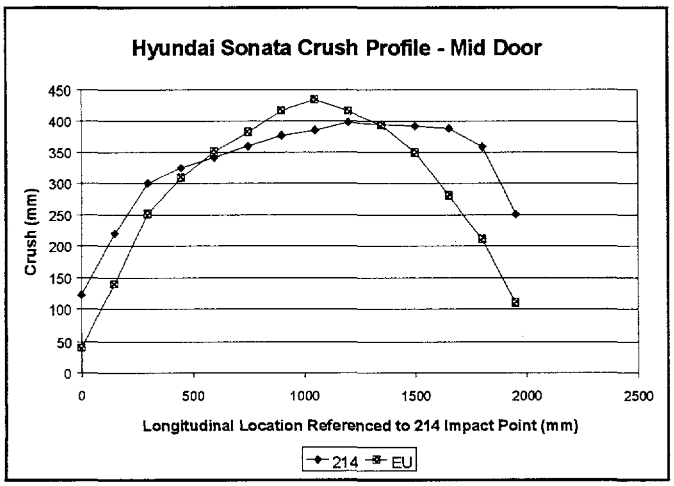

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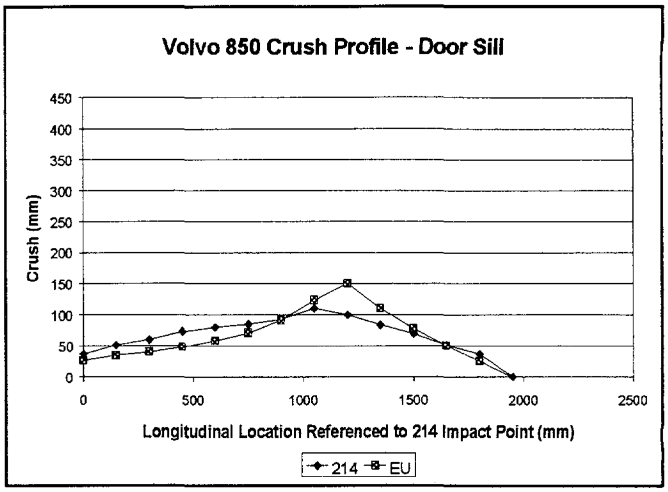

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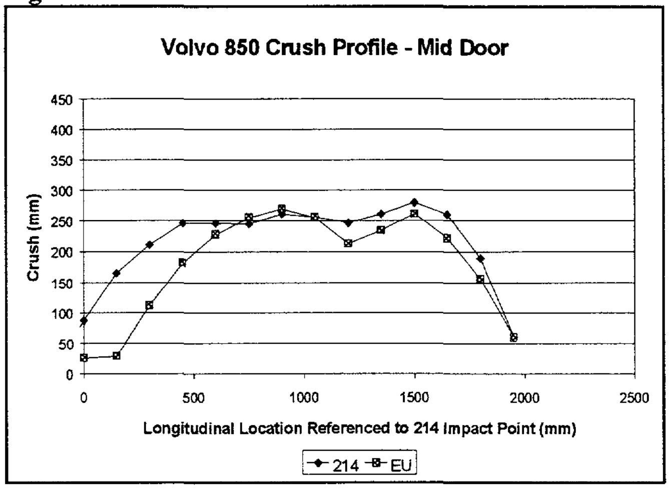

Figure 56.

COMPARISON WITH RELEVANT PREVIOUS RESEARCH

Because of the fluid nature of the European test procedure, the database of full scale vehicle crash tests which can be directly compared to testing performed with the current procedure is limited. The data are further limited if comparisons are required between the same vehicles tested to both the U.S. and EU regulations. Satake et al. reported on 24 full vehicle tests on five Japanese vehicles using the U.S. and (ECE/R.95) procedures [9]. The ECE/R.95 procedure matches that of the EU Directive, however the barrier height was 260 mm rather then 300 mm. Some tests were run at 300 mm for comparison. The barrier face used was made by UTAC of aluminum with a triangular pyramid-shaped design.

In the baseline test, both 4-Dr vehicles exceeded the rib deflection criteria when tested to the ECE. Both 4-Dr vehicles were below the TTI limit in the U.S. test although one was close to it. Comparing the 2-Dr vehicles to the 4-Dr, in the 2-Dr vehicle, the abdominal and pelvic loads increased for the

ECE test, and the rib deflection was lower. For one of these vehicles, the abdominal force exceeded the limit in the ECE test, but for the same vehicle tested to the U.S. procedure, all injury criteria were below their limits. For the other 2-Dr vehicle, the U.S. procedure was more severe, with a very high TTI and pelvic acceleration. The ECE procedure resulted in rib deflection, abdominal loads and pelvic loads at or slightly above the limits. These results were obtained with the barrier height at 260 mm. A 4-Dr vehicle and 2-Dr vehicles were tested with both a 260 and a 300 mm barrier height. All injury criteria were greater for the 300 mm barrier except abdominal force which had about the same result.

The above results may indicate that, for 4-Dr vehicles, the current EU Directive is more difficult to pass than FMVSS 214.

Bergmann et al. also performed tests using the ECE/R.95 procedure [27]. Testing was done at barrier heights of 260 and 300 mm with barrier faces of Kenmont, Fritzmeier, Hexcel and AFL elements. Average results across all tests were determined. Both V*C and RDC for the 4-Dr vehicles were much higher than for the 2-Dr vehicles. V*C was in the vicinity of the criterion limit. However, for APF and PSPF the 2-Dr vehicles had higher values than the 4-Dr.

Beusenberg et al. found a similar dependence on the number of doors a vehicle has when tested to the (EEVC) procedure [10]. Seventeen 4-Dr tests and five two-door tests were analyzed. It is not clear what barrier face construction was used for these tests nor what barrier height was employed. The average and maximum V*C and rib deflection, in general, were below the injury criteria for 2-Dr vehicles. For 4-Dr vehicles the average V*C was above the criteria and the average rib displacement was equal to the criteria. For 2-Dr vehicles the abdominal force was above the criteria. For 4-Dr vehicles the abdominal forces were below the criteria. Pubic loads were higher for 2-Dr vehicles than 4-Dr, but both were well below the criteria.

In the current set of test, it is not clear if the relative severity of each regulation is influenced by the number of vehicle doors. Table 9. gives the vehicle type (2-Dr or 4-Dr) which has the larger normalized injury criteria and the percentage by which it is greater. Also given, is the result of a student's t-test to determine if the difference in the injury criteria is statistically significant. Significance will be determined at $p \leq 0.10$. However, the determination of significance is certainly influenced by the small sample size of 4 vehicles in each category.

The following discussion is limited to the front seat dummy. Some results seem consistent with previous work whereas others do not. This is mainly attributed to barrier height differences and the lack of consistent performance amongst the various European barrier faces. For the EU procedure, the average normalized V*C was 23% greater for 4-Dr vehicles than for 2-Dr vehicles. This is consistent with the results reported in [10] and [27]. However, using a students t-test it is shown that this difference is not significant (p=0.59). The averaged normalized RDC was 7.9% greater for 2-Dr vehicles. This is in contrast to [10] and [27]. This difference is also not significant (p=0.66). For the U.S. procedure, the average normalized TTI was 12% greater for 2-Dr vehicles. This was consistent with results report in [9]. However the difference is not significant (p=0.40). So for the chest injury criteria no consistent or significant difference is evident for either regulation relative to the number of vehicle doors.

For the EU procedure the normalized PSPF was greater for the 2-Dr vehicles by 31% (p=0.31) which is consistent with [9], [10] and [27]. While for the U.S. procedure the normalized PelvicG is nearly the same for both 2-Dr and 4-Dr vehicles, which is not consistent with [9]. Finally, the normalized average APF is 57% greater for 2-Dr vehicles than for 4-Dr vehicles. This difference is considered significant at p=0.053. An increase in APF for 2-Dr vehicles was also reported in [9], [10] and [27].

Table 9.
Vehicle Type With Greater Average Normalized Injury Criteria

	V*C	**RDC**	**TTI**	**PelvicG**	**PSPF**	**APF**
No. Doors	4	2	2	4	2	2
% greater	23	7.9	12	0.64	31	57
p	**0.59**	**0.66**	**0.40**	**0.97**	**0.31**	**0.053**

INITIAL ASSESSMENT OF FUNCTIONAL EQUIVALENCE

From NHTSA's perspective, in basic terms, a foreign vehicle safety standard is considered functionally equivalent to a counterpart U.S. standard when the two standards address the same safety need and provide similar safety benefit in the U.S. crash environment. Relative to the European and U.S. side impact regulations, FMVSS 214 has only recently been in full effect for passenger cars and will apply to LTV's by the end of this year, and EU 97/26/EC is not yet in effect. As such, there is currently insufficient real world safety data to assess the effectiveness of either regulations whether in the U.S. or European real world environments.

Data from compliance testing, such as the series presented in this paper, can be used as a surrogate. Injury risk curves would be used to assess occupant risk in the real world from the computed injury criteria obtained via crash testing. Currently, injury risk curves are not available for the abdominal, pelvic, and head EU injury criteria. In addition, due to the volume and quality of the earlier injury and impact data, the EU injury risk functions originally developed for the thoracic region need to be improved [16]. Moreover, those thoracic injury risk functions were based on the responses of the Production Prototype versions of the Eurosid dummy and would need to be updated for the production Eurosid-1.

In addition, the aspect of how well the test conditions and movable deformable barrier of the EU regulation represent the real world U.S. crash environment cannot be overlooked when assessing the relative safety benefit of the two standards. A dynamic crash test requirement in a safety regulation should simulate the crash environment to the extent possible. More importantly, the dynamic requirement should provide for realistic injury causing mechanisms. The representativeness of the EUMDB as the striking vehicle must be considered because a large portion of the U.S. side impact casualties are the result of impacts with light trucks, vans and sports utility vehicles.

Issues in several areas that need to be addressed before any conclusive determination of the functional equivalence of the two side impact regulations are outlined below.

Table 10.
FMVSS 214 vs EU 96/27/EC Criteria: Pass/Fail (P/F)

Vehicle	Dr	214 P/F	214 80%*	EU P/F	EU 80%*
Volvo 850 SW	4	P	P	P	P
Ford Taurus	4	P	P	P	**F**
Nissan Sentra	4	P	P	**F**	**F**
Hyundai Sonata	4	P	**F**	P	P
Ford Mustang	2	P	P	P	**F**
Lexus SC300	2	P	P	P	P
Geo Metro	2	P	**F**	**F**	**F**
Mitsubishi Eclipse	2	P	**F**	**F**	**F**

* 80 % = Exceed 80% of Criteria

Vehicle Issues

In terms of the overall vehicle performance, similar comparative testing of vehicles designed to European requirements would be needed to assess if such vehicles perform well relative to FMVSS 214. The testing presented in this paper is only one part of a general matrix to assess the respective comparative performance. Testing of vehicles designed to both standards and testing of additional vehicles equipped with side air bag systems, which are becoming prevalent in the U.S. fleet, would be a part of this general matrix. The repeatability and reproducibility of testing to both regulations would also need to be addressed.

Vehicle Compliance and Rankings - Based on this series of comparative testing, FMVSS 214 and EU 96/27/EC did not provide similar vehicle performance rankings nor pass/fail results based on the respective thoracic and pelvic criteria (see Tables 10., 11.,and 12.). Overall, the vehicles tested had been chosen based on compliance to FMVSS 214. However, three out of these eight vehicles failed one or two of the EU criteria for the driver.

For statistical confidence to be achieved, certain manufactures require that, as a vehicle design basis, regulation requirements must be met by a margin considerably below the actual limits specified. As such, pass/fail results based on 80% of the criteria were also investigated for this series of comparative testing. Three of the eight vehicles exceeded 80 % of at least one of the FMVSS 214 requirements while five of the vehicles exceeded 80 % of at least one of the EU requirements. The Metro and Eclipse exceeded 80% of one or more of the requirements for both regulations. The Taurus, Sentra, and Mustang exceeded 80% of the requirements of the EU regulation only while the Sonata exceeded 80% the requirements of FMVSS 214 only.

Considering the vehicle rankings for the 4-Dr vehicles based on the driver dummy criteria, FMVSS 214 TTI(d) rated the Hyundai Sonata as fourth, while the EU RDC rated the Sonata as first and the V*C rated it as second. Rankings based on the pelvic criteria for the 4-Dr vehicles were a much better match with only the third and fourth position switched.

Table 11.
FMVSS 214 vs EU 96/27/EC 4-Dr Vehicle Rankings: Driver

Vehicle	TTI rank	RDC rank	V*C rank	PelvG rank	PSPF rank
Volvo 850	1	2	1	1	1
Ford Taurus	2	3	3	2	2
Nissan Sentra	3	4	4	3	4
Hyundai Sonata	4	1	2	4	3

Table 12.
FMVSS 214 vs EU 96/27/EC 2-Dr Vehicle Rankings: Driver

Vehicle	TTI rank	RDC rank	V*C rank	PelvG rank	PSPF rank
Ford Mustang	1	2	3	1	4
Lexus SC300	2	1	1	2	1
Geo Metro	3	3	2	3	3
Mitsubishi Eclipse	4	4	4	4	2

As to vehicle rankings for the 2-Dr vehicles based on the driver dummy criteria, there was a good match for the thoracic criteria with only the first and second position switched. Rankings based on the pelvic criteria were a poor match. PelvicG rated the Ford Mustang as first while PSPF rated the Mustang as fourth. PelvicG rated the Mitsubishi Eclipse as fourth, while PSPF rated the Eclipse as second.

It is worth noting that the Volvo 850 which ranked first amongst the 4-Dr vehicles for the all the injury criteria of both regulations, with the exception of ranking a close second for RDC, was the only vehicle in the matrix tested which was designed to meet both regulation. In addition, it has a side mounted air bag system. As to the Lexus SC300, which ranked first or second amongst the 2-Dr vehicles for both regulations, it was actually designed to meet FMVSS 214. Its good performance relative to the EU requirements may be attributed to its inherent design, with a sporty wider track and considerable crush space between the occupant and inner door, and between the inner and outer door.

Since the relative rankings of the vehicles tested did not look promising, linear regression analysis was applied to evaluate the degree of correlation between the thoracic and pelvic criteria of the two regulations. ρ^2, *the regression output* that indicates how well one variable can be predicted through a linear transformation of another variable, is presented in Table 13 .

Table 13.
Regression Analysis (ρ^2) of FMVSS 214/EU 92/27/EC Criteria for the 4-Dr/2-Dr Vehicles

	Driver Criteria		Rear Occupant Criteria*	
	TTI(d)	PelvG	TTI(d)	PelvG
RDC	.04/.46	-	.61	-
V*C	.13/.3	-	.61	-
PSPF	-	.77/.11	-	0.17

* Regression was not performed for 2-Dr rear occupant since there was only two data points

Overall, the results indicate mediocre or no correlation between the thoracic and pelvic criteria of the two regulations for the eight vehicles tested. In particular, the correlation for the driver dummy thoracic criteria for both the 4-Dr and 2-Dr vehicles is poor. The correlation for the rear occupant thoracic criteria for the 4-Dr vehicle is mediocre. Finally, the correlation for the driver dummy pelvic criteria is relatively good, ρ^2=0.77, for the 4-Dr vehicles but very poor for the 2-Dr vehicles.

__Real World Vehicle Issues__ - In Figure 6., the FMVSS 214 and EU 96/27/EC thoracic injury criteria values are sorted by vehicle weight from left to right for the 2-Dr and 4-Dr vehicles. The vehicle weights are presented in Table 14. below. In the FMVSS 214 tests, TTI(d) exhibited a trend of better performance, i.e. lower values for the heavier vehicles, for both the 2-Dr and 4-Dr vehicles. This is consistent with the real world performance in the U.S. crash environment as indicated by a recent study by Farmer et al. of vehicle-to-vehicle side impact crash study based on 1988-1992 National Accident Sampling System Crashworthiness Data System (NASS/CDS) [17]. The study, which excluded crashes involving rollovers or ejections, indicated that occupants of heavier vehicles were less likely to be seriously injured (AIS ≥ 3) in a side impact than occupants of lightweight vehicles. For every extra 45.4 kg in the weight of the subject vehicle, there was a corresponding 7-13% decrease in the odds of serious injury. In contrast, in the EU 96/27/RC tests, the lighter 4-Dr Sonata performed better than the heavier Taurus, while the heavier 2-Dr vehicles performed better overall for the EU thoracic criteria.

Also, in earlier comparative full scale testing by Dalmotas et al., using 1988 U. S. production vehicles, the small Chevrolet Sprint performed much better than the large Chevrolet Caprice and Pontiac Bonville when tested to the European procedure [18]. The matrix of seven vehicles used in the comparative testing by Dalmotas et al. exhibited better performance for the larger vehicles when tested to the FMVSS 214 procedure. This trend was relative to TTI(d), computed from the SID and a production prototype Eurosid which was used as the basis of comparative performance for these tests at Transport Canada. Additional full vehicle testing would be needed to further investigate this possible anomaly in the performance of large vehicles relative to the EU requirements.

Table 14.
Weights of 4-Dr Test Vehicles

Vehicle	Mass (kg)	Wheel Base (mm)
Ford Taurus	1738	2760
Volvo 850	1666	2670
Hyundai Sonata	1540	2700
Nissan Sentra	1307	2535
Lexus SC300	1819	2685
Ford Mustang	1617	2574
Mitsubishi Eclipse	1459	2515
Geo Metro	1039	2365

Application of the Standards - FMVSS 214 becomes 100 percent effective for light trucks, vans, and multiple purpose vehicles (LTV's), a growing proportion of the U.S. fleet, in the 1999 MY. In the EU regulation, vehicles with R-point of lowest seat >700 mm are excluded. The H-points of large pickups, sports utility vehicles, large vans, some of the compact pickups, and the majority of minivans are typically larger than 700 mm. As such, the EU regulation does not apply to the majority of LTV's. The current U.S. crash environment (1988-1996 NASS/CDS and Fatality Automotive Reporting System, (FARS)), when viewed as a yearly average, indicates that LTV occupants, are relatively safe when involved in side crashes, accounting for 14 % of involvement and resulting in 10 % of the severe injuries and the 11 % of the fatalities. Never the less, LTV's are currently 34% of vehicle registrations[1], and their proportion of the U.S. fleet is growing as seen by the trend in market share, with LTV's making up 43% of vehicle sales in 1996. As such, there is a need for the EU regulation to address the LTV vehicle class if it were to become applicable in the U.S. Full vehicle testing of LTV's would then also be needed to assess the relative benefits of the U.S. and EU regulations as applied to LTV'S and in particular assess the adequacy of the EUMDB in such tests.

Movable Deformable Barrier and Test Conditions Issues

MDB Issues - As indicated previously, a dynamic crash test requirement in a safety regulation should simulate the crash environment to the extent possible and should also provide for realistic injury causing mechanisms. As shown in Figure 57., over 43% of the fatalities and 37% of the serious injuries (MAIS $\geq$ 3) in U.S. light vehicle side impact crashes are in side impacts where an LTV is the striking or bullet vehicle. This is based on a yearly average from the current U.S. crash environment (1988-1996 NASS/CDS and FARS). As shown in Figure 58., when the trend of fatalities in struck vehicles is reviewed from 1980 through 1996 FARS, fatalities in car to car side crashes are decreasing while fatalities in LTV to car side crashes have more than doubled. In fact, a recent study by Gabler and Hollowell indicated that based on 1996 FARS, side impacts in which an LTV was the bullet vehicle resulted in 56.9% of the all the fatalities in side struck light vehicles [25]. This initial assessment, combined with the fact that the LTV population is growing in the U.S. fleet, suggests the following: The MDB in the dynamic test procedure for a side impact regulation in the U.S. should provide for injury causing mechanisms similar to those caused by the LTV vehicle class in order to provide a good representation of the current and future U.S. side crash environment. The MDB weight, stiffness, and geometry characteristics would need to be evaluated on this basis.

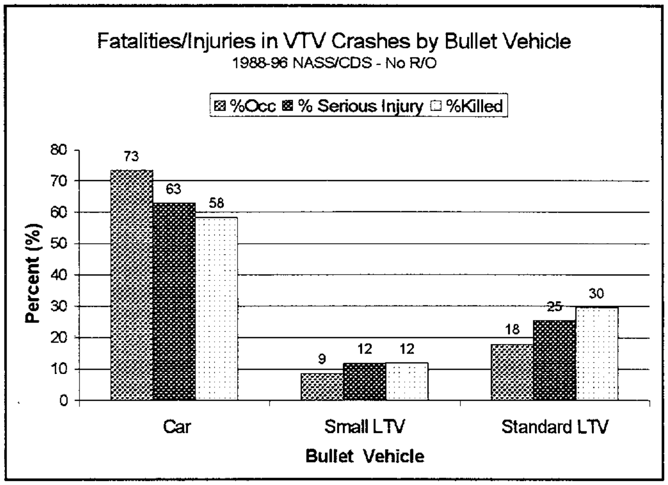

Figure 57.

[1] Source R. L. Polk Co, 1996

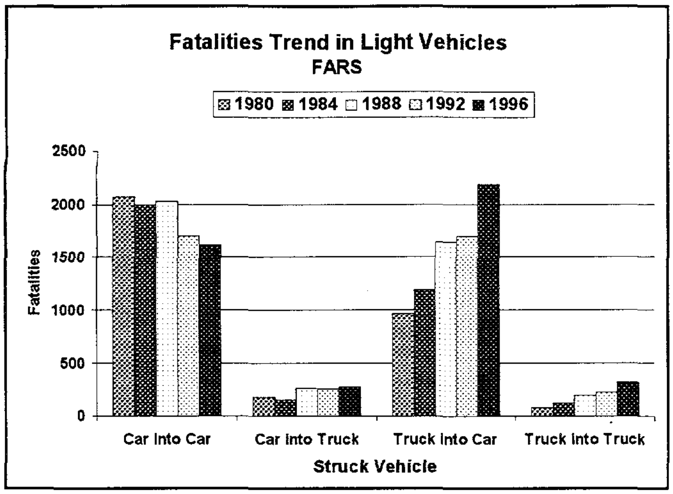

Figure 58.

As a vehicle class, LTVs are heavier on the average as a vehicle class. A study by Kahane of 1985-1993 passenger cars and light trucks indicated that LTVs were on the average heavier by 358 kg than cars with a slowly growing weight mismatch between the two classes [26]. In 1993, the sales averaged mass of LTV at 1770 kg was 422 kg heavier than that of passenger cars at 1348 kg. Figure 59. presents the test weight of the EUMDB and 214MDB along with the average test mass of cars, multipurpose vehicles (MPV) or sport utility vehicles, pickups, and vans in NCAP frontal tests conducted by NHTSA.

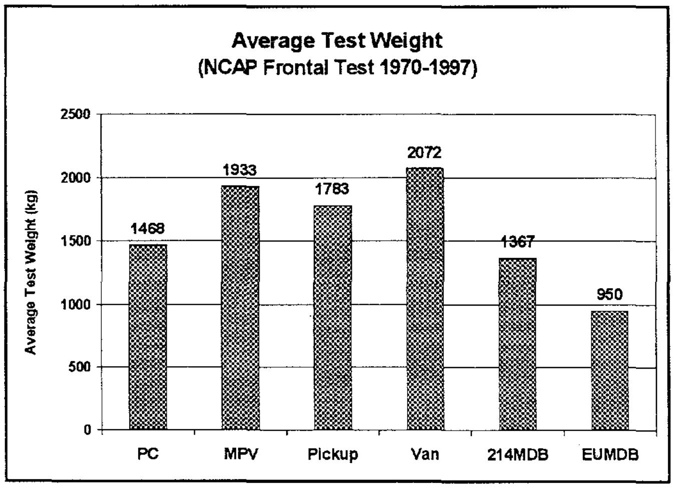

Figure 59.

LTVs also typically have a stiff frame-rail design versus the softer car unibody designs. Figure 60. presents the average stiffness of the Plascore EUMDB calculated from the force deflection performance corridors, and the average stiffness of the 214MDB derived from the force deflection response in a 40 km/h rigid barrier impact. The figure also presents averages of the linear stiffness for cars and LTV vehicle categories based on results from the New Car Assessment Program (NCAP) frontal tests. The quotient of the total barrier force and the corresponding displacement of the occupant compartment was used as a cursory measure of vehicle "linear" stiffness from the NCAP frontal test results. This cursory study indicates that overall, LTVs have about twice the frontal linear stiffness of cars. It is worth noting that the standard deviations in the average linear stiffness for passenger cars and each of the LTV vehicle categories is large. This indicates that there is a wide range of linear stiffness values within each of the vehicle categories. These initial results indicate that the Plascore EUMDB has a frontal stiffness representative of a passenger car and is less stiff than the 214 MDB. Strength comparisons and force versus deflection comparisons of the EUMDB and 214MDB are also presented in Figure 61. and 62.

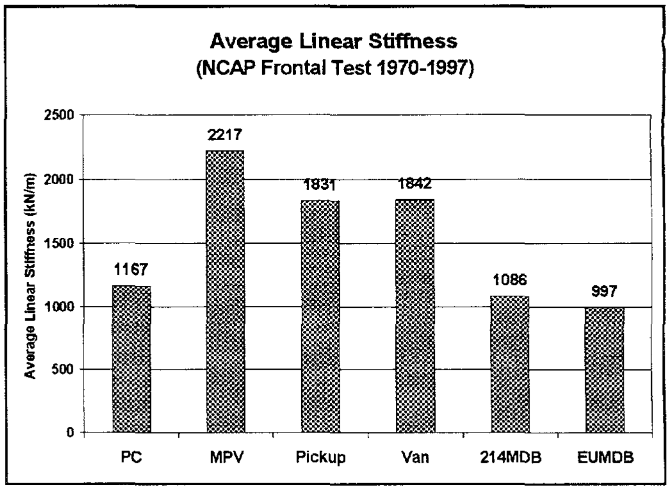

Figure 60.

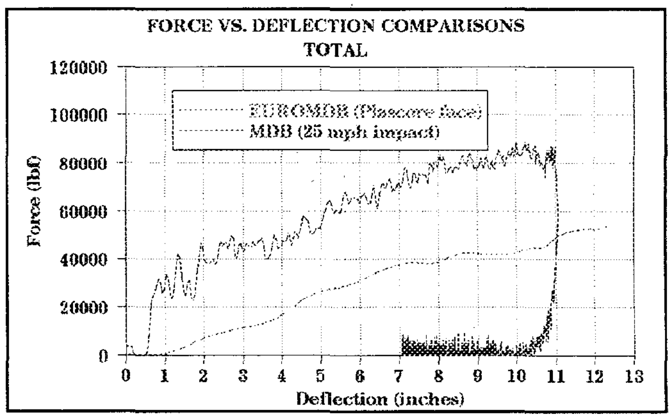

Figure 61. EUMDB and 214MDB Force Deflection Response Comparisons.

As a final note, the geometry of the striking bullet and, as such, a representative side impact MDB should also be addressed. LTV pickup and sports utility vehicles have higher hood height than passenger cars. Also, LTVs typically ride higher than cars. As indicated by the study by Gabler and

Hollowell, the sport utility vehicle category of the LTV class has the highest ride height with an average rocker panel height of 390 mm.

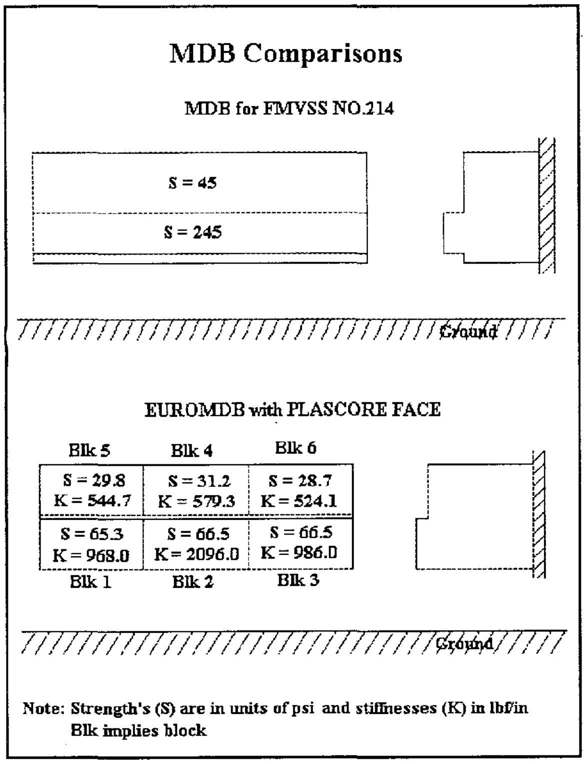

Figure 62. EUMDB and 214MDB Strength Comparisons.

In summary, a quick look at the striking vehicle in the current U.S. crash environment indicates that the EUMDB is inferior to the 214MDB in representing the striking bullet in the current and projected U.S. side crash environment.

Test Conditions Issues - As seen in Figure 63., analysis of the current U.S. side crash environment indicates that the struck vehicle does have a longitudinal component of the change of velocity. This supports the crabbed configuration of the U.S. test procedure. Campbell et al., Satake et al., and Bloch et al. have reported that when the side impact barrier was not crabbed, the injury measures for the front dummy were higher and that the crab angle is a very significant if not the most pervasive factor in the severity of the front dummy loading [28, 9, 29]. As such, the higher thoracic injury measures for front dummy and the high intrusion levels in the area of the rear front door seen in the EU tests, presented in this paper, are not necessarily representative of real vehicle to vehicle side crashes.

In 1991, Dalmotas et al. reported that in a series of vehicle tests performed by Transport Canada, the vehicle deformation patterns or side crush profile produced by the 214MDB in the immediate proximity of the driver's seat, showed closer agreement with vehicle to vehicle damage patterns than those produced by the EUMDB [18].

In 1996, Bergmann et al. reported that in a series of vehicle tests performed by Volkswagen AG, the deformation patterns in the vehicle to vehicle impacts can be compared neither with those in the ECE/R.95 tests nor with those in the FMVSS 214 tests [27]. Nevertheless, the data presented by Bergmann et al. did indicate that the deformation patterns in the FMVSS 214 tests were a closer match than those of the ECE R.95 tests. Bergman et al. also reported that their vehicle to vehicle tests showed severe loading of the struck vehicles in the lower side region, and that the penetration resistance must be increased (safety catch, increased sill overlap area, etc.) for real accidents. They stated that such vehicle design, however, leads to increased thoracic loading in the ECE/R.95 test. They also stated that in the development phase of new vehicles, a vehicle can be well above the injury limits in FMVSS 214 but exhibit very low occupant loadings in ECE/R.95. As mentioned previously, the ECE/R.95 procedure matches that of the current EU Directive, except the barrier height was 260 mm rather then 300 mm.

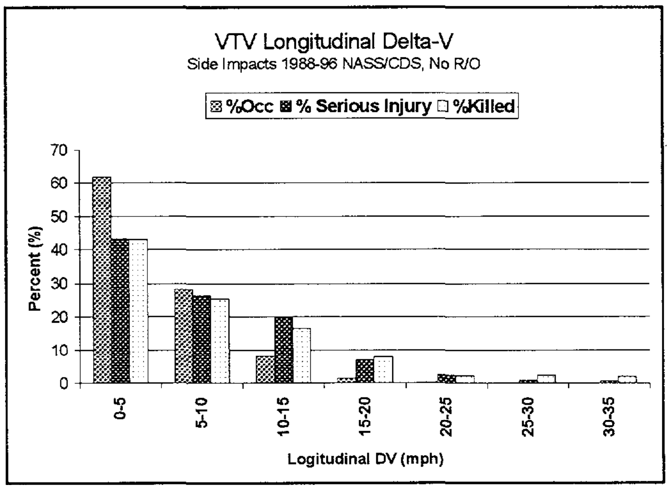

Figure 63.

Injury Criteria Functional Equivalence Issues

<u>Head Protection Criterion Issues</u> - The EU regulation has a head protection criteria while FMVSS 214 does not. The database of FMVSS 214 tests, to date, indicates that for the driver dummy, head contact with the vehicle interior or the MDB does not occur frequently. In the series of tests presented in this paper, HPC averaged less than 10% of the limit for the driver dummy, and less than 30% for the rear dummy with head contact occurring in half the tests. The results imply that, in the context of the current side impact standards, the HPC is not a meaningful or critical criterion. This suggests that neither FMVSS 214 nor EU 96/27/EC provides the correct test conditions to evaluate head injuries in the side impact crash environment.

Abdominal Criterion Issues - The EU regulation has an abdominal criterion while FMVSS 214 does not, and the SID dummy of FMVSS 214 lacks the measurement capabilities even to determine such a criterion. Previous research in this area by Dalmotas et al. [18, 19] indicated that the SID is not sensitive to localized door intrusion, specifically due to the arm rest, which has the potential of causing severe abdominal injuries. The TTI(d) of the SID dummy addresses the hard thorax which includes the liver and spleen. As such, there may be some potential for abdominal protection with vehicle designed to FMVSS 214. However, the cadaveric test conditions, in which TTI was developed, did not include localized loading of the abdominal region [20]. This factor would need to be addressed in assessing functional equivalence.

Thoracic Criteria Issues - Regarding the thoracic criteria, the EU regulation has deflection, or chest compression based criteria while FMVSS 214 has an acceleration based criterion. There has been an ongoing historical debate on which criteria better represent the correct injury mechanism and as such would best predict human occupant injuries.

In earlier research at Wayne Sate University, Cavanaugh et al. argued that C and $V*C_{max}$ are superior to TTI in predicting thoracic injury [21]. In that research, the compression and V*C were calculated for both the arm and the chest and not just the chest as should be done. The results were also based on a small number of cadavers. In recent research at the University of Heidelberg, Kallieris et al. reported that they found the TTI to be the best predictor for the thoracic injury severity [22]. Compression and V*C were also found to be good predictors. Also, in recent research at the Forschungsvereinigung Automobiltechnik FAT, Zobel et al. stated that the overall severity, as reflected by the injury cost scale ICS, is best predicted by TTI, and the European plans to use compression and later V*C are not worth the additional money which they cost the consumer [23].

In more recent research at the Medical College of Wisconsin and the Vehicle Research and Test Center, Pintar et al. concluded that the TTI criterion demonstrated superior injury prediction capability over V*C and C [24]. The data was based on an additional 26 cadaver side impact tests using advanced instrumentation to measure the kinematic variables necessary to generate all current injury criteria measures, including compression, spinal acceleration, V*C and TTI. Additional analyses of the growing database of cadaver tests would be needed to bring closure regarding the merit of the current thoracic injury criteria, and in assessing functional equivalence of the two regulations.

Pelvic Criteria Issue - The EU pelvic criterion is force based while the FMVSS 214 criterion is acceleration based. Further research would be needed to determine which pelvic criterion best addresses real world pelvic injuries.

Side Impact Dummy Issues

Dummy Biofidelity - There is a general consensus in the scientific community that improvements to both biofidelity and instrumentation capabilities of the U.S. SID and the European Eurosid-1 regulation dummies are needed. In 1990, the International Standards Organization (ISO) Working Group on Anthropomorphic Test Devices, ISO/TC22/SC12/WG5, gave the SID an overall rating of 2.34 and the Eurosid an overall rating of 3.22 out of a scale of 10 [30]. The biofidelity rating for the Eurosid-1 has not been fully developed although an estimate of 4.2 has been provided [32]. The ISO ratings for the overall dummy and per body region are listed in Table 15. These ratings correspond to an ISO classification of UNACCEPTABLE for the SID and MARGINAL for both the Eurosid and Eurosid-1 as overall side impact dummies [30]. The 1990 ISO ratings were based on a set of biofidelity requirements that did not account for muscle tone effects which are currently more widely accepted. When the muscle tone effects are taken into account, the overall ratings for SID and Eurosid change to 2.78 and 3.47 respectively. The updated ratings correspond to an ISO classification of MARGINAL for both the SID and Eurosid as overall side impact dummies. Although the other body regions cannot be discounted, it is worth noting that for each of the individual thorax, pelvis and abdomen body regions, the ISO biofidelity ratings of the SID are higher than the Eurosid.

It might be of interest to note, that the most recent addition to the SID of the Hybrid III head and neck for the test purposes of FMVSS 201, Upper Interior Protection, raises the SID ISO biofidelity rating to 3.91 without taking muscle tone into account [38]. If muscle tone were to be added, the SID biofidelity rating would be as high as 4.3.

Table 15.
ISO Biofidelity Ratings of SID and Eurosid [30]

Body Region	SID Ratings Oct 90	SID Ratings Mar 98*	Eurosid Ratings Oct 90	Eurosid Ratings Mar 98*
Head	0.00	0.00	3.33	3.33
Neck	2.31	2.55	3.04	3.70
Thorax	3.19	5.02	4.02	4.78
Shoulder	0.00	0.00	3.42	3.90
Abdomen	4.37	4.38	3.28	3.23
Pelvis	2.76	2.76	2.08	1.76
Overall Dummy	**2.34**	**2.78**	**3.22**	**3.47**

* uses corrected biofidelity equation [31] but is not yet formally accepted by ISO/TC22/SC12/WG5

Eurosid-1 Mechanical Deficiencies - Notwithstanding the biofidelity issues, the Eurosid-1 as referenced by the EU directive has certain mechanical deficiencies as demonstrated by the rib "flat tops" anomalies in the series of tests presented and as indicated by a list of concerns that has been compiled by the American Automobile Manufacturers Association (AAMA) [13]. The AAMA list includes binding in the rib modules as a number one concern. It also includes issues with the Eurosid-1 projecting back plate, bending of the plastic ilium of the pelvis, upper femur contact with the pubic load cell hardware, and clavicle binding in the shoulder assembly. These concerns are widely accepted and TNO has developed a research kit tool upgrade to address some of the outlined Eurosid-1 mechanical dummy issues. As mentioned earlier, the upgrade kit was recently made available to NHTSA for evaluation.

To date, initial evaluation by NHTSA through bumper pendulum testing has demonstrated that the upgrade kit does not address the flat-top anomalies in the rib potentiometer responses. As discussed earlier, those are believed to be partly caused by mechanical binding in the dummy rib cage.

Although minor in nature, it is important to establish how the upgrade kit modifications influence the Eurosid-1 biofidelity and its performance in full scale vehicle testing. To date, TNO has performed only components level testing with the upgrade kit.

Dummy Performance in Higher Severity Testing - The NCAP has been carried out in the United States for almost 20 years. Around the world, other countries have begun their own NCAP programs. Side impact tests were added to the U.S. NCAP starting in 1997. The side impact tests for U.S. NCAP are conducted using the same dynamic specifications as in the FMVSS 214 test procedure but at a higher testing speed. There is an increase of 32% in kinetic energy for the current side impact NCAP test as compared to the FMVSS 214 test. The U.S. SID was evaluated and found to perform in a repeatable and consistent manner in these higher severity crashes before the initiation of the side impact NCAP. It is highly probable that any side impact dummy will be used in higher severity testing. When considering the issues and deficiencies of the Eurosid-1 (or its upgrade or any new side impact dummy), one must consider its performance and durability at the regulation test speed and also at higher test speeds which will be used for sumer programs or advanced side impact protection assessments.

Advanced Side Impact Dummy Developments Efforts - The European community is aware of the need to upgrade the Eurosid-1 and has initiated an upgrade project for the dummy, the SID-2000, sponsored by a European Commission consortium [34]. The SID-2000 project was started in March of 1998 with TNO as the project co-coordinator. An upgraded Eurosid-1 prototype is currently the end product in the year 2000. The SID-2000 program will reassess the European crash environment including distribution of injuries by body region, injury criteria, and the need for different size dummies.

In June of 1997, based on a recognized need to harmonize side impact dummies, the ISO Working Group on Anthropomorphic Test Devices, ISO/TC22/SC12/WG5, initiated a work item to develop and standardize a unique technologically advanced mid-sized side impact dummy. A WG5 Task Group, the WorldSID, with a joint three-way chairmanship consisting of the Americas, Europe, and Asia/Pacific, is currently actively performing this work item. The WorldSID Task Group has a target date of a prototype advanced side impact dummy in January 2000. The thrust of the ISO initiative is to develop a common dummy to be produced worldwide. Given the short development time frame, the upgraded dummy is expected to take the best features of existing dummies, one of the main candidates being the 5th percentile SID-IIs dummy that was recently developed by First Technology Safety Systems and the Occupant Safety Research Partnership of the United States Council for Automotive Research [35, 36].

Recently, the European Commission has approved the integration of the SID-2000 project into the ISO WorldSID work item [37]. The SID-2000 consortium is currently considering modifying the project objectives to ensure its compatibility with the WorldSID work item. In the interest of harmonization, it is hoped that the efforts to merge these two dummy development projects succeed such that the end product is one harmonized advanced side impact dummy to be commonly produced and used world wide.

Other Functional Equivalence Issues

The series of tests presented in this paper has shown that a Eurosid-1 dummy placed in the rear seat in the EU procedure undergoes a relatively less severe impact than that seen by the rear SID in FMVSS 214 procedure based on the injury criteria in each regulation. The reason for this is mainly the combination of the EUMDB barrier design (softer on the sides) and uncrabbed 90° impact of the EU test conditions. Lower loadings on a rear outboard seated dummy due to the uncrabbed 90° has been also demonstrated by Satake [9], albeit in that case an uncrabbed FMVSS 214 test condition with SID dummies was investigated. The current U.S. crash environment (based on a 1988-1996 NASS/CDS and FARS study) indicates that rear occupant severe injuries (MAIS $\geq$ 3) account for only 7.3% of the total severe injuries and 5.1% of the overall fatalities. These low injury rates are at least partially due to the low rear seat occupancy rates. Never the less, it is desirable to require a certain level of protection for the rear occupant by the placement of a rear dummy in a dynamic side impact safety standards. This is mainly due to the premise that, increasingly, the occupants of the rear seat are children whose safety should not be compromised.

Finally, FMVSS 214 has a static crush strength requirement which NHTSA believes provides a certain level of protection against pole or tree impact [26]. This requirement is not currently addressed by the EU directive.

SUMMARY AND CONCLUSIONS

The series of comparative testing, presented in this paper, with current U.S. production vehicles has provided important insights into the performance of vehicles when tested to the requirements of the FMVSS 214 and EU 96/27/EC regulations. However, it can only be viewed as a partial step in determining the overall safety performance of vehicles relative to the two regulations.

The following are concluded from this series of tests:

- Results indicate that vehicles designed to meet FMVSS 214 may not meet EU 96/27/EC.
- Results also indicate that vehicles can be designed to meet both standards.
- Conclusions based on this testing may not be valid due to the measurement anomalies in the Eurosid-1 and the small number of vehicles tested.

Also, the following are highlights of the results from this series of tests:

- Eurosid-1 rib displacements displayed "flat-top" behavior which imply questionable EU 96/27/EC rib deflection (RDC) and soft tissue (V*C) criteria values.
- FMVSS 214 and EU 96/27/EC did not provide similar vehicle performance rankings or pass/fail based on their respective criteria.
- With the caveat of questionable EU thoracic criteria, results indicate a higher severity for the driver dummy in the EU tests for the rib deflection criterion when compared to TTI(d) in the FMVSS 214 tests. No trend is indicated for V*C or the pelvic criterion.
- Results also indicate a much lower severity for rear dummy in the EU tests than in the FMVSS 214 tests for both thoracic criteria. No trend is apparent for the pelvic criterion.
- With the exception of Abdominal Peak Force (ABD) for the Mustang driver dummy, only the V*C and RDC values were relatively high for the EU tests.
- The EU tests crush profile was more rounded, with larger intrusion around the B-pillar and rear front door section, than the FMVSS 214 tests crush profile.

It is important to note that this series of tests is only one part of a general matrix needed to assess the comparative performance of vehicles relative to the two regulations. The general matrix includes testing of European production vehicle to determine how well such vehicles perform relative to FMVSS 214. The matrix also includes testing of vehicles designed for both U.S. and European markets to the requirements of both regulations. Vehicles equipped with side air bag systems would also be part of this matrix as they are becoming prevalent in both the U.S. and European fleet. In addition, since manufacturers seem to design their vehicles for optimum performance in the U.S. NCAP, testing of vehicles to similar higher severity test conditions for both regulations would also be needed. Moreover, a small number of vehicles were tested in this series. A larger number of U.S. production vehicles that more broadly represent the U.S. fleet may need to be tested.

Other issues have also arisen in this research which may in the end confound a definitive functional equivalence determination of the two regulations:

- Light trucks, vans and sports utility vehicles (LTV's) have become a significant and a growing segment of the U.S. fleet. A large portion of the U.S. side impact casualties results from impacts with the LTV class of vehicles. The adequacy of both the FMVSS 214 and the EU movable deformable barrier in representing the striking vehicle in the current and future U.S. crash environment is in question. In particular, the lighter and less stiff EU barrier is less representative of the current and future mix of U.S. vehicles.
- The issue of providing a meaningful test to assess the safety of rear occupants in side impacts is a sensitive one since increasingly the occupants of the rear seat are children whose safety should not be compromised. In this regard, there may be an opportunity for improvements in both regulations, albeit the FMVSS 214 test condition does provide a better loading environment.
- Initial evaluations of the Eurosid-1 research tool kit upgrade, recently developed by TNO, has demonstrated that the upgrade does not address the flat-top anomalies in the rib potentiometer responses. Although minor in nature, it is important to establish how the upgrade kit modifications influence the Eurosid-1 biofidelity and its performance in full scale vehicle testing. One question would be if full scale tests, such as the series presented in this paper, need to be repeated with the upgraded Eurosid-1 to truly assess the comparative performance of vehicles relative to the two side impact regulations.

In terms of struck vehicle deformation patterns, the crush profile in the EU tests was more rounded with larger intrusion around the B-pillar and the rear section of the front door. In the FMVSS 214 tests the crush profile is more rectangular in shape with the intrusion more evenly distributed along the area of barrier-to-vehicle engagement. Earlier research indicates that FMVSS 214 test provides more realistic crush profile when compared to vehicle to vehicle crashes. Notwithstanding the dummy issues, performance in real world crashes for the eight vehicles tested in this series can be assessed by studying real world NASS side impact cases for the same vehicles. Occupant injuries and intrusion profiles would give an indication of which regulation provides a more realistic assessment of this set of vehicles for the U.S. crash environment.

Also, the results from this series of testing were not totally consistent with the relevant full scale testing by other researchers. This is mainly attributed to the fluid nature of the European test procedure, specifically the barrier height changes and the inconsistent performance of the various European barrier faces. Additional comparative full scale testing based on the current European specifications and latest European barrier designs would provide useful data for further assessment.

With the caveats described above, the comparative testing did not provide similar vehicle performance rankings nor pass/fail results based on the respective injury criteria of the two side impact regulations. In fact, there was no direct correlation between the corresponding injury criteria results for the vehicles tested.

On the other hand, the development of an upgraded side impact dummy is planned within two years, whether through the European Commission Consortium SID2000 project or the ISO WorldSID Task Group. The ongoing dummy development efforts reflect the consensus of the world scientific community that, in the interest of safety, an upgraded regulation side impact dummy is needed. Improvements to both biofidelity and instrumentation capabilities of the U.S. SID and the European Eurosid-1 regulation dummies are needed. The Eurosid-1 also has mechanical deficiencies.

In addition, the changes in the composition of the U.S. fleet, with a significant and growing segment of the larger, stiffer, and heavier LTV vehicle class, underscores the need to update the definition of the side impact safety problem in the U.S. crash environment and determine the opportunities for enhancing occupant side impact protection. The test conditions of the dynamic side impact requirement and the characteristics of the striking bullet, i.e. movable deformable barrier, would need to be reassessed relative to the current and future side crash environment. Fixed objects side crashes also need to be studied to investigate additional opportunities for enhancing occupant side impact protection in the U.S. environment.

In conclusion, given the results of the current testing, in particular the measurement anomalies in the Eurosid-1, insufficient data is available at this time to make a tentative determination of functional equivalence of the two side impact standards. Using the NHTSA side impact harmonization plan as a guide, the agency will establish its current position on side impact harmonization based on all available information. From this baseline, a plan will be developed for advancing side impact safety in the U.S. fleet taking into account the level of available resources. It is hoped that the current efforts to merge the European SID2000 and ISO WorldSID dummy development projects succeed and result in an advanced harmonized side impact dummy which can be commonly produced and used world wide. Harmonization research can then focus on evaluating the advanced world side dummy and its application in the next generation side impact safety standard(s). Harmonization of the dummy and injury criteria is a basic premise in achieving a global harmonized side impact regulation. While differences in the fleet composition and crash involvement may preclude totally harmonized test conditions and movable barriers, the use of a single dummy family would significantly alleviate the current burdens of vehicle design, testing, manufacturing, and distribution currently encountered by automobile manufacturers in the growing global market. It should also lead to improved side crash protection world wide.

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EUROSID LUMBAR CERTIFICATION TESTS

APPENDIX A

Original Lumbar #191									
Date	Pulse	Flexion (45-55)	Time (39-53)	Theta A (31-35)	Time (45-55)	Theta B (27-31)	Time (45-55)	Lab	Pass/Fail
05/02/97	ok	49.5	46.4	33.6	49.1	29.4	49.8	FTSS	Pass
05/12/97	99%	52.6	49.5	35.6*	49.5	31.2*	48.3	FTSS	fail
04/09/97	ok	53.3	51.0	37.1*	51.0	32.7*	52.0	MGA	Fail
05/27/97	ok	48.8	50.0	33.2	50.0	29.3	46.0	MGA	Pass
05/29/97	ok	50.9	48.3	35.0	48.6	30.7	47.6	MGA	Pass
05/29/97	ok	50.5	49.3	34.4	49.3	31.3*	45.6	MGA	Fail
02/03/97	ok	49.9	50.1	33.5	49.7	30.5	49.5	TNO**	pass
02/04/97	ok	49.1	47.9	32.9	47.3	30.6	48.3	TNO**	pass
04/11/97	Bit out high	54.1	45.6	37.0*	45.4	32.4*	49.4	TRC	fail
05/13/97	ok	51.4	47.5	35.5*	47.5	31.0	47.5	TRC	fail

* **Does not meet specifications**
** **Original certification**

NOTE 1 : MGA ran with a lighter pendulum base after 4/14 (809 gr vs 1261).
NOTE 2 : MGA ran with a thinner base plate after 5/26 (total pendulum length 72.41 inches)
NOTE 3 : MGA lab temperature prior to 5/30 is 70° F and 68° on 5/30

Lumbar for Eurosid-1 # E1-213									
Date	Pulse	Flexion (45-55)	Time (39-53)	Theta A (31-35)	Time (45-55)	Theta B (27-31)	Time (45-55)	Lab	Pass/Fail
05/12/97	ok	48.1	48.5	30.7*	48.1	27.8	47.5	FTSS	Fail
04/04/97	ok	49.5	47.0	32.2	47.0	30.3	45.0	MGA	Pass
05/27/97	ok	46.9	47.0	32.6	49.0	29.2	48.0	MGA	Pass
05/29/97	ok	47.3	47.8	32.6	47.6	29.1	48.1	MGA	Pass
05/30/97	ok	45.7	44.9	31.0	45.6	28.8	46.0	MGA	Pass
05/13/97	ok	47.0	47.0	32.0	47.1	28.3	46.6	TRC	Pass

EUROSID LUMBAR CERTIFICATION TESTS

Replacement Lumbar #183									
Date	Pulse	Flexion (45-55)	Time (39-53)	Theta A (31-35)	Time (45-55)	Theta B (27-31)	Time (45-55)	Lab	Pass/Fail
04/23/97	good	49.0	46.7	32.37	46.6	29.35	47.8	FTSS	Pass
05/12/97	good	49.5	48.0	33.3	47.9	29.5	49.0	FTSS	Pass
04/11/97	good	48.3	42.7	33.1	42.43*	30.10	46.05	MGA	Fail
04/15/97	bad high	50.52	45	35.41*	46.18	31.33*	45.68	MGA	Fail
04/16/97	95% high	52.0	50.4	36.6*	50.4	31.8*	50.7	MGA	Fail
04/29/97 (11:00)	good	47.82	49.0	33.01	49.0	30.86	45.0	MGA	Pass
04/29/97 (20:02)	good	50.47	50.0	34.91	51.0	32.23*	49.0	MGA	Fail
04/30/97	good	50.4	49.0	34.5	49.0	31.9*	48.0	MGA	Fail
04/30/97	good	49.44	49.0	34.03	49.0	31.32*	50.0	MGA	Fail
05/27/97	good	48.8	46.0	33.5	46.0	28.4	46.0	MGA	Pass
05/29/97	good	49.7	48.1	33.6	48.0	30.4	48.6	MGA	Pass
05/29/97 (17:01)	good	49.9	47.4	34.35	47.5	31.46*	45.6	MGA	Fail
05/30/97	good	48.2	46.1	33.0	46.6	30.46	45.9	MGA	Pass
04/18/97	95% high	52.5	44.0	35.2*	43.8*	31.4*	43.5*	TRC	Fail
05/13/97	good	51.6	46.6	34.0	46.8	30.7	46.9	TRC	Pass