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FIMCAR
III – Car-to-Car Test Results

frontal impact and compatibility assessment research

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CONTENT

EXECUTIVE SUMMARY

The assessment of compatibility in frontal impacts has to address the importance of different vehicle structures. A critical component in the assessment is to identify, quantitatively, what constitutes good performing structures. In particular, the concepts of structural alignment and structural interaction need to be investigated. Structural alignment is incorporated in the FIMCAR candidate compatibility assessments to achieve geometric alignment of identifiable crashworthiness structures. Structural interaction is also a global assessment of how structures interact with a collision partner during the crash. The performance of lower vehicle structures in a crash has been identified as important as they may not be evaluated in a structural alignment assessment, but can contribute to structural interaction and thereby improve collision outcome. There has been, however, no clear definition of the characteristics for lower load paths that improve vehicle safety and how these structures manifest themselves in proposed test procedures.

FIMCAR has developed a vehicle crash test program that investigates the performance of vehicle structures using three different test series. The first test series used Super mini vehicles with different front end architectures. These tests with, and without, geometric alignment allowed the effectiveness of a lower load path to be compared to a case without a lower load path. A second set of tests investigated the importance of lower load paths for SUV type vehicles where the main front structures may not align with the main structures in a collision partner, but a lower load path may offset the consequences of this initial misalignment. A final test series investigated how the lower load paths in higher SUV type vehicles influence safety in side impact conditions and thus identify potential side effects of a new assessment procedure.

Results of the test program show that the presence of a lower load path contributes to a more robust performance of the vehicle. The rearward offset of a lower load path could be reviewed and used to quantify when a lower structure design can contribute to structural interaction in both frontal and side impact configurations.

1 INTRODUCTION

1.1 FIMCAR Project

For the real life assessment of vehicle safety in frontal collisions the compatibility (described by the self-protection level and the structural interaction) between the opponents is crucial. Although compatibility has been analysed worldwide for years, no final assessment approach was defined. Taking into account the EEVC WG15 and the FP5 VC-COMPAT project activities, two test approaches are the most important candidates for the assessment of compatibility. Both are composed of an off-set and a full overlap test procedure. However, no final decision was taken. In addition another procedure (tests with a moving deformable barrier) is getting more and more in the focus of today's research programmes.

Within this project different off-set, full overlap and MDB test procedures will be analysed to be able to propose a compatibility assessment approach, which will be accepted by a majority of the involved industry and research organisations.

The development work was accompanied by harmonisation activities to include research results from outside the consortium and to early disseminate the project results taking into account recent GRSP activities on ECE R94, Euro NCAP etc.

The FIMCAR project is organised in six different RTD work packages. Work package 1 (Accident and Cost Benefit Analysis) and Work Package 5 (Numerical Simulation) are supporting activities for WP2 (Offset Test Procedure), WP3 (Full Overlap Test Procedure) and WP4 (MDB Test Procedure). Work Package 6 (Synthesis of the Assessment Methods) gathers the results of WP1 – WP5 and combines them with car-to-car testing results in order to define an approach for frontal impact and compatibility assessment.

1.2 Objective of this Deliverable

The objective of this report is to analyse and summarise the car-to-car test program performed within the FIMCAR project.

1.3 Structure of this Deliverable

The report starts with a chapter on the background regarding frontal impact compatibility research including available car-to-car test results. In Chapter 3 the objectives of the FIMCAR test programme and the test programme itself including the results are explained. The discussion of the test results takes place in Chapter 4.

2 BACKGROUND

The development of a set of test procedures which address self and partner protection is the focus of the FIMCAR – Frontal Impact and Compatibility Assessment Research - project. The goal is to decrease the injury risks in single and multiple vehicle frontal impact accidents by developing standardised laboratory test conditions that promote more robust vehicle crash performance in the real world. It is expected that compatible vehicles will deform in a stable manner allowing the deformation zones to be exploited even when different vehicle sizes and masses are involved. The challenge for compatibility researchers has been an assessment to identify and quantify the parameters that influence crash performance and a method that assesses them reliably and objectively.

Previous research has exploited a combination of testing and simulation to explore frontal crashworthiness and most agree that structural interaction, compartment strength, and frontal force levels are the parameters that can describe how vehicles interact with a collision partner. While these compatibility concepts are universally agreed upon, individual interpretations and assessments vary and, more importantly, the quantification of the parameters has been elusive.

One of the most comprehensive test programs addressing vehicle-to-vehicle compatibility was the VC-Compat project [Edwards 2007]. The test program comprised car-to-barrier and car-to-car tests using a range of vehicle classes. The test program was designed to evaluate car-to-car crash performance using a reference performance for the vehicle. Obtaining internal design requirements from individual manufacturers was not possible so the use of Euro NCAP test performance was used as reference. Euro NCAP is a duplicate of the current European frontal impact requirements for a car (UNECE Regulation 94) but conducted at a higher speed. EEVC Working Group 11 [Lowne 1996] designed the R94 56 km/h test condition to duplicate an impact of 2 identical cars into each other at 50 km/h (100 km/h closing speed) and 50% overlap. Although the R94 test data is proprietary, the consumer test data from Euro NCAP was available for some vehicles and its 64 km/h impact speed was considered equivalent to 56 km/h (112 km/h closing speed) and 50% overlap vehicle-to-vehicle crash test.

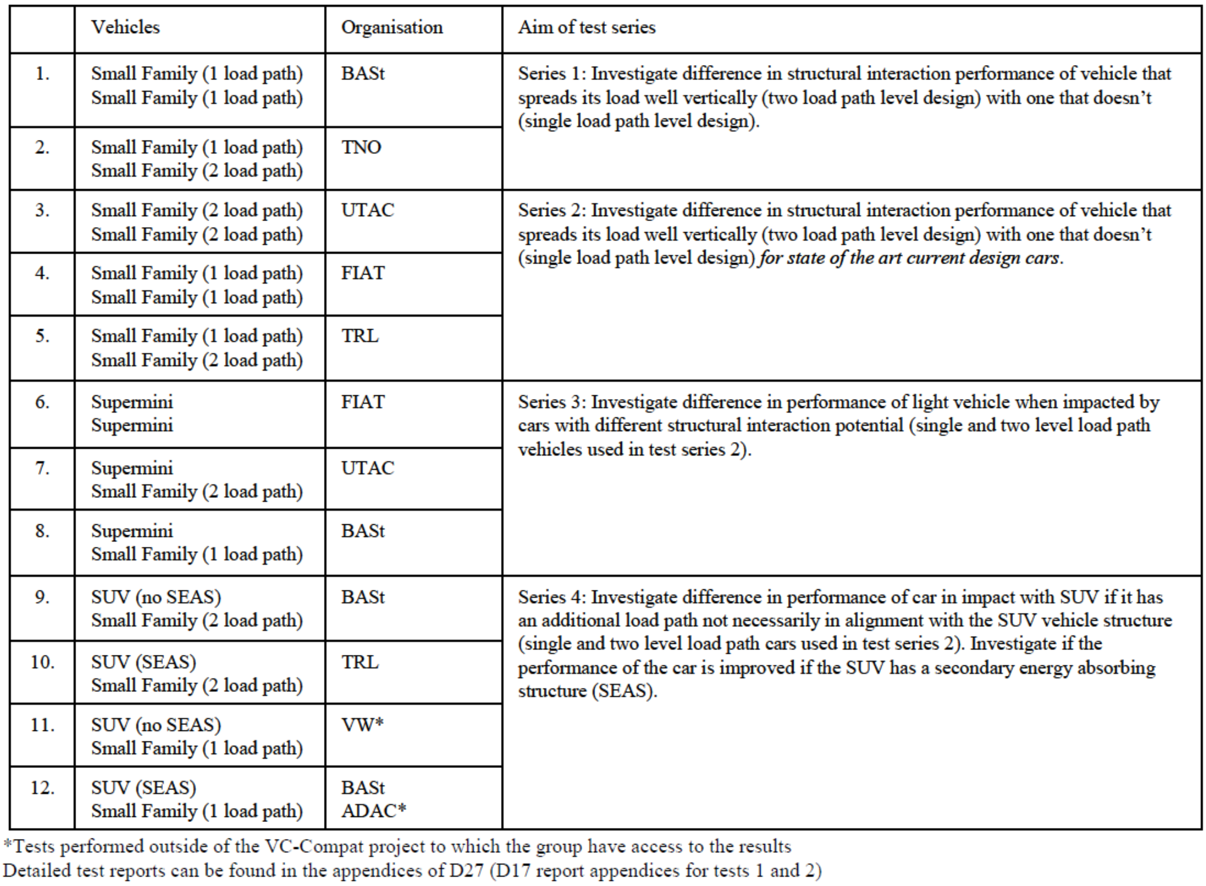
Another approach to vehicle-to-vehicle tests is used by NHTSA where a 100% overlap test condition is used. In contrast to Europe were compatibility research focuses on passenger car-to-passenger car impacts, NHTSA has focused on the LTV-to-passenger car impacts due to the high proportion of LTVs in both vehicle registrations and vehicle casualty crashes [Summers 2003]. The crash tests reported in [Summers 2003] were conducted at 48 km/h (96 km/h closing speed) but subsequent test approaches [Summers 2005] were modified so that a target speed change for the lighter vehicle, 56 km/h, was produced to facilitate comparison of results for different bullet vehicle masses.

FIMCAR research activities focus on the European accident and vehicle designs so the previous test approach used in VC-Compat is the framework for further test programs. This will allow the new data to be readily compared to the previous research, such as the EEVC WG15 [Faerber 2007], VC-COMPAT project [Edwards 2007], and IHRA [O'Reilly 2003].

2.1 Summary of Previous Research

As justified previously, the main starting point for FIMCAR was the VC-Compat database of vehicle test data. The car-to-car tests in VC-Compat are shown in Table 1 could be grouped into four test series which had specific goals.

Table 1: VC-Compat vehicle-to-vehicle crash tests [Edwards 2007].



	Vehicles	Organisation	Aim of test series
1.	Small Family (1 load path) Small Family (1 load path)	BASt	Series 1: Investigate difference in structural interaction performance of vehicle that spreads its load well vertically (two load path level design) with one that doesn't (single load path level design).
2.	Small Family (1 load path) Small Family (2 load path)	TNO	
3.	Small Family (2 load path) Small Family (2 load path)	UTAC	Series 2: Investigate difference in structural interaction performance of vehicle that spreads its load well vertically (two load path level design) with one that doesn't (single load path level design) *for state of the art current design cars*.
4.	Small Family (1 load path) Small Family (1 load path)	FIAT	
5.	Small Family (1 load path) Small Family (2 load path)	TRL	
6.	Supermini Supermini	FIAT	Series 3: Investigate difference in performance of light vehicle when impacted by cars with different structural interaction potential (single and two level load path vehicles used in test series 2).
7.	Supermini Small Family (2 load path)	UTAC	
8.	Supermini Small Family (1 load path)	BASt	
9.	SUV (no SEAS) Small Family (2 load path)	BASt	Series 4: Investigate difference in performance of car in impact with SUV if it has an additional load path not necessarily in alignment with the SUV vehicle structure (single and two level load path cars used in test series 2). Investigate if the performance of the car is improved if the SUV has a secondary energy absorbing structure (SEAS).
10.	SUV (SEAS) Small Family (2 load path)	TRL	
11.	SUV (no SEAS) Small Family (1 load path)	VW*	
12.	SUV (SEAS) Small Family (1 load path)	BASt ADAC*	

*Tests performed outside of the VC-Compat project to which the group have access to the results
Detailed test reports can be found in the appendices of D27 (D17 report appendices for tests 1 and 2)

Some of the main findings of these tests were:

Series 1: The test vehicle used had poor compartment strength and exhibited unstable performance against itself or another partner vehicle. This finding was similar to results in [Summers 2003] when the weak compartment of a target vehicle produced significant intrusions to the occupant compartment, regardless of the bullet vehicle configuration.

Series 2: A multiple load path vehicle exhibited better performance than a single load path vehicle when striking itself or the single load path vehicle. Performance was based on the Euro NCAP performance baseline.

Series 3: The mid-size vehicles in Test Series 2 exhibited similar performance when impacting a smaller target vehicle. The test series confirmed the benefit of vertical load spreading and compartment strength but did not confirm the benefit of the multiple-load path vehicle

Series 4: Large SUVs impacted the mid-sized vehicles in Series 2 with mixed results. The SUV without a lower load path was not as aggressive when striking the single load path SFC from Series 2 and a similar situation was found for the SUV with a lower load path and the multiple load path SFC. There was no clear evidence that one SUV design was better than the other.

The test vehicles used in VC-Compat were designs that could be considered as transitional vehicles during the implementation of R94 which became mandatory in 2003. The vehicles exhibited combinations of different compatibility characteristics which were not consistently good or bad. For example, the small family and SUV vehicles with lower load paths also had weak bumper cross beams while the single load path vehicles had much stronger cross beams. This made any analysis of car-to-car tests difficult as the crashworthiness designs could not be systematically assessed in all configurations due varying deformation modes. General conclusions on benefits for different architectures could be identified but it was not possible to develop evidence that mandated, for example, lower load paths on cars or strong cross beams.

Given the 6 years between the VC-Compat and FIMCAR start dates, as well as new accident data available, it was important for FIMCAR to re-evaluate the performance of recent vehicle designs that could be better correlated to the accident data analysed in FIMCAR Deliverable D.1.1 [Thompson 2013] and Section II, and additional accident analyses [Pastor 2009/1, Pastor 2009/2]. Based on these accident data FIMCAR members have set priorities for the development of the test procedures and metrics.

In order to address compatibility, a list of compatibility characteristics was identified and prioritized within the consortium, see Table 2. The description of the development of the list was described in [Thomson 2012] and Section XIII. The top priorities with respect to this report are that the test procedures should address structural interaction, restraint performance and maintenance of current levels of compartment integrity.

Table 2: Main compatibility topics and associated priorities.

Assessment requirements

	Structural Interaction		**Front End Force / Deformation (Consisting of)**		**Compartment integrity**		**Restraint system**	
	Alignment	Load Spreading (Load paths / connections)	Deformation forces of frontal structures	Energy Absorption Management	Sufficient for single vehicle accident	Enhanced for light vehicles in vehicle to vehicle accident	(Assess over range of pulses)	Test Restraint Capacity
Priorities For FIMCAR	1	1	2	1	1	2	1	1

The importance of structural interaction could be shown in FIMCAR accident analyses and in previous studies [Edwards 2007]. There were lower priorities on the deformation force which means that frontal force mismatching was not identified in FIMCAR as had been expected from earlier studies [Faerber 2007]. The compartment integrity is in most cases sufficient but should not be lowered, however, it is not clear if this is due to the UNECE Regulation 94 requirement or due to the higher requirements from Euro NCAP. There was no clear evidence that this was a particular issue with smaller vehicles. However, special attention should be put on acceleration induced injuries which should be assessed with tests introducing a range of pulses.

3 CAR-TO-CAR TESTING

3.1 Test Programme

Three different test series consisting of eight car-to-car crashes were conducted within the FIMCAR project. Table 3 shows a summary of the test program. Each test series had specific questions that were to be answered by the test results and support the compatibility metrics being developed in parallel activities in FIMCAR.

Note: The third test in Test Series 2 was not performed according the test specification (the original plan was to modify the ride height of the cars in order to achieve misaligned conditions; unfortunately the ride height was not adopted). Due to this mistake, the test did not help to answer all questions that were expected. Following that, the analysis of this test is treated separately at the end of Chapter 3.3.

Table 3: FIMCAR car-to-car test program.

Test Series	**Vehicle**	**Aim of the test**	**Test setup**
1	Supermini 1 (PEAS) Supermini 2 (PEAS & SEAS)	The effect of structural alignment in vehicle equipped with lower load path compared to a case without a lower load path	Frontal car-car 56 km/h 50% offset
2	Small family car 1 (PEAS & SEAS) SUV 1 (PEAS & SEAS) SUV 2 (PEAS)* * test condition different from original plan	The effect of structural alignment and lower load path in SUV type vehicles crashing against a small family car	Frontal car-car 56 km/h 50% offset
3	Large family car 1 SUV 3 (PEAS & SEAS)	Investigate the importance of lower load paths for SUV type vehicles in side impact crash	Side impact car-car 50 km/h

3.2 Test Series 1 – Supermini vs. Supermini

Two different vehicle models with different front end architectures where tested, Supermini 1 (named SM1) equipped with PEAS only, and Supermini 2 (named SM2) with both PEAS and a SEAS in line with the bumper. The vehicles were tested both with aligned and misaligned front structures (see Figure 3.1). The test speed was 56 km/h with a 50% overlap and 50th percentile Hybrid III dummies were positioned in the front seats according UN-ECE Regulation 94 procedure.

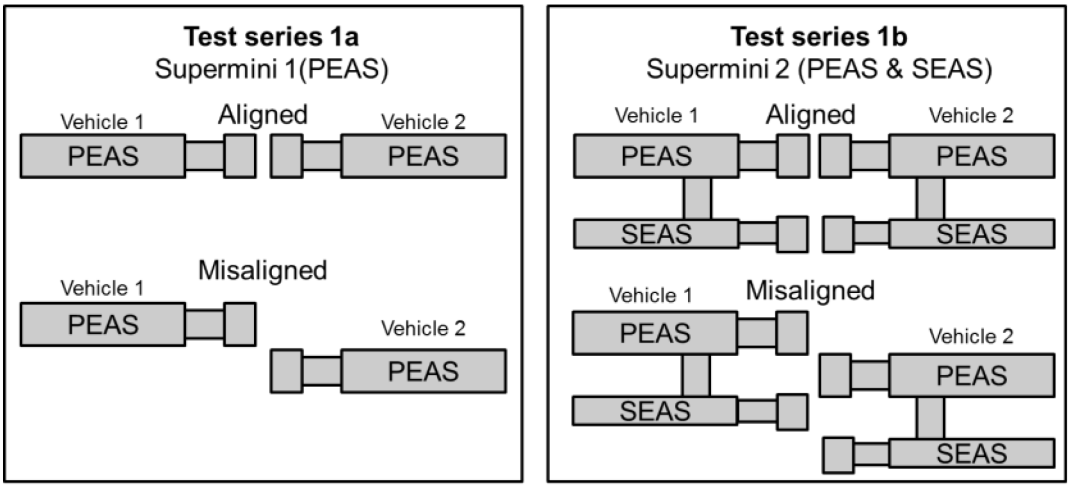


Figure 3.1: Test configurations in Test Series 1.

3.2.1 Results Test Series 1– Acceleration

The most obvious difference between the car model with both SEAS and PEAS (SM2) compared to the car with only PEAS (SM1) is a more rapid build-up of the acceleration in the initial stages of the impact (Figure 3.2). Comparing the mean acceleration for the first 300 mm of stopping distance, the SM2 has more than twice the acceleration of SM1. Both vehicles have a reduced acceleration build-up in the load case with misaligned front structures, but the reduction is greater in the car without SEAS (SM1). Comparing the acceleration to the case when the cars were tested in the Euro NCAP, both cars have higher average acceleration in the first 300 mm in car-to-car tests than in Euro NCAP when tested with aligned front structures. The car without SEAS (SM1) has lower acceleration than Euro NCAP in the misaligned test, while SM2 still has higher acceleration than Euro NCAP even in the misaligned test. The SM2 vehicle also has the highest peak acceleration. Regardless if the structures are aligned or misaligned, the peak acceleration is higher than in the Euro NCAP test. The car with only SEAS (SM1) has roughly the same max acceleration as in Euro NCAP test conditions.

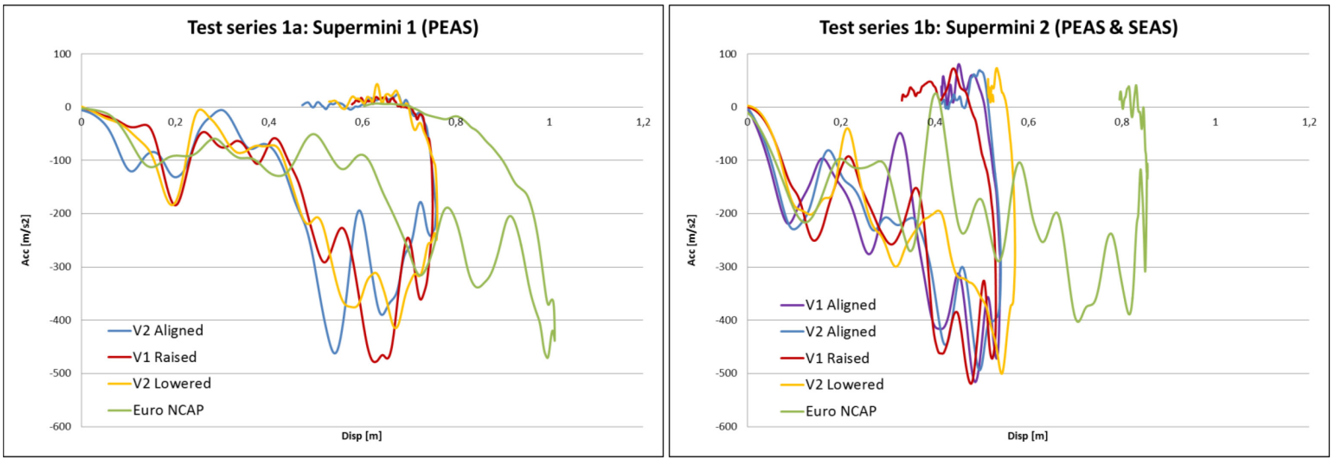


Figure 3.2: Acceleration measurement Test Series 1 (measured on left B-pillar root).

3.2.2 Results Test Series 1 – Intrusions

The car with only PEAS (SM1) has higher intrusions than the car with both PEAS and SEAS (SM2) as seen in the left side of Figure 3.3. The difference is greater when tested with misaligned front structures. Notable is that both cars have a higher A-pillar intrusion compared to the Euro NCAP test, even in the load case with front structures aligned. There is a slight case of over/under ride problems when the vehicles are aligned, which is more pronounced in the misaligned load case. It is always the overridden vehicle that has the highest A-pillar intrusion.

The intrusions in SM2 are shown in the right graph of Figure 3.3. This vehicle obviously has a stronger passenger compartment and front end design as seen in both Euro NCAP and aligned car-to-car test intrusions. It is important to note that the vertical misalignment of SM2 was about 100 mm while it was only 75 mm for SM1. The intrusions in SM2 were consistently lower than SM1 in the misaligned load case and demonstrate the role of multiple load paths when structures are not in complete alignment.

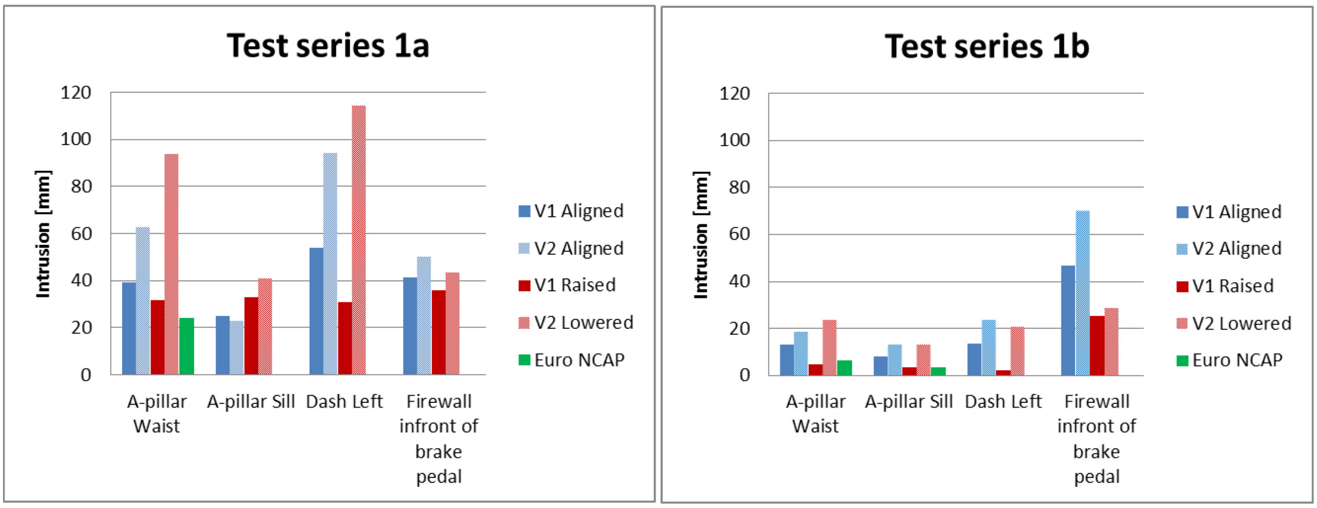


Figure 3.3 : Intrusion measurement test series 1 (left side SM1 and right side SM2).

3.2.3 Results Test Series 1 – Dummy Criteria

The dummy criteria for the driver are shown in Figure 3.4 as a percentage of the ECE Regulation 94 limits. There is no obvious trend between the vehicles and the different load cases. Notable is that both vehicles have dummy criteria that in many cases are higher than in the Euro NCAP test. It could also be seen that SM2 in the aligned load case has two values on or above the ECE Regulation 94 limits (Head Res Acc and HIC36). The passenger seat inner rail lock failed in Vehicle 2 causing the passenger dummy to interfere with the driver dummy. The driver dummy in Vehicle 2 did not contact the airbag was not centered as in Vehicle 1 and this may have contributed to the higher head accelerations.

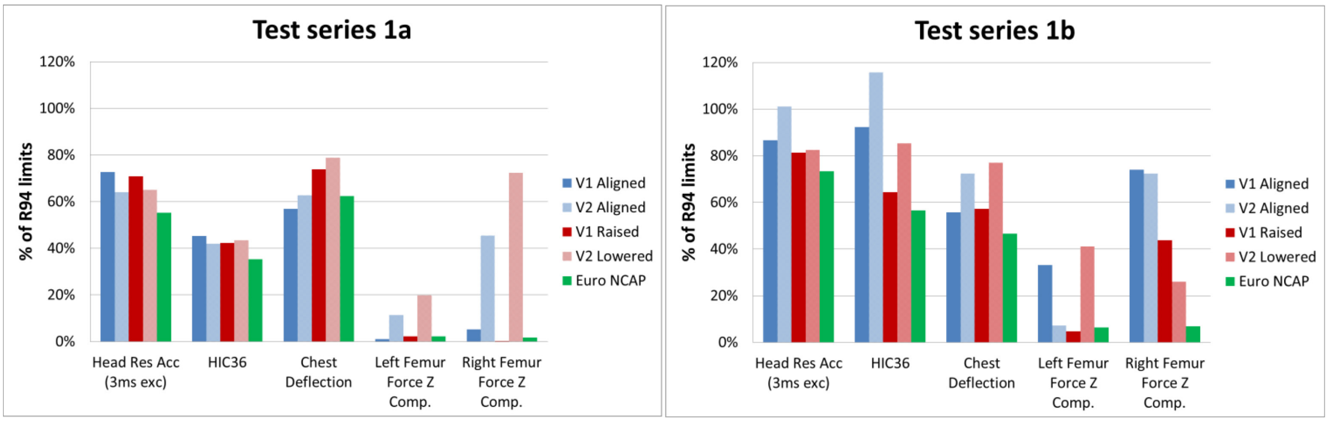


Figure 3.4 : Dummy criteria Test Series 1 as percentage of ECE-R94 limits.

3.3 Test Series 2 – SUV vs. Small Family Car

Two different vehicle types were tested. One SUV (named SUV1) equipped with PEAS and SEAS striking a target small family car (named SFC1) also equipped with PEAS and SEAS. Both vehicles have a SEAS located 100-200mm behind the bumper beam. Two tests were performed, one with misaligned front structures (normal ride heights) and one with the front structures aligned (see Figure 3.5). The test speed was 56 km/h with a 50% overlap and 50th percentile Hybrid III dummy where positioned in the driver seat according to UN-ECE Regulation 94 procedure, and a 5th percentile female dummy in the passenger seat. This test was designed to investigate the issues related to SUVs which are typically designed with high PEAS and need to keep the area in front of the wheels as clear as possible to provide adequate approach angles in off road conditions. There was an open question as to how the SEAS will function in a car-to-car test and how it will be detected in a barrier impact. Figure 3.5 shows the test setup for Test Series 2.

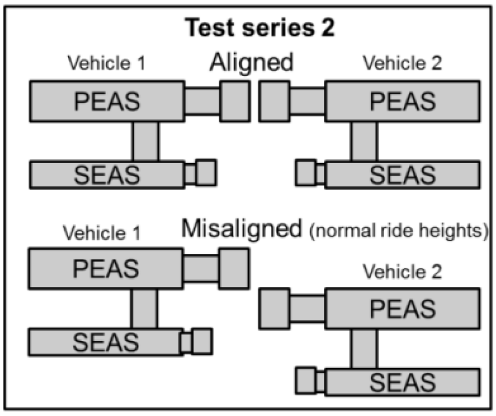


Figure 3.5: Test configurations Test Series 2.

3.3.1 Results Test Series 2 – Acceleration

Figure 3.6 shows the accelerations measured at the B-pillar root on the impact side of the vehicles. The acceleration measurement failed for the SUV1 in the misaligned load case, thus no comparison to the aligned load case is possible. The acceleration data for SFC1 is summarised in Figure 3.6. In the load case with aligned front structures SFC1 has higher mean acceleration the first part of the crash (first 300 mm of deformation) and lower peak acceleration. The delta-v is reduced to a level comparable to what the car has in the Euro NCAP test.

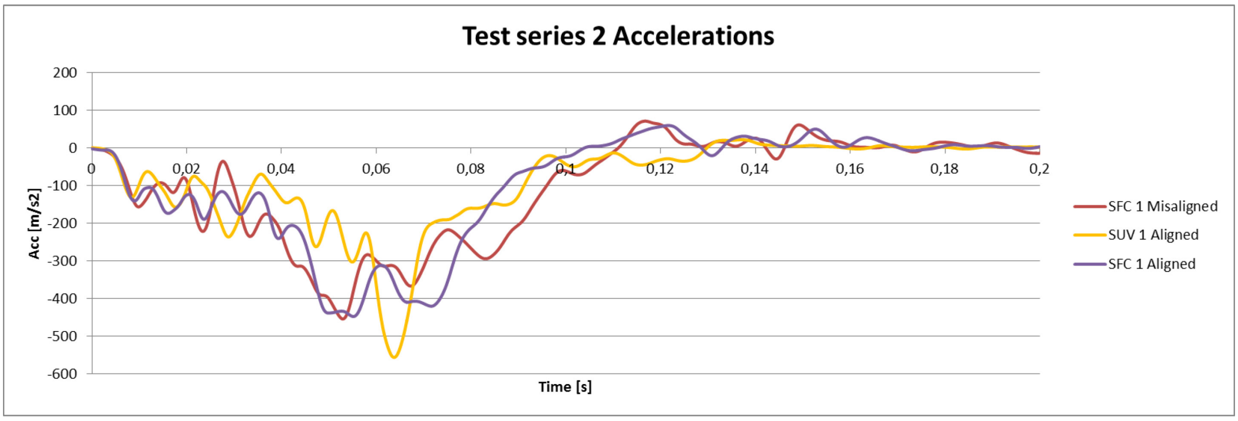


Figure 3.6: Accelerations Test Series 2.

Table 4: Acceleration data small family car Test Series 2.

	Small family car Aligned	Small family car Misaligned	Small family car EU-NCAP
Max displacement [mm]	732	739	1243
Max deceleration [m/s$^{2]}$	447	454	392
Mean decaleration 0-300mm [m/s2]	94	80	No data
DeltaV [km/h]	75,5	78,9	75,6

3.3.2 Results Test Series 2 – Intrusion

Figure 3.7 shows the intrusion measurements. As expected, the smaller car has, in general, higher intrusions than the SUV. The overriding situation of the SFC in the non-aligned test compared to the aligned one results in higher intrusions in the upper area of the cabin (dashboard) but reduced intrusions in the lower part (firewall left floor rest). For the SUV the intrusions are low and with no obvious trend, it is only the measurement at left footrest that stands out. No obvious reason for the intrusions at the footrest has been found.

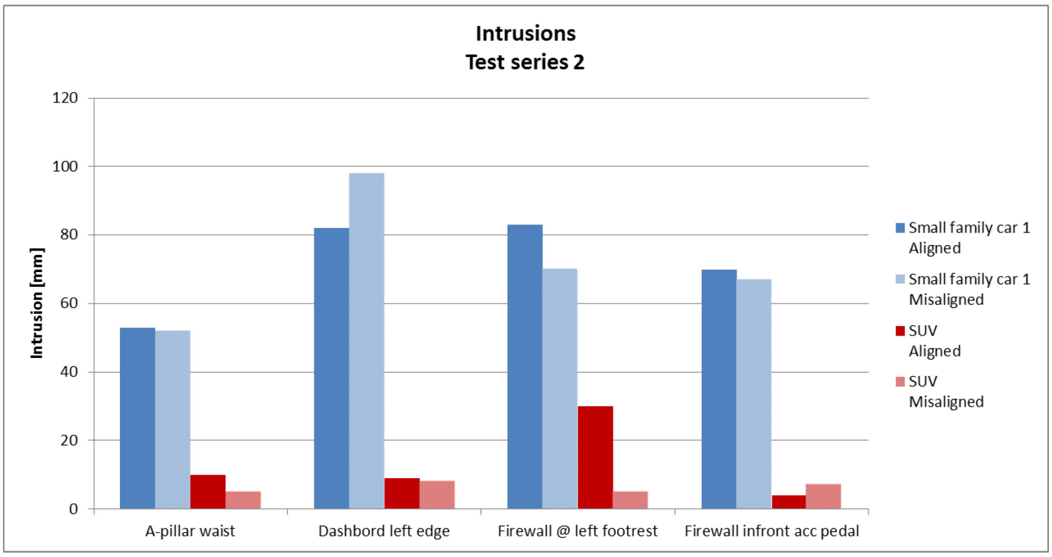


Figure 3.7: Intrusion measurement Test Series 2.

3.3.3 Results Test Series 2 – Dummy Criteria

The dummy criteria are shown in Figure 3.8 as percentages of the ECE Regulation 94 limits. The measurements show no clear trend, but for the SFC, 3 of 4 values (chest deflection, femur compression and tibia index) show an improvement in the load case with aligned frontal structures compared to the non-aligned situation, and for the SUV 3 of 4 values shows deterioration when the cars have their front structures aligned.

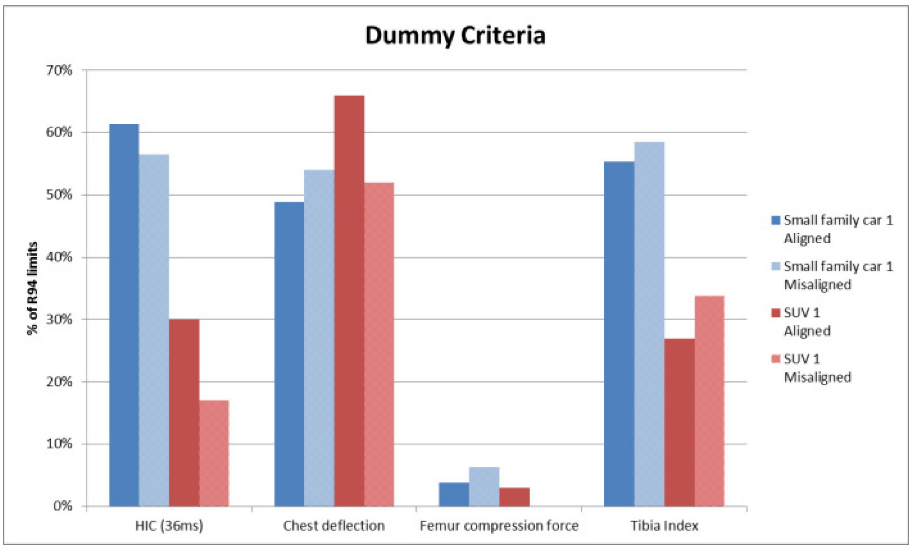


Figure 3.8: Driver dummy criteria Test Series 2.

3.3.4 Additional Test in Test Series 2

Test Series 2 was planned to consist of 3 different tests. The third test was planned to be a production SUV (SUV2) without SEAS in a misaligned test with the Small family car (SFC1). The purpose of that test was to compare the results with those from the first test in the series with an SUV with both PEAS and SEAS in the misaligned load case. This test case would allow for further study of the effect of a lower load path. By mistake this test was performed with wrong ride height on the SUV2 with the result that the vehicles where crashed with the PEAS of both vehicles being almost aligned. Therefore it is impossible to quantify the disbenefit from high PEAS cars without appropriate SEAS. However, literature is proving poor behaviour [Patel 2009].

Despite the incorrect test condition, some interesting observations that highlight the complexity of compatibility are worth discussing. The vehicles were vertically aligned according to Figure 3.9. The cross member of the SUV2 overlaps 96% of the SFC1 cross member, and the SFC1 cross member overlaps 64% of the SUV2 cross member. Despite this (initially) relatively high vertical overlap, the PEAS of the SUV2 was able to locally deform the crossbeam of the SFC1 and impacted the SFC1 gearbox. This “fork-effect” phenomenon could potentially be avoided with a horizontal load spreading requirement, which would require stiffer cross members that could decrease the risk for cross members to deform between the PEAS despite being initially aligned.

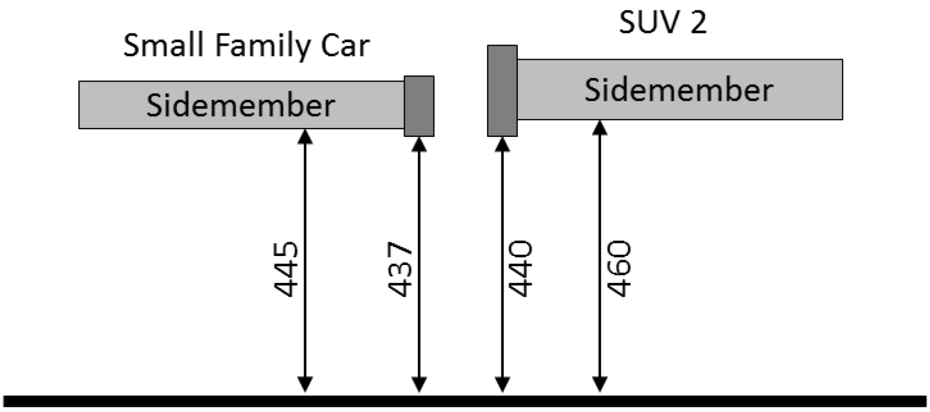


Figure 3.9: PEAS vertical alignment.

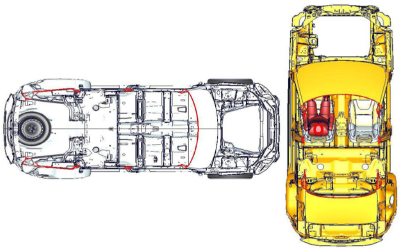
Due to the longitudinal side member of SUV2 impacting the gearbox of SFC1, the gearbox broke while the SUV2 side member remained undeformed. The intrusions in the SFC1 compartment were kept relatively low. The fact that the gearbox of the SFC1 broke could have helped reducing the intrusions, because it is likely that if the gearbox would have remained intact, it would instead have been pushed more rearward in to the compartment area of the SFC1. One other event that worked in favour of the SFC1 was that its longitudinal side member did impact the wheel of the SUV2. This created a load path from the sill of the SUV2 via the wheel into the longitudinal side member of the SFC1, allowing the side member to deform and absorb energy (as it is designed to do). If the SFC1 side member would not have impacted the wheel in such a favourable way (e.g., in an accident with a slightly different off-set), it is likely that the results for the SFC1 would have been much worse. So in summary, one can say that different combinations of local contacts between the crash partners have quite an impact on the result for the smaller car in this test. This highlights the complexity of compatibility, particularly structural interaction, in car-to-car collisions.

3.4 Test Series 3 - SUV vs. Large Family Car

In test series 3, an SUV (named SUV3) originally equipped with a SEAS longitudinally in line with the bumper beam, crashed into the side of a large family car (named LFC1). The SUV3 (bullet vehicle) was travelling at 50 km/h and a 90° angle into LFC1 (target vehicle). The bullet’s longitudinal centre line was in line with the COG of the drivers head in the target vehicle. Two tests were performed, one reference test with SEAS and one test with the SEAS removed. The test setup can be seen in Table 5 and the pre-crash alignment in Figure 3.10.

Table 5: Test Series 3.

<table>
<tr><td rowspan="2">Test Date
1;st test
2;nd test
Location
Topic
Mass Ratio
Test Number
1;st test
2;nd test
Test Protocol</td><td rowspan="2">
Febr. 15, 2012
Febr. 29, 2012
VCSC
Car to Car
1:1.1

122129
122130
Car-to-car test</td><td colspan="4">SUV 2
50 km/h

LFC 1
0 km/h</td></tr>
<tr><td>Vehicle 1:
Type:
Impact side:
Speed:
Overlap:
Test mass:
Dummy:</td><td>SUV
SUV
Front
50 km/h
100 %
1935 kg
LHS – H III 50%</td><td>Vehicle 2:
Type:
Impact side:
Speed:
Details:
Test mass:
Dummy:</td><td>Sedan
Large family car
Left side
0 km/h
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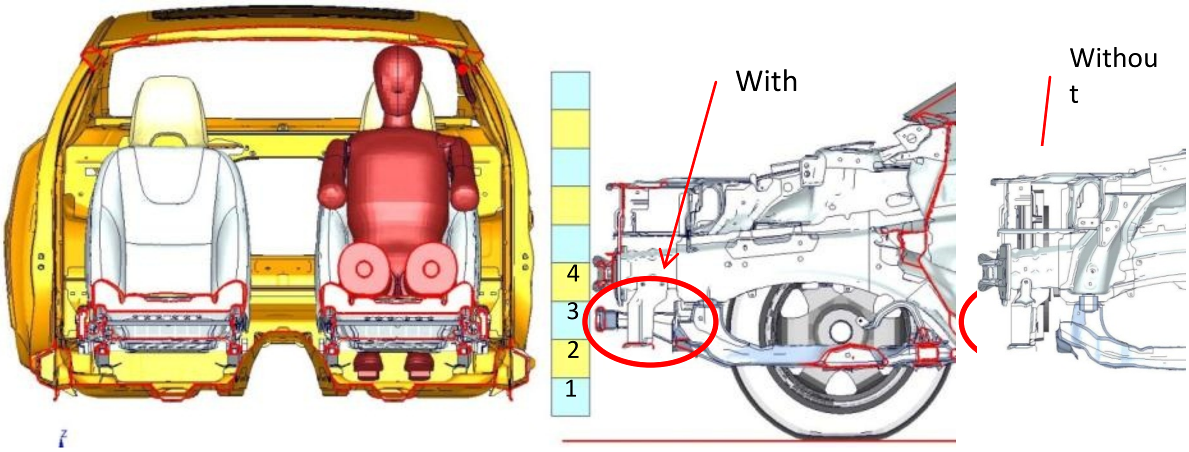


Figure 3.10: Pre-crash alignment compared to load cell wall.

3.4.1 Results Test Series 3 – Structure

The reference vehicle with the lower load path put a higher load on the B-pillar resulting in higher B-pillar velocity and intrusion (measured at the dummy chest location) compared to the modified test without lower load path. This can be seen in Figure 3.11.

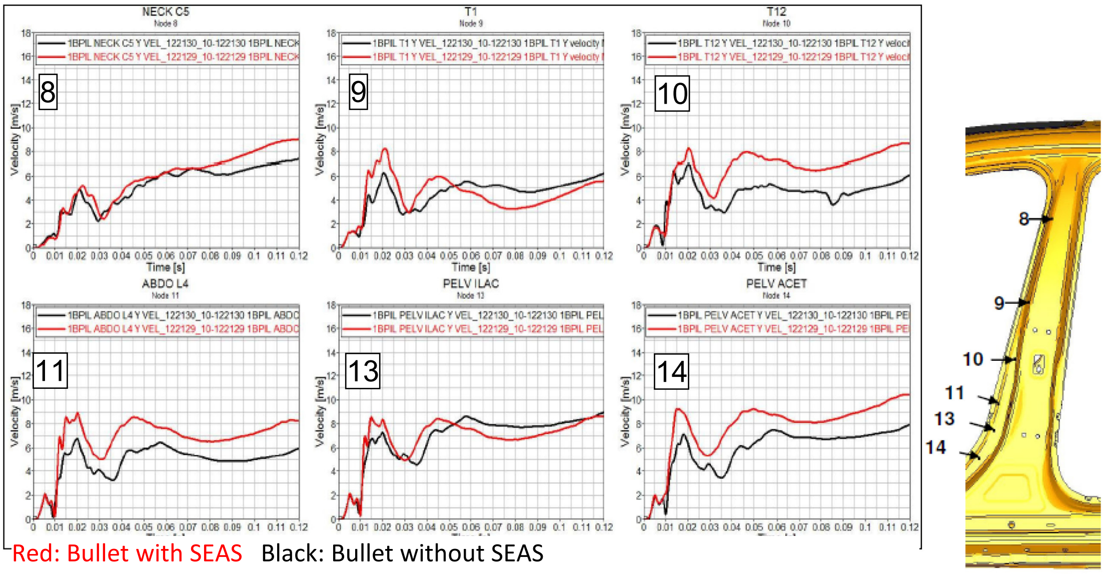
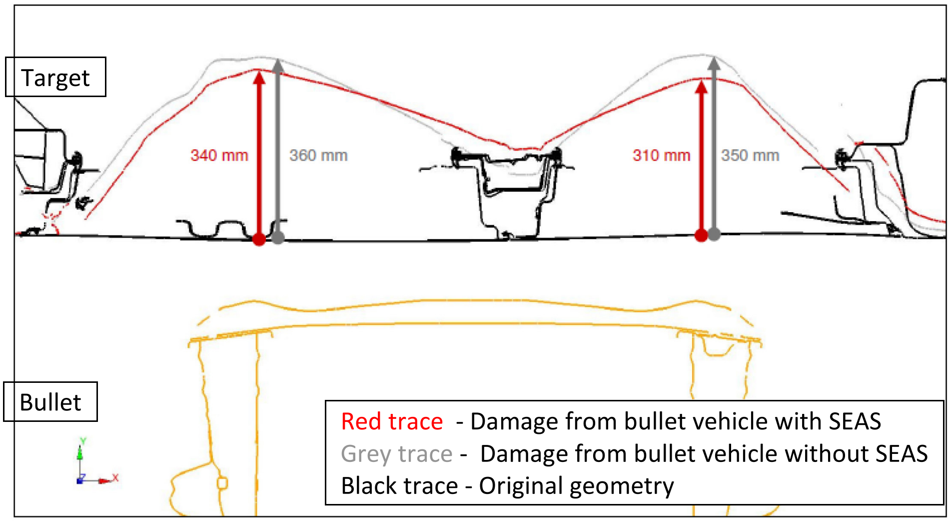
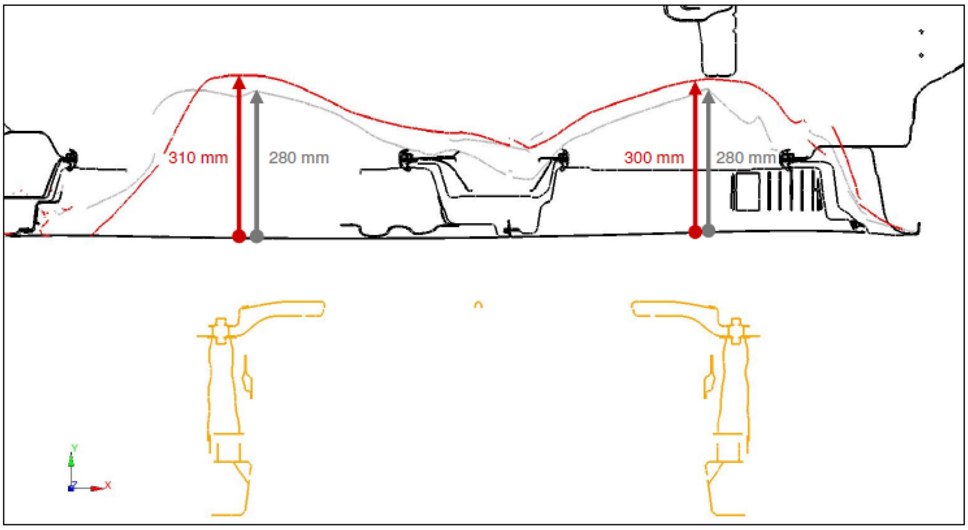


Figure 3.11: B-pillar velocities at different locations.

This behaviour arises when the lower load path on the bullet vehicle hits the B-pillar above the sill. The sills on most passenger cars are located at a height of 200-300 mm. Compared to a load cell wall this represents Row 2, while the lower load path of SUV 2 is located in Row 3 (Figure 3.10) [Adolph 2012]. The deformation of the struck vehicle is shown in the scanning measurements shown in Figure 3.12. The figures are a plan view of a scan section at two different vertical levels. The bullet without a subframe produced increased deformations of the target at the height of the bumper, also the location likely to make contact with the occupant (see Figure 3.10). Conversely, the bullet with a subframe produced more intrusion in the target at subframe level although this deformation is in a less critical area than at bumper level.



a – Scan at Level of Striking Vehicle Bumper



b) Scan at Level of Striking vehicle Subframe

Figure 3.12: Pre scan of target vehicle deformations (measurements are approximate).

The modified bullet (no forward SEAS) had a higher deformation at the centre of the bumper cross beam (see Figure) than the standard vehicle (with forward SEAS). This resulted in a 40 mm lower deformation of the target B-pillar at the point where the crossbeam contacts the target as compared to the test with the original structure. The deformation of the crossbeam resulted in a change of loading to the target, shedding loads from the target B-pillar to the surrounding door structure. The longitudinal side members in the modified SUV3 began to penetrate the doors and the left longitudinal side member began to load the dummy's femur, introducing a bending moment that was higher than for the standard bullet vehicle. The dummy values would have been higher if the impact location on the target vehicle was shifted rearward, so the longitudinal side member would directly load the dummy (due to door intrusions) or the B-pillar.

Figure 3.13: Deformation of bumper beam in modified SUV.

3.4.2 Results Test Series 3 – Dummy Criteria

For the SUV bullet vehicle, both tests showed a better result compared to the Euro NCAP test. The test speed of 50 km/h, lower than Euro NCAP frontal impact, and 10% lower mass on the target, produced lower crash loads on the bullet vehicle.

The large family car target vehicles driver dummies, in both tests, had higher values than in the Euro NCAP side collision. The bullet vehicles had higher weights, 1935 kg compared to the Euro NCAP MDB's weight of 950 kg resulting in a higher impact energy. The dummy in the reference vehicle recorded higher criteria in the chest and abdomen as a result of higher B-pillar intrusion (shown previously).

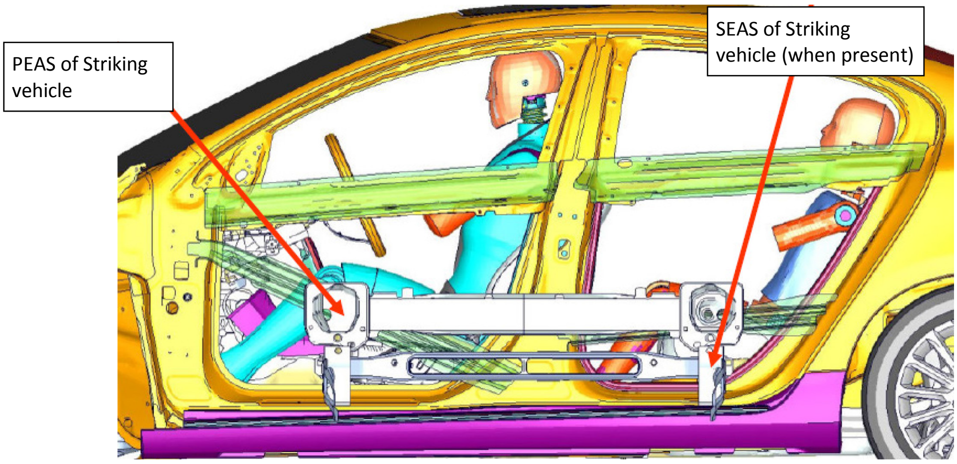


Figure 3.14: Deformation of bumper beam in modified SUV

A summary of the dummy injury values for the front and rear near side dummies is presented in Table 3.6. The results are counter-intuitive when first reviewed. In general, the vehicle struck with a vehicle equipped with a lower load path had less intrusion than when stuck with the same vehicle without the lower load path. As pointed out in the previous section, the wider distribution of the deformation caused higher B-Pillar velocities when struck with SEAS equipped vehicles. This was reflected in higher injury risks for the chest and abdomen. The influence of localised deformation can be observed in the rear seat passenger lower extremities. The lower chest, pelvis, and lateral-medial moments in the legs showed that the rear seat passenger was affected by the more focused deformation of the door when a non-SEAS equipped vehicle was the bullet. A simulation parameter study showed that the dummy injury readings were worse if the striking vehicle was shifter rearward placing the longitudinals of the bullet vehicle closer to the occupants.

The test results in Table 3.6 are not consistent with the expectations that a SEAS equipped vehicle will have improved partner protection, compared to a non-SEAS equipped vehicle, in a side impact. The target vehicle exhibited good self-protection in all cases and may have not been as sensitive to the bullet vehicle's geometry. Further testing should be conducted to confirm the simulation studies.

Table 3.6: Occupant injury assessment in struck vehicle.

	Loaded by	Euro NCAP MDB	Bullet Vehicle with SEAS	Bullet Vehicle without SEAS
	Position	Driver	Driver	Driver
	Dummy	ES2	ES2	ES2
Head				
Peak resultant acceleration - g		20.6	32.03	25.13
Resultant Acc. 3 ms - g		19.93	30.42	23.56
HIC 15		26	99	62
Chest Top				
Compresson - mm		10.61	29.61	21.22
Viscous Criterion - m/s		0.04	0.47	0.24
Chest Mid				
Compresson - mm		8.95	27.89	17.13
Viscous Criterion - m/s		0.03	0.36	0.15
Chest Bottom				
Compresson - mm		10.17	28.45	17.67
Viscous Criterion - m/s		0.05	0.33	0.14
Abdomen				
Peak Lateral Force - kN				
Front		0.1	0.32	0.16
Mid		0.19	0.45	0.29
Rear		0.21	0.47	0.29
Total		0.44	1.24	0.75
Pelvis				
Pubic Symphysis Force - kN		1.24	2.72	1.89

	Loaded by	Bullet Vehicle with SEAS	Bullet Vehicle without SEAS
	Position	Rear Left	Rear Left
	Dummy	Sid2S	Sid2S
Head			
Peak resultant acceleration - g		56.79	67.49
Resultant Acc. 3 ms - g		54.93	66.46
HIC 15		278	418
Chest	Top		
Compresson - mm		36.4	33.3
Viscous Criterion - m/s		0.386	0.424
Chest Mid			
Compresson - mm		31.41	28.73
Viscous Criterion - m/s		0.301	0.413
Chest Bottom			
Compresson - mm		25.57	29.56
Viscous Criterion - m/s		0.25	0.336
Abdomen			
Abd. Rib Defl. - mm	Upper	24.76	28.98
Abd. Rib VC - m/s		0.221	0.416
Abd. Rib Defl. - mm	Lower	24.29	25.63
Abd. Rib VC - m/s		0.26	0.378
Pelvis			
Pubic Symphysis Force - kN		1.24	1.34
Femur			
A-P Moment (3ms) - Nm		44.71	37.32
L-M Moment (3 ms) - Nm		151.2	199.3
Resultant Moment - Nm		310.6	287.5
A-P Force (3 ms) - kN		0.601	0.343
L-M Force (3 ms - kN		0.849	1.13
Axial Force (3 ms) - kN		1.08	0.73

4 DISCUSSION

All the vehicles tested in the FIMCAR project are examples of vehicles designed to the existing legislation and consumer tests in Europe. These vehicles therefore did not have structures or occupant restraint systems designed to the anticipated FIMCAR compatibility requirements. It is important to consider that the dummy measurements reported in this study would not be expected once vehicles are designed to the anticipated requirements from FIMCAR.

The findings from Test Series 1 show that the vehicle with multiple load paths has a clearly more rapid acceleration build-up than the single load path vehicle in both aligned and misaligned cases. This is important for both restraint system trigging and the function of the restraint systems. The vehicle with both PEAS & SEAS has in general lower intrusions, and is less sensitive for misalignment regarding intrusion on A-pillar and dash. This early engagement in the crash indicates better energy absorption and a more effective use of the deformation zone of the vehicle.

Test Series 1 also showed the importance of controlling the stiffness of frontal structures for self protection reasons as expected from the introduction of a full-width test. Supermini 2 had extremely high accelerations in car-to-car collisions and this was also the case in FWDB tests. This confirms the need to control energy absorption and acceleration induced injuries with a full width test. Both vehicles in Test Series 1 were not originally designed for the North American market and it would be expected that these models would have exhibited lower accelerations in all test conditions if they had been more focus on full width test performance. The addition of a full with the test procedure would also require the restraint systems to handle a wider variety of crash pulses, which should give a better field performance.

Test Series 2 shows that structural alignment increases the mean acceleration initially and reduces the peak acceleration and delta-v for the smaller vehicle facing a heavier opponent in a frontal crash. But the improvements for the smaller vehicle can come to the cost of impairments for the heavier vehicle such as higher delta-v leading to higher acceleration generated dummy criteria. It is important to note that the SFC had no significant change in the accelerations (Figure 3.6) when impacting the aligned or misaligned SUV1. Both vertical positions of the SUV1 resulted in a positive FWDB result indicating that the FWDB test and assessment procedures could confirm that SUV1 would perform satisfactorily in frontal car-to-car crashes. Unfortunately the third test of this test series with the plan of using a single load path SUV in misaligned conditions was not performed as intended. Therefore it is impossible to quantify the disbenefit from high PEAS cars without appropriate SEAS. However, literature is proving poor behaviour [Patel 2009].

Test Series 3 shows the importance of SEAS for distributing the deformation in a side impact. Without SEAS, the longitudinals can produce local deformations that can be hazardous to the struck vehicle occupants. The larger contact area created by the distribution of forces over both Rows 3 and 4, as well as the presence of a subframe in Row 2, albeit further back, resulted in a better door intrusion profile for the occupant. Even though the dummy showed slightly better readings when struck by the modified (non-SEAS) vehicle, global performance of the original bullet vehicle indicates a better safety level. This was confirmed with a complementary simulation activity where different characteristics of the bullet vehicle were modified. The worst results for the struck vehicle were encountered when the modified vehicle had a stiff bumper crossbeam which focused its loads on Row 4 on the FWDB. The sill on most passenger cars are located at a height of 200-300 mm. Compared to a load cell barrier this represents Row 2 [Adolph 2012] (see Figure 3.10).

5 CONCLUSIONS

The results of the 3 test series demonstrate a common benefit for multiple load path vehicles, independent of the collision type. Multiple load paths exhibited a much more stable response in frontal impacts and could tolerate larger variations in structural misalignment than a single load path vehicle before serious degradation in performance were observed. Multiple load paths in SUVS were shown to be beneficial for collision partners with these higher vehicles. The SEAS tested and simulated in this test program were able to effectively engage the partner vehicle’s front structures. As both of the SUV vehicles exhibited good FWDB results (assessment criteria is described in [Adolph 2012] and Section X) and car-to-car test results, there is further confirmation that the FWDB and associated metric is able to detect good structural alignment and promote car-to-car crash safety. In addition, no significant detrimental effects (in terms of acceleration and intrusions) were observed when SUV and SFC structures were aligned.

The side impact tests provided useful input to the metric developments as well as identifying the importance of evaluating frontal impact compatibility characteristics. Even though the safety level in the struck vehicle was good in the 2 different test configurations, the different deformation profiles of the bullet vehicle demonstrated that concentrating loads on a limited number of load paths will introduce higher, local, intrusions in the struck vehicle with negative consequences for the occupants, as observed of the rear seat passenger. The fact that better target deformation was demonstrated with a bullet vehicle that spreads load vertically over Rows 3 and 4 instead of just Row 4 highlights the need for structural alignment in Rows 3&4 as well as vertical load spreading.

6 GLOSSARY

Head Res Acc	Head resultant acceleration over 3 ms (a_{3ms})
HIC	Head Injury Criterion (time weighted head acceleration metric)
HIC36	HIC analysed over a maximum period of 36 ms
LFC	Large Family Car
LTV	Light Truck Vehicle
MDB	Movable Deformable Barrier
PEAS	Primary Energy Absorbing Structures (main rails)
SEAS	Secondary Energy Absorbing Structures (lower load path)
SFC	Small Family Car
SM	Super Mini
SUV	Sports Utility Vehicle

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