EVALATION OF THE PERFORMANCE OF COMPETITIVE HEADFORMS AS TEST TOOLS FOR INTERIOR HEADFORM TESTING

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ABSTRACT

The European Research Project APROSYS has evaluated the interior headform test procedure developed by EEVC WG 13, representing the head contact in the car during a lateral impact. One important aspect within this test procedure was the selection of an appropriate impactor. The WG13 procedure currently uses the Free Motion Headform as used within the FMVSS 201. The ACEA 3.5 kg headform used in Phase 1 of the European Directive and the future European Regulation on Pedestrian Protection is still discussed as a possible alternative.

This paper reports work performed by the Federal Highway Research Institute (BASt) as a part of the APROSYS Task 1.1.3. The study compares the two headform impactors according to FMVSS and ACEA, in a series of basic tests in order to evaluate their sensitivity towards different impact angles, impact accuracy, the effect of differences to impactors of the same type and the effects of the repeatability and reproducibility of the test results. The test surface consisted of a steel tube covered with PU foam and PVC, representing the car interior to be tested.
Despite of the higher mass of the FMH the HIC values of this impactor were generally lower than those of the ACEA headform. The FMH showed a higher repeatability of test results but a high sensitivity on the angle of roll, the spherical ACEA impactor performsed better with regards to the reproducibility. In case of the ACEA impactor-, the angle of roll had no influence.

INTRODUCTION

The terms of reference of WG 13 indicate a critical review of the competing headforms:

> ...
> 5) Interior Surface Test.
> Review the proposed EEVC interior surface test procedure, including any validation testing that has been completed and, if necessary, refine the procedure such that it is fit for regulatory application.
> *Deliverables*
> *a. A report of the outcome of validation testing and a critical review of the competing headforms*
> *b. Development of a refined test procedure that is suitable for regulatory application.*
> *EEVC Steering Committee March 2006*
> ...

To identify differences and advantages from one headform to the other an elementary test programme was necessary. Tests on simplified structures representing surfaces like, A-, B-, C-pillars and side roof rails were of interest.

The following investigations assess the quality of test results by checking how sensitive the headforms are at small variations of the

- impact angle
- target accuracy
- head orientation
- use of different headforms of the same type.

CHOICE OF HEADFORMS AND USE IN REGULATIONS

The EEVC WG13 test procedure currently uses the FMH (Free Motion Headform) impactor to assess the interior car structure concerning head injury risk in lateral impacts. Due to difficulties in head alignment and in finding the appropriate impact target

on the calibrated impact zone of the FMH impactor, the question was raised to review suitable headforms. To simplify testing, a headform that is all-over calibrated and not sensitive on impact direction would be beneficial. A spherical headform like those used in pedestrian testing fulfils these requirements. Therefore the ACEA (European Automobile Manufacturer Association) headform impactor used for headform to bonnet rating in EC-Directive 2003/102/EC was chosen.

Both headforms, the FMH and ACEA, are used in regulations to assess the severity of a head contact during a crash. The FMH is used in the American FMVSS201 for interior headform testing, the ACEA headform is used in the European EC-directive 2003/102/EC and the Japanese Regulation TRIAS 63 for pedestrian headform testing.

The first obvious difference of the two competing headforms is the shape. While the FMH is only symmetrical to its z-x plane, the ACEA headform is symmetrical to its z-x and z-y plane with the exception of the backplate.

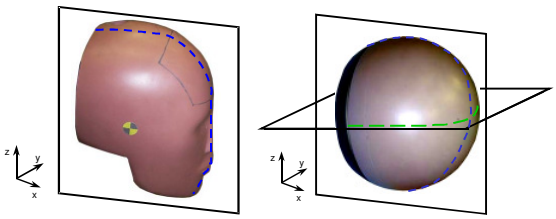


Figure 1. Side view of competing headforms.

Further information about the differences of the impactors are available in Annex A.

BASIC TEST SPECIFICATION

The validation and comparison of two different types of impactors requires a simple and robust experimental set-up. Each impactor gets tested on the structure several times. Therefore it is very important that the structure offers the same basic conditions at each test run to achieve reliable and comparable results. To minimise the influence of the tested structure, a very repeatable and homogeneous structure was necessary.
A structure was chosen, that fulfils the following requirements:

Test structure:

- Rotation-symmetric assembly (tube)
- Similarity to typical car structures (e.g. B-pillar)
- Mix of typical car-body materials
- Dimensioning of sample structure on realistic HIC values
- No plastic deformation after test

Also fixed boundary conditions are necessary to avoid any interference, simplify testing and reduce tests costs.

Boundary conditions

- High stiffness of restraints
- Stress-free deformation of the tube
- Vibration-free bearing of the test tube
- Rotational free supports
- Easy replacement of the test sample
- Removable and simple assembly
- Low cost

This resulted in the following test structure:

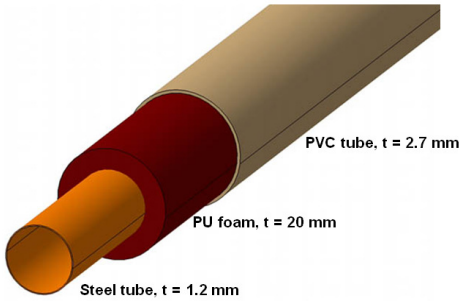


Figure 2. Rig testing tube assembly.

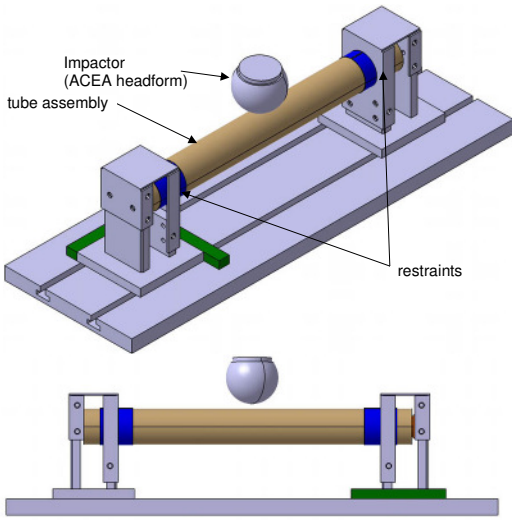


Figure 3. ISO and side-view of the complete rig testing set-up.

For more detailed test specification please see Annex B.

Test set-up and parameters

The test runs are carried out on the test bench of BASt.

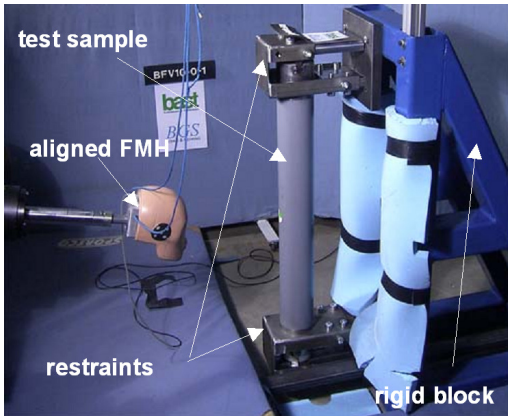


Figure 4. Test-set-up showing aligned FMH impactor.

Sensitivity on impact angles variation

Finding the correct perpendicular vector to the selected target is often complicated at curved structures. The configurations shown in the figures below should lead to information about the influence of the angle deviation in headform testing.

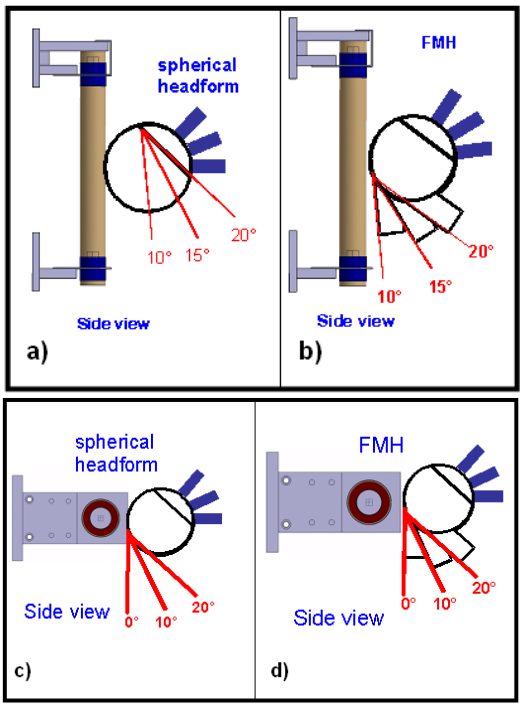


Figure 5.
Top: Angle variation on vertical tube (a, b).
Bottom: Angle variation on horizontal tube (c, d).

Sensitivity on target accuracy

It was observed, that the contact on the impactor during a test varied from one test laboratory to another. On the one hand this was due to a missing definition of contact location in the calibrated field. Therefore a consistent procedure was developed. On the other hand variations in contact location in the calibrated can still occur. The test procedure allows a 10mm radius accuracy of the target point. This means possible target locations can be 20mm apart. It is of interest how both headforms react on deviations from the initial position.

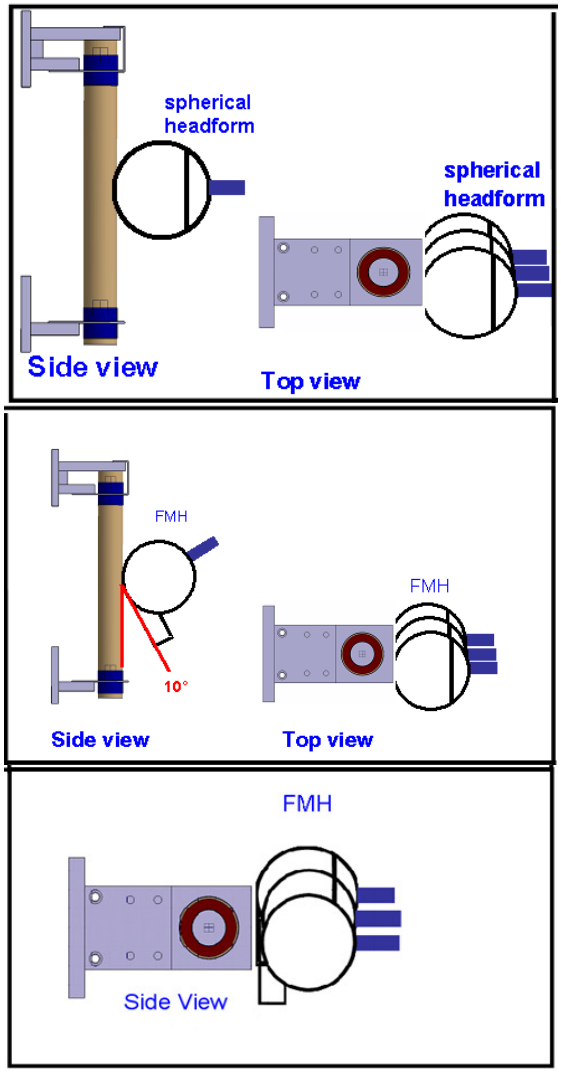


Figure 6. Top: ACEA headform - target deviation on vertical tube (same set-up on horizontal tube).
Mid: FMH headform on target deviation vertical tube.
Bottom: FMH headform on target deviation horizontal tube.

Influence by using different headforms / reproducibility

Variations in test results may not only occur because of differences in the test set-up. It may also occur because of differences in the test device / headform. Therefore comparisons of different impactors of the same type can provide information about the reproducibility of test results.

The following figures show the used headforms. Already visible are differences of the FMH impactors.

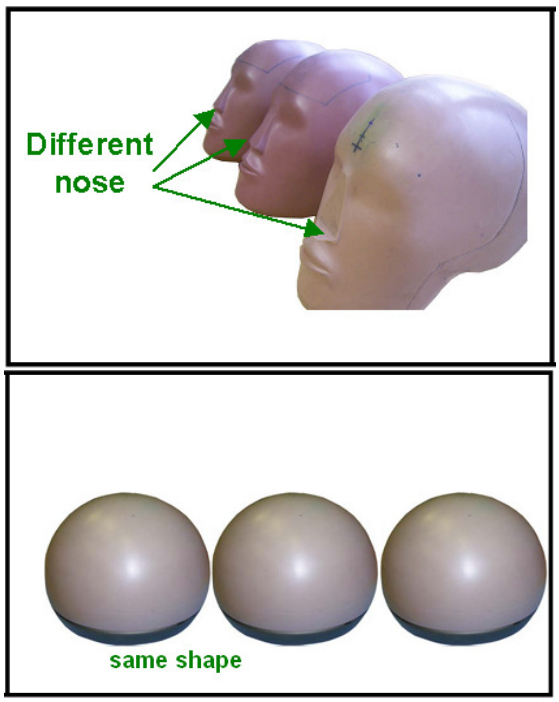


Figure 7. Different FMH and ACEA headforms.

Assessment parameters

Both impactor types will be compared by the HIC value and not the HIC_d value. The HIC_d is calculated from the measured HIC of the FMH taking into account the connection of the dummy head to the rest of the body ($HIC_d = 0.75446 * HIC_{FMH} + 166.4$)
This formula cannot be used for the ACEA headform as the dummy related HIC_d value is only related from the FMH impactor to the dummy headform.

For both impactor types the absolute HIC deviation and the deviation in percentage, within test repetitions, are determined to evaluate reproducibility. The deviation of HIC in dependency of an increasing impact angle and a displacement of impact vector will be shown and analysed regarding the impactors' sensitivities.

To achieve reliable results and to obtain additional information about repeatability, tests were performed three times. Additionally information could be gained about repeatability. After one test the tube was turned by 180° and after the second test the tube was replaced by a new tube.
Altogether 73 tests were performed (see test matrix in the Annex C)

RESULTS: INVESTIGATION ON IMPACT ANGLE SENSITIVITY

Sensitivity on impact angle (vertical tube)

In the case of vertical tube orientation, the initial alignment of both impactors is pitched by 10°. This action is required by the clean-contact requirement of the FMH. Plotting the average HIC values for FMH and ACEA headform, in dependency of an increasing impact angle, shows a nearly similar and linear allocation for both impactor types (see figure 8 and 9). The absolute HIC values of the ACEA headform are always higher in average than those of the FMH. This can be explained by less headform rotation, caused by the mid-central position of the spherical headform's CoG. Increasing the impact angle by additional 5° causes a HIC value decrease of about 11 % for both impactor types. A further increase up to a total impact angle deviation of 10° from the initial position shows a HIC decrease of 18.5 % for the FMH and 15.8 % for the ACEA headform.

The variation of the HIC values, within test repetitions, is quite different between the impactors. Testing under vertical tube orientation, the FMH results do vary 0.6 % between minimum and maximum value in the initial position of 10° head pitch, the ACEA headform varies about 10 times higher. With a variation of about 10 % at 15° head pitch, the ACEA varies twice as high as the FMH. Under these test conditions the FMH shows a better test repeatability.

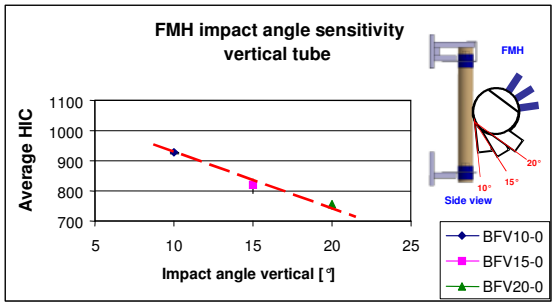


Figure 8. Variation of impact angle, FMH vertical tube.

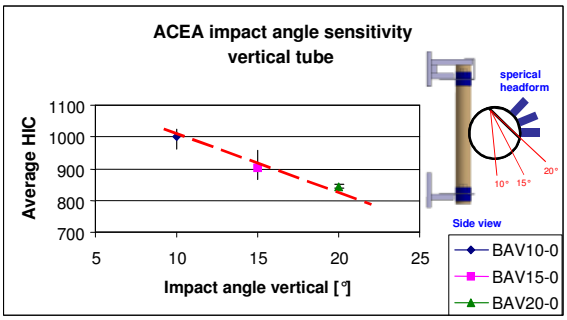


Figure 9. Variation of impact angle, ACEA headform vertical tube.

Sensitivity on impact angle (horizontal tube)

The horizontal tube orientation defines the initial position of both impactors at 0° head pitch and 0 mm lateral offset relative to the test tube.

The measured values show a nearly similar dependency between impact angle and HIC-value decrease for the ACEA and FMH impactor. Under horizontal tube orientation the load level between FMH and ACEA differs considerably to that seen in the vertical tube position. This is caused by the fact that the external diameter of the tube is smaller than the size of the FMH and therefore the FMH impactor freely rotates without having a secondary impact with its chin on the structure.
While the HIC results between FMH and ACEA headform differ in average about 10 % in case of vertical tube orientation, the difference at horizontal tube testing was an average of 21 %.

The following figures show the variation of the HIC values under horizontal tube alignment. Up to 10° impact angle, the deviation is nearly identical for both impactor types. While the variation of the FMH impactor decreases below 5 % when increasing the impact angle up to 20°, the HIC values of the ACEA headform was very sensitive to further angle deviation, with a variation of about 20 %. It should be noticed that the number of repeated tests is too low to draw a precise conclusion.

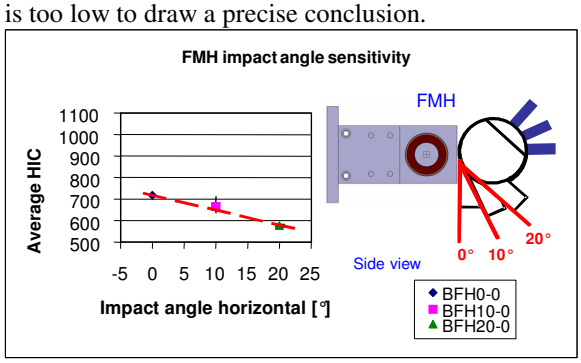


Figure 10. Variation of impact angle, FMH horizontal tube.

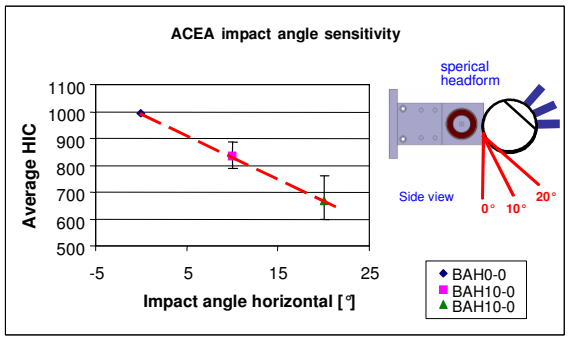


Figure 11. Variation of impact angle, ACEA headform horizontal tube.

Table 1 gives an overview of the HIC results for the FMH and ACEA impactors. In addition to the absolute HIC values the relative deviation for each test setup is shown.

tube orient.	FMH			ACEA		
	impact angle [°]	average HIC	HIC decrease [%]	impact angle [°]	average HIC	HIC decrease [%]
Vertical	10	926		10	1002	
	15	821	11.4	15	900	10.2
	20	755	18.5	20	844	15.8
Horizontal	0	719		0	992	
	10	666	7.4	10	834	15.9
	20	577	19.8	20	668	32.6

Table 1. Results of physical rig tests (impact angle)

The following figures show the data quality in accordance to the impact angle. The values of repeated tests of the FMH impactor are closer together than the values of the ACEA impactor.

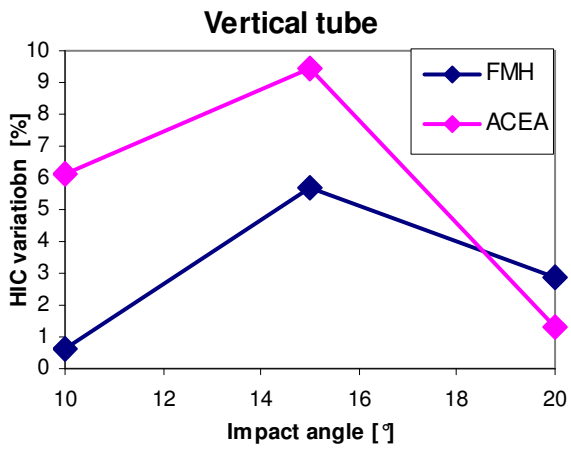


Figure 12. Comparison of test variation for impact angle deviations (vertical).

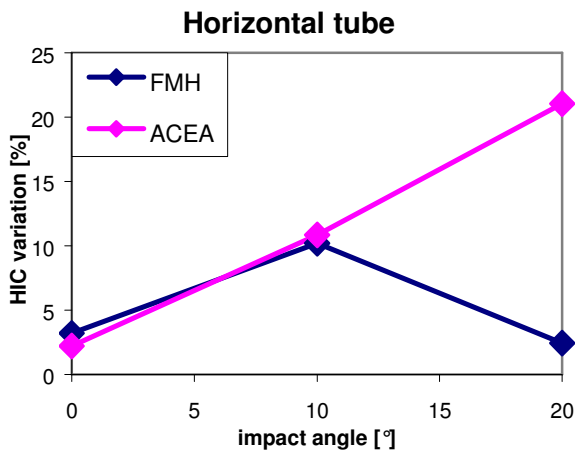


Figure 13. Comparison of test variation for impact angle deviations (horizontal).

INVESTIGATION ON IMPACT VECTOR DISPLACEMENT SENSITIVITY

Sensitivity on impact vector displacement (vertical tube)

The initial position of the FMH is defined as 10° head pitch and 0 mm offset to the vertical tube axis; the ACEA headform will be aligned under 0° head pitch and 0 mm offset. The impactors get aligned with a lateral vector offset to the headform's horizontal axis in increments of 10mm.

The ACEA impactor shows a linear decrease of HIC values due to an offset of the impact vector (see figure 14). At a displacement of 10 mm from the initial position, the HIC-value decreases about 2.5 %, at 20 mm 5.4 %. For the FMH the HIC values decrease about 1.6 % for 10 mm axis offset and 7.4 % at 20 mm offset.

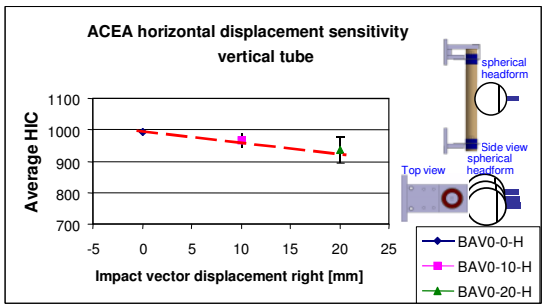


Figure 14. Sensitivity on impact vector displacement, ACEA headform (vertical tube).

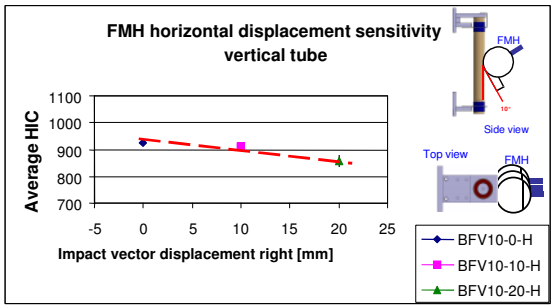


Figure 15. Sensitivity on impact vector displacement, FMH (vertical tube).

Sensitivity on impact vector displacement (horizontal tube)

Under horizontal tube orientation the impactors get aligned with an increasing impact vector offset moving down on the head's local z-axis. The performance characteristic of both headforms is nearly linear as on vertical tube alignment. The FMH's lower face parts do "under-run" the test structure. Because of the zx-symmetry of the ACEA headform, testing under a lateral vector offset needs only to be performed in the vertical tube position. The influence of gravity during the short free flight distance can be neglected.

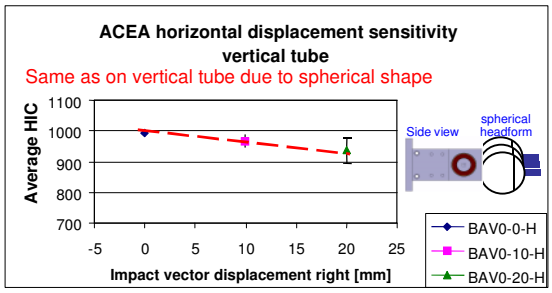


Figure 16. Sensitivity on impact vector displacement, ACEA headform (horizontal tube).

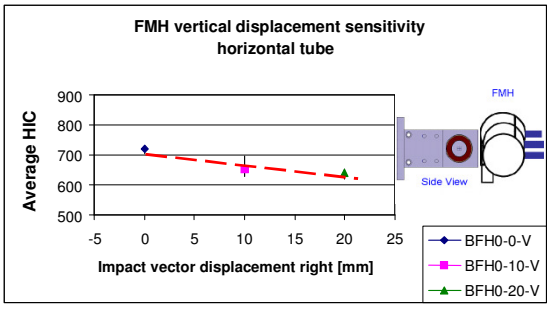


Figure 17. Sensitivity on impact vector displacement, FMH (horizontal tube).

Table 2 gives an overview of the HIC results for the two different impactor types FMH and ACEA.

tube orient.	FMH			ACEA		
	offset [mm]	average HIC	HIC decrease [%]	offset [mm]	average HIC	HIC decrease [%]
vertical	0	926		0	992	
	10	912	1.6	10	967	2.5
	20	858	7.4	20	938	5.4
horizontal	0	719		-	-	-
	10	652	9.4	-	-	-
	20	639	11.2	-	-	-

Table 2. Results of physical rig tests (impact vector offset)

The variation of results within the test repetitions is shown in figure 18 and 19. For both impactor types the reliability of the results is decreasing due to an increase of impact vector offset under vertical tube orientation. Up to 10 mm deviation the variation is in an acceptable range, minor to 5 %. At 20 mm offset the ACEA impactor shows a nearly 50 % higher variation in the HIC-values than the FMH.

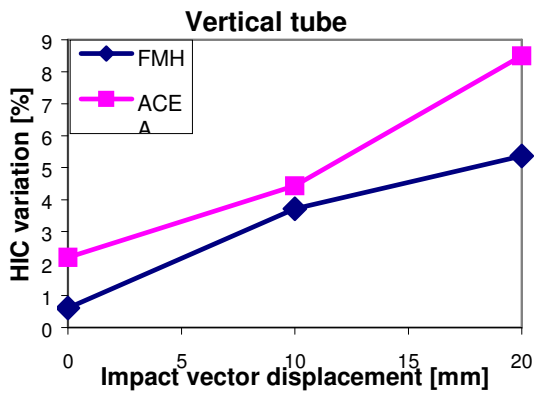


Figure 18. Comparison of test variation for impact displacement deviations (vertical).

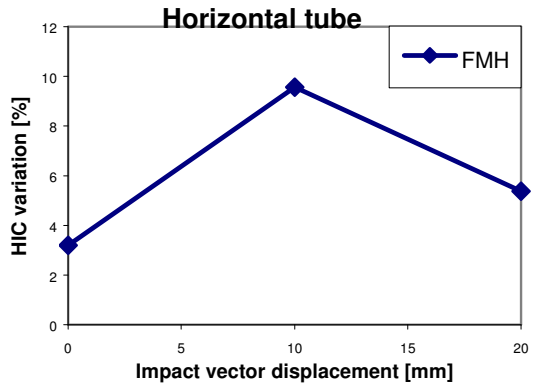


Figure 19. Comparison of test variation for impact displacement deviations (horizontal).

COMPARISON OF IMPACTORS OF SIMILAR DESIGN

Additional tests were performed to check the reproducibility depending on the differences in design between impactors. Therefore two ACEA and FMH impactors have been borrowed from TÜV to be compared with the BASt impactors. In addition to this the skins have been exchanged between the BASt and TÜV impactors. Some of the previous mentioned test conditions were used for the impactor comparison.

An optical comparison between the three FMH, regarding outer geometry and surface condition, shows significant geometrical differences (see figure 20). While the nose of the BASt FMH is completely removed and the lips stick out, the FMH models from the TÜV are designed with a visible nasal-bone reaching down to the lips. The differences in the FMH skins probably are the result of different manufacturers (Denton and FTSS). A definition of the nose shape is quite dificult. The ACEA spherical headform is easier to define. Because of the head rotation over its face, those differences in nose design could cause deviations in the kinematic behaviour of the FMH headform impactor.

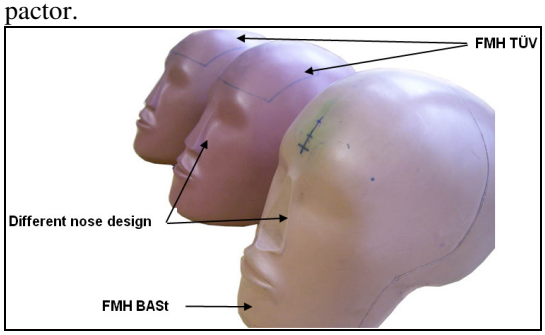


Figure 20. Different designs of FMH impactors.

The analysis of the high-speed videos show "fluttering" of the TÜV FMH skin on the aluminium body and a marginal relative displacement of the skin in the direct contact area on the forehead. The skin of the FMH impactor from BASt is tightly fixed to the inner skull and does not slide under impact. All three FMH impactors do have the same mass of 4.5 kg.

Figure 21 shows clear differences in HIC results between the compared FMH impactors. The BASt FMH achieves about 14 % higher HIC-values in average than the TÜV FMH impactors. The exchange of the skins demonstrates that the BASt skin causes higher HIC-values. The inner aluminium skulls of all three impactors are identical in mass and geometry. Both TÜV impactors achieve nearly identical results. The results support the assumption that the different skin design has an influence on the results. But also the inner skulls do vary as they are not completely identical. On the inside balance weights are attached to compensate the differences of the moment of inertia Using the BASt skin with the TÜV 1 skull also reduced the HIC. As a result, skins and skulls cause variations in HIC results for the FMH. Calibrations have been performed after changing the skin.
The variation within the respective test repetitions does not exceed 5 %.

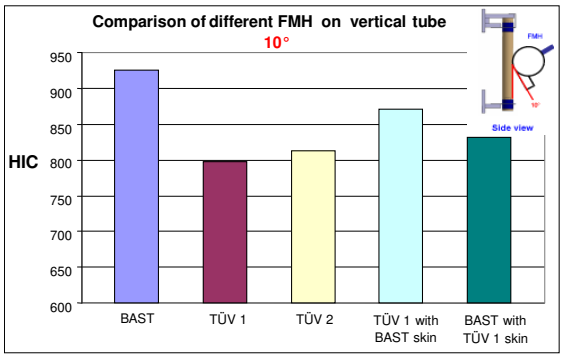


Figure 21. Comparison of different FMH impactors.

The same tendency could be observed by horizontal displacement of the both FMH types (with and without nose) at 10mm and 20mm displacement.

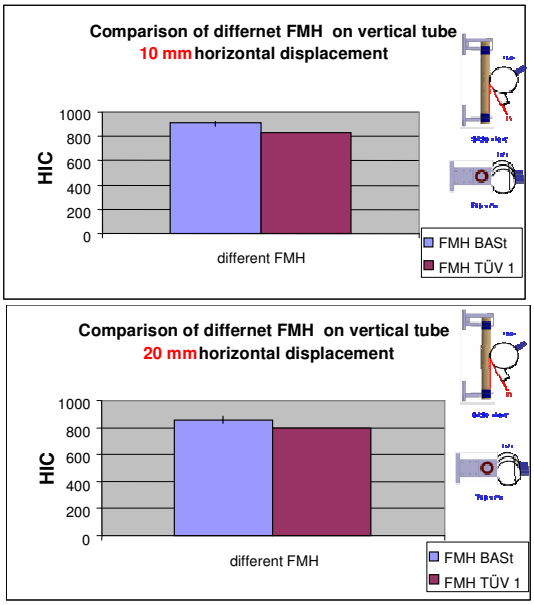


Figure 22. Comparison of different FMH impactors with impact displacement.

The comparison of the ACEA headforms (see figure 23) indicates lower differences between the impactors. The average deviation between BASt and TÜV HIC is below 3 %; the variation within the respective test repetitions is about 4%, that means higher than the deviation between the headforms itself. Furthermore the ACEA impactors do not show any differences in geometry, surface design or mass.

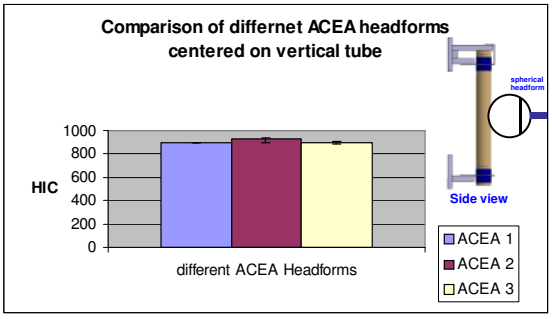


Figure 23. Comparison of different ACEA impactors.

SENSITIVITY ON HEADFORM ORIENTATION

The current WG13 interior headform test procedure includes a 90° roll of the FMH, in case the gap between chin and structure is less than 10°. It was of interest to investigate differences in HIC result, when testing identical targets with the same impactor with this two possible head orientations. A rotation up to 90°, leads to a HIC-value decrease of

about 30% for the FMH. The analysis of the high-speed videos shows higher head rotation than in vertical tube position, caused by the missing secondary contact of the chin. Beside the 90° roll of the impactor, this would also mean a 30% difference, testing identical target structures on a vertical pillar or horizontal side roof rail.
Because of the over-all symmetry of the ACEA headform, testing 90° rolled has no influence on the HIC.

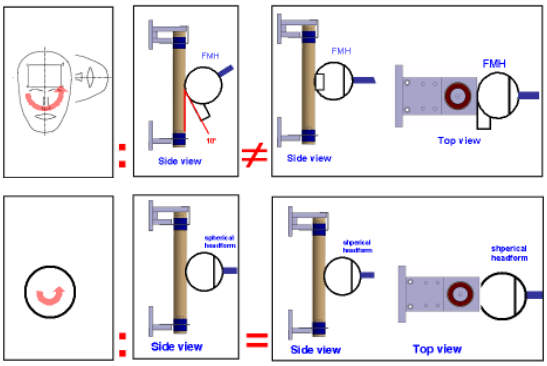


Figure 24. Influence of head roll.

CONCLUSION

In this study two different headform impactors have been compared, regarding their sensitivities to deviations of defined test parameters. A test rig and a specific test sample, representing a typical car structure (e.g. B-pillar), were developed and produced. Extensive test runs were performed at the test facility of BASt.
A simplified summary of the sensitivities of the different headform impactors towards a variation of impact parameters are shown in Table 3.

	FMH	ACEA Headform
repeatability	+	o
head orientation (90°roll)	--	++
sensitivity in impact angle	+	+
sensitivity on target accuracy	o	o
use of different headforms of the same type	o	+

++ very good, + good, o acceptable. – insufficient, -- very insufficient

Table 3. Comparison of impactor sensitivities

At vertical tube orientation the FMH and the ACEA headform impactor show similar results. An exact impactor alignment regarding the head pitch is very important. Both headforms are more sensitive to deviations of the head impact angle than to lateral offset of the impact vector from the mid-axis. The variation of the ACEA impactor rig test results is higher than the variation of the FMH.
At horizontal tube orientation the FMH impactor shows lower variation and sensitivities to the test parameters than the ACEA headform. The rig test results of the ACEA headform impactor show a high variation and sensitivity to impact angle deviations.

The FMH impactor is sensitive to the orientation of the tube structure. In the initial alignment position, the HIC results differ about 30 % between vertically and horizontally orientated tubes. This is unacceptable. In contrast, the spherical ACEA headform impactor shows no sensitivity to this parameter and offers an easier handling during rig tests.

To achieve reproducible and comparable results for tests on real car structures precise first-contact point alignment has to be clearly defined.

The comparison of FMH impactors of same design shows differences in geometry and surface design. A different nose design of the FMH impactors influences the kinematic behaviour and the HIC results. The FMH impactors from the TÜV achieve 13 % lower HIC-values than the FMH impactor from BASt.

The ACEA headform impactors from TÜV achieve less than 3 % lower HIC-values than the ACEA impactor from BASt. This is less than the deviation using the same impactor. The geometry, surface design and mass of the compared ACEA headforms are identical.

REFERENCES

[1] Free Motion Headform Impactor for RADIOSS, IMPERIA GmbH, Aachen

[2]: Code of federal regulations, Title 49-Transport, §571.201, Occupant protection in interior impact

[3] ACEA Headform Impactor for RADIOSS, IMPERIA GmbH, Aachen

[4] Directive 2003/102/EC of the European Parliament and of the Council of 17.11.2003, relating to the protection of pedestrians and other vulnerable road users before and in the event of a collision with a motor vehicle and amending Council Directive 70/156/EEC

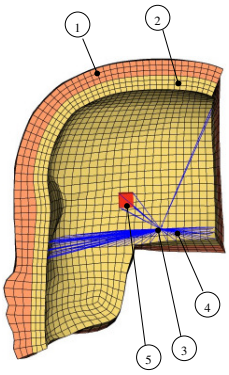
ANNEX A

DESCRIPTION OF THE IMAPCTORS

Characteristics of the FMH impactor - FMVSS201

The FMVSS 201 was introduced by the NHTSA (National Highway Traffic Safety Administration) in the US to enhance the safety standards for the protection of passengers regarding head impacts on interior structures. Since the year 2002 this regulation is applied to all vehicles up to 4.5 tons total mass.

The impactor is the head of the Hybrid 3 Dummy with its nose removed. This Free-Motion-Headform (FMH) impactor of 4.5 kg mass gets impacted on selected target points on the car interior surface, with a minimum free-flight distance of 25 millimetres and a speed of 24.1 km/h, the latter being the average velocity for the onset of severe injuries in a car accident. Typical target areas in the passenger compartment are the A- and B-pillars, the steering wheel, the dashboard and exposed parts like the belt fixing and handholds.



pos.	description
1	Part 1: Skin PVC-Rubber
2	Part 2: Aluminium Skull
3	Part 3: Rigid Body
4	Part 4: Added Balancing Mass
5	Part 5: Accelerometer

Figure 25. Characteristics of the FMH impactor [1].

The test procedure mandates that the calibrated forehead region of the FMH hits the target point first without contacting any other part outside of the specified impact zone.

The severity of head impacts is assessed by the HIC_d

$$HIC_d = 0.75446 \times HIC + 166.4$$

Figure 26. HIC_d formula, calculation for comparison with dummy values.

The HIC_d is a dummy-related value which diminishes high HIC values and considers the fact that the headform is detached from the neck of the Hybrid 3 dummy. The acceptance criterion is $HIC_d < 1000$.

Calibration Procedure FMH impactor

According to FMVSS 201 the free-motion headform impactor must be calibrated and verified. Therefore a free-fall drop test is described (see figure 27). The headform gets dropped from a height of 376mm +/- 1mm on a flat rigid steel plate. To avoid secondary contact of the chin a rotation of the impactor of 28° +/- 0.5° about the horizontal axis is required. The measured resulting acceleration must not exceed a value of 250g +/- 25g.

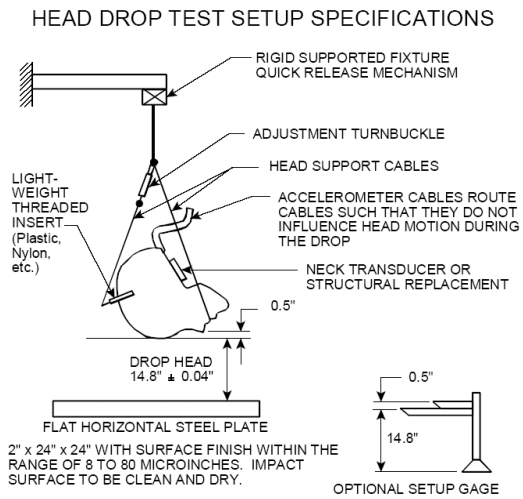
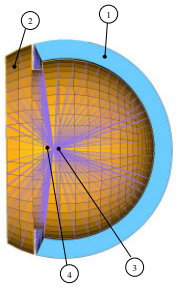


Figure 27. FMH head drop test setup specifications [2].

Characteristics of the ACEA impactor - EC-Directive 2003/102/EC

Since 2005 the new pedestrian safety legislation is effective as EC-Directive 2003/102/EC phase 1. Besides leg and hip impact tests, two types of free motion head impactors are impacted on the front end of passenger cars. These headforms are of spherical shape with 165 mm in diameter and correspond to the ACEA design. The child / small adult headform of 3.5 kg and the adult headform of 4.8 kg mass get impacted on selected target points within defined areas on the bonnet and windshield. An internal tri-axial acceleration sensor measures the corresponding acceleration-time function from which the Head Performance Criterion HPC (equal to HIC described under FMVSS 201) is computed.



pos.	description
1	Part 1: Skin PVC-Rubber
2	Part 2: Aluminium Skull
3	Part 3: Rigid Body
4	Part 4: Accelerometer

Figure 28. Characteristics of the ACEA head-form impactor [3].

Calibration Procedure ACEA impactor

The calibration of the ACEA spherical headform impactors is different to the FMH drop-test procedure. While the FMH impactor is calibrated only in a limited area on the forehead, the ACEA headform is calibrated in a wide area of the sphere surface.

As shown in the figure below, the headform is suspended on a wire with the rear face at an angle between 25° and 90° with the horizontal. A linear guided certification impactor of 1 kg mass is propelled horizontally at a velocity of 7 m/s into the stationary headform. The certification impactor must be positioned so that the centre of gravity of the headform impactor is located on the centre line of the certification impactor with a tolerance of five millimetres. The tests have to be performed on three different impact locations on the headform impactor. Previously used and/or damaged skins shall be tested in those specific areas.

The peak resultant acceleration measured by one tri-axial accelerometer in the headform shall not be less than 290 g and not more than 350 g. The resultant acceleration time curve shall be uni-modal.

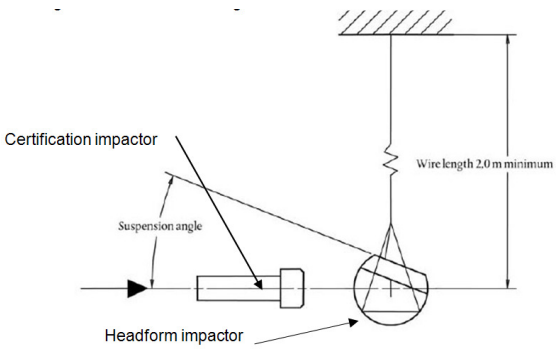


Figure 29. Calibration test setup for ACEA spherical headform [4].

ANNEX B

DEFINITION OF TEST SET UP

The adequate design of the test sample support has an important influence on the informational value of the results. On the one hand a fixed clamping on both sides of the tube represents a nearly realistic connection of a vehicle pillar at the roof rail and rocker-rail. On the other hand stress-free deformation is not warranted. So the complete restraints and its fixing to the test rig could deform. Resulting vibrations can influence the quality of measurement.
Figure 30 shows a mechanical replacement system including a simply supported bearing of the test-tube according to a three point bending test. The tube can bend freely in the direction of impact.

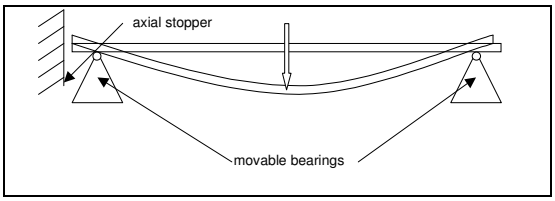


Figure 30. Substitute mechanical system for rig testing set-up.

Construction of test object and test rig
The headform impactors get impacted on a tube-assembly of 1000 mm length. The external overall diameter is 110 mm, the inner diameter measures 62.6 mm. The structure as shown in figure 2 consists of a thin walled steel tube with a gauge of 1.2 mm, an energy absorbing PUR-foam of 20 mm thickness and a PVC tube of 2.7 mm thickness.
This assembly should represent a typical car body structure, like a B-pillar which consists of an inner steel sheet, damping material and interior covering. The rotation-symmetric setup determines a specific mounting position in the test rig. To avoid rotation of the different material layers amongst each other, a light press fit is applied.

Figure 31 shows the assembled test rig with aligned ACEA headform. To avoid deformation and vibrations in the test rig the tube assembly gets supported according to a three point bending test.

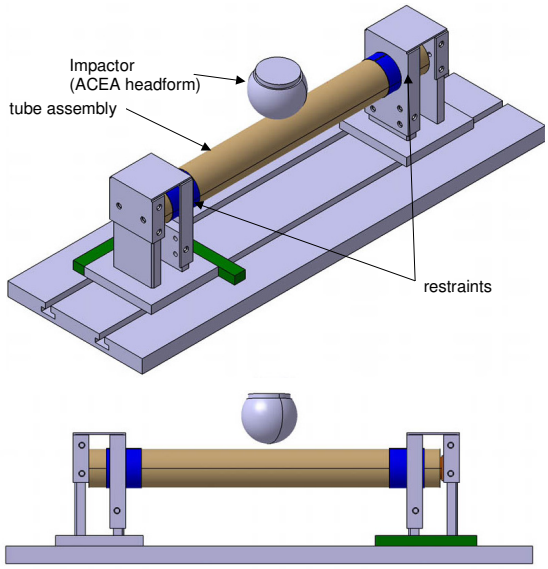


Figure 31. ISO and side-view of the complete rig testing set-up.

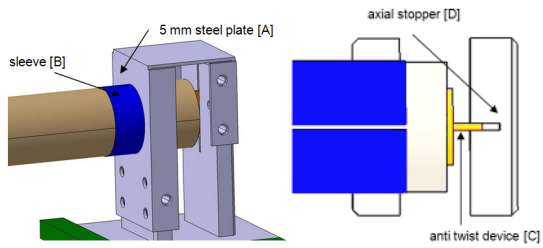


Figure 32. Tube clamping and anti-twist device.

On both sides of the restraints the tube assembly bears on a steel plate [A] of 5 mm thickness. The small overlap between sleeve [B] and steel plate in relation to the total tube length of one meter ensures a nearly freely jointed bearing.

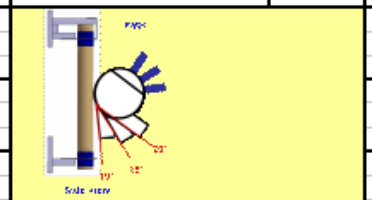
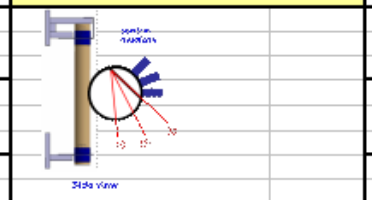
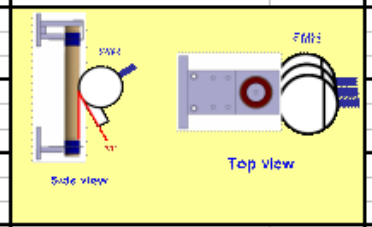
Test configurations with an impact vector vertical to the tube axis could cause twisting of the tube assembly. Therefore a so called anti twist device [C] is welded on one side of the steel tube as shown in figure 32, right side. This device fits in a groove which is milled in the axial stopper [D] of the restraint. The tube can still bend freely but rotation around its longitudinal axis is suppressed. The foam and outer PVC tubes are joined with a press fit.

To avoid stress concentration and carving of the steel plate in the outer PVC tube, two slotted, thin-walled steel sleeves are mounted on each side of the restraints.

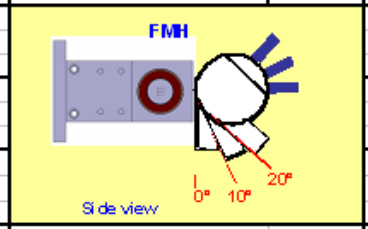
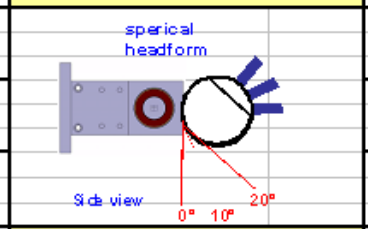
ANNEX C

Test Matrix Basic Tests at BASt

Comparison BASt FMH vs. BASt ACEA headform

No.	Test	Headform	tube orientation	Impact angle [°]	Impact vector displ. [mm]	Impact vector displ. orientation	V [m/s]	Acceleration [g] max	HPC	HPCd	average HPC	maximum deviation HPC	difference per step HPC			HPC from one setup to the other [%]	Scattering [%] refered to max. value	Difference ACEA to FMH	Difference ACEA to FMH average
1	BFV10-0-1	FMH	vertical	10	0	-	6,57	250,6	922,5	862,4	926,3							8,2	
2	BFV10-0-2	FMH	vertical	10	0	-	6,65	143,6	928,1	866,6	1,9	5,7					0,6		
3	BFV10-0-3	FMH	vertical	10	0	-	6,70	147,7	928,2	866,7	3,8		-105,1						
4	BFV15-0-1	FMH	vertical	15	0	-	6,60	132,1	791,9	763,9	821,1					11,4		9,6	9,9
5	BFV15-0-2	FMH	vertical	15	0	-	6,69	136,8	831,7	793,9	18,7	47,9					5,7		
6	BFV15-0-3	FMH	vertical	15	0	-	6,63	139,2	839,8	800,0	29,2		-66,0						
7	BFV20-0-1	FMH	vertical	20	0	-	6,63	129,7	760,2	739,9	755,1					18,5		11,7	
8	BFV20-0-2	FMH	vertical	20	0	-	6,72	129,0	763,6	742,5	8,5	22,1					2,9		
9	BFV20-0-3	FMH	vertical	20	0	-	6,73	130,7	741,5	725,8	13,6								
10	BAV10-0-1	ACEA	vertical	10	0	-	6,71	167,6	1023,7	938,7	1002,3								
11	BAV10-0-2	ACEA	vertical	10	0	-	6,69	158,6	961,1	891,5	21,4	62,6					6,1		
12	BAV10-0-3	ACEA	vertical	10	0	-	6,73	165,3	1022,0	937,5	41,2		-102,0						
13	BAV15-0-1	ACEA	vertical	15	0	-	6,72	152,6	866,8	820,4	900,3					10,2			
14	BAV15-0-2	ACEA	vertical	15	0	-	6,68	151,1	877,1	828,1	56,7	90,2					9,4		
15	BAV15-0-3	ACEA	vertical	15	0	-	6,73	156,8	957,0	888,4	33,5		-56,7						
16	BAV20-0-1	ACEA	vertical	20	0	-	6,71	151,5	841,2	801,1	843,6					15,8			
17	BAV20-0-2	ACEA	vertical	20	0	-	6,74	145,6	850,4	808,0	6,8	11,2					1,3		
18	BAV20-0-3	ACEA	vertical	20	0	-	6,75	155,1	839,2	799,5	4,4								
19	**BFV10-0-H-1**	FMH	vertical	10	0	right	6,57	250,6	922,5	862,4	926,3							7,0	
20	**BFV10-0-H-2**	FMH	vertical	10	0	right	6,65	143,6	928,1	866,6	1,9	5,7					0,6		
21	**BFV10-0-H-3**	FMH	vertical	10	0	right	6,70	147,7	928,2	866,7	3,8		-14,8						
22	BFV10-10-H-1	FMH	vertical	10	10	right	6,72	134,0	917,6	858,7	911,5					1,6		6,1	7,5
23	BFV10-10-H-2	FMH	vertical	10	10	right	6,71	135,2	925,6	864,7	14,1	34,4					3,7		
24	BFV10-10-H-3	FMH	vertical	10	10	right	6,73	135,2	891,2	838,8	20,3		-53,5						
25	BFV10-20-H-1	FMH	vertical	10	20	right	6,72	134,6	833,7	795,4	858,0					7,4		9,3	
26	BFV10-20-H-2	FMH	vertical	10	20	right	6,73	138,2	859,3	814,7	22,9	47,2					5,4		
27	BFV10-20-H-3	FMH	vertical	10	20	right	6,77	137,8	880,9	831,0	24,3		133,6						
28	BAV0-0-H-1	ACEA	vertical	0	0	right	6,67	173,1	1003,8	923,7	991,6								
29	BAV0-0-H-2	ACEA	vertical	0	0	right	6,71	167,7	989,1	912,6	12,2	22,0					2,2		
30	BAV0-0-H-4	ACEA	vertical	0	0	right	6,73	165,0	981,8	907,1	9,8		-24,8						
31	BAV0-10-H-1	ACEA	vertical	0	10	right	6,69	163,6	945,6	879,8	966,7					2,5			
32	BAV0-10-H-2	ACEA	vertical	0	10	right	6,72	163,2	965,2	894,6	22,7	43,8					4,4		
33	BAV0-10-H-3	ACEA	vertical	0	10	right	6,73	164,2	989,4	912,9	21,1		-29,2						
34	BAV0-20-H-1	ACEA	vertical	0	20	right	6,72	165,2	976,9	903,4	937,6					5,4			
35	BAV0-20-H-2	ACEA	vertical	0	20	right	6,73	158,2	893,9	840,8	39,3	83,0					8,5		
36	BAV0-20-H-4	ACEA	vertical	0	20	right	6,70	160,4	941,9	877,0	43,7								

Comparison BASt FMH vs. BASt ACEA headform

No.	Test	Headform	tube orientation	Impact angle [°]	Impact vector displ. [mm]	Impact vector displ. orientation	V [m/s]	Acceleration [g] max	HPC	HPCd	average HPC	maximum deviation HPC	difference per step HPC		HPC from one setup to the other [%]	Scattering [%] refered to max. value	Difference ACEA to FMH	Difference ACEA to FMH average
37	BFH0-0-1	FMH	horizontal	0	0	-	6,76	143,5	723,1	712,0	719,1							
38	BFH0-0-2	FMH	horizontal	0	0	-	6,69	143,2	728,8	716,3	9,7	23,3						
39	BFH0-0-3	FMH	horizontal	0	0	-	6,67	140,3	705,5	698,7	13,6		53,2					
37	BFH10-0-1	FMH	horizontal	10	0	-	6,73	137,4	649,3	656,3	666,0						25,2	20,5
38	BFH10-0-2	FMH	horizontal	10	0	-	6,72	132,5	638,1	647,8	44,5	72,4				10,2		
39	BFH10-0-3	FMH	horizontal	10	0	-	6,73	142,4	710,5	702,4	27,9		-89,0					
40	BFH20-0-1	FMH	horizontal	20	0	-	6,74	121,8	568,5	595,3	577,0				13,4		15,8	
41	BFH20-0-2	FMH	horizontal	20	0	-	6,69	120,1	579,9	603,9	5,6	14,1				2,4		
42	BFH20-0-3	FMH	horizontal	20	0	-	6,71	129,2	582,6	605,9	8,5							
43	**BAV0-0-H-1**	ACEA	vertical	0	0	-	6,67	173,1	1003,8	923,7	991,6							
44	**BAV0-0-H-2**	ACEA	vertical	0	0	-	6,71	167,7	989,1	912,6	12,2	22,0						
45	**BAV0-0-H-4**	ACEA	vertical	0	0	-	6,73	165,0	981,8	907,1	9,8		-157,5					
43	BAH10-0-1	ACEA	horizontal	10	0	-	6,69	147,9	790,3	762,6	834,0							
44	BAH10-0-2	ACEA	horizontal	10	0	-	6,67	152,3	825,5	789,2	52,3	96,0				10,8		
45	BAH10-0-3	ACEA	horizontal	10	0	-	6,67	151,6	886,3	835,1	43,7		166,1					
46	BAH20-0-1	ACEA	horizontal	20	0	-	6,66	122,2	598,7	618,1	667,9				19,9			
47	BAH20-0-2	ACEA	horizontal	20	0	-	6,76	131,0	646,8	654,4	90,3	159,5				21,0		
48	BAH20-0-3	ACEA	horizontal	20	0	-	6,77	142,9	758,2	738,4	69,2							
49	BFH0-0-V-1	FMH	horizontal	0	0	down	6,76	143,5	723,1	712,0	719,1						37,9	
50	BFH0-0-V-2	FMH	horizontal	0	0	down	6,69	143,2	728,8	716,3	9,7	23,3				3,2		
51	BFH0-0-V-3	FMH	horizontal	0	0	down	6,67	140,3	705,5	698,7	13,6		67,6					
52	BFH0-10-V-1	FMH	horizontal	0	10	down	6,65	135,9	628,3	640,4	651,6				9,4		48,4	44,4
53	BFH0-10-V-2	FMH	horizontal	0	10	down	6,72	142,7	694,7	690,5	43,1	66,4				9,6		
54	BFH0-10-V-3	FMH	horizontal	0	10	down	6,68	133,8	631,7	643,0	23,3		12,9					
55	BFH0-20-V-1	FMH	horizontal	0	20	down	6,72	131,4	643,4	651,8	638,6				11,2		46,8	
56	BFH0-20-V-2	FMH	horizontal	0	20	down	6,68	134,9	653,8	659,7	15,2	35,1				5,4		
57	BFH0-20-V-3	FMH	horizontal	0	20	down	6,70	138,7	618,7	633,2	19,9							
58	BAV0-0-H-1	ACEA	vertical	0	0	right	6,67	173,1	1003,8	923,7	991,6							
59	BAV0-0-H-2	ACEA	vertical	0	0	right	6,71	167,7	989,1	912,6	12,2	22,0				2,2		
60	BAV0-0-H-4	ACEA	vertical	0	0	right	6,73	165,0	981,8	907,1	9,8		-24,8					
61	BAV0-10-H-1	ACEA	vertical	0	10	right	6,69	163,6	945,6	879,8	966,7				2,5			
62	BAV0-10-H-2	ACEA	vertical	0	10	right	6,72	163,2	965,2	894,6	22,7	43,8				4,4		
63	BAV0-10-H-3	ACEA	vertical	0	10	right	6,73	164,2	989,4	912,9	21,1		-29,2					
64	BAV0-20-H-1	ACEA	vertical	0	20	right	6,72	165,2	976,9	903,4	937,6				5,4			
65	BAV0-20-H-2	ACEA	vertical	0	20	right	6,73	158,2	893,9	840,8	39,3	83,0				8,5		
66	BAV0-20-H-4	ACEA	vertical	0	20	right	6,70	160,4	941,9	877,0	43,7							

Comparison vs. 3 different FMHs and vs. 3 different ACEA headforms

No.	Test	Headform	tube orientation	Impact angle [°]	Impact vector displ. [mm]	Impact vector displ. orientation	V [m/s]	Acceleration [g] max	HPC	HPCd	average HPC	maximum deviation HPC	difference between different impactors		HPC from one impactor to the other [%]	Scattering [%] refered to max. value
58	BFV10-0-1	FMH	vertical	10	0	-	6,57	250,6	922,5	862,4	926,3			BASt		
59	BFV10-0-2	FMH	vertical	10	0	-	6,65	143,6	928,1	866,6	1,9	5,7		BASt		0,6
60	BFV10-0-3	FMH	vertical	10	0	-	6,70	147,7	928,2	866,7	3,8			BASt		
61	BFV10-0-4	FMH	vertical	10	0	-	6,70	130,8	781,5	756,0	797,1		129,2	F1074 (TÜV)	13,9	
62	BFV10-0-5	FMH	vertical	10	0	-	6,70	129,9	808,4	776,3	11,3	26,9		F1074 (TÜV)		3,3
63	BFV10-0-6	FMH	vertical	10	0	-	6,69	123,7	801,4	771,0	15,6			F1074 (TÜV)		
64	BFV10-0-7	FMH	vertical	10	0	-	6,70	109,1	827,0	790,3	813,1		-16,0	F1076 (TÜV)	12,2	
65	BFV10-0-8	FMH	vertical	10	0	-	6,69	127,8	788,3	761,1	13,9	38,7		F1076 (TÜV)		4,7
66	BFV10-0-9	FMH	vertical	10	0	-	6,72	134,0	824,0	788,1	24,8			F1076 (TÜV)		
67	BFV10-0-10	FMH	vertical	10	0	-	6,74	128,6	870,2	822,9			-57,1	F1074 (TÜV) mit BF1 (Bast) Haut (02270066)	6,1	
68	BFV10-0-11	FMH	vertical	10	0	-	6,69	137,4	831,3	793,6			38,9	BF1 (Bast) mit F1074 (TÜV) Haut (1046)	10,3	
69	BFV10-10-H-1	FMH	vertical	10	10	right	6,72	134,0	917,6	858,7	911,5					
70	BFV10-10-H-2	FMH	vertical	10	10	right	6,71	135,2	925,6	864,7	14,1	34,4		BASt		3,7
71	BFV10-10-H-3	FMH	vertical	10	10	right	6,73	135,2	891,2	838,8	20,3		-53,5			
75	BFV10-10-H-4	FMH	vertical	10	10	-	6,74	127,3	831,7	793,9				F1074 (TÜV)	8,8	
72	BFV10-20-H-1	FMH	vertical	10	20	right	6,72	134,6	833,7	795,4	858,0					
73	BFV10-20-H-2	FMH	vertical	10	20	right	6,73	138,2	859,3	814,7	22,9	47,2		BASt		5,4
74	BFV10-20-H-3	FMH	vertical	10	20	right	6,77	137,8	880,9	831,0	24,3		-63,9			
76	BFV10-20-H-4	FMH	vertical	10	20	-	6,67	128,4	794,1	765,5				F1074 (TÜV)	7,4	
77	BFV20-0-1	FMH	vertical	20	0	-	6,63	129,7	760,2	739,9	755,1			BASt		
78	BFV20-0-2	FMH	vertical	20	0	-	6,72	129,0	763,6	742,5	8,5	22,1		BASt		2,9
79	BFV20-0-3	FMH	vertical	20	0	-	6,73	130,7	741,5	725,8	13,6		-755,1	BASt		
80	BFV20-0-4	FMH	vertical	20	0	-	6,66	123,7	637,8	647,6				F1074 (TÜV)	15,5	
81	BAV0-0-H-5	ACEA	vertical	0	0	-	6,65	156,2	932,9	870,2	922,9			F1093 (TÜV)		
82	BAV0-0-H-6	ACEA	vertical	0	0	-	6,70	151,4	898,4	844,2	14,4	38,9		F1093 (TÜV)		4,2
83	BAV0-0-H-7	ACEA	vertical	0	0	-	6,66	149,5	937,3	873,6	24,5			F1093 (TÜV)		
84	BAV0-0-H-8	ACEA	vertical	0	0	-	6,73	156,6	907,7	851,2	898,7			F1094 (TÜV)	2,6	
85	BAV0-0-H-9	ACEA	vertical	0	0	-	6,66	152,0	888,2	836,5	9,0	19,5		F1094 (TÜV)		2,1
86	BAV0-0-H-10	ACEA	vertical	0	0	-	6,65	151,2	900,2	845,6	10,5			F1094 (TÜV)		
87	BAV0-0-H-11	ACEA	vertical	0	0	-	6,66	152,5	900,4	845,7				BASt	-0,2	