A NEW GENERIC FRONTAL OCCUPANT SLED TEST SET-UP DEVELOPED WITHIN THE EU-PROJECT SENIORS

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ABSTRACT

One main objective of the EU-Project SENIORS is to provide improved methods to assess thoracic injury risk to elderly occupants. In contribution to this task paired simulations with a THOR dummy model and human body model will be used to develop improved thoracic injury risk functions. The simulation results can provide data for injury criteria development in chest loading conditions that are underrepresented in PMHS test data sets that currently proposed risk functions are based on. To support this approach a new simplified generic but representative sled test fixture and CAE model for testing and simulation were developed. The parameter definition and evaluation of this sled test fixture and model is presented in this paper.

The justification and definition of requirements for this test set-up was based on experience from earlier studies. Simple test fixtures like the gold standard sled fixture are easy to build and also to model in CAE, but provide too severe belt-only loading. On the other hand a vehicle buck including production components like airbag and seat is more representative, but difficult to model and to be replicated at a different laboratory. Furthermore some components might not be available for physical tests at later stage. The basis of the SENIORS generic sled test set-up is the gold standard fixture with a cable seat back and foot rest. No knee restraint was used. The seat pan design was modified including a seat ramp. The three-point belt system had a generic adjustable load limiter. A pre-inflated driver airbag assembly was developed for the test fixture.

Results of THOR test and simulations in different configurations will be presented. The configurations include different deceleration pulses. Further parameter variations are related to the restraint system including belt geometry and load limiter levels. Additionally different settings of the generic airbag were evaluated.

The test set-up was evaluated and optimized in tests with the THOR-M dummy in different test configurations. Belt restraint parameters like D-ring position and load limiter setting were modified to provide moderate chest loading to the occupant. This resulted in dummy readings more representative of the

loading in a contemporary vehicle than most available PMHS sled tests reported in the literature. However, to achieve a loading configuration that exposes the occupant to even less severe loading comparable to modern vehicle restraints it might be necessary to further modify the test set-up.

The new generic sled test set-up and a corresponding CAE model were developed and applied in tests and simulations with THOR. Within the SENIORS project with this test set-up also volunteer and PMHS as well as HBM simulations are performed, which will be reported in other publications. The test environment can contribute in future studies to the assessment of existing and new frontal impact dummies as well as dummy improvements and related instrumentation. The test set-up and model could also serve as a new standard test environment for PMHS and volunteer tests as well as HBM simulations.

INTRODCUTION

Accident data analysis has shown that elderly car occupants are at high injury risk for chest injury even in frontal car crashes with low or moderate impact severity (Carroll et al. 2010). To address this one major aim of the EC funded SENIORS project is to contribute to the improvement and further development of frontal impact chest injury criteria and injury risk functions for the THOR dummy. The focus is the improvement of the risk function in the low severity range to enable better protection of older car occupants.

The traditional approach to develop dummy based injury criteria and risk functions is to perform paired tests with dummies and post mortem human subjects (PMHS). The possible criteria based on dummy measurement are then compared to the injury level observed in the PMHS tests. A literature study within the SENIORS project has shown that most of the available PMHS data involved a single loading condition, i.e. concentrated loading to the thorax from a diagonal seat-belt, which is not representative of the loading from a modern restraint system with seat-belt, airbag and load limiter (Hynd et al. 2016). In addition, most of the PMHS data involves either no injury or a very high level of injury. Test condition with intermediate injury levels – which are more likely with modern restraint systems and which may still have significant implications for older occupants are missing.

To overcome these limitations of the available PMHS data within the SENIORS project a new approach will be applied by performing paired simulations with a THOR dummy model and human body model. A test and simulation plan was defined which includes loading conditions which are underrepresented in available PMHS test data sets that currently proposed risk functions are based on. Furthermore additional new PMHS tests were performed within the SENIORS project for human model validation and to add PMHS test data, which shows the desired moderate loading condition.

To define a frontal impact sled set-up the idea of a generic but still representative test fixture was developed. The reason for this was based on experience from work on injury criteria in previous projects like THORAX (Lemmen et al. 2013; Davidsson et al. 2014). Sled test data representative of contemporary restraint systems including a full vehicle buck with production vehicle seat and airbag shows a representative loading to the occupant. However, it is difficult to reproduce the tests later with a dummy. The components might not be available anymore. Also for a simulation approach it might be difficult to develop and validate a model of restraint parts due to intellectual property right and patent issues.

Due to this the idea of a sled test set-up only including well defined simple generic components was developed. In the literature some sled test data mainly with generic set-ups was available (Shaw et al. 2009; Yoganandan et al. 2012). However, no distributed loading was included and the injury severity was too high.

Based on these observations, requirements for a new generic test set-up for frontal occupant testing and simulation were defined. The test fixture should be as generic and simple as possible to make sure it is possible to re-build it also by other researchers at any time in the future. Furthermore it should not involve any production components to make sure the components are available in the future to repeat the test and the components can be easily modeled in a CAE model.

On the other hand the loading to the occupant should be as representative for a contemporary restraint system as possible. This means the distributed airbag loading should be included, load limitation of the shoulder belt should be possible and a representative occupant to seat interaction is desired.

Within the SENIORS project this new generic sled test fixture will be used for the paired simulations approach and to conduct new PMHS and volunteer tests. However, further application of such a generic test set-up will be possible. For example for the R&R (repeatability and reproducibility) and sensitivity studies of new or updated frontal dummy studies in a robust, repeatable and representative loading environment. Furthermore it can be used to evaluate, if dummy updates are performance relevant.

To support the injury criteria work within the SENIORS project the new simplified generic was developed and restraint parameters were tuned to provide a moderate loading to the occupant. This paper will describe the development and parameter tuning of the test fixture in THOR dummy tests and the validation of the corresponding CAE model.

METHODS

The basis of the SENIORS generic sled test set-up is the gold standard fixture (Shaw et al. 2009) with a cable seat back and foot rest. Compared to the gold standard test set-up no knee restraint was used and the seat plate was modified. The seat pan design was modified including a seat ramp. Furthermore the test rig consisted of a three-point belt system with a generic adjustable load limiter and a pre-inflated driver airbag specifically developed for this purpose. Figure 1 shows the test set-up with the THOR-50M dummy. The components will be described in detail.

Figure 1. Set-up of sled tests with THOR-50M

Belt system

A three-point belt system was defined with adjustable anchor points to allow investigations of the effect of different belt geometries on the chest deflection pattern and injury risk. At the upper shoulder belt anchor point a steel D-ring without any plastic cover was used, which did not need to be exchanged between the tests (Figure 2). For further simplification and improved repeatability instead of a production buckle a generic buckle was implemented including a uni-axial load cell to measure the sum force of lap and shoulder belt in a reliable way (Figure 3). The only production parts of the belt system that had to be replaced between tests were the belt webbing (6% elongation, 27 kN minimum tensile strength) and the buckle tongue (Figure 3).

To achieve representative but still repeatable limitation of the shoulder belt load a generic load limiter was integrated into the test rig (Figure 4 and 5). This generic load limiting device was developed by the Center for Applied Biomechanics at the University of Virginia. It was already used in PMHS tests with the gold standard test fixture (Shaw et al. 2009). The test results with the load limiter in the gold standard fixture and a detailed description of the device are not published yet. For the SENIORS project this generic load limiter was rebuilt by University of Virginia and provided to the SENIORS project.

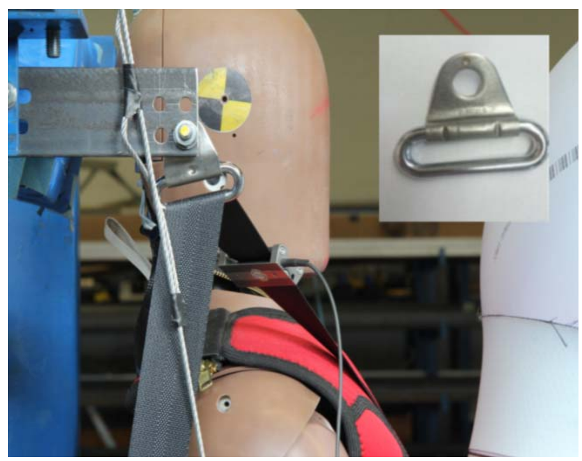

Figure 2. D-ring

Figure 3. Generic buckle with uni-axial load cell

Figure 4. Generic seat belt load limiter

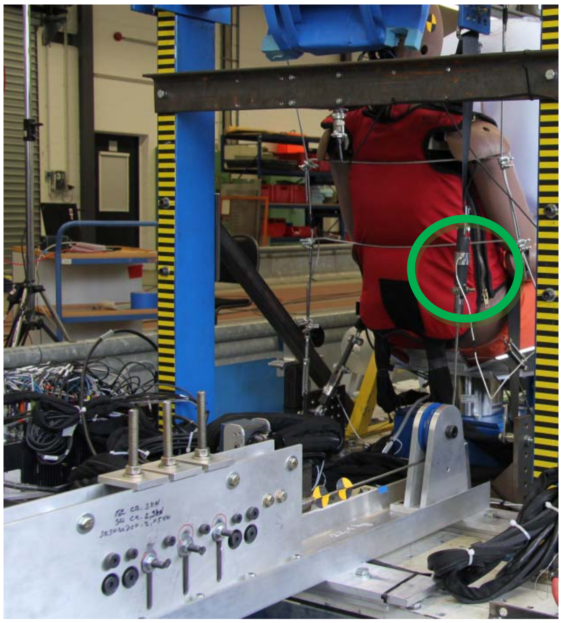

Figure 5. Generic belt load limiter in the SENIORS test set-up with uni-axial load cell between load limiter belt to measure B1 belt load

Seat pan

In the gold standard test fixture the pelvis of the occupant is restraint by a knee block. To enable an interaction between pelvis and the seat pan which is more representative of a real vehicle seat, it was decided not to use any knee support in the SENIORS test fixture. Furthermore a modified rigid seat design was used. The seat design was developed in an earlier project funded by SAFER and is referred to as "SAFER seat" (see Figure 6). The design specifications of the seat were defined by comparative HMB simulations to limit the x- and y-displacement of the occupant pelvis similar to a real vehicle seat. Further details can be found in the publication by Pipkorn et al. (2016). To measure the loads between occupant and seat a 6-axis load cell was used (Figure 7).

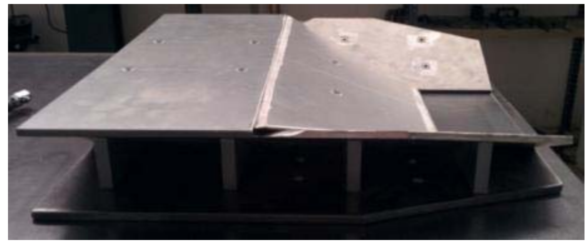

Figure 6. SAFER seat (Pipkorn et al. 2016)

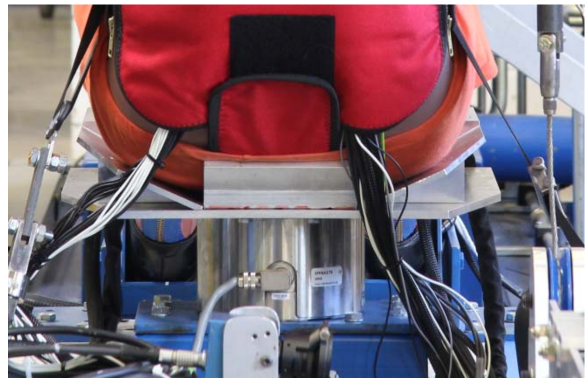

Figure 7. 6-axial load cell between seat and sled platform

Generic driver airbag

To enable distributed airbag loading to the occupant and at the same time not include an airbag with production components like gas generator which might not be available to repeat the tests in the future, it was decided to develop a generic statically pre-inflated driver airbag (Figure 8). The generic airbag was pre-inflated at constant pressure.

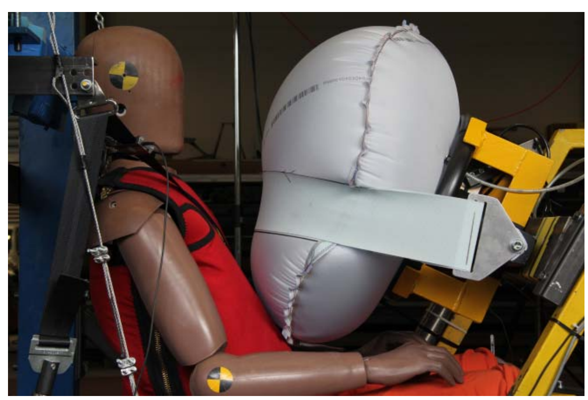

Figure 8. Generic driver airbag in the SENIORS test set-up

The airbag was evaluated in several component tests (Figure 9).
The airbag parameters which can be varied are:

- Initial pressure
- Size and shape by varying the length and position of the external strap
- Venting size
- Venting trig time

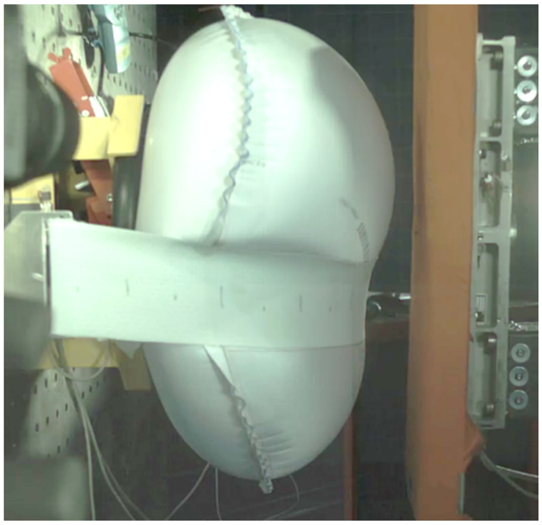

Figure 9. Strapped generic driver airbag module during impactor test.

The generic module was designed to be airtight so the initial pressure could be sustained. The ventilation was designed with a possible maximum area of 8700 mm². The adjustment of the ventilation area was made with a controllable airtight lid. This could be put closer or further away from the module house (Figure 10.

Figure 10. Ventilation mechanism, steering wheel support and external strap.

The lid was opened via a pneumatic cylinder. Timing of the opening could be controlled by an electric circuit. The fabric in the airbag is not fully airtight so there has to be a constant pressure supply. Also a control device to obtain correct pressure for testing is needed.
The external strap made it possible to reach the desired shape of a standard airbag. Furthermore the external strap minimised the risk of leakage compared to an internal strap. The strap also reduced the oscillation of the bag before occupant contact and ensured a more repeatable loading condition. To have a well defined support condition the design comprises a steering wheel.

Tuning of the restraint components

Several tests and simulations with THOR-M test in the generic test set-up were conducted in different configurations to adjust restraint and design parameters to the desired loading performance to the occupant. The target was to achieve reasonable occupant kinematics and a distributed chest loading which results in an low range of AIS3+ chest injury risk.

The investigated test configurations included two different deceleration pluses (25 km/h, peak 13 g and 35 km/h, peak acceleration 17 g) shown in Figure 11. The main parameter variations are related to the restraint system including belt geometry and load limiter levels. Furthermore different airbag shapes and design of the strap were investigated. A test matrix showing a part of the tests that were performed is shown in Table 1.

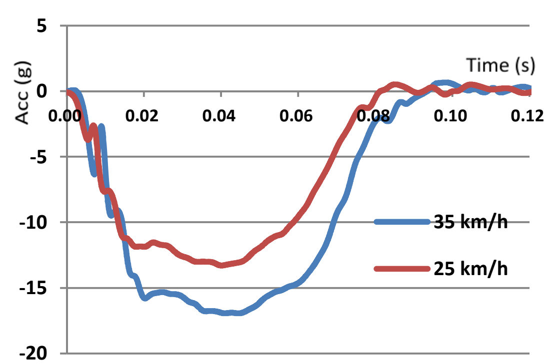

Figure 11. Deceleration pulses

Three different positions of the upper shoulder belt anchor point were investigated D1, D2 and D3 Figure 12 shows the differences in belt path on the chest for D-ring positions D1 versus D2. The three D-ring positions are provided in Table 1

Additionally to belt only tests without load limitation several settings of the generic load limiter were evaluated in sled tests. The settings medium and low in Table 1 refer to the same configurations of the load limiting device. However, the actual load limiting level at the shoulder belt depends on various factors like deceleration pulse and belt geometry.

Table 1.
Parameters of THOR Test and simulation matrix in the SENIORS generic test set-up (D-ring positions x,y,z in mm w.r.t. THOR H-point)

Test number	V (km/h)	D-ring	x	y	z	Airbag	Load limiter setting
S02	25	D1	469	244	649	No	No LL
S03	35	D1	469	244	649	No	No LL
S10	25	D1	469	244	649	No	medium
S11	35	D1	469	244	649	No	medium
S19	35	D2	422	303	739	No	medium
S20	25	D2	422	303	739	No	medium
S32	35	D3	271	256	726	Yes	medium
S34	35	Yes	271	256	726	Yes	low

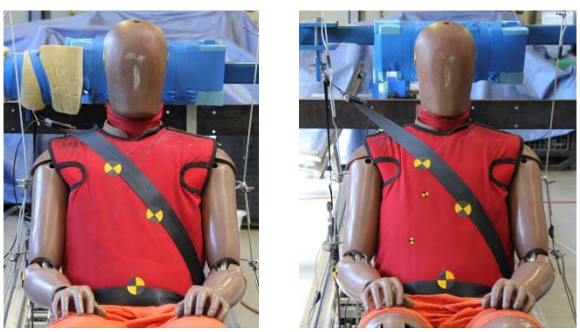

Figure 12. Variation of belt routing on chest due to different D-ring position (left: D1; right D2)

CAE Model of the generic test set-up

A Finite-Element-Simulation model of the generic driver airbag was developed (Figure 13).

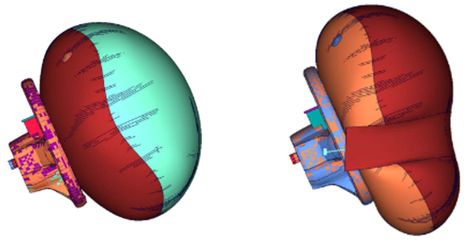

Figure 13. Generic driver airbag FE-model without strap and with outer strap.

The response of the generic airbag model was correlated by means of linear impactor tests in 7m/s using an impactor mass of 22kg (Figure 14).

Three test setups without external strap, with an initial pressure of 20kPa and with varying venting size were used in the correlation. The venting hole size was varied between 1740mm^2 (1), 2610mm^2 (2) and 2819 mm^2 (3).

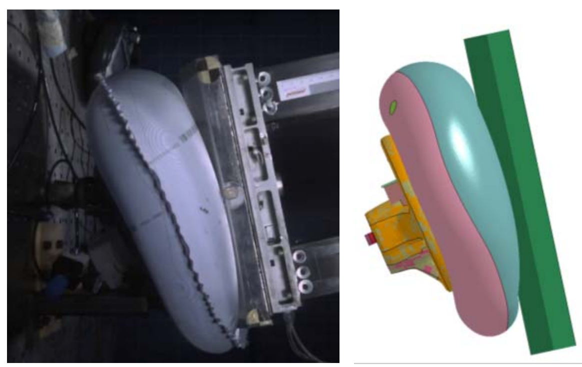

Figure 14. Impactor test and FE-model simulation at 70ms after trigger time.

FE-model impactor acceleration, impactor displacements and airbag pressure were compared to the corresponding responses from the mechanical tests.

The generic DAB model was integrated into the SENIORS generic sled model (Figure 15). The sled model includes all features of the test rig and was validated against all tests shown in Table 1.

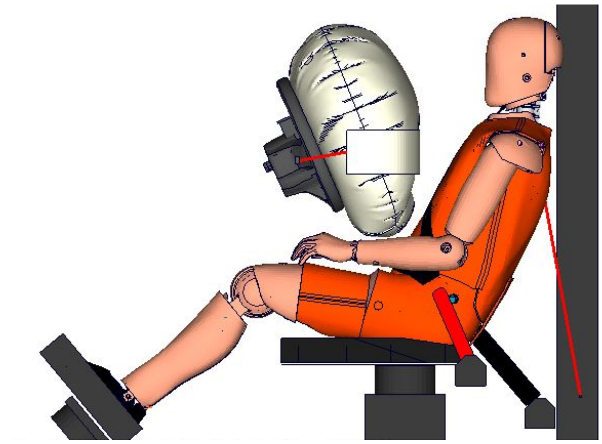

Figure 15. Simulation model of SENIORS generic test rig.

RESULTS

Experimental study

Table 2 shows the belt forces of the tests with the THOR-M according to the test matrix in Table 1.

Due to the design of the load limiter the same load limiter setting did not result in the same force level at the shoulder belt due to the dependency on other test parameters like pulse and belt geometry. Figure 14 shows the B3 shoulder belt load of the tests with load limiter.

Table 2.
Belt forces at the load limiter and at the upper shoulder belt B3.

Test Numbers	S02	S03	S10	S11	S19	S20	S32	S33	S34
Retractor B1 kN	3,8	5,4	1,9	2,2	2,4	1,9	2,6	2,8	1,9
Shoulder Belt B3 kN	4,2	6,1	2,8	3,4	3,7	3,3	3,8	4,5	2,8

In Figure 17 resultant IR-Tracc deflections in belt only tests with 25 km/h are shown. The change of D-ring position from D1 to D2 (47 mm forward, 59 outboard, 90 mm up) results in a reduction of all resultant IR-Tracc deflections.

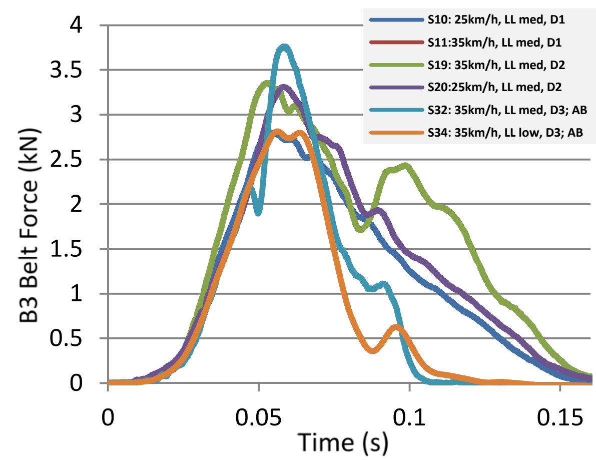

Figure 16. Shoulder belt load B3.

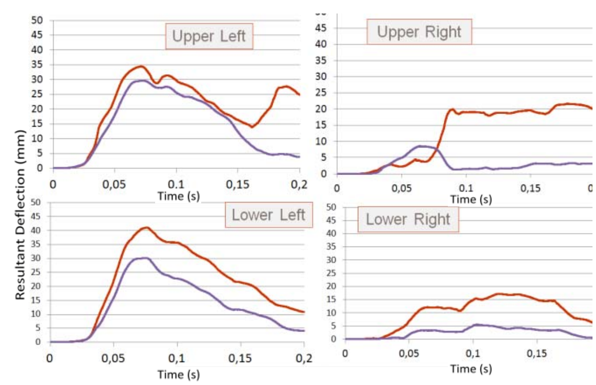

Figure 17. Comparison of resultant IR-Tracc deflections - belt only test with 25 km/h with D-ring positions D1 (red) versus D2 (blue).

Figure 18 shows the resultant IR-Tracc deflections in tests with airbag at 35 km/h and D-ring position D3. The chest deflections indicate a more distributed loading to the chest which might be due to the airbag and also due to the modified belt geometry. Furthermore the reduction of load limiter level clearly shows a reduction in peak deflection. Table 3 summarizes the IR-Tracc peak deflections in all tests. In Table 4 the injury criteria PCA and R_{max} and the AIS3+ injury risk for a 45 and 65 year old occupant are calculated according to Saunders et al. (2015).

Figure 18. Comparison of resultant IR-Tracc deflections - test with airbag 35 km/h at different load limiter settings; blue LL medium; red LL low).

Table 3.
IR-Tracc Resultant Peak Deflections

Test number	Test Condition	Upper Left	Upper Right	Lower Left	Lower Right
S02	25km/h, no LL, D1	47	23	48	22
S03	35km/h, no LL, D1	59	26	59	24
S10	25km/h, LL med, D1	34	20	41	17
S11	35km/h, LL med, D1	40	31	49	16
S19	35km/h, LL med, D2	41	25	48	15
S20	25km/h, LL med, D2	30	9	30	6
S32	35km/h, LL med, D3; AB	36	37	43	19
S34	35km/h, LL low, D3; AB	32	31	38	9

Table 4.
Injury Criteria and Risk: R_{max} and PCA

Test number	Rmax	AIS3+ (45yo)	AIS3+ (65yo)	PCA	AIS3+ (45yo)	AIS3+ (65yo)
S02	47	42%	81%	7,74	69%	98%
S03	59	82%	100%	9,26	93%	100%
S10	41	24%	57%	6,09	33%	73%
S11	49	48%	87%	7,18	57%	94%
S19	48	44%	84%	6,93	51%	90%
S20	30	5%	16%	4,62	11%	32%
S32	43	28%	64%	6,18	35%	75%
S34	38	17%	43%	5,01	16%	42%

Based on the PCA criterion the AIS3+ injury was reduced from 75% to 42% by reduction of the load limiter level in the test with airbag and belt geometry D3. The test condition S34 with a (based on PCA) estimated AIS3+ injury risk of 16% for a 45 year old occupant or 42% for a 65 year old was proposed as final configuration for further investigation in human model simulations and PMHS tests.

Computational study

Additionally to the hardware implementation of the generic test rig the simulation model of the final test set-up was developed and validated according to the test and simulation matrix in Table 1.

Figure 19 shows the results of the airbag validation based on component tests. Compared to the mechanical tests, the generic DAB model predicts slightly stiffer response for venting size 1 (1740 mm^2) and slightly softer response for venting sizes 2 and 3.

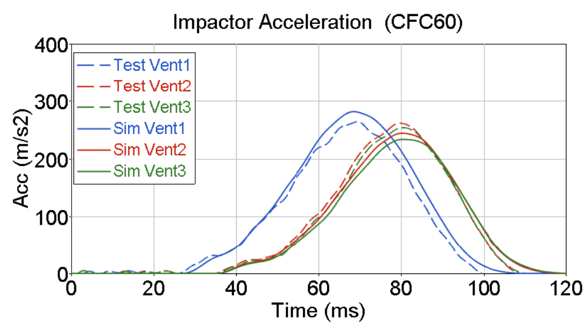

Figure 19. Impactor accelerations for three venting sizes (mechanical tests and FE-model).

To simulate the sled tests the Humanetics THOR dummy model V1.3 was used. The dummy model was positioned in the sled according to 3D-coordiateds measured during the positioning of the dummy in the tests (Figure 20).

During the validation process friction between belt and D-ring was adjusted. Furthermore the seat was modeled deformable to achieve of better correlation pelvis acceleration signals. Finally the relevant dummy signal in simulation and test showed a reasonable correlation. Also belt and seat forces showed good agreement. A qualitative comparison of occupant kinematics between test and simulations also showed good correlation (see Figure 21). The model can be used for further application within the SENIORS project for the paired dummy and human body model simulations.

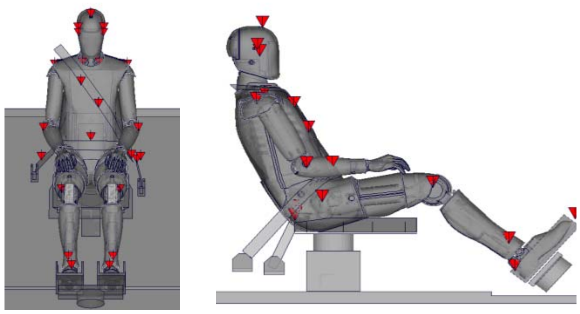

Figure 20. Positing of the dummy model according to 3D targets.

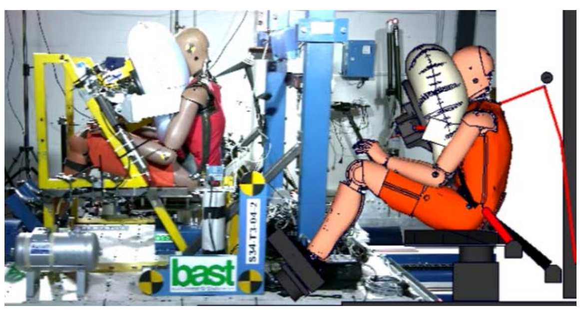

Figure 21. Comparison of dummy kinematics in experiment versus simulation - Test condition S34 (35km/h, airbag, low load limiter level, D-ring position D3)

DISCUSSION AND LIMITATIONS

Evaluation of the test set-up with THOR-M in different test configurations resulted in dummy readings more representative of the loading in a contemporary vehicle than most available PMHS tests. The finally proposed parameter configuration still shows a predicted injury risk higher than the desired moderate loading. A reason might be that the test set-up does not include a pretensioner or a knee restraint which are restraint components available in most contemporary vehicles. It was decided not to use a pretensioner in this generic test rig to keep it as simple as possible without using production components.

Also a knee restraint should not be included, because a knee block like used in the gold standard would not be representative of a loading condition in a typical contemporary vehicle. An impact surface representing a knee airbag would not be repeatable and reproducible in the future, if some kind of foam or honey comb material would be used. These decisions also reflect the need for reliable numerical modelling of this environment in particular.

To achieve the desired loading with moderate severity chest loading in the future, it might be necessary to either develop generic restraint components like pretensioner or knee restraint for implementation in this generic test set-up. Another option could be to modify the load limiter to be able to further reduce the load limiter level.

Furthermore one general limitation might be the currently discussed THOR dummy injury criteria and risk curves which are developed based on a limited data set. Due to this it could be possible that the applied criteria and risk functions are not correctly predicting the risk for the loading conditions considered in this study and thus might be misleading. This could be answered in PMHS studies this tests environment under equal loading conditions or estimated in paired human body model simulations, which are planned to be carried out within the SENIORS project.

CONCLUSIONS

Within the SENIORS project a generic sled test set-up was developed to support the activities focused on car occupant injury risk. The design status of the test rig and the simulation model will be further optimized in tests and simulations within the project.

The use of generic components makes sure the tests can be repeated in future if needed to further develop and to evaluate new injury criteria. The test set-up can also be used in tests with updated dummies or new or dummy instrumentation as well as for further PMHS or volunteer tests in order to extend the existing data sets.

The generic components have shown to be easier implemented in a simulation sled model without major validation or patent issues. The generic test set-up can be used for further applications such as the new frontal dummy repeatability and reproducibility evaluation, or dummy sensitivity studies in a robust, repeatable and representative loading environment. Another possible application of this generic test rig is to evaluate if dummy updates are performance relevant.

The final specifications and proposed parameters of the sled set-up are well documented and will be made available for further use within subsequent project tasks as well as by interested stakeholders outside of the project.

The generic test rig will be further used within the SENIORS project in tests with the THOR dummy and will be used in PMHS and volunteer tests. The numerical representation of the test rig will be applied in HBM simulations which will be reported in further publications.

The test set-up and model could also serve as a new harmonized standard test environment for PMHS and volunteer tests as well as numerical human body models. In this test set-up it would be possible to compare and assess biofidelity of kinematics and impact response between the different physical and virtual surrogates in a standardized representative loading environment.

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