Validation of 3yrs and 6 yrs FTSS dummy models for check of OoP suitability

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Abstract:

For a planned airbag simulation model including 3yrs and 6yrs child dummy models, it is necessary to investigate available dummy models and choose the best suitable model.
Firstly a market research study was undertaken to find out, which models are available. The chosen models were investigated by pendulum tests and compared to the simulation model. The results of the comparison between simulations and tests are discussed.

Keywords:

Market research study, validation 3yrs and 6yrs FTSS dummy model, comparison simulation - test

1 Dummy selection:

For a new airbag simulation model the most suitable dummy models should be use, therefore a market research study was undertaken. Three groups of dummy models were investigated:

1.1 Madymo Dummy Models:

Ready-developed, suitable models are widely available. The only significant disadvantage of the Madymo models for the project was the fact, that the 3yrs and 6yrs child models which were reviewed were available only in a pedestrian model, which was unsuitable for our requirements. Recently FE models of the 3yrs and 6yrs have been published. These FE models are not as stable as the ellipsoid models (figure 1), but provide more exact results. In 2006, so-called “facet dummy models” will be available for the 3yrs and 6yrs, too, which offers the best compromise between accuracy, calculation time and stability.

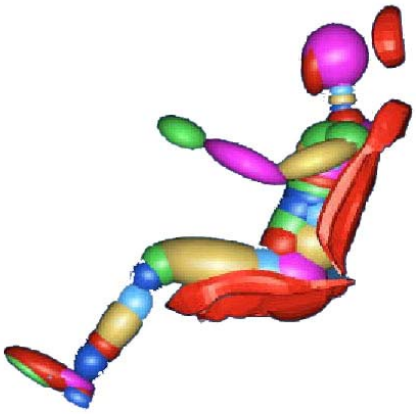


Figure 1: Madymo Dummy Model

To use the Madymo Models, they have to be coupled with LS-Dyna, as the most important calculation code is written in LS Dyna code. This makes two licences necessary (Madymo + LS-Dyna), so raising the license costs.

They consist of coupled ellipsoids, which are defined by the formula

$$\left(\frac{y}{b}\right)^n + \left(\frac{z}{c}\right)^n = 1 \qquad (1)$$

For higher values of n the ellipsoids become more “square”, so the geometric structure can be mapped only by variation of the ellipsoid parameters. As a result it is easy to understand that only FE-Models will give a good surface approximation, especially for the head, nose, neck and chest area.

1.2 FTSS Dummy Models:

FTSS Dummy models consist of around 22.000 nodes and 24.000 elements; therefore, the modelling is very exact and the geometric surface is more precise compared to the Madymo models. The fine geometry of the head and neck surface that is available is very suitable for our purposes. The material behaviour can be adjusted very easily. But their most important advantage is the availability of 3yrs and 6yrs child models. Additionally the FTSS dummy models can be adjusted very easilyl in ALTAIR HyperMesh® via “body parts”, so the positioning takes only a few minutes.

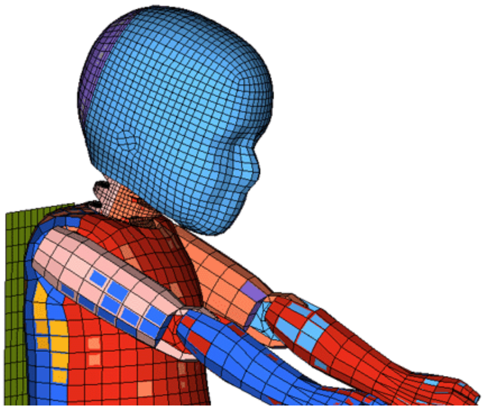


Figure 2: FTSS Dummy Model

1.3 GEBOD Dummy Models:

As GEBOD dummy models are included in LS-Dyna (keyword command *COMPONENT_GEBOD_OPTION) they can be considered free of charge. A second advantage is the availability of child dummy models, which can be defined by their age in months.
The material parameters cannot be defined exactly, as they are defined only by giving load curves. Furthermore, the geometric definition is not as exact as that of the FTSS dummy models. As a result GEBOD dummy models should only be used for “rapid” examinations.

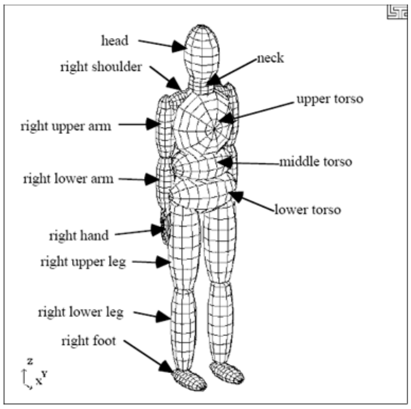


Figure 3: GEBOD Dummy Model (LS-Dyna manual)

In view of these facts it was easy to choose the FTSS dummy models. For these models general validations have already been made (for example neck flexion tests, thorax impactor and pendulum tests; see FTSS manual “Component Modelling Summary Reports”, 1997 for the 3yrs and the User Manual, 2002, for the 6yrs). As the special OoP conditions were not investigated, it was necessary to add some OoP tests to ensure the FTSS dummy model suitability.

2 Test configuration:

Figure 4: Pendulum

The dummy was mounted on a rigid seat, which was fixed with the ground. To avoid a side tilt, the dummy was fixed using adhesive tape at chest height.
The pendulum was mounted in a framework fixed to the ground (Figure 4) with a rotating point 2,5 m above the floor. The total mass of the pendulum (the rotating part, excluding the framework) was 20,02 kg, the reduced mass at the pendulum impact point is 6,80 kg. To ensure an impact velocity of 15 km/h the pendulum was lifted to the appropriate start position using an angle scale and then fixed with an electromagnetic locking bolt.
A high speed camera was set at a rate of 1000 frames per second. The recording time was set to 500 ms, so allowing the whole pendulum motion with the dummy’s head impact could be filmed.

Note: The test results are discussed with regard to the FMVSS 208.

2.1 The 3yrs dummy:

Firstly we look at the pendulum movement and the dummy's reaction to it:

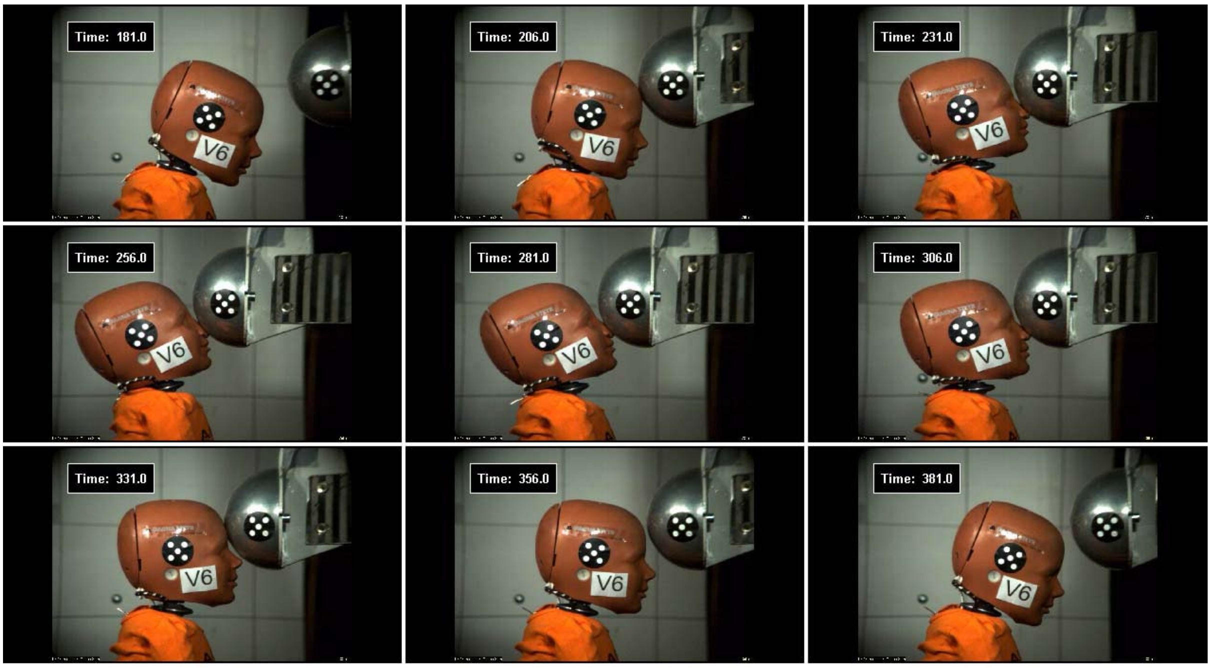


Figure 5: Test pendulum impact with 3yrs child dummy

To guarantee the absence of deviations three tests were performed and the measured curves were compared. In the following diagrams the most important measured results are shown and discussed.

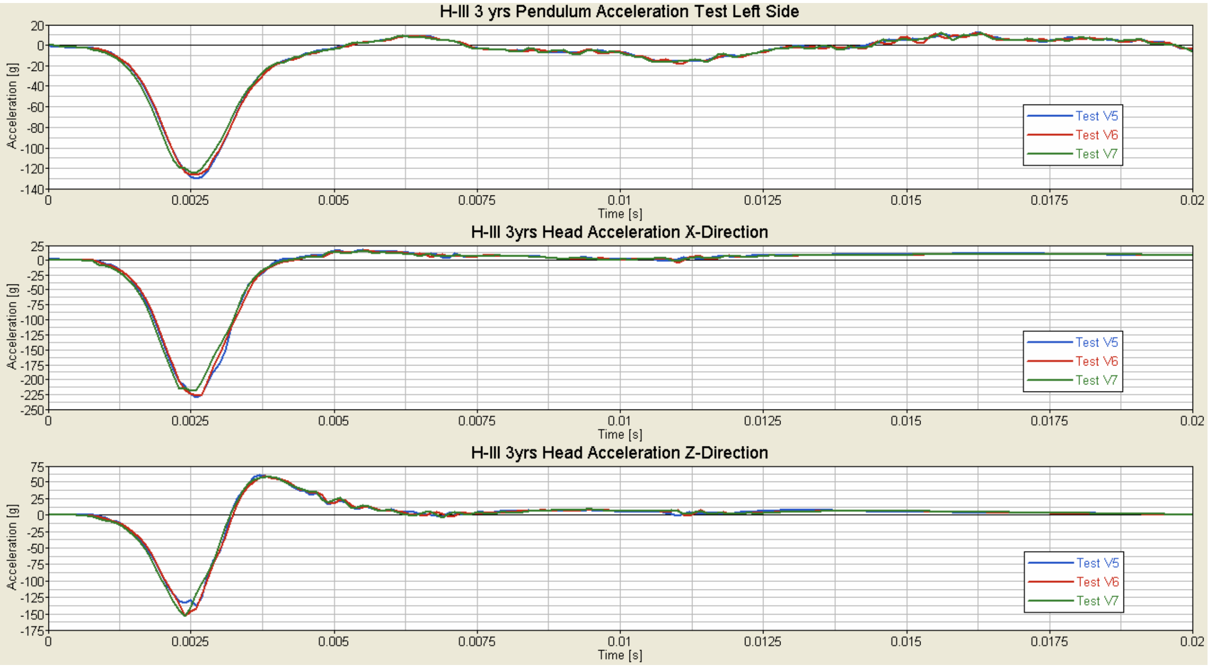


Figure 6: Measured acceleration values

All measured accelerations are good fit. The largest deviation occurred in the Z-direction head acceleration and was 12% - the maximum peak of test V5 is 137g, of test V6 and V7 152g.

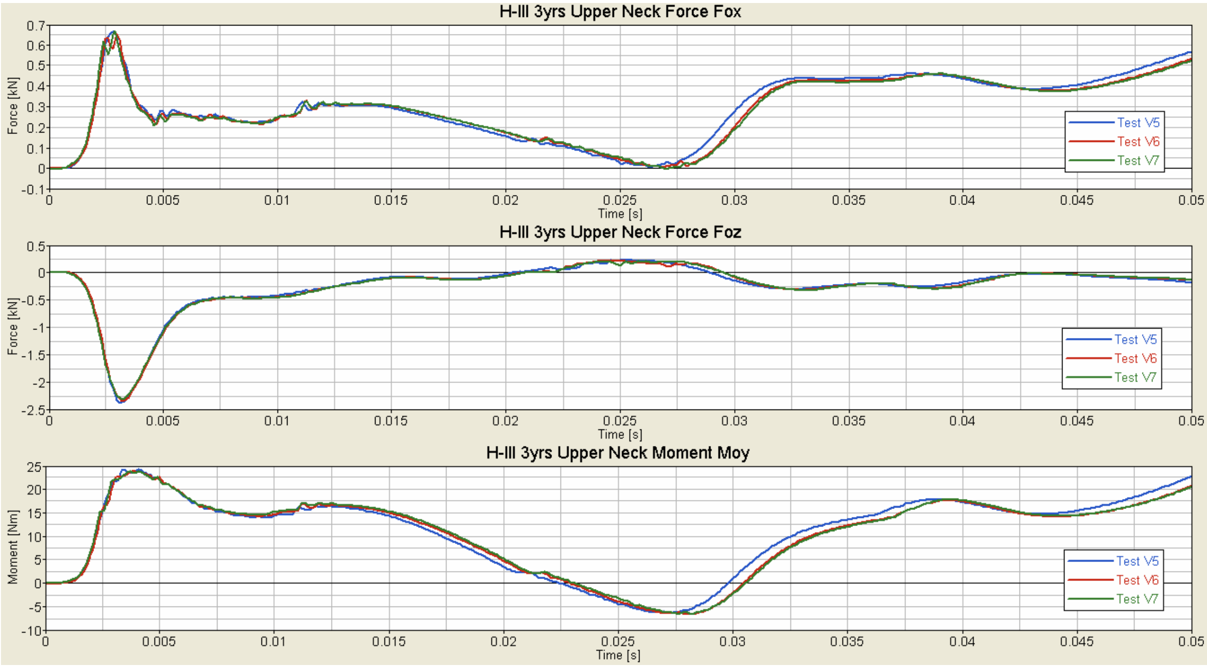


Figure 7: Measured force values

In figure 7 the measured values are also in a good accordance. Only at later times (30 ms) the test V5 curve rises a bit earlier than the others. To compare the tests with the simulations, test curve V6 will be used.
It should be noted that we have no "ideal" test constellation. After 31 ms a second contact between the dummy's head and the pendulum occurs, so after this time we differences in the measured values may occur. Friction also is very important here as a slight deviation may lead to very different results.

2.1.1 Comparison 3yrs simulation – test:

For the simulation the FTSS 3yrs child dummy model (Version 3.0, April 25 2003) was used. Newer models are now available, but they haven't been examined yet. The next figures show the comparison between the test (blue line) and the simulation (red line).

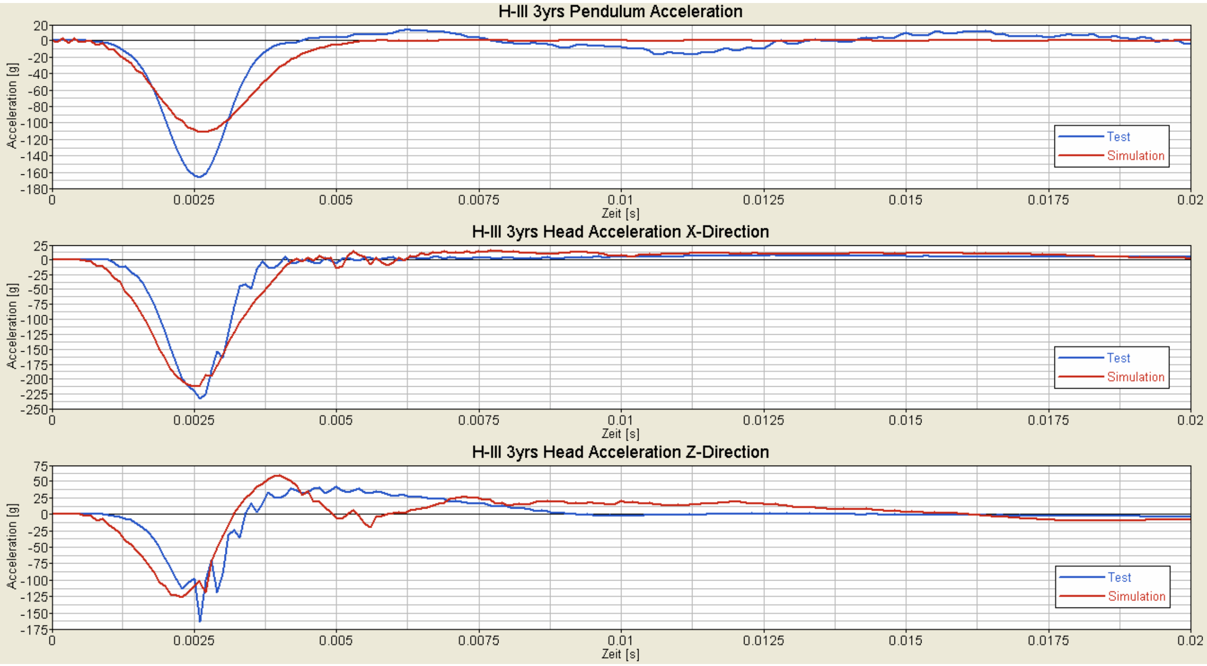


Figure 8: Comparison acceleration simulation - test

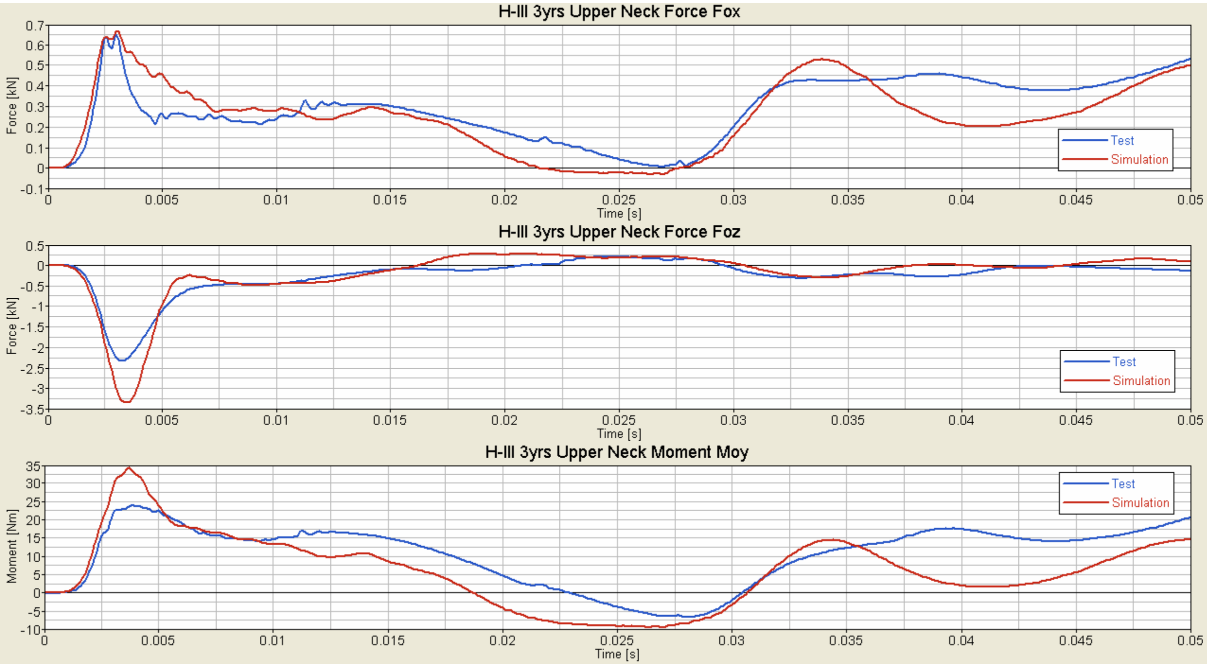


Figure 9: Comparison force simulation - test

The simulation curve follows the test curve rather well. In a few cases (Pendulum Acceleration, Upper Neck Force Fo_z, Upper Neck Moment Mo_y) the simulation amplitude is significant larger than the test curve.
Closer inspection of the largest deviations shows that for the upper neck force Fo_z we have a test measured amplitude of 2350 N, and a simulation value of 3310 N at 3ms, i.e. a 39% difference. At 3 ms the measured value (test) of the upper neck moment Mo_y is 24 Nm, and the simulation value is 34 Nm; a difference of 42%.
So this dummy model is considered as validated for all criteria except the upper neck force Fo_z and the upper neck moment Mo_y.

2.1.2 Evaluation of the injury criteria for the head:

For the 3yrs child dummy the critical value for the HIC_{15} (Head Injury Criteria) is 570 $g^{2.5}$ s (FMVSS 208) and is defined as:

$$HIC = \max\left\{(t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t1}^{t2} a(t)dt\right]^{2.5}\right\} \text{ [g}^{2.5}\text{ s]} \qquad (2)$$

with

a(t): resulting translatory acceleration in centre of gravity of dummy-head [g]
t_1: start time of interval, in which the function is calculated [s]
t_2: end time of interval, in which the function is calculated [s]
The HIC_{15} value applies to: $(t_2\text{-}t_1) \leq 15$ ms.

In HyperView the HIC value is read by the “HIC-function” and represents the head acceleration in X-direction for the test of 599, for the simulation 620, which is a difference of 3,5%. For the head acceleration in Z-direction the HIC test value represents 138, for the simulation the value is 136, so the difference is only 1,4%. The deviations are negligible.

2.1.3 Evaluation of the injury criteria for the neck:

The NIJ value (Neck Injury Criterion) is defined as:

$$NIJ = \frac{F_z}{F_{\text{int}}} + \frac{M_y}{M_{\text{int}}} \text{ [1]} \qquad (3)$$

with

F_z: axial force [N]
F_{int}: critical intercept value of axial force [N]
M_y: bending moment [Nm]
M_{int}: critical intercept value of bending moment [Nm]

The critical values are for F_{int} (tension) 2120 N, F_{int} (compression) 2120 N, M_{int} (flexion) 68 Nm and for M_{int} (extension) 27 Nm. The NIJ values are calculated four times with the four critical values. None of the four NIJ values shall exceed 1.0 at any time during the event.
Calculating these four values for NIJ, we have a maximal difference of 41%, which is found at the N_{te} value (test 0,34; simulation 0,48) and at the N_{ce} value (test 1,35; simulation 1,91).

It’s no wonder, that the simulation value is significant higher than the test value, as we have too high amplitudes in simulation (see graph).
Therefore it is necessary to take care regarding the simulation values for NIJ criteria and to re-calculate them for the worst case.

2.2 The 6yrs dummy:

Once again we first examine the video sequences for the 6yrs child dummy.

Figure 10: Test pendulum impact with 6yrs child dummy

As in the tests for the 3yrs dummy, 3 tests were performed on the 6yrs dummy to guarantee the absence of deviations. The measured forces and accelerations are again compared:

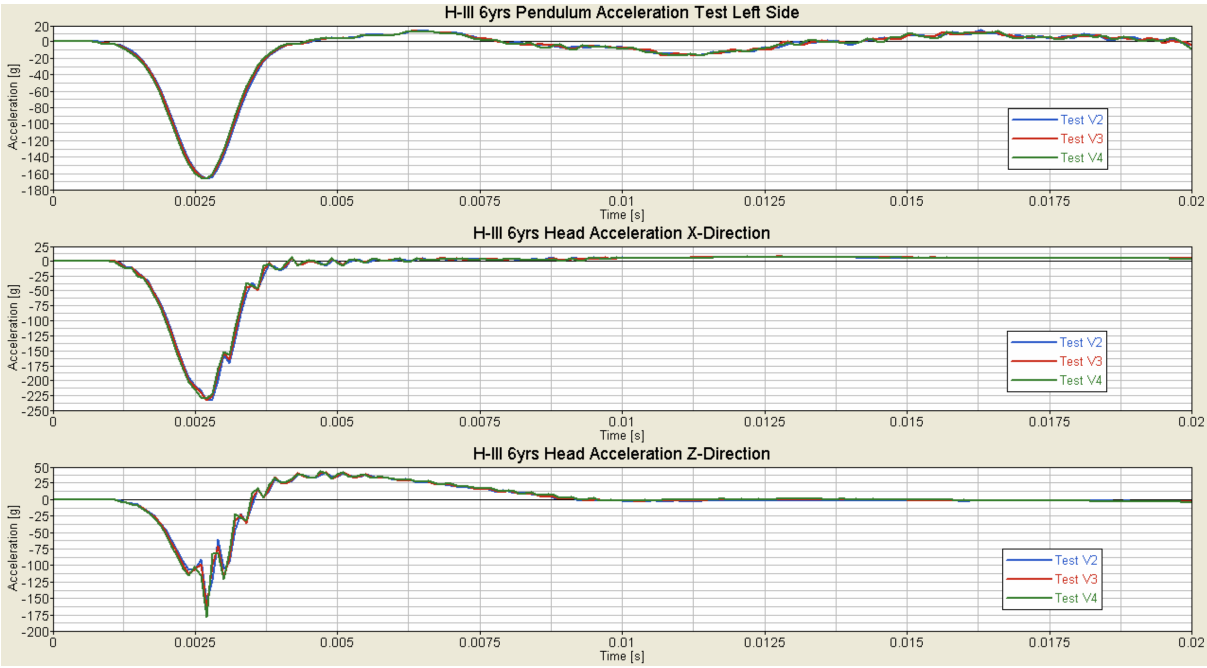


Figure 11: Measured acceleration values

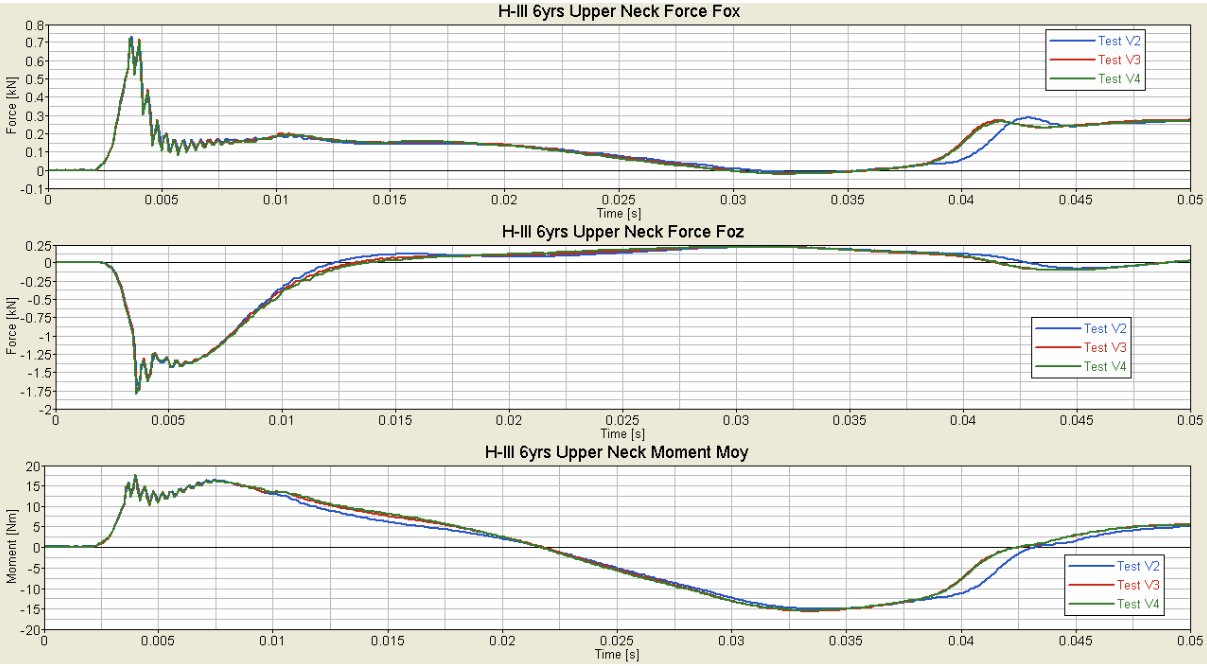


Figure 12: Measured force values

In the head acceleration curves, no deviations can be found. Only at the neck forces and at the neck moment a little deviation with test V2 can be registered at later time. The curves can be considered as “in line”, especially during the most important time range of 0 - 15 ms. For the comparison of tests and simulations the V3 curve will be used.
As in the tests with the 3yrs dummy model, we have a non-ideal test constellation with a second contact between pendulum and dummy’s head at 43 ms. So deviations are not excludable after this time..

2.2.1 Comparison 6yrs simulation – test:

For the simulation the FTSS 6yrs child dummy model (Version 2.2, April 11 2003) was used. Like the 3yrs child dummy model, newer models of the 6yrs child dummy models are now available, too. The next figures show the comparison between the test (blue line) and the simulation (red line).

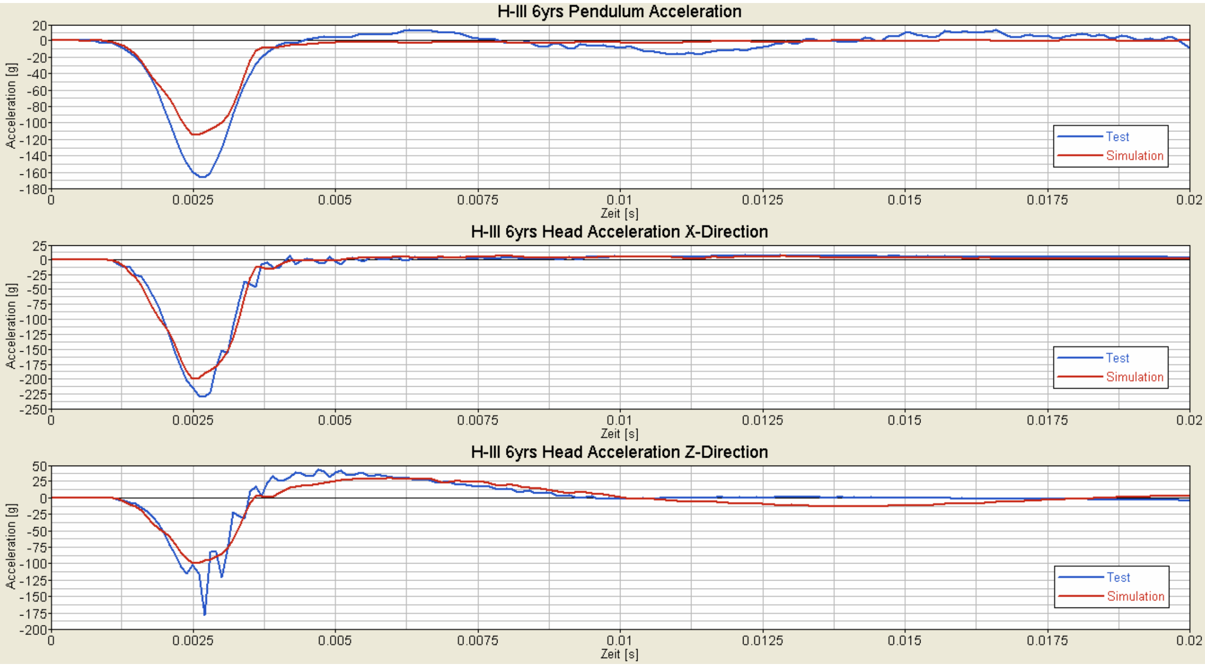


Figure 13: Comparison acceleration simulation - test

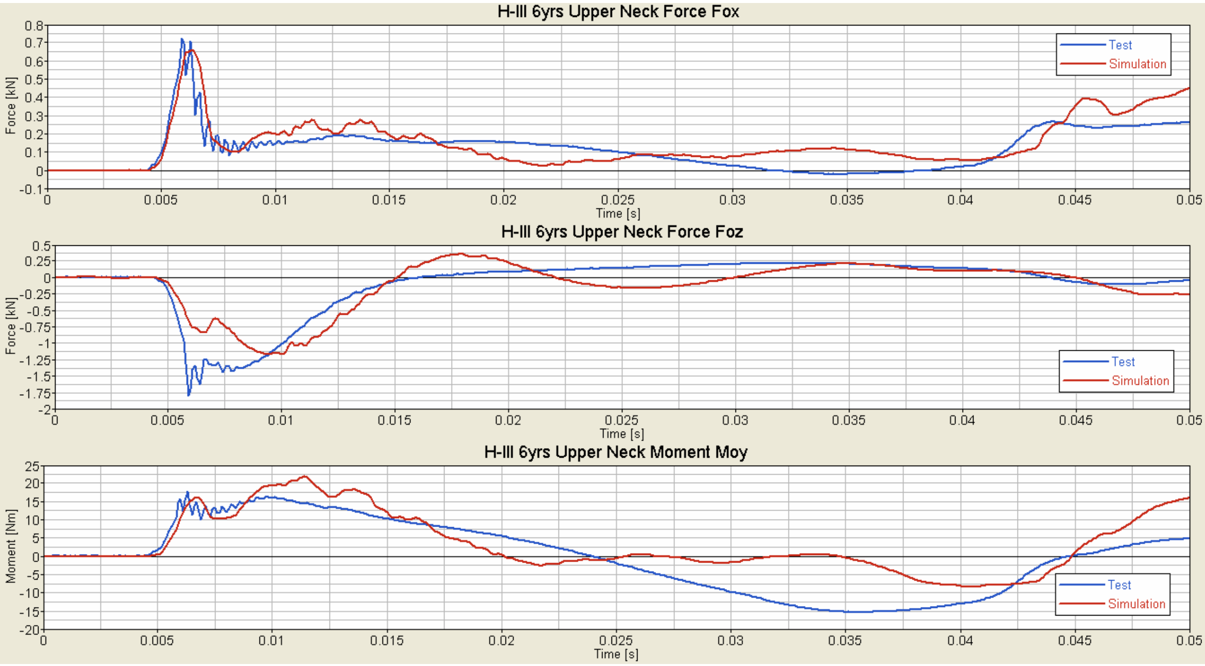


Figure 14: Comparison force simulation - test

It is easy to see the curves with the largest difference between test and simulation which are the curves fot the pendulum acceleration and the upper neck force Fo_z. All other curves are show a goot fit (the head acceleration in Z-direction test curve was not filtered by the test department, but it fits well to the simulation curve).

2.2.2 Evaluation of the injury criteria for the head:

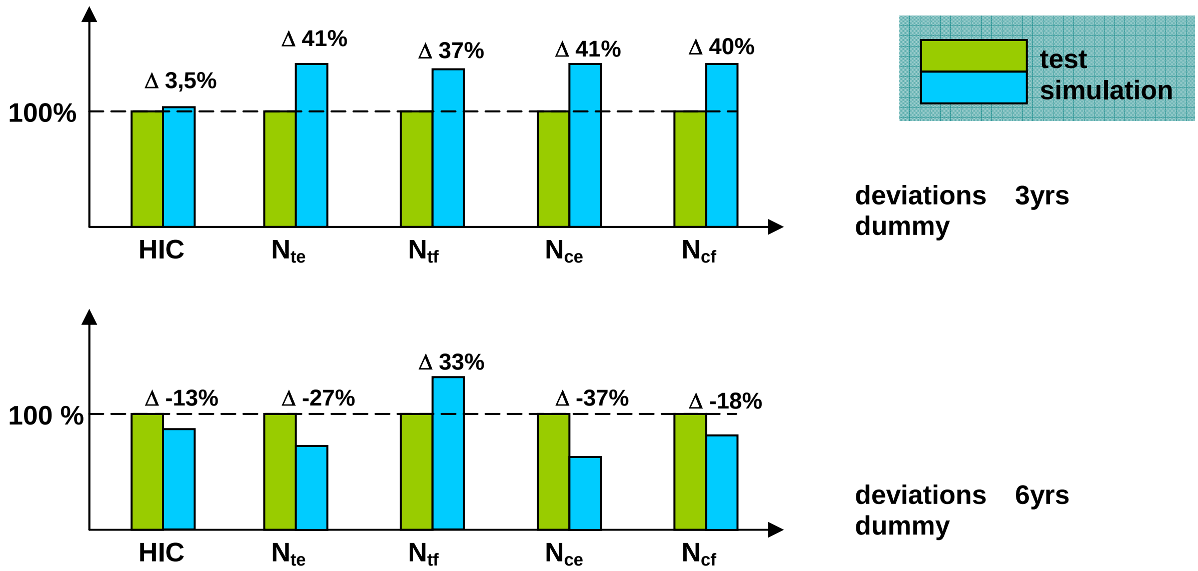
For the 6yrs child dummy the critical value for the HIC_{15} (Head Injury Criteria) is 700 $g^{2.5}$ s (FMVSS 208).
In HyperView the HIC value is read by the “HIC-function” and represents for the head acceleration in X-direction for the test a value of 521, and for the simulation a value of 451, i.e. a 13% difference. For the head acceleration in Z-direction the HIC test value was 103, and the simulation value was 77, so a -25% difference. But note that both values are below the critical value. When the simulation value comes near to the critical value, it will be necessary to re-check the HIC criteria accurately.

2.2.3 Evaluation of the injury criteria for the neck:

For the 6yrs NIJ critical values (FMVSS208) the following maximal values are allowed:
F_{int} (tension) 2800 N, F_{int} (compression) 2800 N, M_{int} (flexion) 93 Nm and for M_{int} (extension) 37 Nm.
By calculating all four values, we get a maximal difference of -37% for the N_{ce} value. But – all NIJ values for the tests are below the critical values (and meet the NIJ $\leq$ 1 criteria). So if the simulation value is 37% or less below the critical value, an exact calculation will be necessary.

2.3 Comparison test – simulation:

The diagram shows the deviations of the 3yrs and 6yrs dummy models, compared to the test results. The test results were all set to 100% to get a unique basis, the deviations of the simulation results are based at these test results.
Note: The values of N_{te}, N_{tf}, N_{ce} and N_{cf} are the four values of NIJ, which results in order of the calculated force or moment (see chapters 2.1.3. and 2.2.3).



The deviations of the 3yrs dummy model concerning the HIC value are very small, so the HIC value can be used without doubt. For the NIJ value, all four deviations are rather high, but almost in the same range of 37-41%. So they can be used, too, by “calculating back” to the test results.

The deviations of the 6yrs dummy model are more inconsistent. The HIC value shows a larger deviation than the 3yrs model. The greatest differences can be seen in the NIJ values, where the range goes from -37% up to +33%. Simulation results evaluating the NIJ values must be considered carefully.

3 Conclusions:

As OoP cases get more and more important and will be included in further occupant restraint systems, the OoP validations should be included in the validation tests made by the dummy model developers. Examples of possible OoP validation tests were described in this paper, but other test constellations are possible, too.
The FTSS dummy models discussed may be useable for OoP simulations. However, for values which are close to the FMVSS208 limits, a critical view is necessary and the values have to be checked again carefully.

References:

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