

Development of Advanced HIII Abaqus dummies

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Abstract: Hybrid III dummies are among the most frequently used dummies in both industry and academia for vehicle crash safety. Abaqus is one of most widely applied finite element codes in the world. To meet the needs of crash safety analysis and to exploit the potential of the Abaqus/Explicit code, a family of HIII dummies, including HII 50th male, 5th female and 95th male dummies, were developed at FTSS in collaboration with Simulia and BMW. This paper describes in detail the development of the HIII dummies with specific reference to the HIII 50th dummy. Firstly correct material models based on material test data are verified. Secondly variety of FTSS standard (certification-based) and non-standard finite element validation tests at component level, i.e. head drop, neck pendulum, lumbar spine, knee slider, knee impact and single rib tests, and at full dummy level, such as thorax pendulum, sled seatbelt and sled airbag tests, were accomplished. In addition, a suite of extra test, developed by the Partnership for Dummy Technology and Biomechanics (PDB), was integrated into the dummy development to enhance the fidelity and robustness of the dummy performances. Those tests include head impact (forehead and cheek), thorax impacts, tibia tests and foot and shoe tests. Based on these series of stringent validation tests, a family of HIII dummies have been successfully developed, which greatly facilitates virtual vehicle development and design process of the occupant safety in the automotive industry.

Keywords: Dummy, Anthropomorphic Test Devices (ATD), Occupant protection, vehicle crash safety, Finite element Analysis

1. Introduction

Since 2001, fatalities due to traffic accidents have been identified as the leading cause of death for people age 2 through 34 years old in the United States [R. Subramanian, 2003, 2005, 2006, and 2007]. Among all traffic fatalities, nearly 40% resulted from front impact accidents. The front impact therefore becomes one of the key crash safety areas targeted by both automobile manufacturers (OEMs) and academic researchers. Front impact dummies have been playing very important roles in front impact analysis for over two decades. Advances in processing power and explicit solver code capability in the last decade has created the possibility for detailed finite element dummy models to deliver timely high quality injury predictions for safety engineers, expanding what had previously been the realm of the fast running multi-body approach. In the past, safety-related CAE relied heavily on a multi-body approximation of dummy mechanics and injury prediction. With the progress in biomechanics and the onset of much more stringent front impact safety regulations, the demands for better performance predictions in front impact safety analysis/development are constantly increasing. Finite element (FE) dummies like the Abaqus HIII series are the right tools to meet these demands. Advances in computer technologies make the

application of the FE dummies affordable in front impact simulations, in terms of financial cost and efficiency.

Dyna 3D, Pamcrash and Radioss have been used by most OEMs and suppliers worldwide in their crash safety development and analysis. In recent years, as one of most widely applied FE codes, Abaqus/Explicit has gained application in the crash safety area. First Technology Safety System has developed SID-IIs, ES2, ES2_RE FE Abaqus dummies and HIII 5th, 50th and 95th Abaqus ballast dummies in last few years. To meet the needs of the front crash safety analysis and to exploit the potential of the Abaqus/Explicit code, a family of HIII dummies, including HII 50th male, 5th female and 95th male Abaqus dummies, have been developed at FTSS in collaboration with Simulia and BMW. The FE HIII Abaqus dummies developed by FTSS are shown in Figure 1.

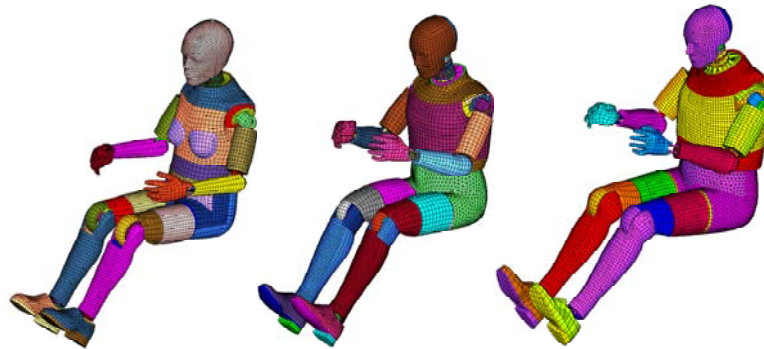


Figure 1 Hybrid III 5th, 50th, 95th FE Abaqus dummy models

The procedure for developing an FE dummy consists of a few key steps. To ensure the dummy performs well in terms of bio-fidelity and robustness, the first step is to obtain correct dummy geometry data so that the FE dummies will resemble in their physical counterparts. FTSS dummy geometries were obtained from the engineering drawings for the machined parts and from 3D scans for some other parts with complicated geometries and for deformable vinyl and foam parts. A series stringent FE validation tests at different level have then to be conducted, from material level, component level to finally full dummy level.

2. Tests at Material Level

Developing accurate material models is a fundamental requirement for achieving good dummy behavior. Key drivers of the dummy performance include flesh components, i.e. hyperelastic polyurethane and elastomer foam flesh, vinyl skins and rubber neck and lumbar spine. A wide range of testing applications is used in developing material models for Abaqus dummy models. The type of material and known behavior characteristics help in deciding the appropriate material testing. For example, foams with rate sensitivity may utilize multiple compression load cases at

varied speeds to capture this behavior. In such a test, as illustrated in Figure 2, the drop head acceleration is used as a performance measure.

Marlow model is used in Abaqus for modeling the vinyl skins in the dummy development. The Marlow model is a first-invariant hyperelastic material model and its main strength is in that with a dependence on the first-invariant, it does not need curve-fitting procedures and can exactly reproduce the test data and performs quite well in other modes of deformation. [Abaqus v6.7, 2007].

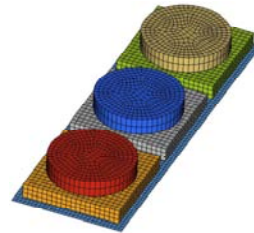


Figure 2 Ensolute foam 3-speed test model

Figure 3a shows the calibration of the Marlow model to the corresponding physical sample test. All foam materials in the dummies are modeled with the Abaqus rate sensitive foam material model [Abaqus v6.7, 2007]. Figure 3b, c and d illustrate the modeling results of the foam with the model, which exhibit excellent correlations.

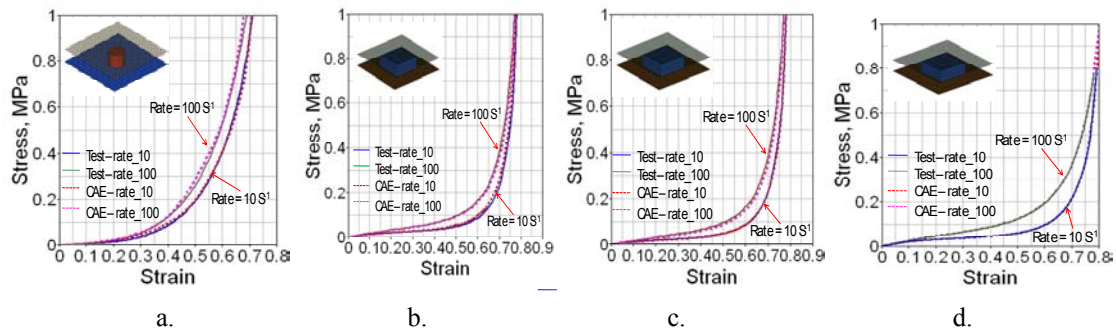


Figure 3 Material validations: a. vinyl, b. Pelvis foam, c. Jacket foam, d. Abdomen foam

3. Tests at Component Level – FTSS Tests

During the dummy development, a series validation tests at component level are performed. These include the following tests: head drop, knee impact, knee slider, single rib, lumbar spine pendulum, neck pendulum (extension & flexion), abdomen foam, single rib, thorax drop, hip joint rotation range of motion, knee impact and knee slider [SAE, 1998]. The following sections present test results for some of these tests.

3.1 Head Drop Test

Head injury criteria (HIC) is one of the most important dummy numbers in all related safety regulations, which is an acceleration based parameter. To ensure that the dummy can capture

acceleration responses accurately, a head drop test is conducted at two different impact velocities, i.e. at two different drop heights, 376 mm and 505 mm. This test assesses the forehead response to frontal impact with hard surface. The plots in Figure 4 show excellent correlation between the CAE and the tests.

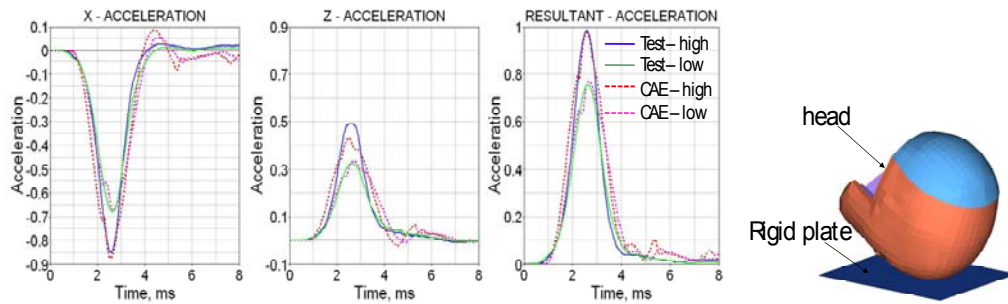


Figure 4. Head drop test results.

3.2 Knee Impact Test

In the knee impact test, the knee assembly is fixed at the end of the femur bone and an impactor with a mass of 5.0 kg impacts the knee at a velocity of 2.1 m/s, as shown in Figure 5. The impact force defined as the product of the impactor mass and its acceleration, and is recorded. A fair good correlation is achieved as illustrated in Figure 5.

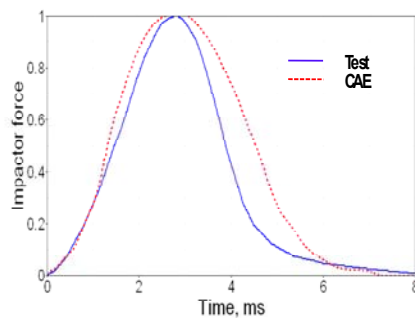


Figure 5a. Knee impact results

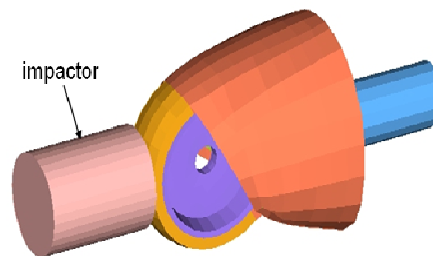


Figure 5b. CAE model

3.3 Knee Slider Impact Test

This test is to characterize the knee slider properties. To transfer impact energy into the knee slider assembly, a load distribution bracket is required. A test probe with a mass of 12.0 kg impacts the bracket at a velocity of 2.75 m/s. The knee slider displacement and the femur force are recorded and compared with those of the physical test. The comparison, depicted in Figure 6, appears very good.

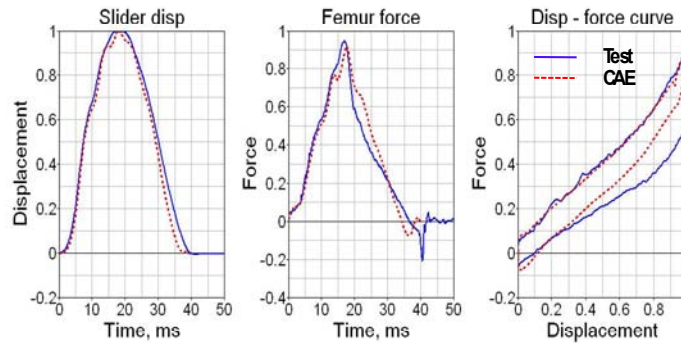


Figure 6a . Knee slider test results

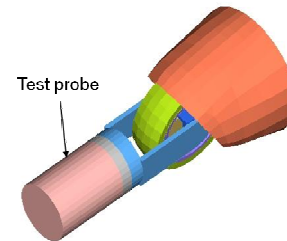


Figure 6b . CAE model

3.4 Single Rib Drop Test

To facilitate the calibration of the rib damping material, a special drop impact test is designed as plotted in Figure 7. The drop head is released at two different heights to achieve two different impact velocities respectively. The rib deflection and impactor acceleration are recorded. The comparison of the CAE model correlates with those of the physical test quite well.

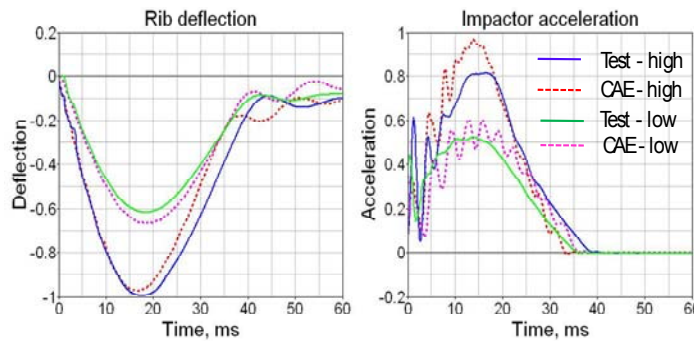


Figure 7a. Single rib test results

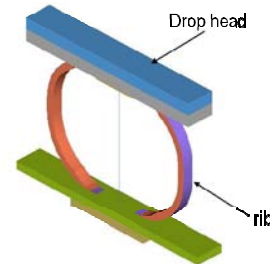


Figure 7b. CAE model

3.5 Lumbar Spine Test

As an important load path between the upper and lower torso of the dummy, the performance of the lumbar spine plays a determining role in whole dummy performances, especially in unstrained impact scenario. In this test, the lumbar spine assembly is attached at one end of a pendulum and the pendulum is pin-fixed at the other end. A rigid block is fixed at the other end of the spine. The pendulum is then released at a height, which enables the spine to arrive at a specific impact velocity when it hits the honeycomb stopper. Figure 8 displays the test results and the FE model.

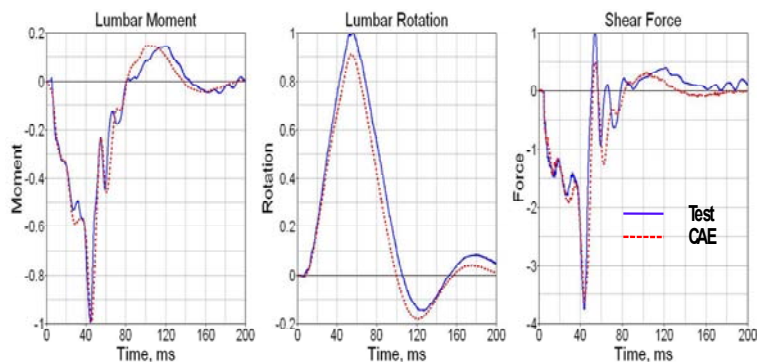


Figure 8a. Lumbar spine test results

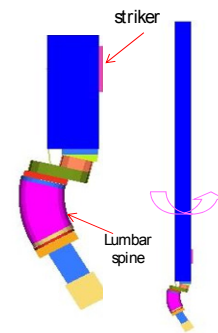


Figure 8b. and FE model

3.6 Neck Pendulum Tests

In this test, the head-neck assembly is fixed at the end of a pendulum and the other end of the pendulum is pin-fixed so that the pendulum and the head-neck assembly can rotate around the pin point. During the test, the pendulum is released and fall freely from two different heights to obtain a high and a low impact velocity respectively for the extension test and for the flexion test. The neck moment and shear force, and the neck rotation are monitored. It can be seen that the performances of the CAE neck are very similar to those of the physical tests, as shown in Figure 9 for the extension tests and Figure 10 for the flexion tests.

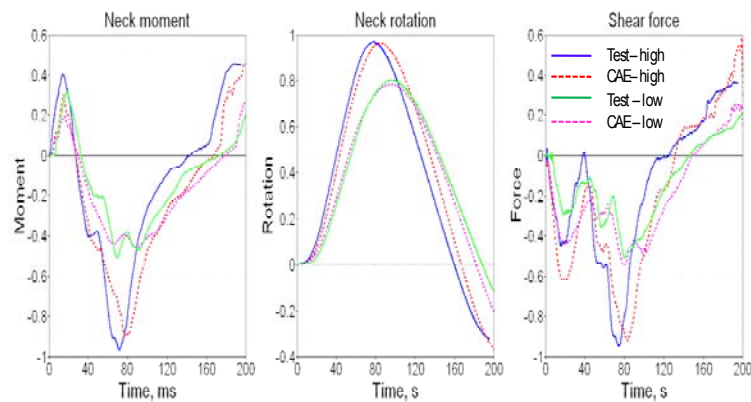


Figure 9a. Neck pendulum extension test results

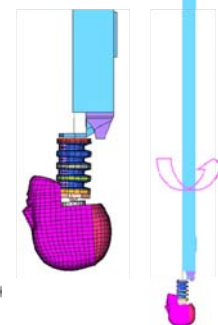


Figure 9b. CAE model

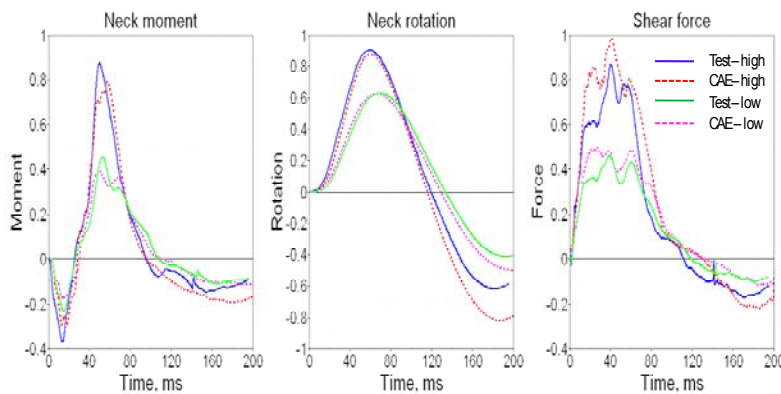


Figure 10a. Neck pendulum flexion test results

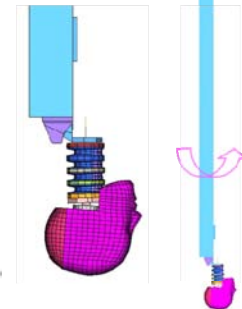


Figure 10b. CAE model

3.7 Thorax Drop Test

The thorax is the most complicated component in the H350 dummy model. The thorax drop tests with a circular drop head simulate the performances of the assembled thorax box under variety of loadings. The mass of the circular drop head is constant and the drop height varies at 4 different levels. This induces a chest deflection of 20 mm, 30 mm, 40 mm and 60 mm respectively. While in the thorax drop tests with a square drop head, both mass and drop height of the drop head changes, which forces the thorax box deform at different deformation rates. Very good correlations are provided in Figure 11 and Figure 12.

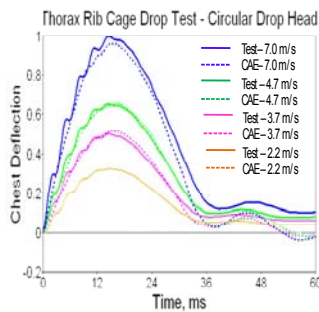


Figure 11. Thorax drop test (circular head)

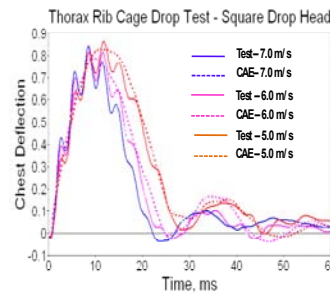
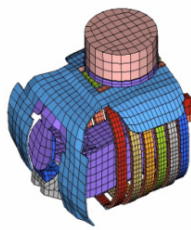
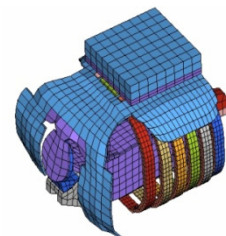


Figure 12. Thorax drop test (square head)



4. PDB Tests

The partnership for Dummy Technology and Biomechanics (PDB) is a Germany organization, consisting of 5 automobile manufacturers. To assess and optimize dummy performances for vehicle safety, special tests were designed for dummy validations. The PDB tests related to HIII

dummies are divided into four groups: head impact tests, neck impact tests, thorax impact tests and tibia, foot/shoe impact tests.

4.1 Head Impact Tests

The PDB head impact test consists of two different tests. In both PDB head impact tests, the head-neck assembly is fixed at lower end of the neck. The first one is called cheek impact where the impactor hits the cheek of the head-neck model and the second forehead impact where the impactor targets the forehead of the model. Figure 13 and Figure 14 show head acceleration correlation between the CAE and the corresponding physical tests for both validation tests, at a satisfactory agreement level.

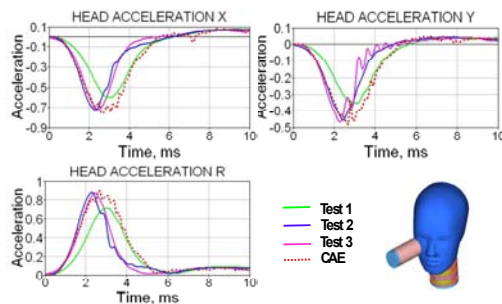


Fig.13. Cheek impact test

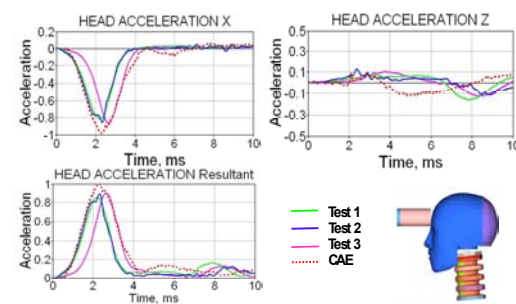


Figure 14. Forehead impact test

4.2 Neck Impact Tests

There are two different PDB neck impact tests, namely 2D and 3D tests. In both tests, the head-neck assembly is fixed at the skull back plate. For the 2D test, two fork-like loading devices are attached to the lower end of the neck in orthogonal directions. For the 3D test, three such loading devices are attached to the neck, which are perpendicular to each other. During the tests, the neck is undergoing 2D loading for the 2D test, and 3D loading for the 3D test. The upper neck loadcell is monitored and the outputs of the loadcell are correlated to those of the physical tests. Figure 15 and

Figure 16 present a fairly good correlation for the 2D and 3D tests respectively.

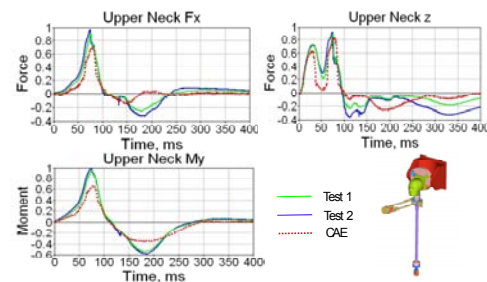


Figure 15 2D neck impact test

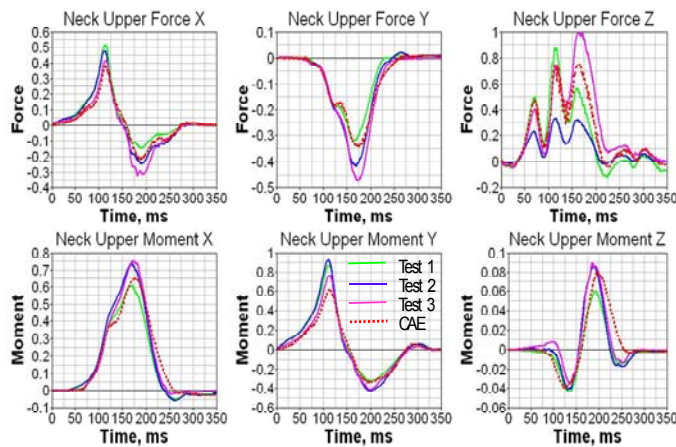


Figure 16a. 3D neck impact: results,



Figure 16b. CAE model

4.3 Thorax Impact Tests

The PDB thorax impact tests, as shown in Figure 17, can be cataloged as two groups of tests. The first one has 5 tests, which simulate seatbelt loadings at different locations of the front thorax. The

second one has two tests, which imitate steering wheel loadings on the front thorax of dummies in two different sitting positions. The tests are designed to validate chest deflection for the dummy simulation models. The loading for the thorax impact test is applied with a prescribed displacement at a specific velocity level. Figure 18 and Figure 19 shows the reasonably good correlation results for the sternum central tests – with/without jackets respectively.

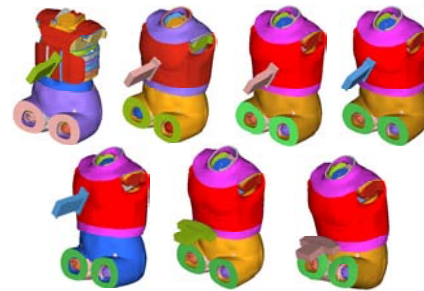


Figure 17. Thorax impact test models

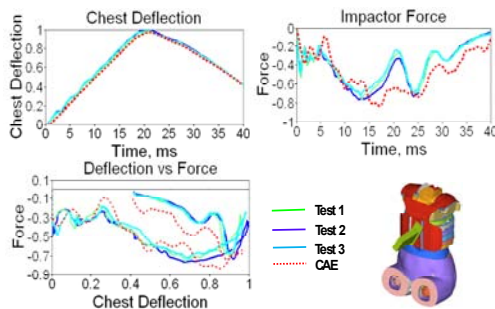


Figure 18. Sternum central impact/ without jacket

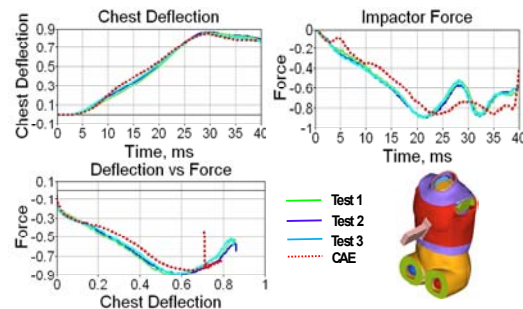


Figure 19. Sternum central impact/ with jacket

4.4 Tibia and Foot/Shoe Tests

There are three tests for the tibia test where the impactor hits the tibia at 3 different positions with a prescribed displacement and five for the foot/shoe test where the impactor impacts the foot (with or without shoes) at different locations and from different directions, as shown in Figure 20a. The simulation results for the upper and lower tibia loadcells have been plotted in Figure 20b where the impactor strikes at the middle of the tibia.

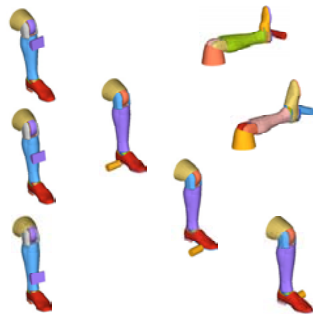


Figure 20a. Tibia, foot/shoe test models

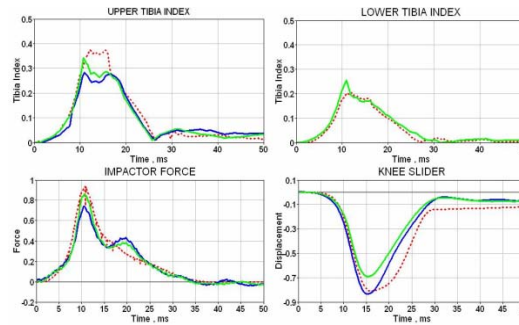


Figure 20b. IP2a impact test results

5. Tests at Full Dummy Level

After all validation tests at component levels are completed, three full dummy tests need to be conducted: thorax pendulum test, sled seatbelt test and sled airbag test.

5.1 Thorax Pendulum Impact Test

In this standard thorax pendulum test, a pendulum impactor with a mass of 23.4 kg strikes the dummy in the thorax at a velocity of 6.7 m/s, as shown in Figure 21a. Figure 21b demonstrates very good correlation of the chest deflection and impactor force against those of the physical test.

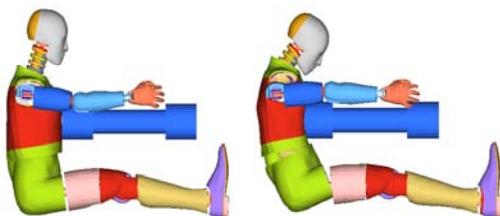


Figure 21a. Thorax pendulum impact model

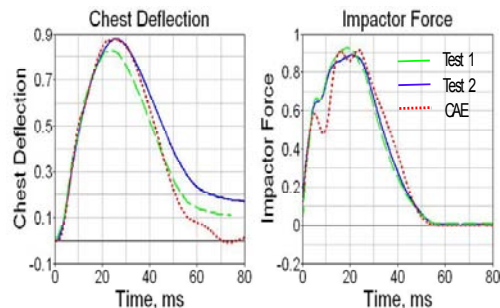


Figure 21b. Thorax pendulum test results

5.2 Sled Seatbelt Test

As shown in Figure 22a, in the sled seatbelt test, the dummy is sitting on a rigid seat, which in turn is fixed on the sled. The dummy is restrained by a shoulder belt and a lap belt. A sled velocity pulse is applied, which represents a 30 mph front impact. Figure 23b illustrates correlations of the head, chest, pelvis acceleration and chest deflection of the dummy to those of the physical test. A comparison of the CAE belt forces with the test belt forces are provided in Figure 23c. In general, the correlations for this test are satisfactory.

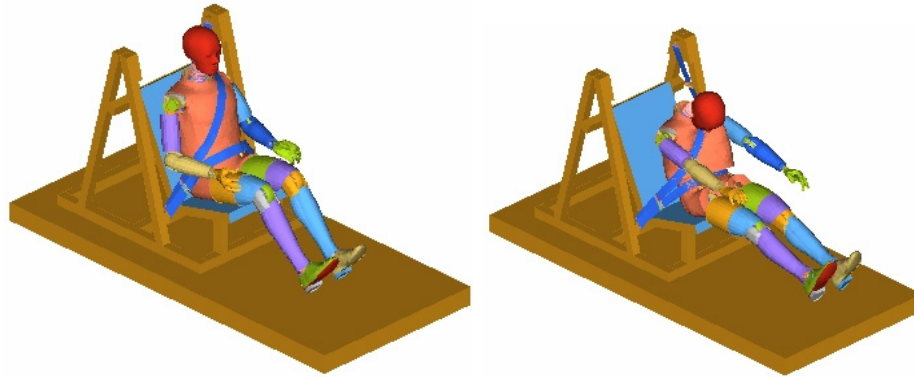


Figure 22a. Sled seatbelt model

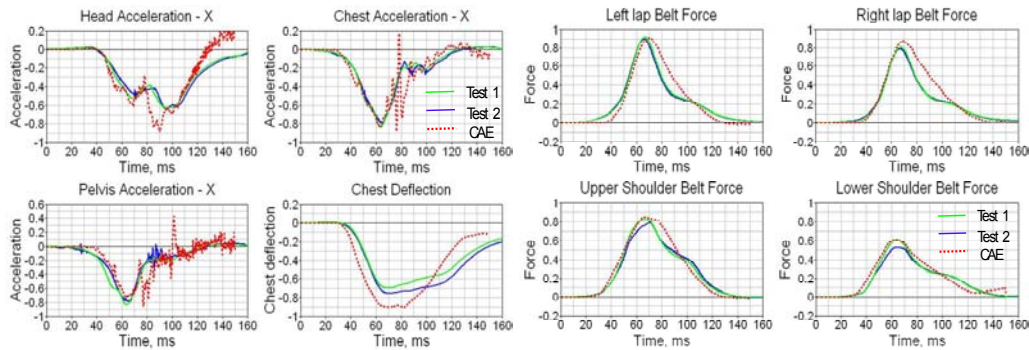


Figure 22b. Sled seatbelt test results

Figure 22c. Sled seatbelt test results

5.3 Sled Airbag Test

Similar to the sled seatbelt test, in the sled airbag test model, the dummy is sitting on a rigid seat, which in turn rests on the sled, but without seatbelt restraint. Instead there is an unfolded airbag in front of the dummy on the steering wheel, as shown in Figure 23a. The loading for this test is the same as that applied in the sled seatbelt test. Figure 23b shows a reasonably good comparison of the head, chest and pelvis accelerations and the chest deflection against those of the real test.

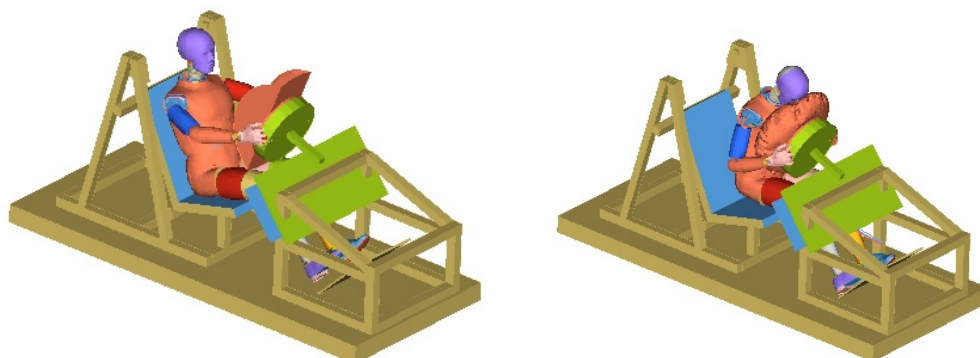


Figure 23a. Sled airbag test model

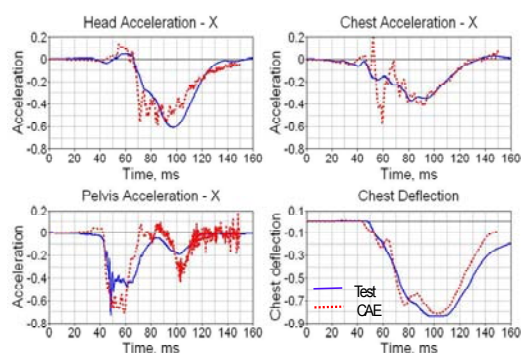


Figure 23b. Sled airbag test results

6. Model Summary

Thin parts are modeled with 3-node and/or 4-node shell elements S3(S3R), S4R and some thin parts are modeled with continuum shell elements, SC6R and SC8R, which are better in coping with bending situation with only one layer of the elements than the shell elements. All block parts are modeled with 3D solid elements, C3D4, C3D6 and C3D8R. For the above mentioned elements, only linear, reduced integration elements are available in Abaqus/Explicit. The cable parts are modeled with the truss elements, T3D2. All loadcells are modeled with connector elements of type CARTESIAN and CARDAN. The revolute joints are model with the connector element of type HINGE and the spherical joints are simulated with the connector element of type JOIN and CARDAN. All accelerometers are built with the connector elements of type ACCELEROMETER.

There are total 64300 nodes and 58444 elements in H350 dummy model. Table 1 lists a mass comparison of different dummy parts between the CAE dummy and the physical dummy for H350. The dummy instrumentation is tabled in Table 2.

Table .1 Mass comparison

Assembly	Mass, kg	
	Physical dummy	Abaqus dummy
Head assembly	4.54±0.05	4.522
Neck assembly	1.54±0.05	1.366
Upper torso with jacket	17.19±0.36	16.65
Lower torso assembly	23.04±0.36	23.87
Upper leg assembly, left	5.99±0.09	6.772
Upper leg assembly, right	5.99±0.09	6.772
Low leg assembly, left	5.44±0.14	6.066
Low leg assembly, right	5.44±0.14	6.065
Upper arm assembly, left	2.00±0.05	1.979
Upper arm assembly, right	2.00±0.05	1.977
Lower arm/Hand, left	2.27±0.09	2.365
Lower arm/Hand, right	2.27±0.09	2.365
Total dummy weight	77.70±1.18	77.65

Table 2. Dummy instrumentation

Location	Instrumentation	Connector Element
Head	Accelerometer (1)	ACCELEROMETER
Neck	Loadcell - upper (1)	CARTESIAN, CARDAN
	Loadcell - lower (1)	CARTESIAN, CARDAN
Thorax	Accelerometers (3)	ACCELEROMETER
	Loadcell (1)	CARTESIAN, CARDAN
	Rotational meter (1)	CARDAN
Lumbar spine	Loadcell (1)	CARTESIAN, CARDAN
Pelvis	Accelerometers (3)	ACCELEROMETER
Upper legs	Loadcells - Left (2)	CARTESIAN, CARDAN
	Loadcells - Right (2)	CARTESIAN, CARDAN
Lower legs	Loadcells - Left (2)	CARTESIAN, CARDAN
	Loadcells - Right (2)	CARTESIAN, CARDAN
Knee	Loadcells - Left (2)	CARTESIAN, CARDAN
	Loadcells - Right (2)	CARTESIAN, CARDAN
Foot	2 Accelerometers	ACCELEROMETER

7. Conclusions

An Abaqus family of HIII dummies has been successfully developed following a rigorous development procedure. This procedure includes a series of stringent validation tests, ranging from material level, component level to full dummy level. Based on the validation results for the H350 dummy shown in this paper, the dummies are capable enough to be used in front impact analysis for the purpose of vehicle/occupant safety, though there is room for further improvement. All three HIII dummies have been successfully used in the automobile industry.

8. ACKNOWLEDGEMENT

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9. REFERENCES

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Notes: All curves in this paper are normalized.