Development of LSTC WorldSID Dummy Finite Element Model (50th Percentile Male)

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Abstract

A finite element model in LS-DYNA® of the WorldSID 50th Percentile Male Dummy has been developed by the Center for Collision Safety and Analysis at George Mason University (CCSA – GMU) in collaboration with Livermore Software Technology Corporation (LSTC). The dummy parts have been meshed and were assembled based on the dummy 2-D and 3-D drawings that the World Side Impact Dummy (WorldSID) Task Group designed and approved under the direction of the International Organization for Standardization (ISO), Road Vehicles technical committee (ISO/TC22/SC12/WG5).

The dummy model consists of six main assemblies: head, neck, torso (thorax, abdomen, & shoulder), pelvis, half arms, and legs. Each part was positioned and connected to its adjacent parts based on the connection detailed in the drawings. Some parts were modeled with rigid bodies and others were assigned the appropriate deformable material properties.

The assembled dummy model was setup according to the certification specification and was given the initial conditions specified in the tests. The simulations were performed using LS-DYNA and compared to physical dummy test curves. There are seven calibration tests: Head drop test; Neck pendulum test; Shoulder pendulum test; Thorax with half arm pendulum test; Thorax without half arm pendulum test; Abdomen pendulum test; and Lumbar spine and pelvis pendulum test. The first two tests were component tests while the others were full dummy tests.

The overall results from all the calibration tests were satisfactory and the WorldSID finite element dummy beta version was released on the LSTC website. Additional validations will follow in the future based on sled and full-scale crash tests when available.

Introduction

Crash test dummies, also called Anthropomorphic Test Devices (ATD), are used as surrogates to human beings in crash testing. They are life-size mannequins that simulate human bodies with similar weight proportions and body articulations. They are instrumented to dynamically measure data during the test, such as forces, moments, and accelerations. The data is then interpreted to predict injury probabilities and threatening conditions. There are a large variety of crash test dummies available for different human sizes and shapes and for specific crash modes, such as frontal, side, or rear impacts.

The high cost of crash test dummies and crash testing as a whole in comparison to the cost effectiveness and the reliability of Computer Aided Engineering (CAE) has paved the way for the use of computer modeling to simulate real crash tests. CAE has become a standard practice in many industries, including the automotive industry, since simulations offer timely, predictive tools in product design and assessments. This has increased the desire to develop finite element (FE) models for the use by the industries. Additionally, LS-DYNA is a leading commercial general-purpose multi-physics finite element program capable of simulating complex real world problems developed by Livermore Software Technology Corporation (LSTC) [1].

LSTC is developing many crash test dummy models in-house and in collaboration with partners to support LS-DYNA users in various fields. LSTC models are available free of charge to licensees of LS-DYNA who are current with their annual license fees (Annual License) or maintenance fees [2].

The Center for Collision Safety and Analysis (CCSA) researchers at George Mason University, in collaboration with LSTC, have been developing a family of detailed Hybrid III ATD LS-DYNA FE models. In this paper, CCSA and LSTC are presenting the World Side Impact Dummy (WorldSID) 50th percentile adult male FE model.

For side impacts, the WorldSID dummy was developed according to International Standard Organization (ISO) road vehicles technical committee (ISO/TC22/SC12/WG5) that began in 1997 and was funded by a worldwide consortium. The goal was to achieve harmonization via the use of the same dummy in all worldwide markets [3]. The WorldSID 50th percentile adult male dummy was put in production in 2004.

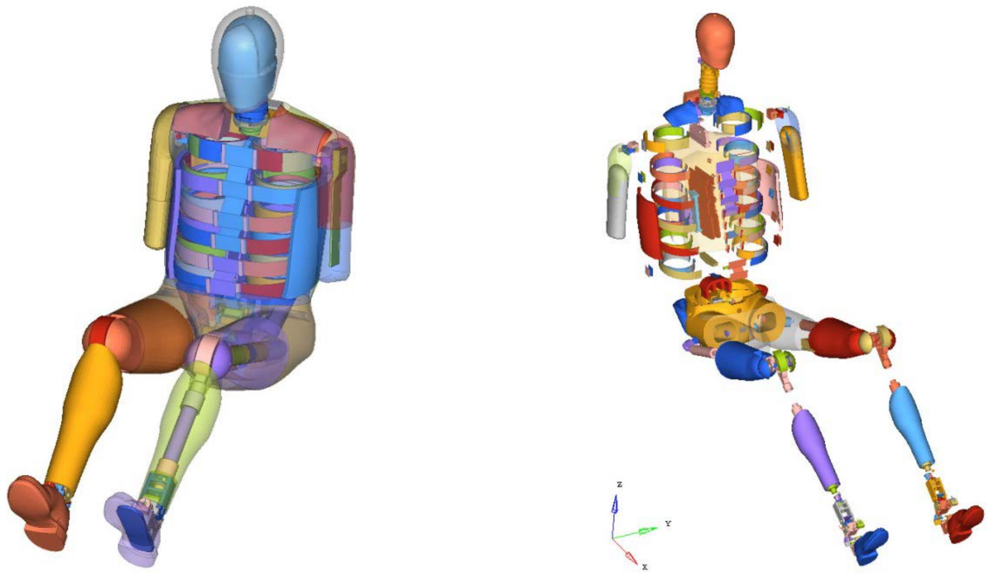
Dummy Model Description

The WorldSID model was developed from 2-D and 3-D drawing packages. Each dummy component was modeled explicitly to guarantee the proper mass distribution and contact interaction. The mesh was generated using TrueGrid meshing software [4]. A uniform mesh size is used to ensure good dummy interface within its components and its surroundings, such as the restraints and the vehicle interiors. Some parts were modeled with rigid material properties, while others were assigned appropriate deformable material properties. The mass comparison of major parts in the model and the physical dummy are listed in Table 1 [5]. The model was assembled using joints and different connections based on the detailed drawings. The accurate geometry, connections, and proper material properties replicate the behavior of their physical dummy counterparts.

Table 1 – Mass specification and FE model values comparison [5]

Part	**Specification [Kg]**	**Mass [Kg]**
Head	4.22 ± 0.05	4.22
Neck	3.23 ± 0.15	3.29
Thorax/abdomen/shoulder	20.55 ± 1.0	20.09
Half arms (Right or Left)	1.77 ± 0.09	1.86
Lumbar spine and pelvis	17.75 ± 0.90	17.07
Upper legs (Right or Left)	6.71 ± 0.30	6.81
Lower leg, ankle, and foot (Right or Left)	5.09 ± 0.13	5.19
Clothing / Skin	1.85 ± 0.09	1.90
Total	**74.88 ± 3.74**	**74.26**

The dummy model consists of six main assemblies: head, neck, torso (thorax, abdomen, & shoulder), pelvis, half arms, and legs. The WorldSID model fully assembled and in exploded view is shown in Figure 1. The metal parts that can be assumed as non-deformable are modeled as rigid material, type 20, and the deformable metals are modeled as elastic material, type 1, in LS-DYNA. The dummy ribs, skin, shoes, and other parts are made of elastic material, type 1. Rubber materials are modeled as plastic kinematic material, type 3. The dummy thorax rib dampers, pelvis and dummy head cover are modeled as visco-elastic material, type 6. Both shoulder and thorax pads and the leg flesh are modeled as low density foam, type 57. The neck and half arms are modeled as viscous foam material, type 62. The lumber spine rubber is modeled as simplified rubber/foam material, type 181. The total number of parts is 266 and the total number of elements is 430,553. The time step used in the model is 1 microsecond. To simulate 60 millisecond simulation using 16 nodes of Intel-MPI 3.2.2 Xeon64 processor on Linux operating system, the computer clock time was 30 minutes. LS-DYNA mpp version R6.1.2 Revision 85139 was used.



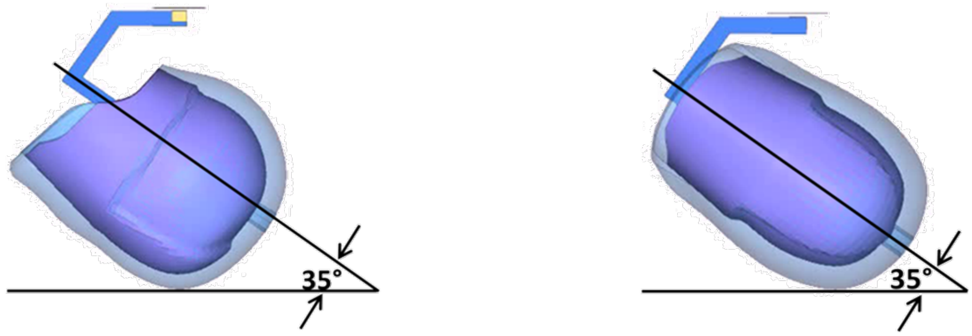
Isometric view **Exploded view**

Figure 1 – WorldSID FE model

Dummy Model Calibration

There are two drop test and six pendulum test requirements for the WorldSID certification. These consist of two head drop tests and pendulum tests of neck, shoulder, thorax with half arm, thorax without half arm, abdomen, and pelvis [6]. The head and neck tests are component level tests, while the rest of the tests are performed with a fully assembled dummy. The FE simulation results of the calibration tests are compared to WorldSID dummy calibration data published by the National Highway Traffic Safety Administration (NHTSA). All relevant curves were digitized in order to be used for comparison in this section. The physical dummy ID is ISO 15830-2 Serial No. 14. The physical dummy's calibration certificate (cert. # 11) was performed by Transportation Research Center, Inc. for NHTSA test V08344 (TRC test # 120815) [7].

Head Drop Test – The dummy head certification test requires a free drop of the head assembly onto a rigid surface from a height of 376 mm for the forehead (front) drop test and 200 mm for the lateral drop test. The initial drop angle for the frontal drop test is 35° with the impact surface. The lateral drop test initial angle measured from the midsagittal plane with the impact surface and its anterior-posterior axis is 35° [6]. Figure 2 shows the initial drop conditions at impact for each test. The peak resultant and lateral accelerations met their corresponding requirements and the values are summarized in Table 2 for both tests.



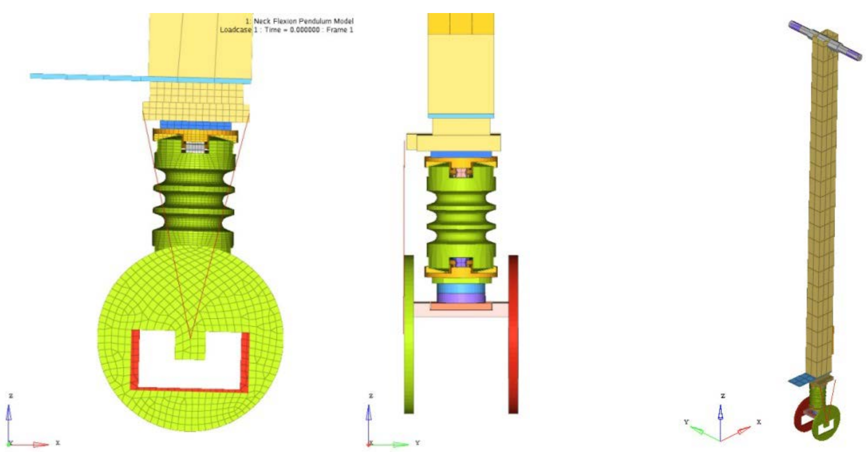
Frontal head drop angle **Lateral head drop test**

Figure 2 – Head drop angle tests

Table 2 – Frontal and lateral head drop tests summary results

	Variable	Requirements	Simulation
Frontal head drop test	Peak resultant acceleration frontal [g]	225 to 275	226.2
	Peak lateral acceleration (average) [g]	< 15	<1
	Maximum percentage, subsequent-to-main peak[%]	<10	<1
Lateral head drop test	Peak resultant acceleration frontal [g]	99 to 121	118.6
	Peak lateral acceleration (average) [g]	<15	<1
	Maximum percentage, subsequent-to-main peak [%]	<10	<1

Neck Lateral Pendulum Test – The neck certification test is a lateral pendulum test. The velocity at impact is 3.4 m/s and the pendulum is stopped by an aluminum honeycomb with a density of 28.8 kg/m3 and dimensions of 102.0 mm × 102.0 mm × 76.2 mm. Figure 3 shows the neck assembly and the full pendulum setup. The pendulum acceleration and velocity, the occipital neck moment, and the headform flexion, forward and rear rotations are compared in Figure 4. The pendulum, neck, and headform results met their corresponding requirements except for the peak occipital condyles moment decay to zero which is above the peak range by 2.99%. The values are summarized in
Table 3.



Neck assembly **Neck full arm pendulum**

Figure 3 – Neck pendulum FE model setup

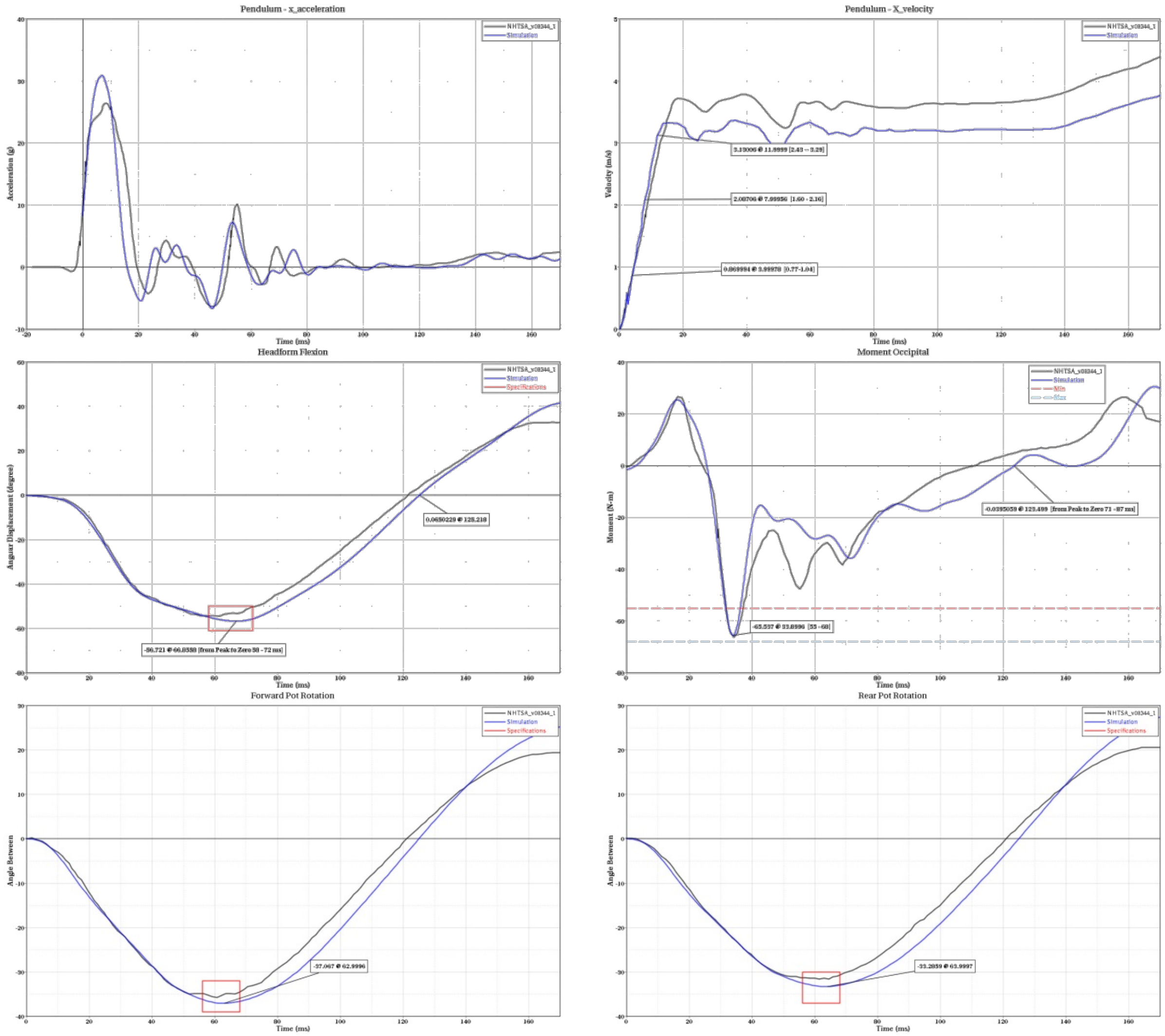
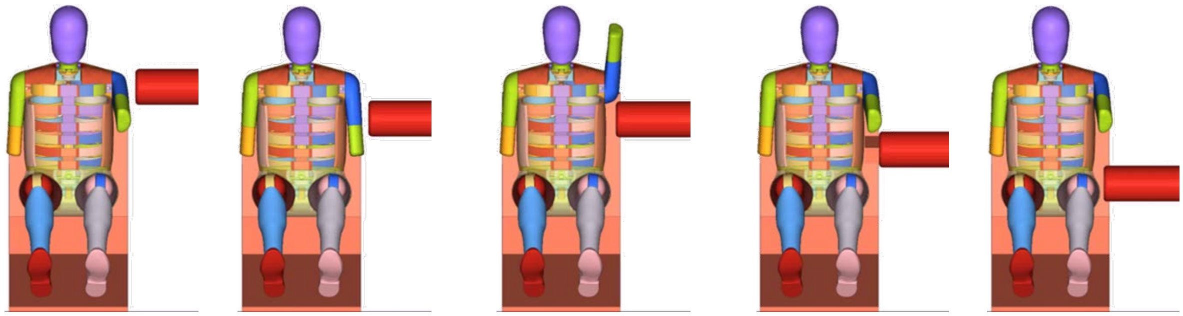


Figure 4 – Neck and headform pendulum test curves comparison

Table 3 – Neck pendulum test summary results

Variables	Requirements	Simulation
Pendulum Velocity change at 4 ms [m/s]	0.77 to 1.04	0.870
Pendulum Velocity change at 8 ms [m/s]	1.6 to 2.16	2.087
Pendulum Velocity change at 12 ms [m/s]	2.43 to 3.29	3.130
Max headform flexion angle, beta [degree]	50 to 61	56.7
Decay time of peak headform flexion to 0 degrees [ms]	58 to 72	58.4
Peak occipital condyles moment [Nm]	55 to 68	65.5
Peak occipital condyles moment decay to zero [ms]	71 to 87	89.6
Peak forward potentiometer ang disp [degree]	32 to 39	37.1
Time for peak forward potentiometer angular disp [ms]	56 to 68	63.0
Peak rearward potentiometer ang disp [degree]	30 to 37	33.3
Time for peak rearward potentiometer angular disp [ms]	56 to 68	64.0

The pendulum tests of the shoulder, thorax with half arm, thorax without half arm, abdomen, and pelvis are performed with a fully assembled dummy, as shown in Figure 5.



a- Shoulder | **b- Thorax with half arm** | **c- Thorax without half arm** | **d-Abdomen** | **e- Pelvis**

Figure 5 – Fully assembled dummy pendulum tests

Shoulder Pendulum Test – The shoulder certification test is a pendulum test that uses the 49 CFR Part 572, subpart E Hybrid III 50th percentile adult male dummy pendulum that weighs 23.4 kg and has a 152.4 mm face diameter. The full dummy is used in this test and it is seated on a test bench covered by Teflon sheets. The pendulum centerline impacts the centerline of the shoulder at 4.3 m/s, as shown in Figure 5a. The pendulum force and the shoulder rib intrusion are compared in Figure 6. The pendulum and shoulder rib results met their corresponding requirements and the values are summarized in Table 4.

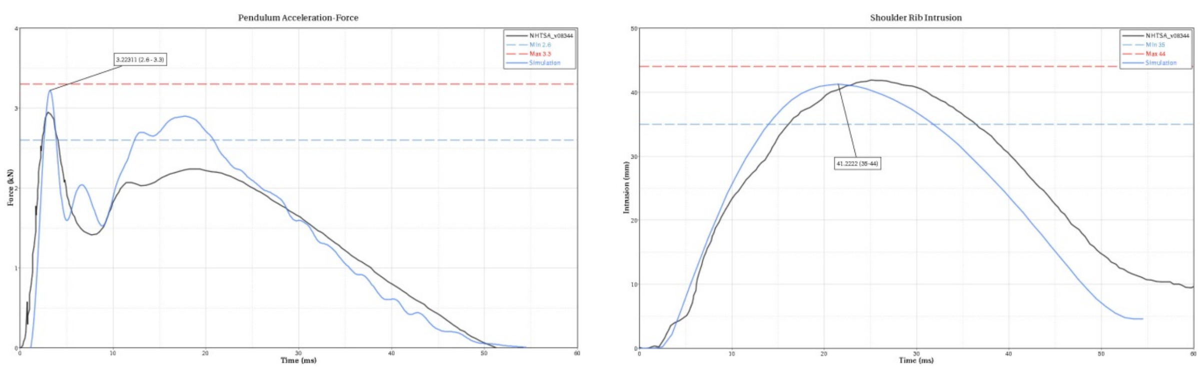


Figure 6 – Shoulder pendulum test curves comparison

Table 4 – Shoulder pendulum test summary results

Variables	Requirements	Simulation
Peak pendulum force [kN]	2.6 to 3.3	3.22
Shoulder rib deflection [mm]	35 to 44	41.2

Thorax with Half Arm Pendulum Test – The thorax with half arm certification test is a pendulum test that uses the full dummy setup similar to the thorax test. The pendulum centerline impacts the centerline of the middle thorax rib at 6.7 m/s, as shown in Figure 5b. The pendulum force, the upper and lower spine accelerations (T4 & T12, respectively), and the thorax ribs intrusion are compared in Figure 7. The pendulum, spine and thorax ribs results met their corresponding requirements except for the lower spine acceleration and the thorax rib 1 deflection which are above the peak range by 16% and 0.2 %, respectively. The values are summarized in Table 5.

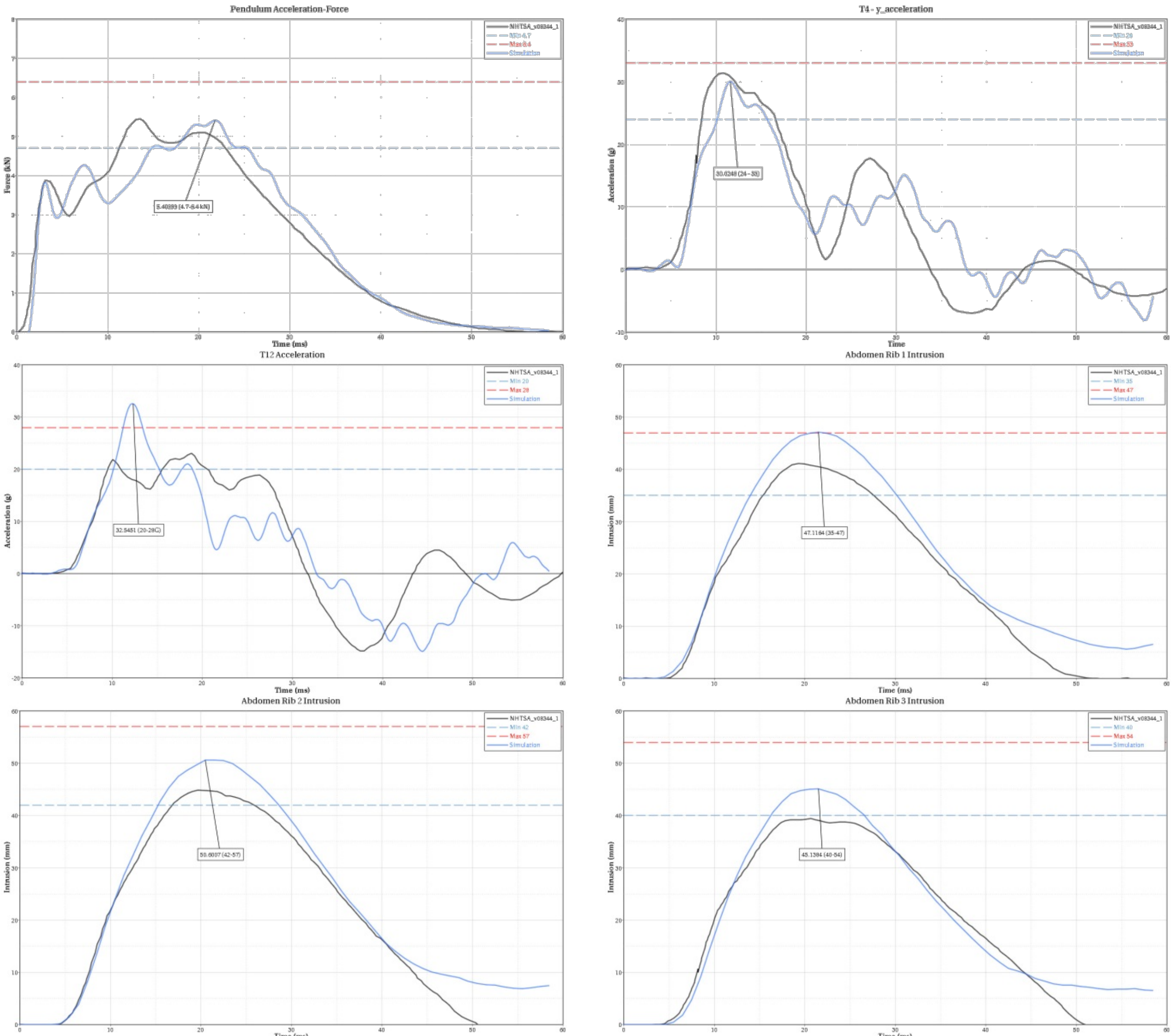


Figure 7 – Thorax with half arm pendulum test curves comparison

Table 5 – Thorax with half arm pendulum test summary results

Variables	Requirements	Simulation
Pendulum force [kN]	4.7 to 6.4	5.41
Peak T4 acceleration [g]	24 to 33	30.0
Peak T12 acceleration [g]	20 to 28	32.5
Peak thorax rib 1 deflection [mm]	35 to 47	47.1
Peak thorax rib 2 deflection [mm]	42 to 57	50.6
Peak thorax rib 3 deflection [mm]	40 to 54	45.1

Thorax without Half Arm Pendulum Test - The thorax without half arm certification test is a pendulum test that uses the full dummy setup similar to the thorax test while the half arm is rotated out of the way, as shown in Figure 5c. The pendulum centerline impacts the centerline of the middle thorax rib at 4.3 m/s. The pendulum force, the upper and lower spine accelerations (T4 & T12, respectively), and the thorax ribs intrusion are compared in Figure 8. The pendulum, spine and thorax ribs results met their corresponding requirements and the values are summarized in Table 6.

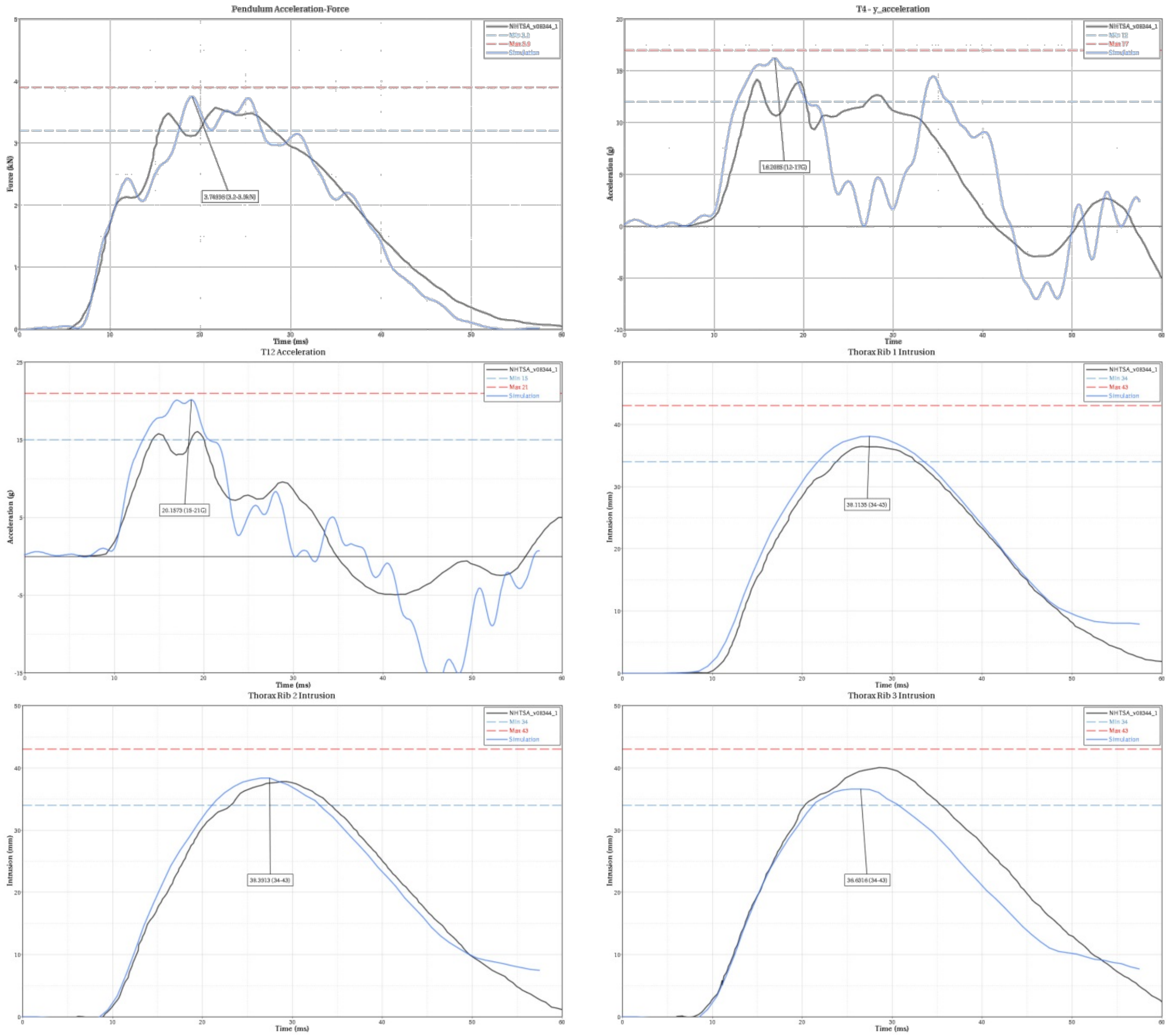


Figure 8 – Thorax without half arm pendulum test curves comparison

Table 6 – Thorax without half arm pendulum test summary results

Variables	Requirements	Simulation
Pendulum force [kN]	3.2 to 3.9	3.75
Peak T4 acceleration [g]	12 to 17	16.2
Peak T12 acceleration [g]	15 to 21	20.2
Peak thorax rib 1 deflection [mm]	34 to 43	38.1
Peak thorax rib 2 deflection [mm]	34 to 43	38.4
Peak thorax rib 3 deflection [mm]	34 to 43	36.6

Abdomen Pendulum Test - The abdomen certification test is a pendulum test that uses the full dummy setup similar to the thorax test. The pendulum and a wood block impact in between the two abdomen ribs at 4.3 m/s, as shown in Figure 5d. The pendulum force, the lower spine accelerations (T12), and the abdomen rib intrusions are compared in Figure 9. The pendulum, spine and thorax ribs results met their corresponding requirements except for the pendulum force which is above the peak range by 6.7%. The values are summarized in Table 7.

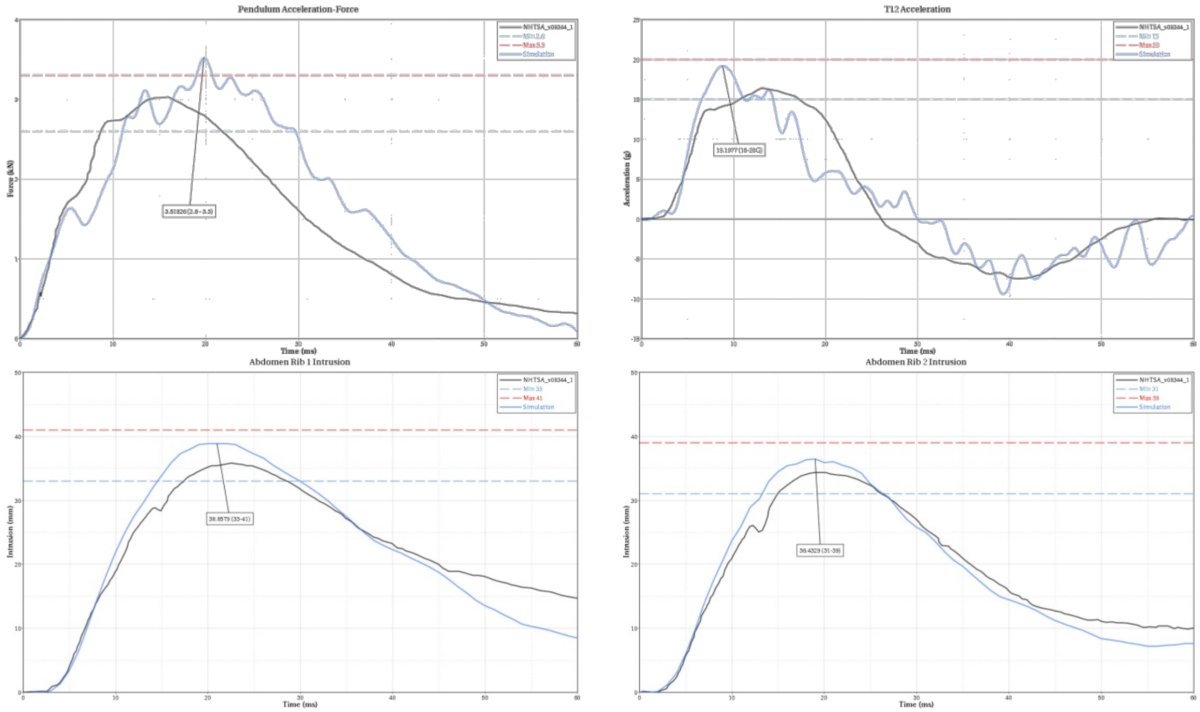


Figure 9 – Abdomen pendulum test curves comparison

Table 7 – Abdomen pendulum test summary results

Variables	Requirements	Simulation
Pendulum force [kN]	2.6 to 3.3	3.52
Peak T12 Y-acceleration [g]	15 to 20	19.2
Peak abdomen rib 1 deflection [mm]	33 to 41	38.9
Peak abdomen rib 2 deflection [mm]	31 to 39	36.4

Pelvis Pendulum Test - The pelvis certification test is a pendulum test that uses the full dummy setup similar to the thorax test. The pendulum centerline impacts the centerline of the H-point at 6.7 m/s, as shown in Figure 5e. The pendulum force, the pelvis and lower spine accelerations (T12) are compared in Figure 10. Despite the simulation curves being not precisely matching the physical dummy calibration tests, the pendulum, pelvis and spine results met their corresponding requirements and the values are summarized in Table 8.

Table 8 – Pelvis pendulum test summary results

Variables	Requirements	Simulation
Pendulum force [kN]	6.3 to 7.8	7.33
Peak acceleration along y axis [g]	41 to 51	44.8
Peak T12 Y-acceleration [g]	10 to 14	11.9

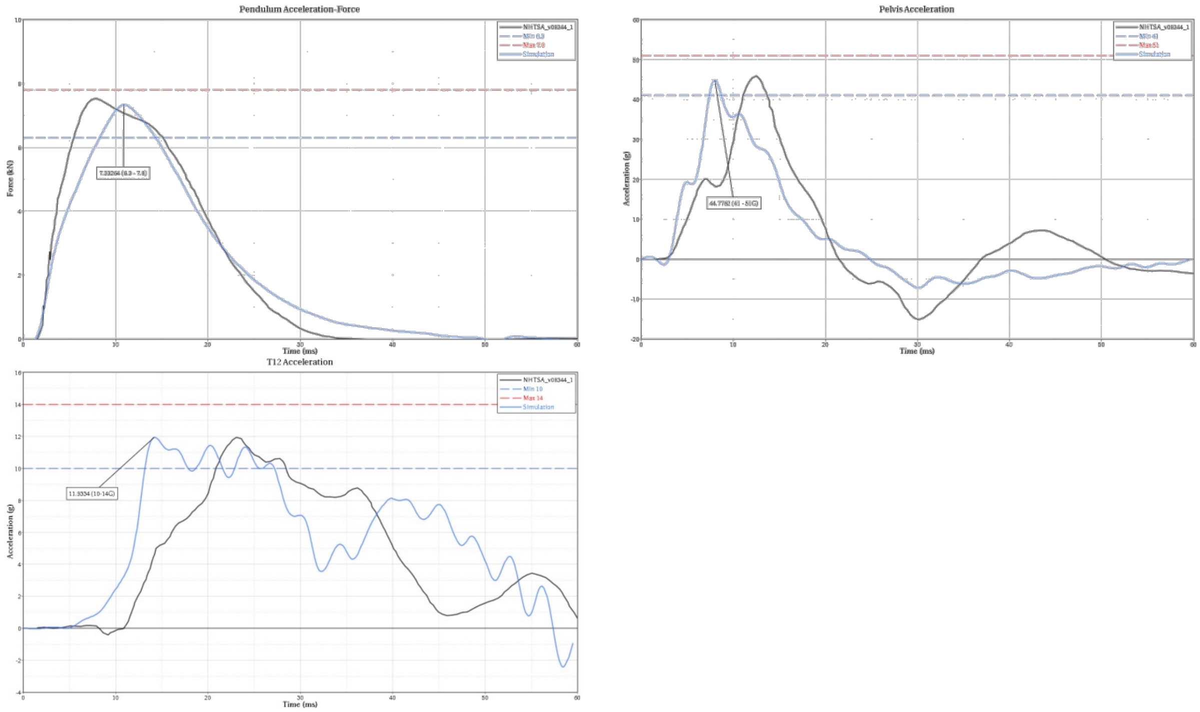


Figure 10 – Pelvis pendulum test curves comparison

Summary

A finite element model of the WorldSID 50th Percentile Male Dummy based on ISO task group design has been developed and validated. All the dummy parts were meshed, positioned, and connected to build the full FE dummy model. Some parts were modeled with rigid bodies and others were assigned the appropriate materials and optimized in order to match the corresponding experimental certification tests data. The model shows reliably good correlation to the calibration tests. Additional sled test simulations are under consideration for future releases and if any full-scale crash tests for an available vehicle model become obtainable, the data will be used to further validate the WorldSID FE model.

Acknowledgements

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