Investigation of WorldSID-50M FE model response variation in shoulder, thorax without arm, and abdomen qualification simulations from thorax CG variation

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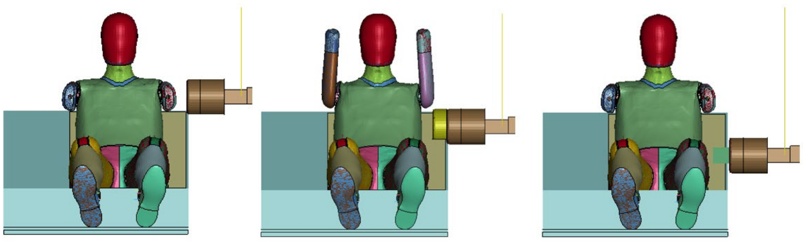
I. INTRODUCTION

The WorldSID-50M anthropomorphic test device (ATD) can be configured with multiple different onboard data acquisition systems (DAS), each of which may alter the thorax CG properties. The purpose of this research is to determine the effect on the dummy's responses caused by potential movement of the thorax CG due to different DAS. The current recommended tolerance for the center of gravity (CG) location of the thorax region of the WorldSID-50M ATD is ± 2.5 mm [1]. NHTSA research with the WorldSID-50M ATD has primarily utilized the G5 DAS. Due to the possibility of utilization of the WorldSID-50M ATD with different DAS in the future and a lack of current experimental data, the current study aimed to 1. investigate qualification response variation with thorax CG variation in 5 mm increments from 0 mm (baseline) to ±10 mm in 3D space after an initial validation effort for the baseline thorax CG location through a finite element (FE) modeling approach, and 2. identify the coordinate axis along with the associated increment which contributed most to the response variation through a statistical approach. The WorldSID-50M FE model used in the current study has been previously validated in the qualification simulations [2].

II. METHODS

The WorldSID-50M v8.1 FE model was positioned on the qualification test bench model in LS-PrePost v12.0 (Fig. 1a-c) according to positioning procedures in [3]. An initial velocity of 4.3 m/s was provided to the pendulum impactor model. The inertia properties of the ballast part on the right-side spine plates were transferred to a single node located at the CG of the ballast part (Fig. 2a) and the node was constrained to the ballast part. The ballast node was then moved in space to vary the thorax CG location in the neck bracket coordinate system (Fig. 2b). The simulation matrix showing the thorax CG location targets as offsets along each of the coordinate axes (X, Y, Z) with respect to a baseline location (0, 0, 0) is shown in Table 1. The baseline location responses were validated against NHTSA qualification corridors (column 3 - Table 2). The variations in the model peak responses were compared to the corridor widths for the responses (column 4 - Table 2). A multiple regression analysis was setup and run in Minitab with X, Y and Z coordinates as factors (categorical variables) with 5 possible levels: 0, -5, +5, -10, and +10, and the response itself as the dependent variable. A Pareto standardized effect output was generated as a part of the multiple regression analysis for each response to identify the coordinate axis that had the highest relative effect magnitude at a significance level of 0.1 (column 5 - Table 2). The regression model term with the highest T-value was identified as the thorax CG offset along the coordinate axis (identified from Pareto analysis) that contributed the most to response variation at a significance level of 0.1 (column 6 - Table 2).



(a) Shoulder (b) Thorax without arm (c) Abdomen

Fig. 1. Qualification simulation setup.

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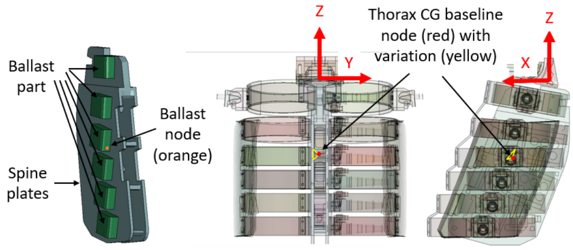

(a) Ballast node development (b) Variation in thorax CG location

Fig. 2. Thorax CG modification through ballast node location update.

Table 1: Simulation matrix.

Thorax CG location	X (mm)	Y (mm)	Z (mm)
Baseline	0	0	0
5NNN	-5	-5	-5
5NNP	-5	-5	+5
5ZNZ	0	-5	0
5ZPZ	0	+5	0
5PZZ	+5	0	0
5NZZ	-5	0	0
5ZZP	0	0	+5
5ZZN	0	0	-5
10NNN	-10	-10	-10
10NNP	-10	-10	+10
10ZNZ	0	-10	0
10ZPZ	0	+10	0
10PZZ	+10	0	0
10NZZ	-10	0	0
10ZZP	0	0	+10
10ZZN	0	0	-10

III. INITIAL FINDINGS

The baseline simulation case resulted in peak responses that were within the corresponding NHTSA corridors. All the response variations except the variation for T12 y-acceleration in the abdomen qualification were lower than the corresponding NHTSA corridor widths. The thorax CG Z-axis location variation contributed the most to the variations in the ATD kinematics and the variation in probe forces was influenced by the thorax CG Y-axis location, as indicated by Pareto standardized effect evaluation. The ± 10 mm thorax CG offsets had a greater effect on response variation than the ± 5 mm thorax CG offsets as indicated by T-values in the multiple regression models (Table 2).

Table 2: Simulation response comparisons with NHTSA corridors and multiple regression analysis outcomes at a significance level of 0.1. S: Shoulder, T: Thorax, A: Abdomen, def.: deflection, acc: acceleration

Qual. Test	Response	FE model – baseline (corridor min-max)	FE model variation (corridor width)	Coordinate axis (Pareto standardized effect)	Thorax CG offset (T-value)
Shoulder	S. rib def. (mm)	39.5 (34.8-42.5)	1.9 (7.7)	Z (17.2)	+10 (18.8)
	y-force (kN)	1.5 (1.5-1.8)	0.05 (0.3)	Z (9.2)	+10 (9.6)
	Probe force (kN)	2.9 (2.6-3.2)	0.04 (0.6)	Y (5.1)	-10 (-5.3)
Thorax w/o arm	T. rib 1 def. (mm)	38.6 (34.1-41.7)	0.8 (7.6)	Z (51.4)	-10 (-49.8)
	T. rib 2 def. (mm)	38.6 (36.5-44.6)	0.2 (8.1)	Z (4.8)	+10 (-6.5)
	T. rib 3 def. (mm)	36.8 (31.6-38.6)	0.7 (7.0)	Z (61.9)	+10 (-58.5)
	Probe force (kN)	3.3 (3.2-3.9)	0.07 (0.7)	Y (3.2)	-10 (-3.5)
Abdomen	A. rib 1 def. (mm)	36.1 (31.3-38.3)	2.1 (7.0)	Z (12.4)	-10 (9.7)
	A. rib 2 def. (mm)	31.6 (31.1-38.0)	2.4 (6.9)	Z (11.6)	-10 (9.6)
	T12 y-acc. (g)	17.2 (15.6-19.0)	4.2 (3.4)	Z (8.8)	+10 (7.1)
	Probe force (kN)	3.1 (2.9-3.5)	0.16 (0.6)	Y (1.9)	-10 (2.9)

IV. DISCUSSION

The T12 y-acceleration variation in the abdomen qualification simulations was likely due to the low peak magnitude and noise of this response post-filtering. An offset in the thorax CG location along the Z-axis either caused mass accumulation or dispersion closer to the impactor depending on the direction of the offset, and possible stiffening or softening of the spine-end of the ribs at the impactor height in the qualification tests. The variation in ATD kinematics was thereby mainly explained through the Z-axis location of the thorax CG in the Pareto standardized effect evaluation. The ± 10 mm thorax CG offsets changed the thorax CG distance from the center of the impactor face more than the ± 5 mm thorax CG offsets, resulting in a greater response variation, also confirmed through the T-values for coefficients in multiple regression models. The Pareto standardized effects for probe forces were much lower than the ATD kinematics, and the variation was explained through the Y-axis location of the thorax CG on the non-impact side. The CG offset of -10 mm possibly reduced the ATD-probe contact interface stiffness, leading to variation in the contact forces in the qualification tests. Although the variation of responses (except T12 y-acceleration) corresponding to all thorax CG offsets were less than the NHTSA corridor widths, the statistical analysis indicated that the response variation tended to increase with an increase in the thorax CG offset along the Z- and the Y-axes for the qualification tests. The ATD manufacturers should thereby exercise caution when switching to an onboard DAS that varies the thorax CG more than 10 mm.

V. REFERENCES

[1] WSID 50th ISO task group, WorldSID.org, 2020

[2] Stahlschmidt *et al.*, WorldSID 50th – v8.1 user's manual, 2024.

[3] Rhule, DOT tech. report, 2024