Design and Implementation of a New Biofidelic ATD Neck for Rear Impacts

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INTRODUCTION

- Current anthropomorphic test device (ATD) necks lack biofidelity, especially in rear impact scenarios. [1,2]

- Biofidelity is the ability of an ATD to produce a humanlike response in an experimental scenario.

- The most popular ATD, the Hybrid III, is too stiff. It Is also designed for frontal impacts, although a regulation permits its use for simulated rear impacts. [1,2,7]

- A neck that has been identified as biofidelic, the BioRID II, has a major limitation in that it only permits one kinematic degree of freedom: rotation in the sagittal plane. [3,4]

- The purpose of this study was to design a neck that retains biofidelity while also allowing for more degrees of freedom. Doing so will ultimately improve the tools with which we design safety features in automobiles such as head restraint systems.

DESIGN & FABRICATION

Figure 1: Final neck design
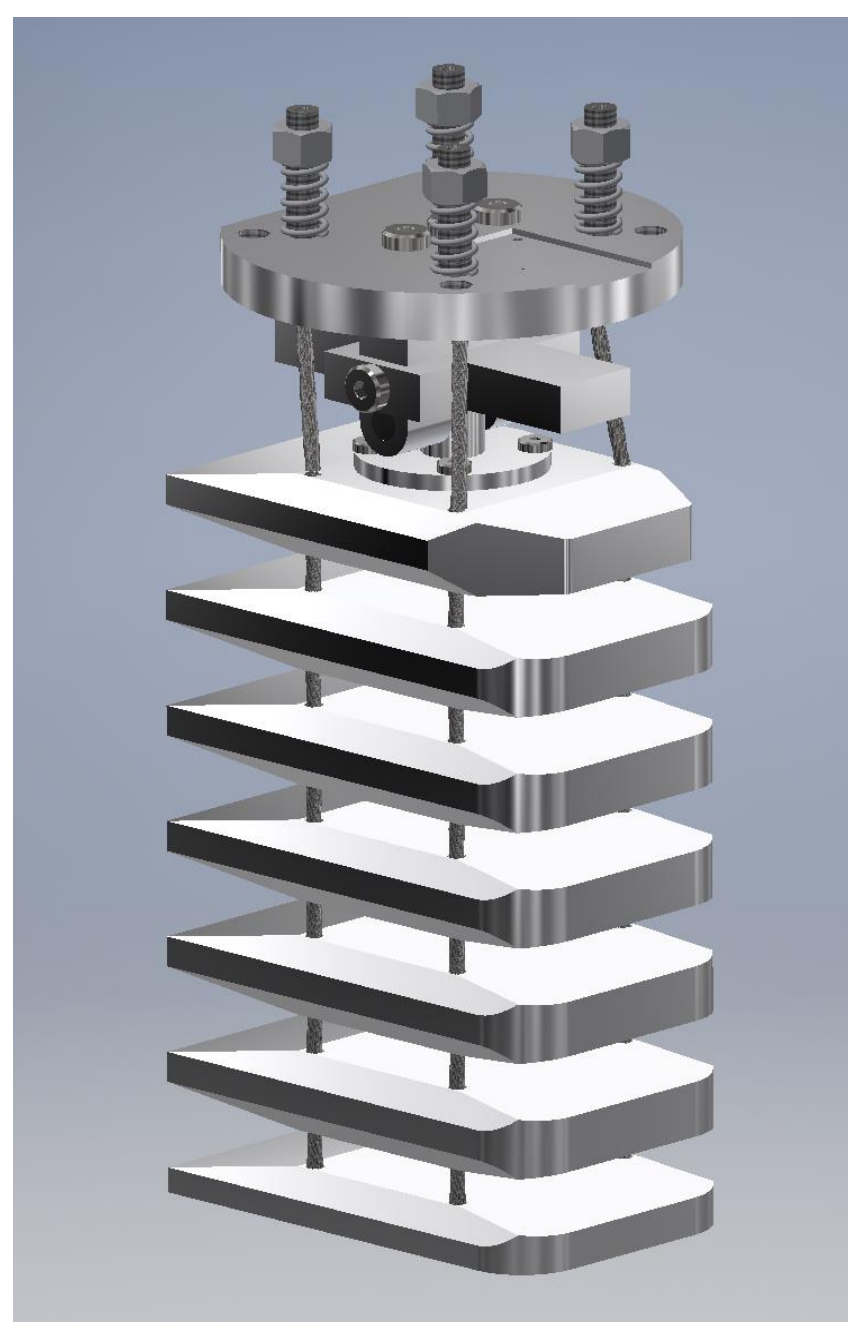
- The vertebral bodies are made of aluminum because it is lightweight, machinable, and durable.

- Polymer damping components are placed in-between vertebral pairs to control flexion and extension kinematics.

- Spherical joints utilized to mate each vertebral body and permit three degree-of-freedom of movement.

- 18-8 stainless steel wire ropes (1/8" diameter), two anterior and two posterior, give the neck structural support and help to control and stabilize the kinematics.

- Hinge joint between C2 and C1 replicates realistic atlantoaxial rotation of upper cervical spine joints of the same kind, while the occipital condyle joint allows movement of the skull with respect to the spine.
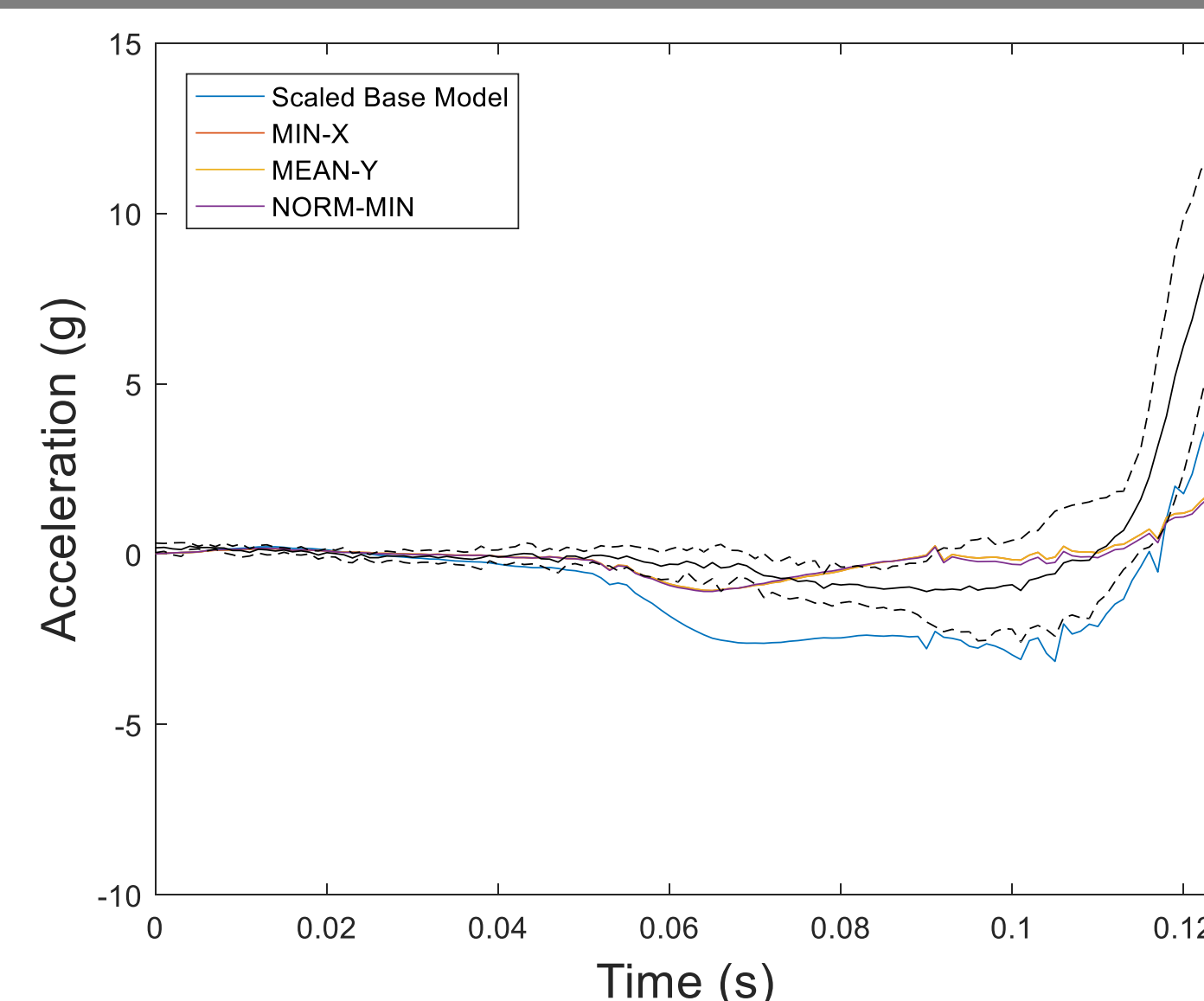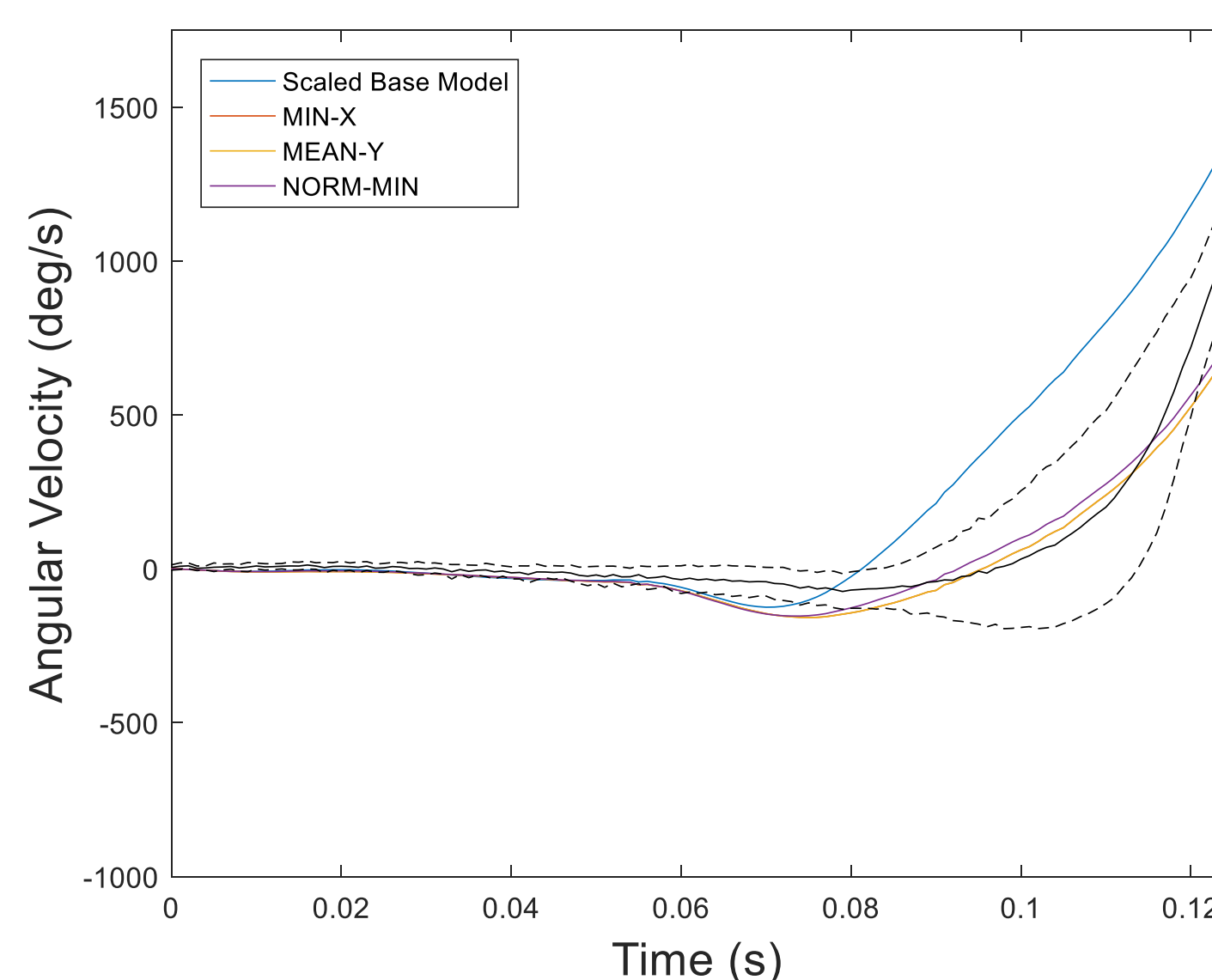
VIRTUAL MODEL OPTIMIZATION

Figure 2: X acceleration PMHS corridor [6]

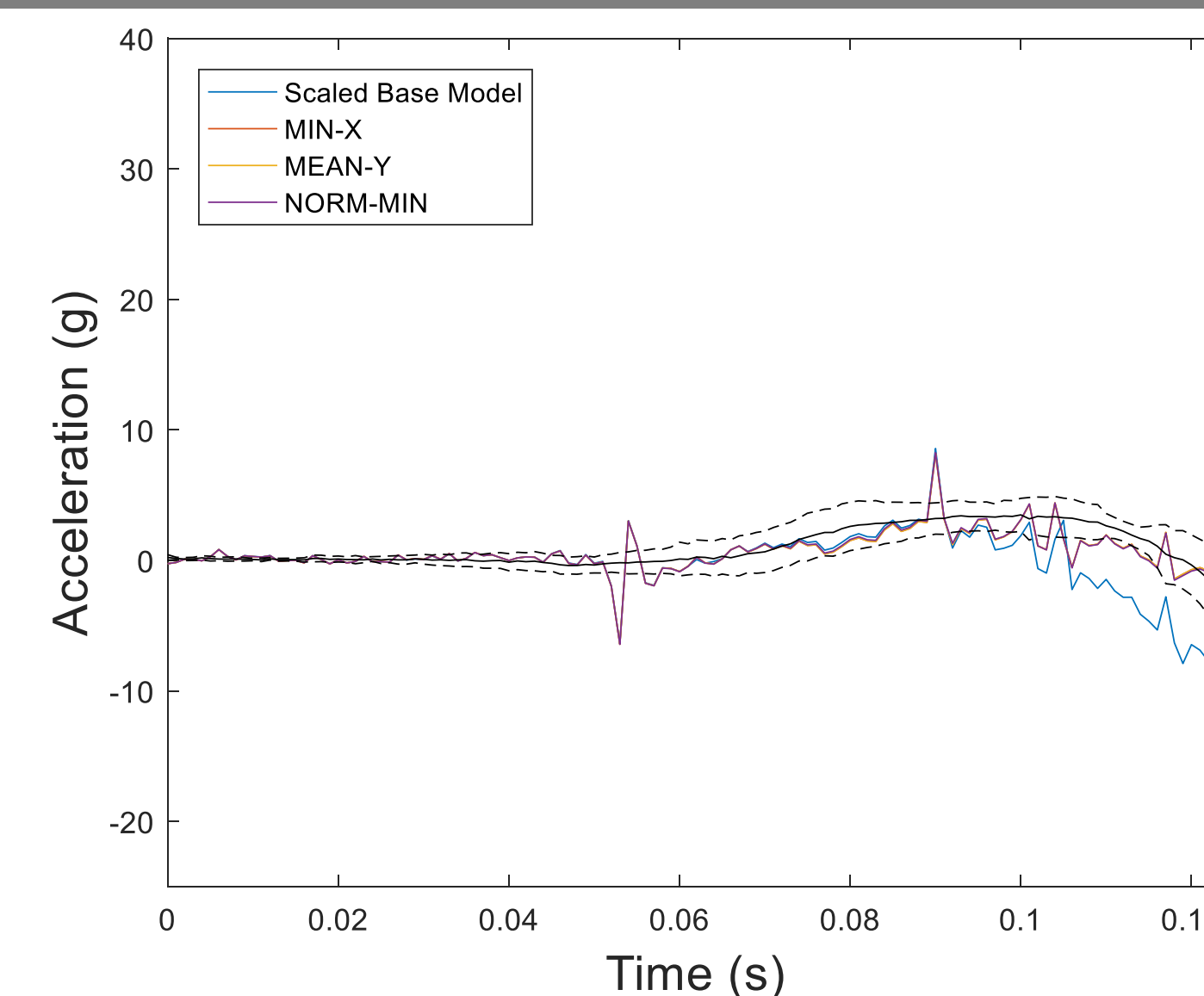**Figure 3:** Z acceleration PMHS corridor [6]

Figure 4: Y angular velocity PMHS corridor [6]

- The neck design was modeled using MSC ADAMS to validate kinematics prior to fabrication of the physical model.

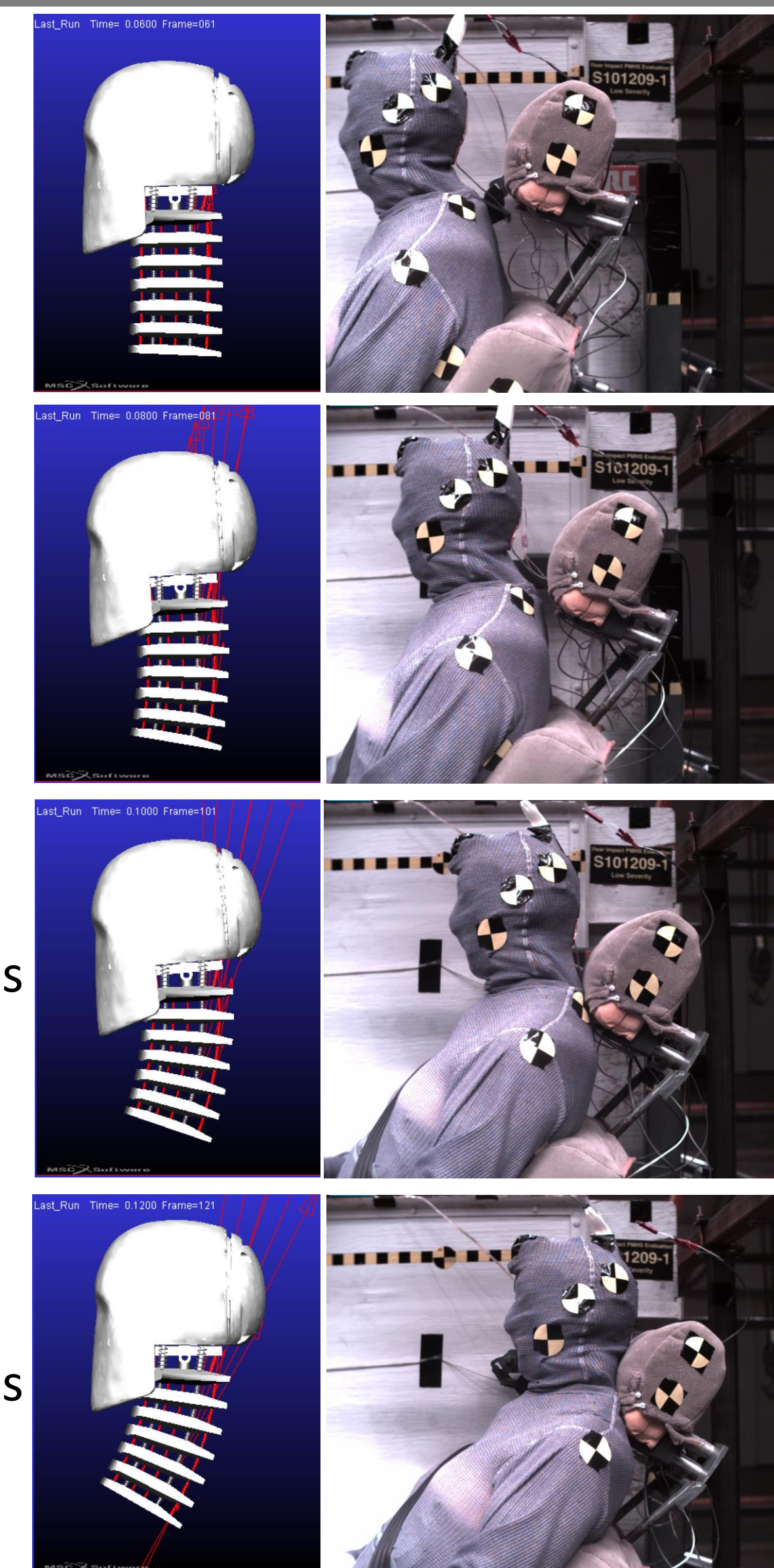Note: Neck response prior to 60 ms showed little flexion/extension

Figure 5: Simulation vs experiment [6]

PHYSICAL MODEL TESTING

- The physical model was testing using a sliding head and neck fixture to simulate a rear impact. [8]

- Fixture allowed for an input in the x direction but no rotational input for the T1 vertebra. The x acceleration input was matched to the input to T1 from the previous PMHS study. [6]

- Biofidelity evaluation will be reserved for when a rotational input can be incorporated as an input into the mini-sled setup.

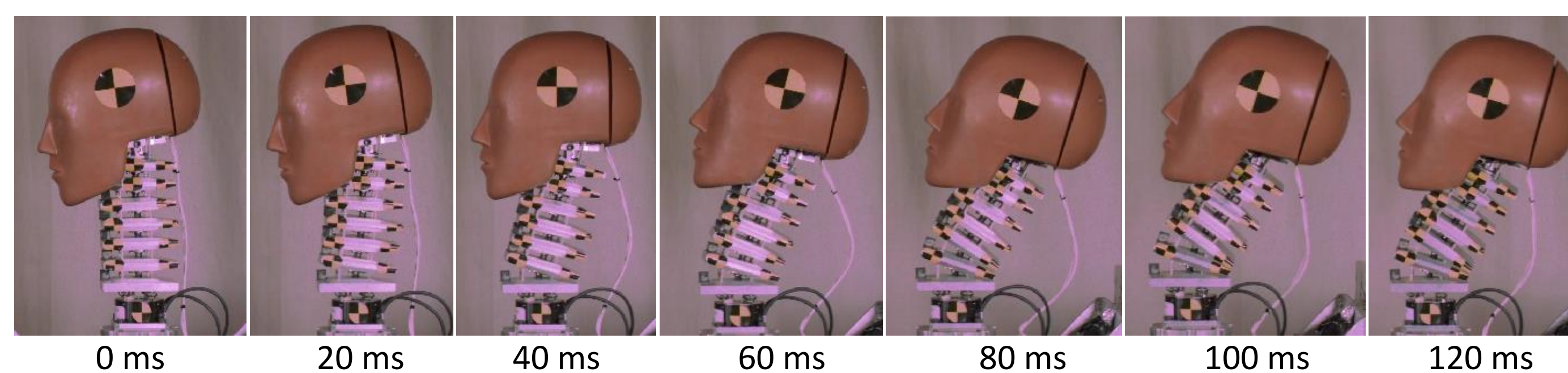- Tests were evaluated for repeatability for each measured parameter across five trials.
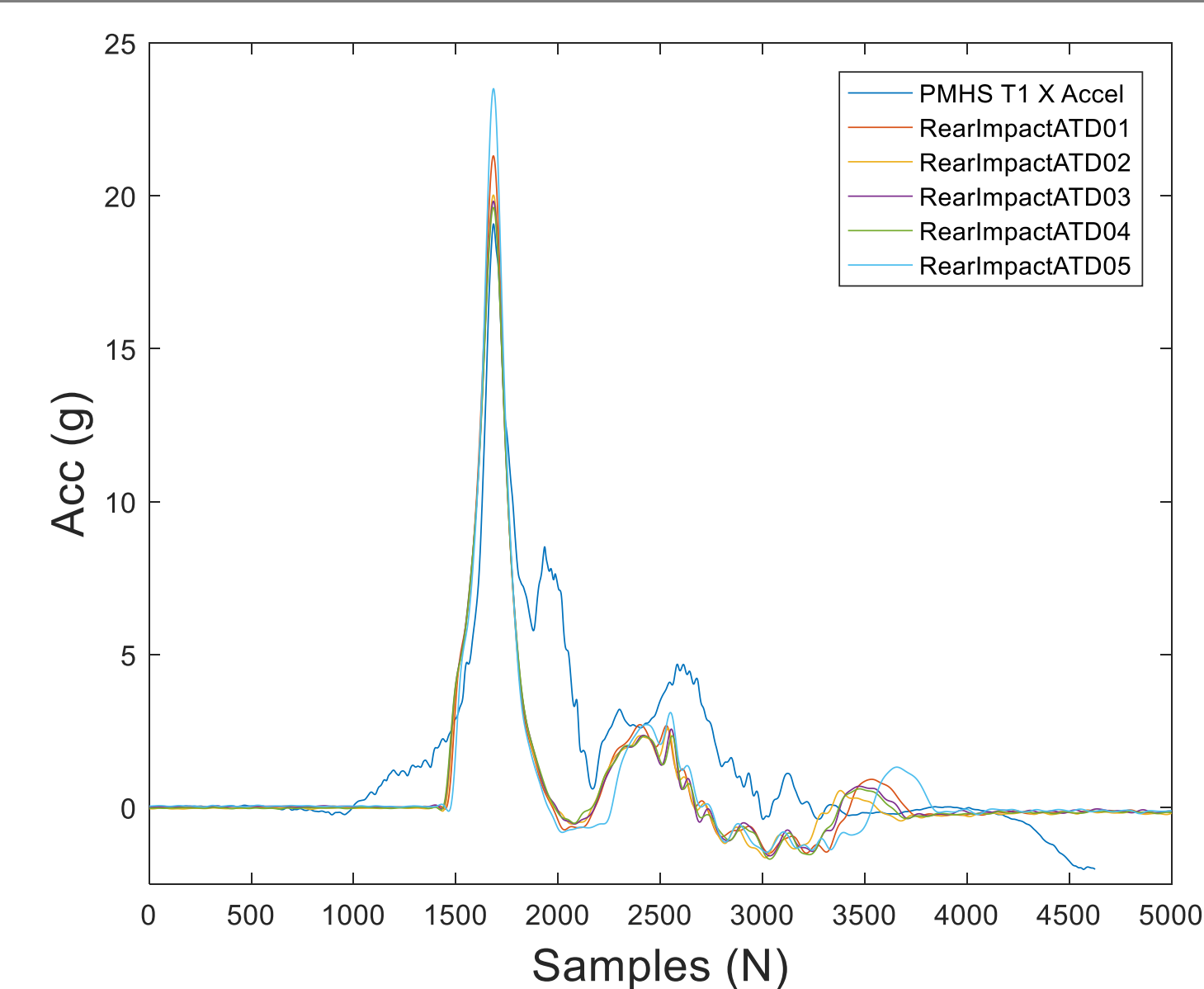

Figure 6: Physical model test input

0 ms   20 ms   40 ms   60 ms   80 ms   100 ms   120 ms

Figure 7: Physical model test

Table 1: Coefficient of variation of physical testing parameters [9]

Response	Coefficient of Variation (%)
X Acceleration	4.64
Z Accelertation	7.29
Y Rotational Velocity	1.21

RESULTS & DISCUSSION

Table 2: Biorank of three best simulations and the baseline simulation against average PMHS response

Optimization	Biorank a_x	Biorank a_z	Biorank ω_y	Average Biorank
BASE-SCALED	1.635	1.425	1.767	1.609
MIN-X	0.838	0.815	0.613	0.755
MEAN-Z	0.897	0.791	0.504	0.731
NORM-MIN	0.898	0.782	0.510	0.730

- Biorank of less than 1 indicates that response is, on average, less than one standard deviation from the mean PMHS response.

$$BR = \frac{\sum_{i=1}^{n} |x_{i,model} - x_{i,avgPMHS}|}{\sum_{i=1}^{n} x_{i,stdPMHS}}$$

- Resulting optimized stiffness from the simulation can be used in the physical model by varying the stiffness of the polyurethane damping components.

- Physical testing showed repeatability within 10% (based on maximum parameter value).

CONCLUSIONS

- Modeling the neck design using ADAMS shows the design is biofidelic, allowing for the continuation into the next phase of design validation.

- A neck design allowing for multi DOF, biofidelic kinematics was successfully designed and preliminarily validated.

- Future work will include further refinement of the physical model by adjusting the polyurethane dampers. Also, the fixture should be modified so that a rotational input about the y axis can be applied to T1 in order to more accurately reflect both the simulation and PMHS sled tests.

- Because of the improved mobility of the design, work will be done to validate its performance in other types of car collisions that engender a kinematic response outside of the sagittal plane.

- The provision of an improved ATD design has implications to enhance passenger safety systems in vehicles.

REFERENCES CITED

[1] Davidsson, J., Flogard, A., Lovsund, P. and Svensson, M. Y., "BioRID P3 – Design and Performance compared to Hybrid III and Volunteers in Rear Impacts at ΔV=7 km/h," SAE Technical Paper 99SC16, 1999.
[2] Scott, M. W., McConnell, W. E., et al., "Comparison of Human and ATD Head Kinematics During Low-Speed Rearend Impacts," SAE Technical Paper 930094, 1993.
[3] Moorhouse, Kevin, et al. "Evaluation of the Internal and External Biofidelity of Current Rear Impact ATDs to Response Targets Developed from Moderate-Speed Rearend Impacts of PMHS." Stapp Car Crash Journal, 6, 171-229, 2012.
[4] Davidsson, Johan, Svensson, Mats Y et al. "BioRID I – A New Biofidelic Rear Impact Dummy." IRCOBI Conference Paper. 1998.
[5] Yoganandan, N., Kumaresan, S., and Pintar, F.A. "Biomechanics of the cervical spine Part 2. Cervical spine soft tissue responses and biomechanical modeling." Clinical Biomechanics 16(1) pp. 1-27. 2001.
[6] Kang, Yun-Seok, Bolte IV, John H et al. "Biomechanical Responses of PMHS in Moderate-Speed Rear Impacts and Development of Response Targets for Evaluating the Internal and External Biofidelity of ATDs." STAPP Car Crash Journal. Vol. 56, pp. 105-170. 2012.
[7] EEVC. "Dummy Requirements and Injury Criteria for a Low-speed Rear Impact Whiplash Dummy." Working group 12 report, 2007.
[8] Kang, Yun-Seok, et al. "PMHS Lower Neck Load Calculation using Inverse Dynamics with Cervical Spine Kinematics and Neck Mass Properties." International Research Council on Biomechanics of Injury (2016).
[9] Rhule, D., Rhule, H., Donnelly, B., "The Process of Evaluation and Documentation of Crash Test Dummies for Part 52 of the Code of Federal Regulations." NHTSA Document, 05-0284.

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