Study of Advanced Occupant Models to Quantify Injury Risk for eVTOL Vehicles

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Background

- Electric Vertical Take-off and Landing (eVTOL) vehicles create a big opportunity in urban air travel
- Improved transport:
  - Cargo
  - Passengers
  - Emergency services
- These vehicles are designed to be small and lightweight to benefit mobility and efficiency



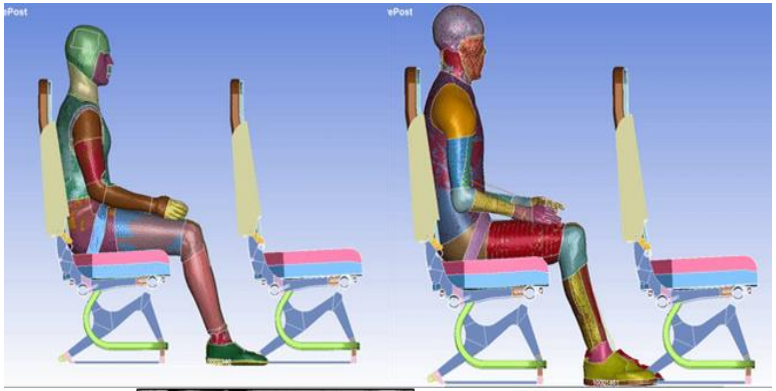
Motivation

- FAA regulations added considerations for eVTOLs in § 110.2 of title 14 of the Code of Federal Regulations (14 CFR)
- Current safety regulations are still in development for the application to these novel aircraft designs
- Testing of these aircrafts will need to be extensive to ensure safety during the adoption of these new mechanism of travel

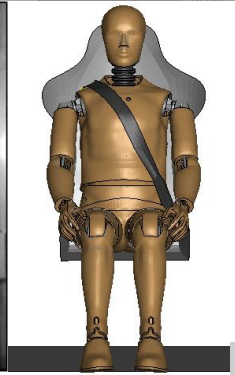
(FAA), F. A. A., 2023, "Update to Air Carrier Definitions - 88 FR 48072," FAA.

Previous Evaluations

- Utilization of advance human body models in aircraft loading environments
- Physical eVTOL seat testing
- Development of finite element (FE) seat model







Jones, N., Untaroiu, C., Putnam, J.B., " Numerical Investigation of Occupant Injury Risks during a Realistic Transport Aircraft Crash Conditions," 61st SAFE Symposium, October 10-12,2023.

Putnam, J.B., Littell, J.D., Gardner, N., Mennu, M., "Component Characterization of an eVTOL Reference Model for Crashworthiness Studies," Proceedings from the Vertical Flight Society 80th Annual Forum and Technology Display, May 7-9, 2024.

Limitations of Traditional Analysis

- The current standard, Hybrid III (H3) anthropomorphic test device (ATD), is less biofidelic then advanced human body models (HBMs)
- The H3 was developed decades ago and is limited in its instrumentation and its response within complex loading environments

Foster, J. K., Kortge, J. O., and Wolanin, M. J., 1977, "Hybrid III—A Biomechanically-Based Crash Test Dummy," SAE Transactions, 86, pp. 3268-3283.

Goals

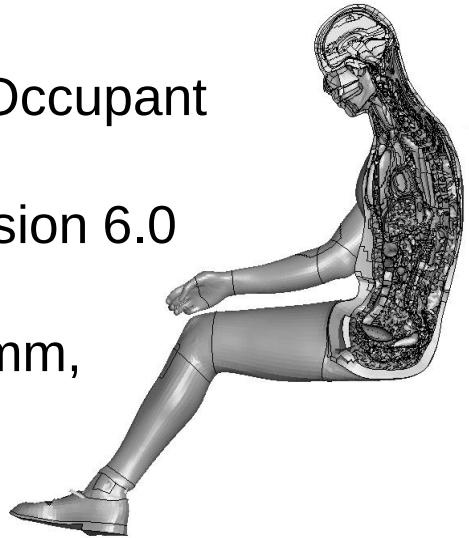
Goal: Utilize advanced HBM - Global Human Body Model Consortium (GHBMC), and advanced ATD - Test Device for Human Occupant Restraint (THOR), to quantify sensitivity of injury risk predictions to the use of different occupant surrogates within vertical impact loading scenarios

Advanced Model Comparisons

GHBMC

Male 50th percentile Occupant Detailed model Version 6.0

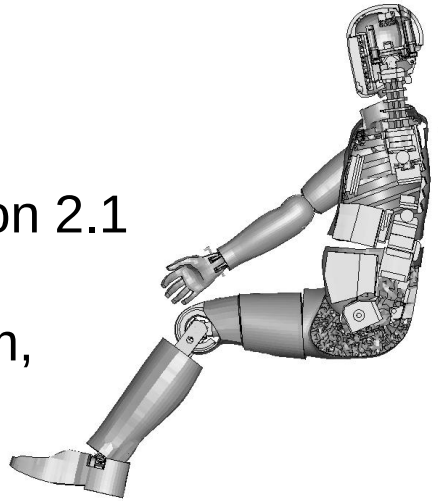
Units: Kg, mm, msec



THOR

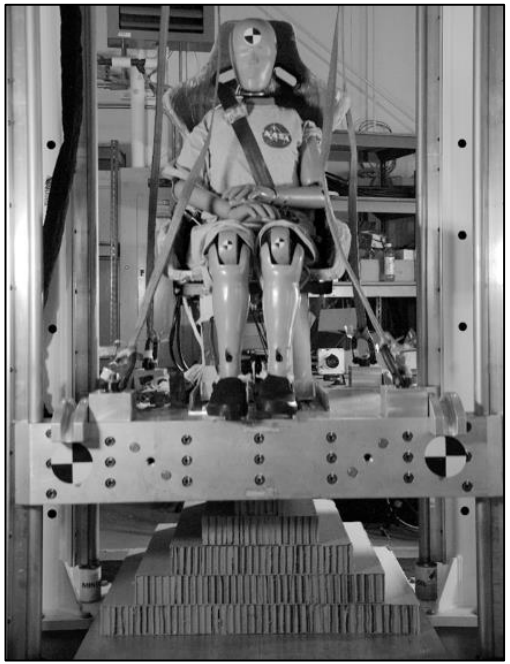
Male 50th percentile Occupant model Version 2.1

Units: Kg, mm, msec

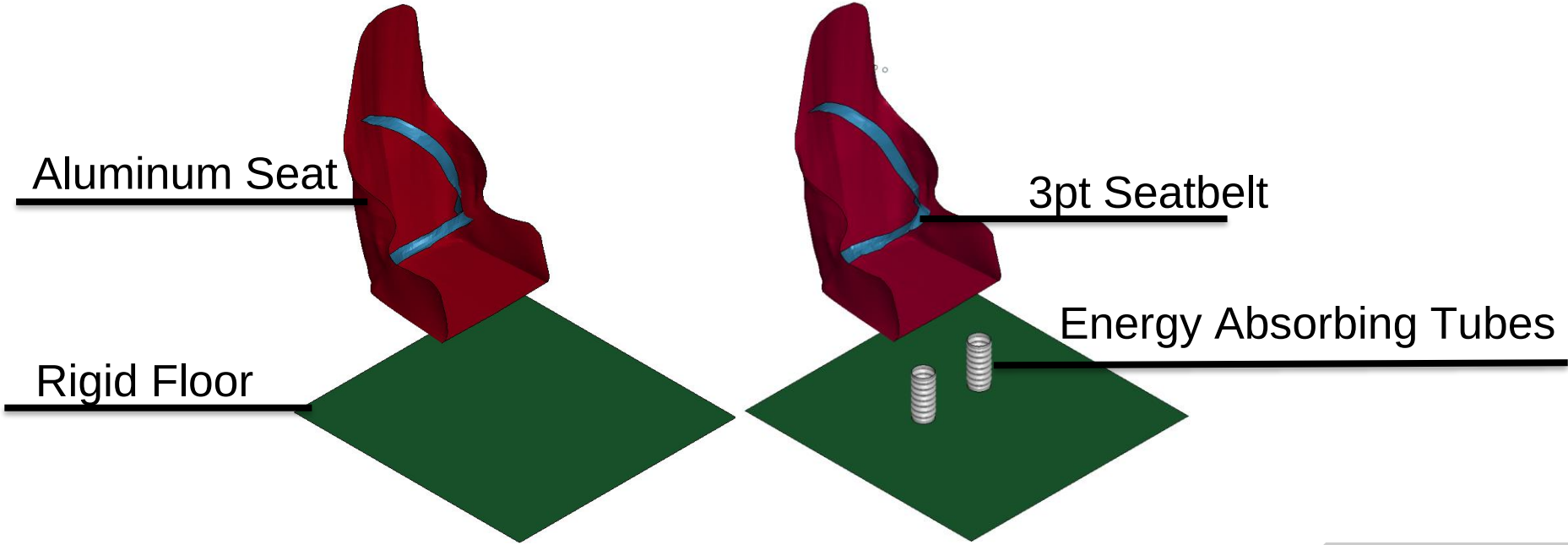


Methods: Test Environment

- Seat level impact tests conducted at NASA 30 ft drop tower facility
  - Pure vertical impact conditions
  - Acceleration pulses generated using drop height and honeycomb stacks under impact mass



Methods: Seat Comparisons

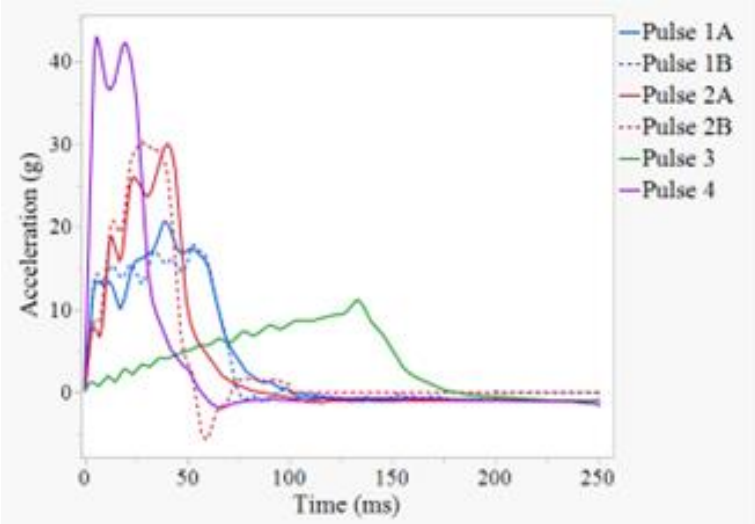


Methods: Crash Pulses

- Four vertical acceleration pulse conditions evaluated
  - Pulse 1: 19g*
  - Pulse 2: 30g**
  - Pulse 3: 10g***
  - Pulse 4: 42g****
- Acceleration time history measured at seat base used to drive simulation

*Approximation of 14 CFR 23.562
**Approximation of 14 CFR 27.562
***Approximation of physical helicopter test performed at NASA LaRC
****Approximation of physical drop test of composite aircraft body test performed by Nasa LaRC

Acceleration Pulse Time Histories



- Both "B" conditions correspond to inclusion of energy absorption (EA) tubes

Federal Aviation Administration. “Emergency Landing Dynamic Conditions.” 14 CFR § 23.562. Amended December 2, 2011.
Federal Aviation Administration, “Emergency Landing Dynamic Conditions,” 14 CFR § 27.561, Amended November 13, 1989.
Littell, J.D., “Full-Scale Crash Test of an MD-500 Helicopter,” Proceedings from the American Helicopter Society 67th Annual Forum, May 3-5, 2011

Methods: Model Positioning

Feet and leg positioning
THOR: Utilizing included model positioning tree
GHBMC: Utilizing ANSA Beta positioning software

→

3 step positioning Simulation

1)Gravity settling
2)Marionette repositioning
3)Seatbelt retraction

→

Crash Pulse simulation

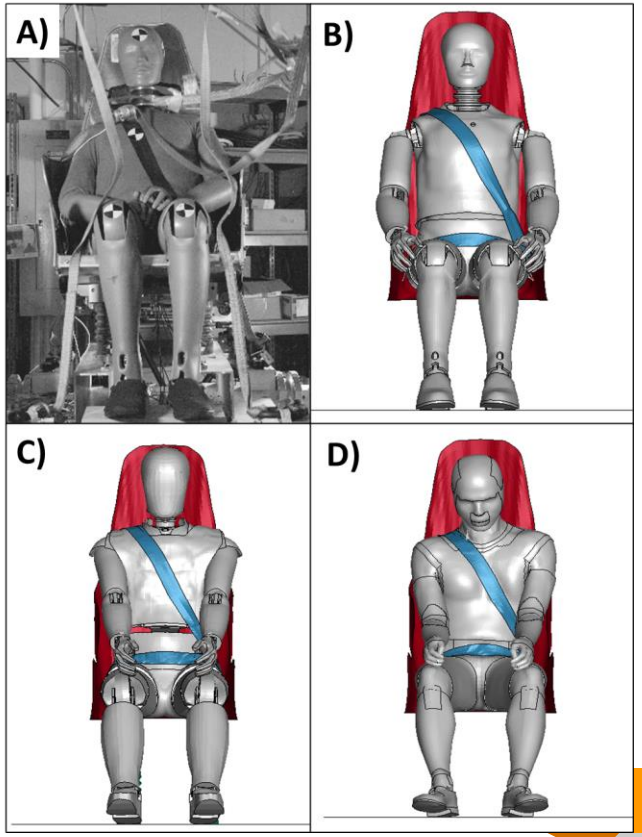
Methods: Initial positionings

A) Physical H3

B) FE H3

C) FE THOR

D) FE GHBMC



Methods: Injury Measures

Injury metrics calculated for each model

Head

$$HIC_{15} = 15\left(\frac{1}{15}\int_{t1}^{t2} a(t)dt\right)^{2.5}$$

Eq 1

Neck

$$N_{ij} = \frac{F_z}{F_{int}} + \frac{M_y}{M_{int}}$$

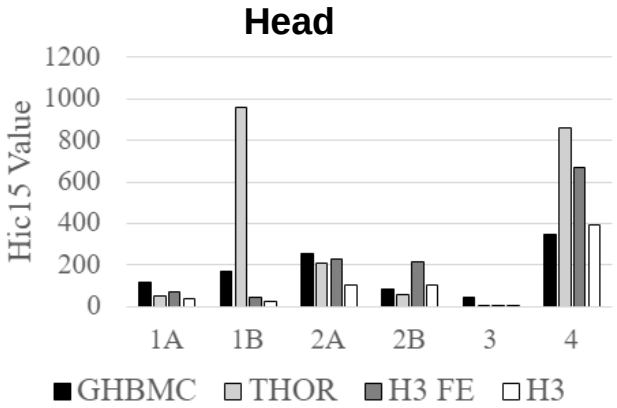
Eq 2

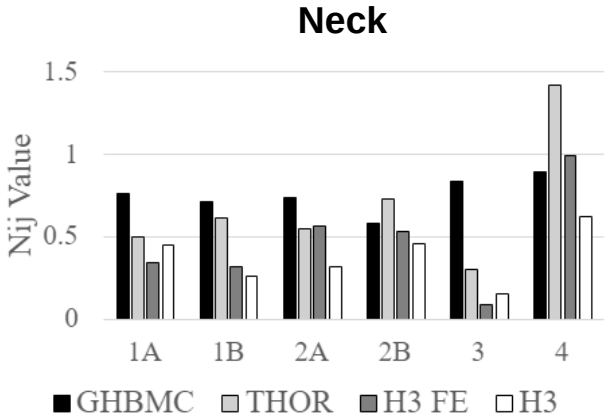
Spine

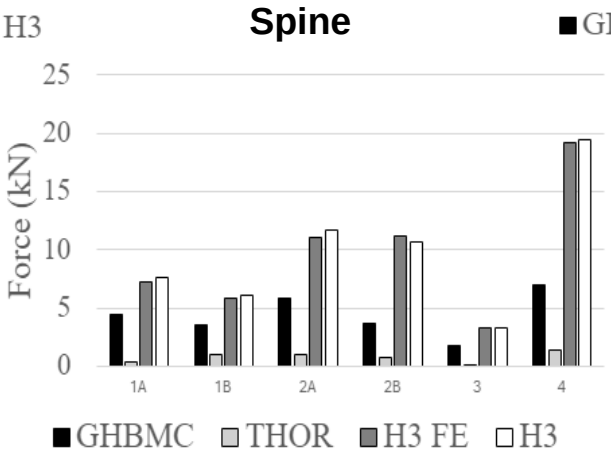
Peak lumbar force at the L5 surrogate joint (kN)

Hodgson, V. R. and L. M. Thomas (1972). "Effect of long-duration impact on head." Society of Automotive Engineers SAE 720956.
Prasad, P. and R. P. Daniel (1984). "A biomechanical analysis of head, neck, and torso injuries to child surrogates due to sudden torso acceleration." SAE TRANSACTIONS: 784-79.

Overall Results

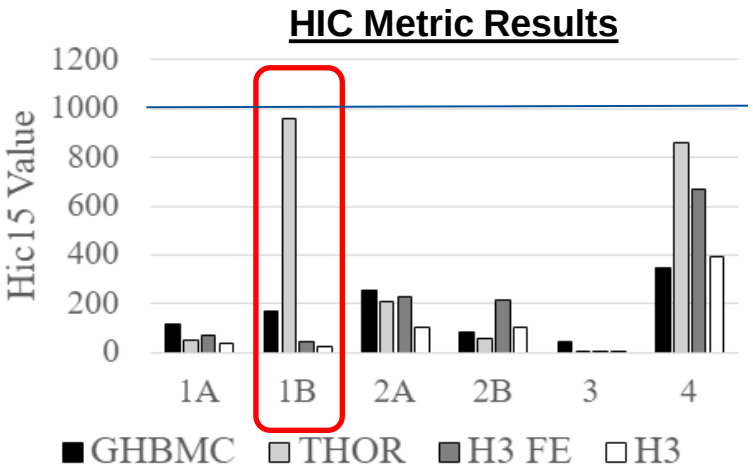




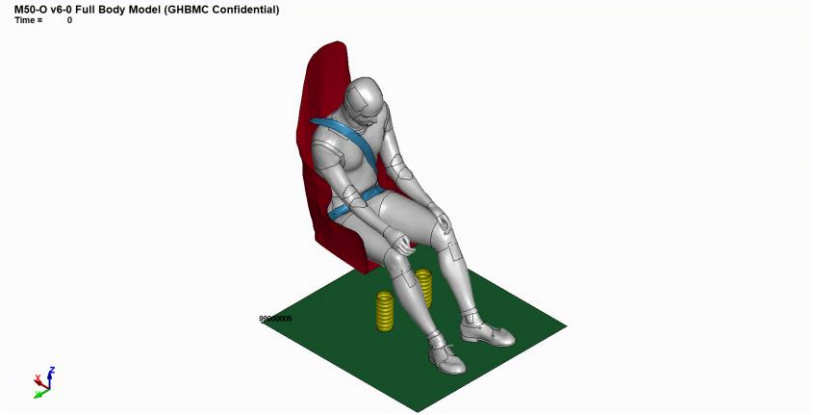


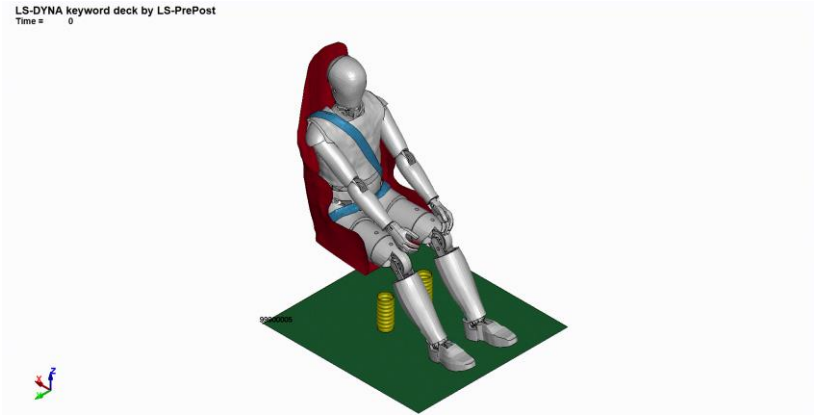
Results: Head Injury Risk

- The physical H3 model demonstrates slightly lower Hic15 response in all tests compared to FE H3
- The THOR model bisects the two H3 results in all but test 1B and test 4



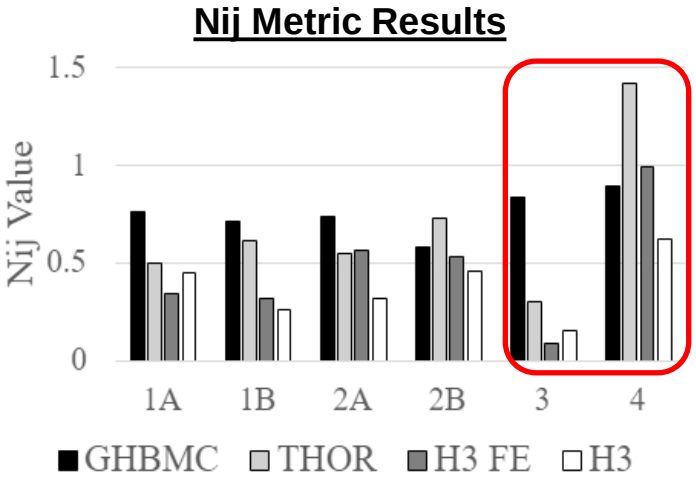
Results: Test 1B Head impact





Results: Neck Injury Risk

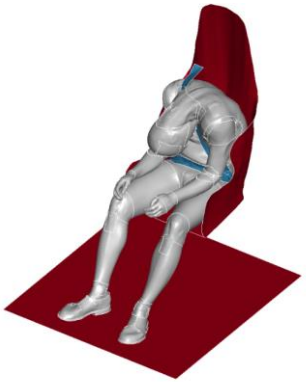
- The H3 tests are closest at the lower magnitude acceleration pulses
- THOR had slightly higher Nij for all tests except 2A compared to H3
- GHBMC exhibited the least total variation of Nij values



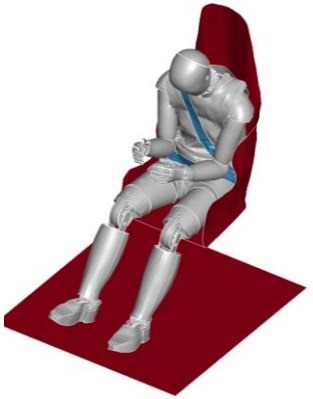
Results: Neck Injury Lateral deformation

- The GHBMC model identified significant lateral deformation of the neck
- All other modes showed little to no lateral movement of the neck
- Potential intervention of four-point seatbelt my prevent significant lateral deformation observed in GHBMC

GHBMC

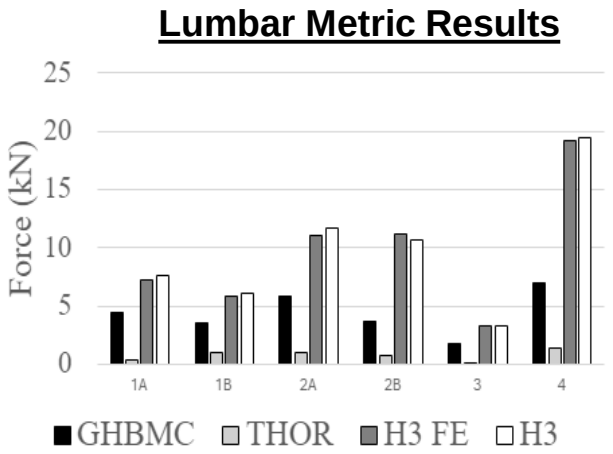


THOR



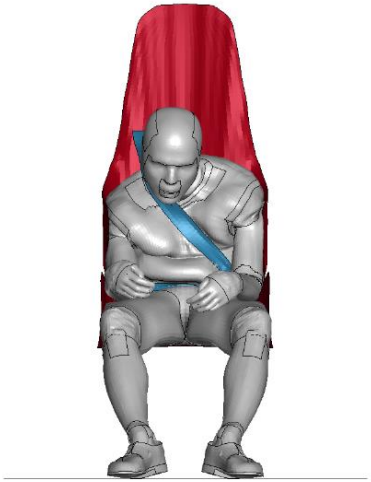
Results: Lumbar Injury Risk

- The H3 tests are nearly identical for all tests highest variation of 0.6 Kn in test 2A
- THOR had the lowest spine injury metric for all tests
- GHBMC exhibited variation related to pulse magnitude and the highest reduction in lumbar load with the addition of EA tubes



Results: Lumbar Injury Risk

- Lower magnitude lumbar loads in GHBMC and THOR compared to H3
  - GHBMC and THOR both have increased spinal flexibility
  - GHBMC and THOR have abdominal structures which may offload lumbar spine
- Previous testing has shown similar trends between THOR and H3*



*Xu, L., Jensen, J., Byrnes, K., Kim, A., Agaram, V., Davis, K. L., Hultman, R. W., Kostyniuk, G., Marshall, M. E., Mertz, H., Nusholtz, G., Rouhana, S., and Scherer, R., 2000, "Comparative Performance Evaluation of THOR and Hybrid III," SAE Transactions, 109.

Discussion

- Effect of seat type, acceleration magnitude, and acceleration duration on predicted occupant injury risk dependent on occupant surrogate analyzed
- Head strike risk identified by the THOR model indicates need for added padding to the head rest location to reduce head injury risk
- Neck injury risk identified by the GHBMC suggests the need for a more sufficient restraint system to prevent the large forward and lateral movement of the head and neck
- The predicted effectiveness the energy absorbing mechanisms was dependent on the occupant surrogate analyzed

Conclusions

- FE modeling tools are valuable for studying a variety of human surrogates for use in crash safety analysis
- Further development of HBMs and ATDs within aerospace loading environments will provide value in developing this field of research
- Future studies may evaluate additional factors such as occupant size, occupant positioning, new HBMs, or more complex impact environments
- These models allow for identification of mechanisms of injury to influence the safety features necessary for the development of these eVTOLs

Acknowledgements

-NASA Langley Research Center

-Virginia Tech Center for Injury Biomechanics

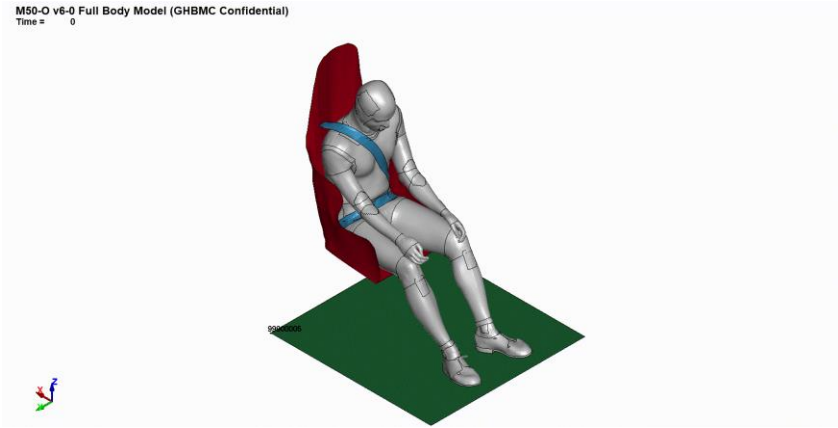
-Mr. Jacob Putnam
Research Aerospace Engineer - NASA

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Associate Professor - Virginia Tech

Questions?

Appendix: Test 1A

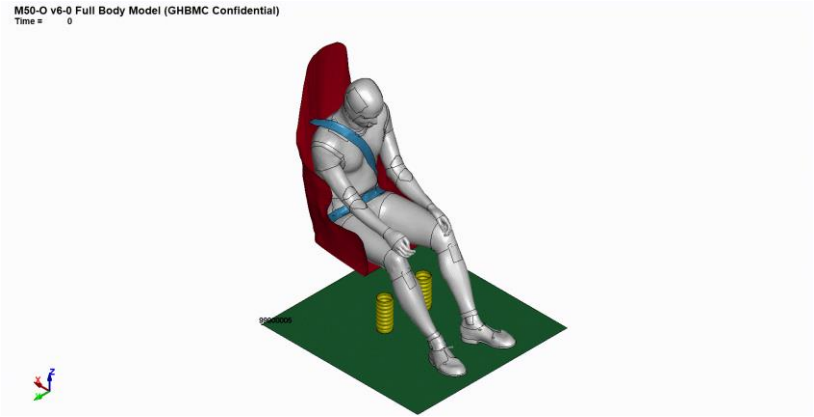
	GHBMC	THOR	H3 FE	H3
Hic	118.52	51.70	67.86	34.97
Nij	0.76	0.50	0.34	0.45
L5 F	4.50	0.37	7.22	7.58

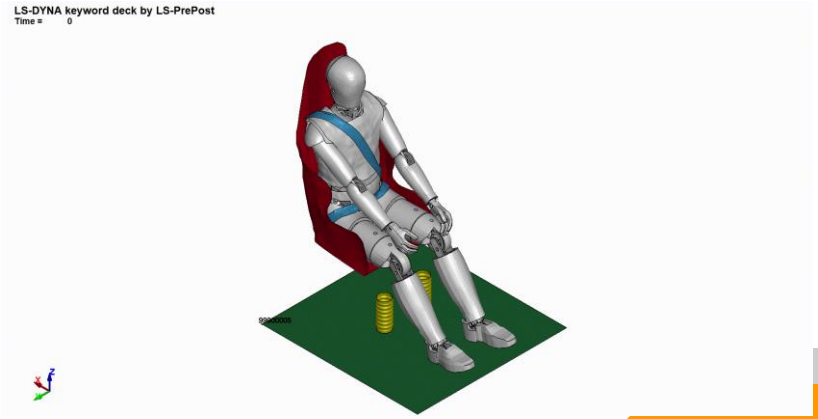




Appendix: Test 1B

	GHBMC	THOR	H3 FE	H3
Hic	167.67	961.21	44.81	26.52
Nij	0.71	0.61	0.32	0.26
L5 F	3.58	0.94	5.85	6.09





Appendix: Test 2A

	GHBMC	THOR	H3 FE	H3
Hic	256.79	211.00	229.00	104.00
Nij	0.74	0.55	0.57	0.32
L5 F	5.86	1.00	11.10	11.70

Appendix: Test 2B

	GHBMC	THOR	H3 FE	H3
Hic	81.87	59.77	216.00	105.00
Nij	0.58	0.73	0.53	0.46
L5 F	3.73	0.72	11.20	10.70

Appendix: Test 3

	GHBMC	THOR	H3 FE	H3
Hic	43.09	7.03	5.78	4.33
Nij	0.84	0.30	0.09	0.15
L5 F	1.83	0.17	3.32	3.25

Appendix: Test 4

	GHBMC	THOR	H3 FE	H3
Hic	344.67	859.00	672.00	393.00
Nij	0.89	1.42	0.99	0.63
L5 F	6.98	1.39	19.20	19.50