Overview of THOR-AV Design, Biofidelity, Injury Risk Cures and Readiness

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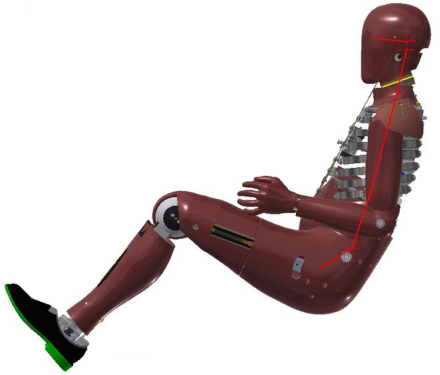
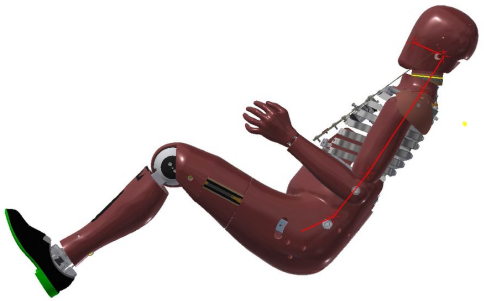
THOR-AV BACKGROUND

- THOR-AV, a modified THOR, was developed to address upright and reclined occupant safety in autonomous vehicles (AV).
- Synergy between reclined seat and zero gravity seat.
- The project started in 2018 with the aim of providing a quick tool to address the immediate needs for restraint system development.
- Project Goals:
  - Expand THOR capability to represent reclined occupant
  - Achieve good biofidelity in both postures
  - One dummy for both upright, reclined seat testing and rearward facing with frontal crash pulse



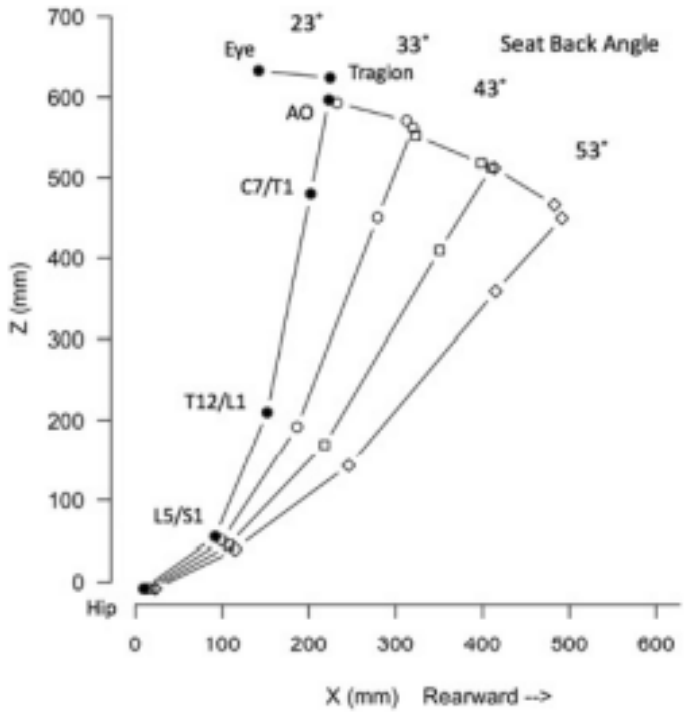


TASKS COMPLETED AS OF TODAY

- Total three dummies were fabricated for testing, plus 2 additional conversion kits for testing and evaluations
- The first two dummies went through lab probe and pendulum tests,18 different sled test conditions, and demonstrated good to excellent biofidelity.
- THOR-AV dummies have been tested in US, Europe, South Korea, China and Japan.
- The dummy design is stable. Both umbilical and integrated DAS designs are in production.
- User's manual/qualification procedure and corridors are available
- Injury risk functions were developed for the regions modified
- Dummy positioning procedure was developed by CAERI
- The dummy is specified in China Insurance Automobile Safety Index Management Regulation (C-IASI) 2026 version

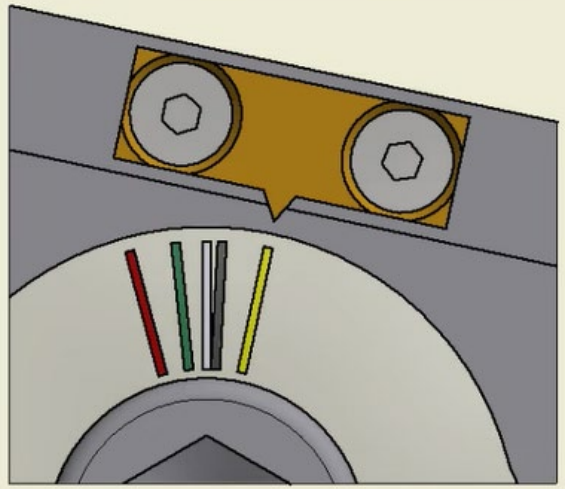
THOR-50M AV | Human Posture Match In Reclined Positions

- UMTRI volunteer seating postures in reclined seat
  - Regression model for prediction of occupant seating postures
  - Reed et al. 2019 *Traffic Injury Prevention*
- THOR-50M AV was designed to follow UMTRI model



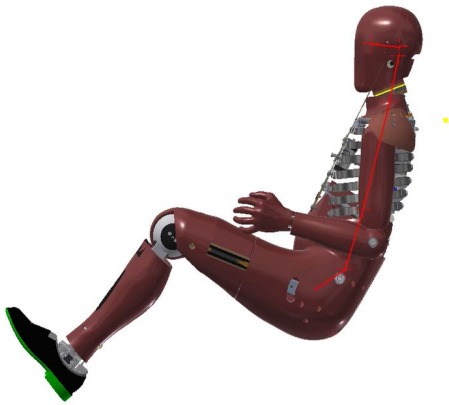
Adjustable Joint to match UMTRI postures

POSTURE CHART		
POSTURE	COLOR	ANGLE
60° SEATBACK	RED	15°
45° SEATBACK	GREEN	6°
NEUTRAL	WHITE	0°
SLOUCHED	BLACK	-3°
SUPER SLOUCHED (25° SEATBACK)	YELLOW	-12°



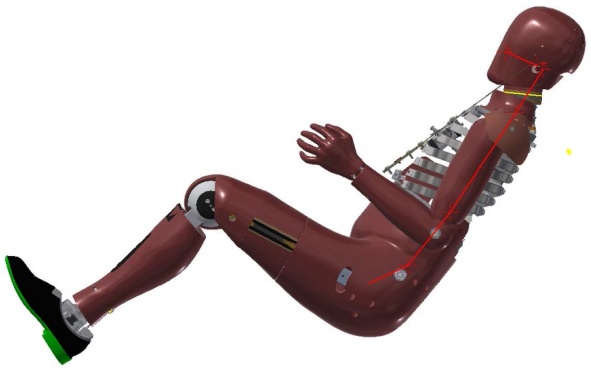
THOR-AV RECLINED LAYOUT PER REED 2019

Pelvis: +33.2°
Head: +2.1°
Lumbar Pitch: yellow
(super slouched)



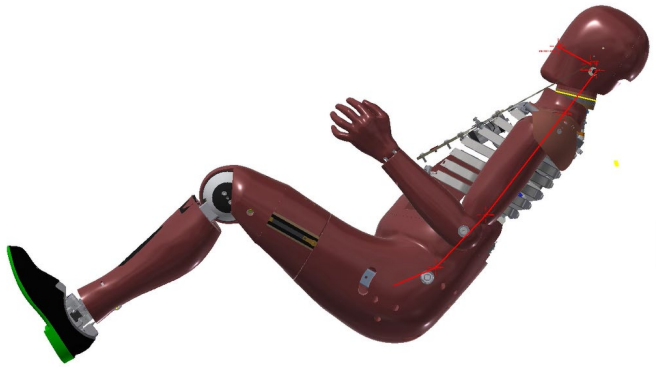
25°

Pelvis: +39.9°
Head: +1.5°
Lumbar Pitch: green



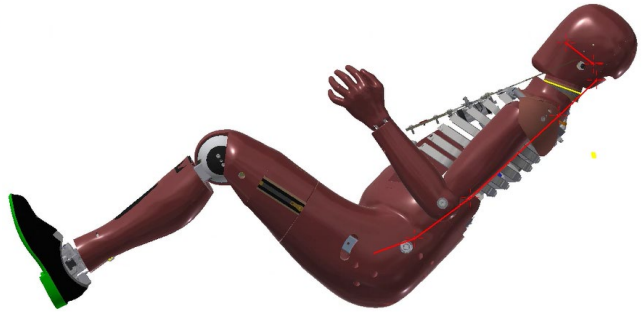
45°

Pelvis: +41.5°
Head: +4°
Lumbar Pitch: (3° forward from red, not marked yet)



50°

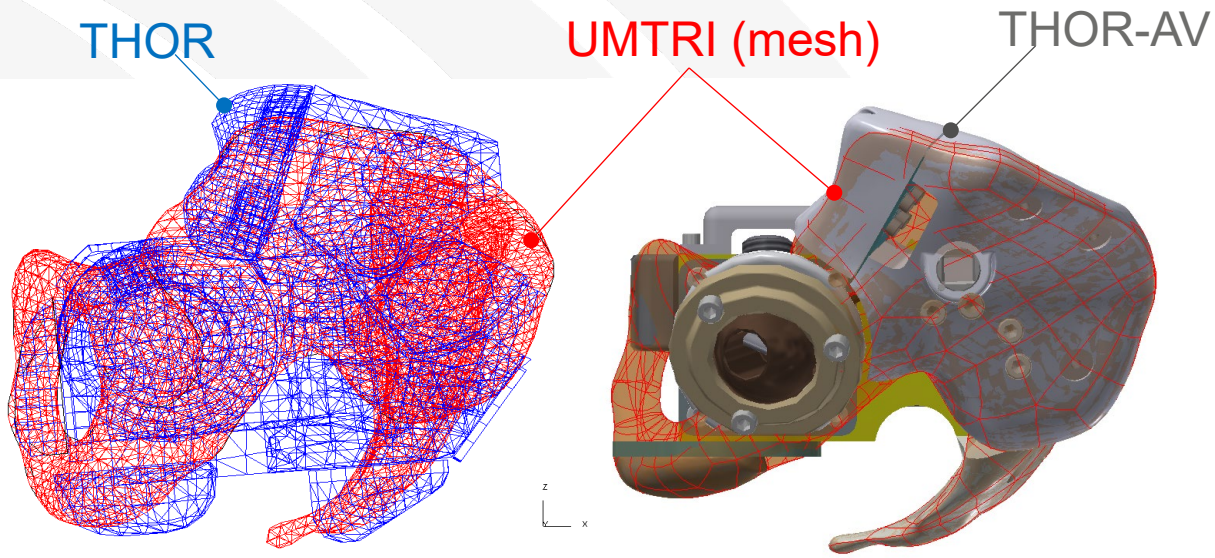
Pelvis +44.8°
Head +1.8°
Lumbar Pitch: red



60°

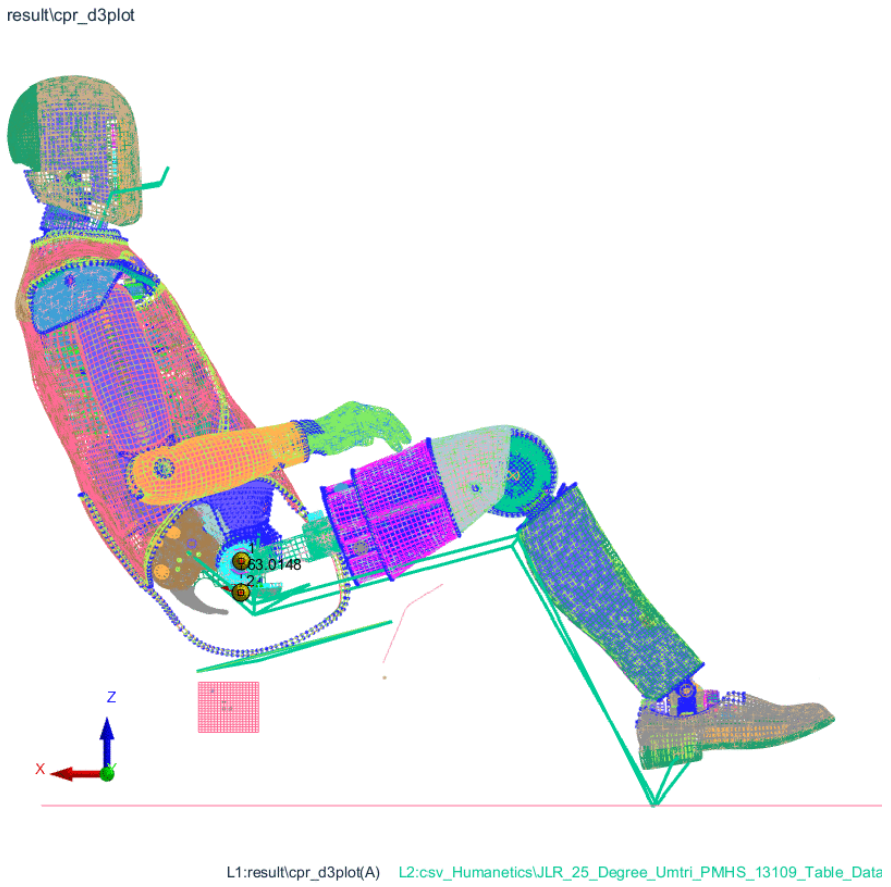
PELVIS CHANGES

Pelvis bone geometry

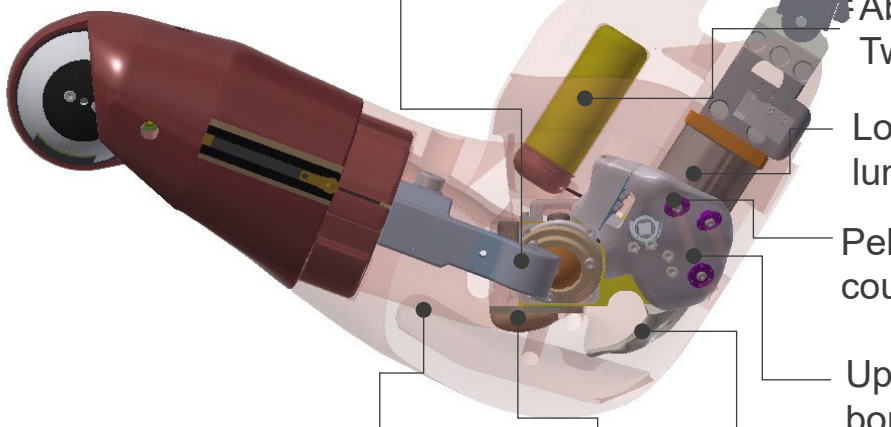


ASIS shape was revised according to Muehlbauer et al. 2020 IRCOBI

Increased pelvis flesh compression to match human



THOR-AV | FINAL PACKAGE



Molded abdomen
(better reproducibility)

Representative
Trochanter

Abdomen Pressure
Twin Sensors

Longer and circular
lumbar spine

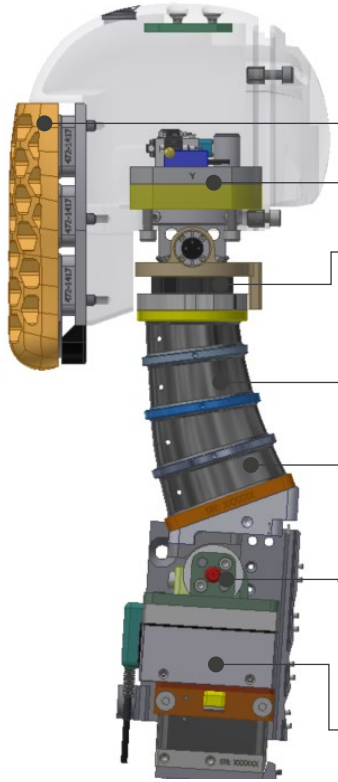
Pelvic bone and flesh
couplings

Updated pelvic
bone geometry

Soft flesh for
reclined seat

Representative
Ischium

Representative
coccyx geometry
and stiffness



Honeycomb face
insert

Upper neck load cell
relocated inside head

Torsion element ± 45°
stops

Cervical spine curvature

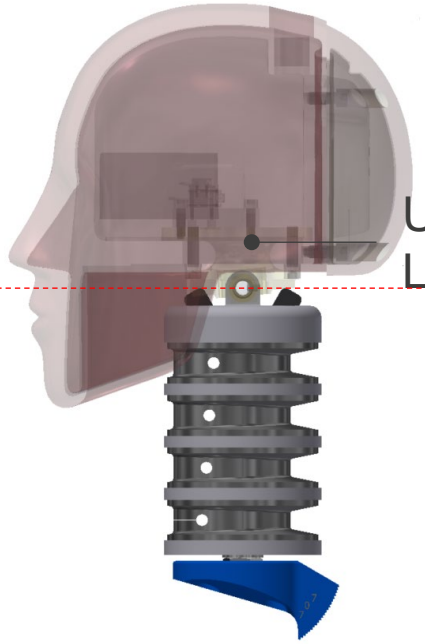
Increased cross section
from C1 to C7

Upper spine joint move up to
increase head neck RoM

Lower neck load cell
swapped position with
spine joint

THOR-AV Neck vs THOR & H350th Neck

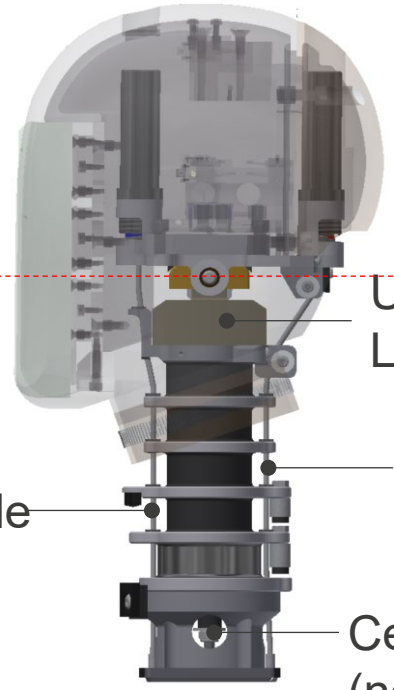
Hybrid III



Upper Neck Load Cell

Central cable (hidden)

THOR



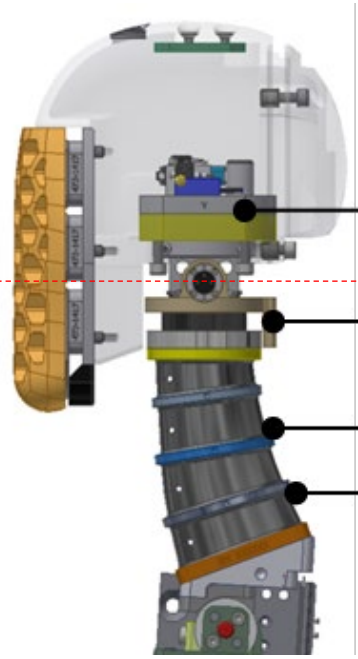
Upper Neck Load Cell

Rear Cable

Front Cable

Central cable (not engaged)

THOR-AV



Upper neck load cell relocated inside head

Torsion element (±45° stops)

Cervical spine curvature

Increased cross section from C1 to C7

No central cable

THOR-AV Neck BioRank Scores

Test	Reference	THOR-AV	THOR	H350
Frontal	Thunnissen et al (1995)	1.32	1.33	1.68
	Kang et al (2018)	1.28	1.80	2.13
Lateral	Wismans et al (1983)	2.19	1.14	2.09
	Kang et al (2018)	0.87	1.00	1.26
Oblique	Kang et al (2018)	2.06	2.94	3.14
Torsion	Kang et al (2018)	1.11	3.08	1.46
	Average	**1.47**	**1.88**	**1.96**

BioRank Score	B ≤1.0	1.0 < B ≤ 2.0	2.0 < B ≤ 3.0	3.0 < B
Biofidelity	Excellent	Good	Marginal	Poor

THOR-AV BIOFIDELITY SUMMARY

BRS	B≤1.0	1.0<B≤2.0	2.0<B ≤ 3.0	3.0<B
Biofidelity	Excellent	Good	Marginal	Poor

Test Configurations		Test Conditions	Submarining*	THOR-AV BioRank	Publications
Neck Evaluation	6 configurations	frontal (2x), oblique, lateral (2x), torsion		1.47	Wang et al. 2021 IRCOBI
Uriot et al. 2015	Front Seat (22°)	50 km/h, PT load limit 7.0 kN	No	0.84	Wang et al. 2022 IRCOBI
	Rear Seat (22°)		Yes	0.77	
UMTRI AVOK	25°	32 km/h, no PT, load limit 3.5 kN	No	0.73	Wang et al. 2022 IRCOBI
	45°		No	0.89	
Kang et al. 2020 (rearward facing)	25°	56 km/h, Honda Odyssey 2nd row seat		1.95	Wang et al. 2022 SAE WCX
	45°			1.38	
Richardson et al. 2020	49°	50 km/h, dual PT, load limit 3.5 kN	No		BASt
UMTRI AVOK 2nd test series	25°	50 km/h, load limit 3 kN	No	~1.0	Planned in 2025 or 2026
	45°		No	0.80	
VT Volunteer AEB pulse	0° and 30° oblique	1g and 2.5 g		1.02	Albert et al. 2024 IRCOBI
Baudrit et al. 2022	60°	50 km/h, load limit 3 kN	No	1.14	Wang et al. 2025 IRCOBI
VT Rear Seat	NCAP85 pulse	2017 Mazda CX-3	Yes	Tests completed	Publication in 2026
		2018 Mercedes GLC 300	moderate		
		2018 Nissan Maxima	moderate		
		2018 Toyota Camry	No		

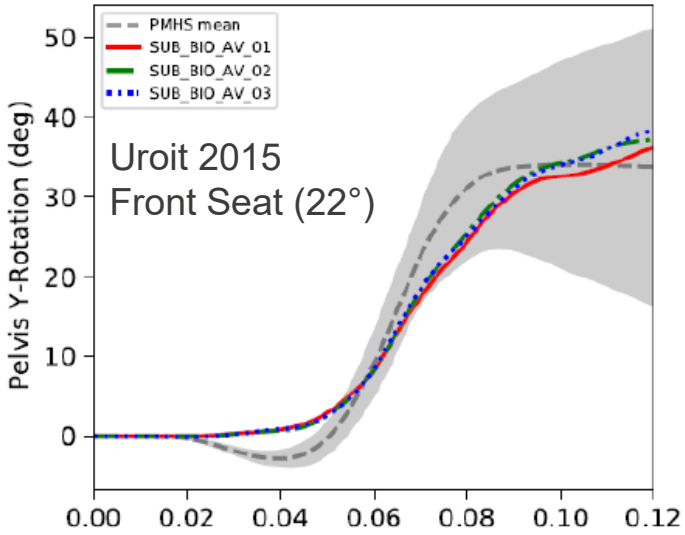
Total 18 Sled Test Cases

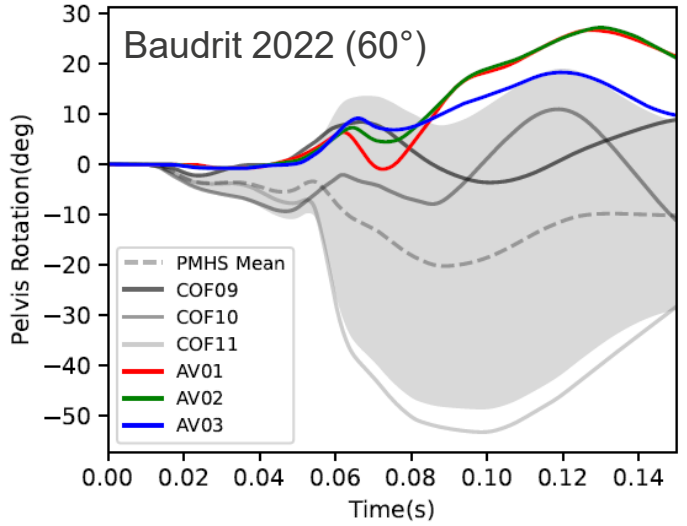
*Green color in submarining/non-submarining: THOR-AV matches PMHS

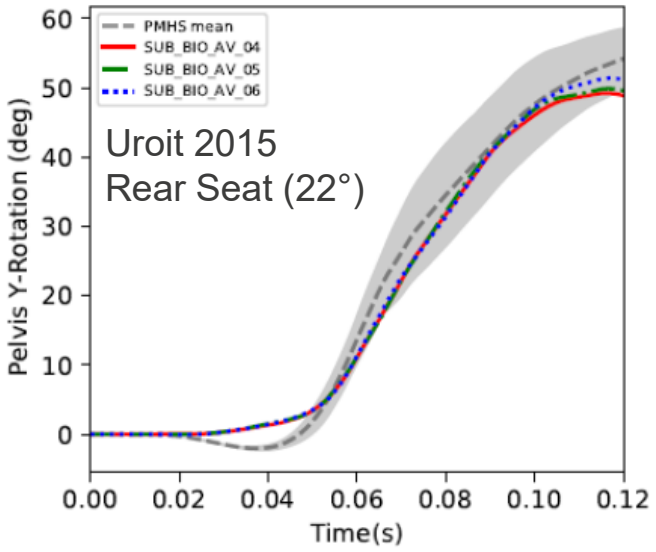
HUMANETICS

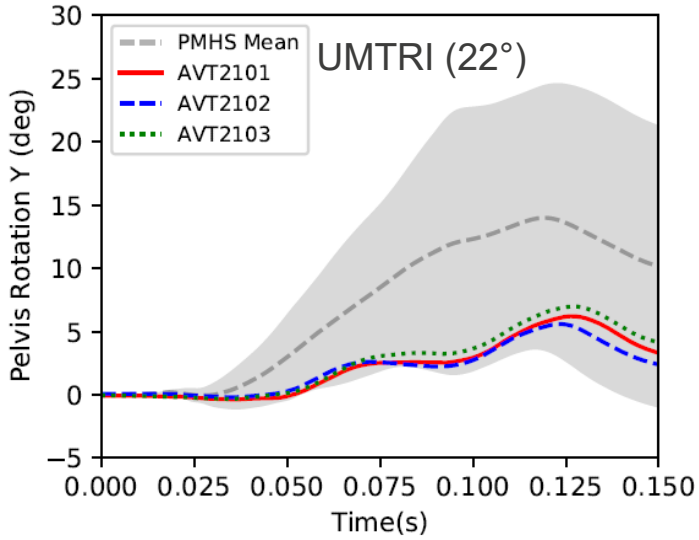
THOR-AV PELVIS ROTATION

- Pelvis Rotation was evaluated in a few sled test conditions
  - Uriot et al. 2015 (22°)
  - UMTRI (25°/45°)
  - Baudrit et al. 2022 (60°)
  - Richardson et al. (45°)
- Holistic study instead of emphasis on a single test condition









HUMANETICS

INJURY RISK FUNCTIONS

- No design changes – reference THOR
  - Head, Femur/Knee, Leg
- Design changes - New
  - Neck
    - Wang et al. 2025, IRCOBI, submitted
  - Abdomen, Pelvis, Lumbar
    - Wang et al. 2024 Stapp

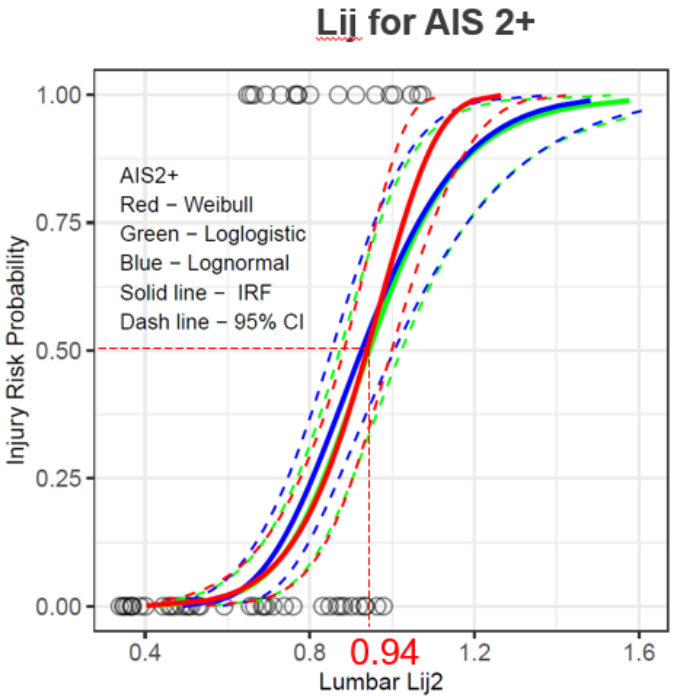
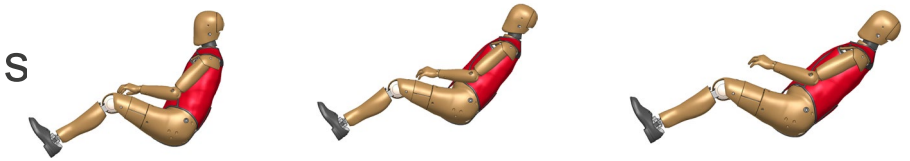


Table 6. Lumbar Lij survival functions and injury risk values at 5%, 25% and 50% risk probabilities for MAIS2+ cases.

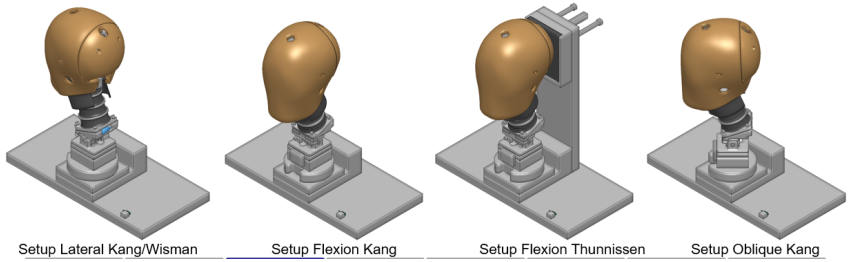
AIS	Fit	Shape	Scale	AIC	GKG	AUROC	Qual. Index	Injury Risk Values		
								5%	25%	50%
MAIS2+	Weibull	3.76565	0.86306	50.1	0.65	0.83	0.28	0.39	0.62	0.78
	Loglogistic	3.41687	0.77032	61.2	0.56	0.78	0.41	0.33	0.56	0.77
	Lognormal	2.09312	0.76526	60.8	0.56	0.78	0.40	0.35	0.55	0.77

THOR-AV FE MODEL STATUS

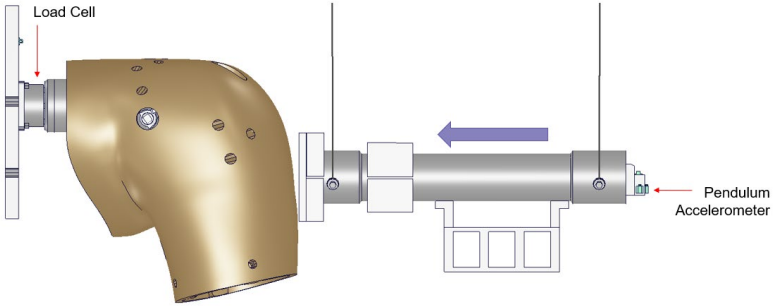
- THOR-AV 50M LS-DYNA (V0.7.2) and PamCrash Models
  - Three seatback angle postures: 25°, 45° and 60°
- 12 new validation cases in addition to THOR FE model
  - Neck, APTS, lumbar, full body pendulum, sled
- Latest Release: Version 1.0

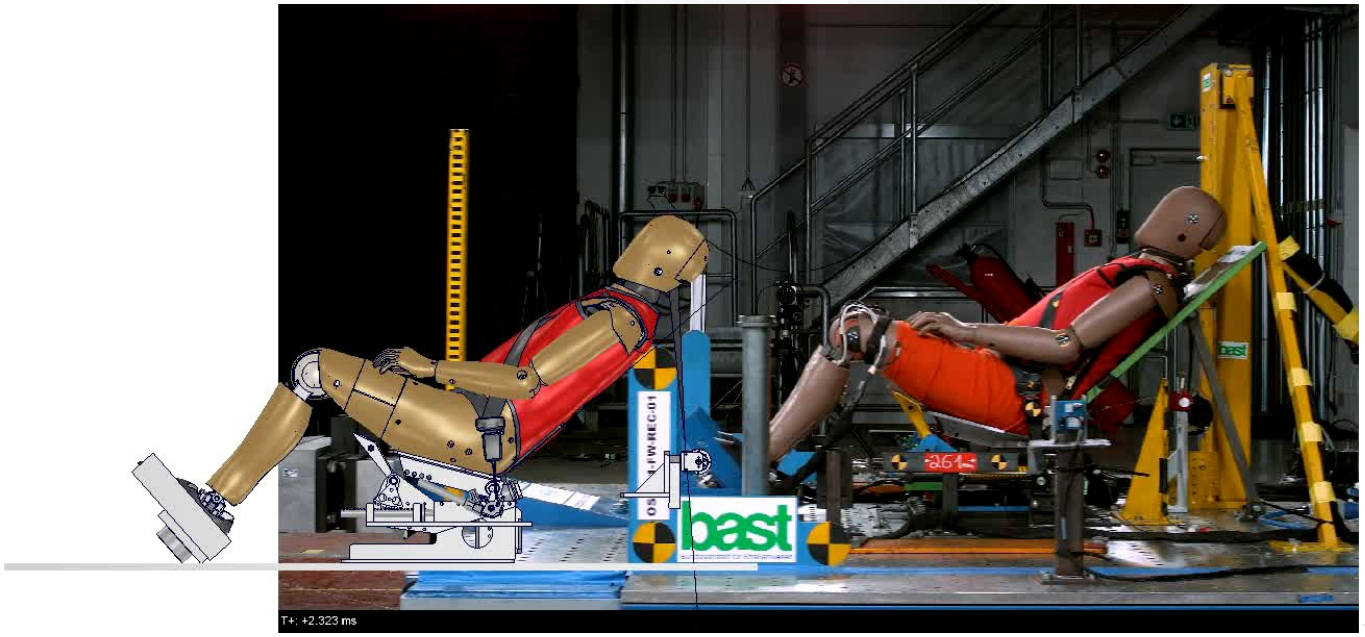


Test	Description	Initial Velocity	Orientation
Lateral Neck Test Kang	Minisled Test using Pulse defined by Kang[1]	0 m/s	90°
Lateral Neck Test Wisman	Minisled Test using Pulse defined by Wisman[3]	0 m/s	90°
Flexion Neck Test Kang	Minisled Test using Pulse defined by Kang[1]	0 m/s	0°
Flexion Neck Test Thunnissen	Minisled Test using Pulse defined by Thunnissen[2]	5.25 m/s	0°
Oblique Neck Test Kang	Minisled Test using Pulse defined by Kang[1]	0 m/s	45°



Test	Description
Pelvis Pendulum Test	Pendulum tests at 2 m/s





HUMANETICS

THOR-AV READINESS

Tasks	Description	Results	Status
THOR-AV			
Design	25°/45°/50°/60°	Reed et al. 2019	✓
Biofidelity	Probe and pendulum & 18 sled cases	“good” to “excellent”	✓
Injury Risk Functions	neck/lumbar/pelvis/abdomen	completed	✓
User’s Manual	umbilical & integrated DAS	Revision A	✓
Qualification Manual and Corridors	wedge probe for thorax, buttock impact, lumbar test	Revision A	✓
Dummy Positioning	CAERI Zero Gravity Seat	HPM-II	✓
FE Model	4th Release	Version 1.0	✓

NEW STANDARD IN C-IASI – WILL TAKE EFFECTIVE IN 2026

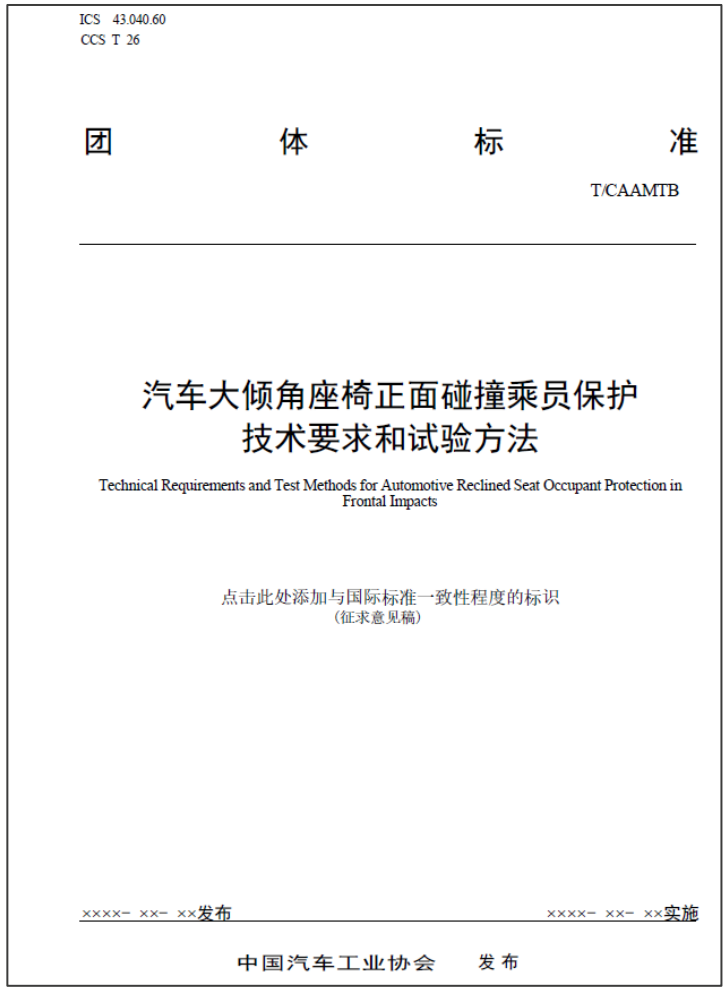
Group Standard

(Written in GBT – Chinese National Standard)

Technical Requirements and Test Methods for Automotive Reclined Seat Occupant Protection In Frontal Impacts

(Released for Public Comments)

Chinese Automobile Industry Association



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T/CAAMTB

汽车大倾角座椅正面碰撞乘员保护
技术要求和试验方法

Technical Requirements and Test Methods for Automotive Reclined Seat Occupant Protection in Frontal Impacts

点击此处添加与国际标准一致性程度的标识
(征求意见稿)

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中国汽车工业协会 发布

RELATED PUBLICATIONS

- Wang Z.J., Loeber B., Tesny A. Hu G., Kang, Y-S. (2021) Neck Biofidelity Comparison of THOR-AV, THOR and Hybrid III 50th Dummies, Proceedings of IRCOBI Conference, 2021, online.
- Wang J., Zaseck L., Reed M., (2022) THOR-AV 50th Percentile Male Biofidelity Evaluation in 25° and 45° Seatback Angle Test Conditions with a Semi-Rigid Seat, Proceedings of IRCOBI Conference, 2022, Porto, Portugal.
- Wang J., Richard O., Lebarbe M. Uriot J., Kabadayi E., Kleessen C. (2022) Biomechanical Responses of THOR-AV in a Semi-Rigid Seat that Mimics the Front and Rear Seat of a Midsize Car, Proceedings of IRCOBI Conference, 2022, Porto, Portugal.
- Wang Z., "Biomechanical Responses of the THOR-AV ATD in Rear Facing Test Conditions," SAE Int. J. Adv. & Curr. Prac. in Mobility 4(6):2089-2105, 2022, https://doi.org/10.4271/2022-01-0836.
- AVOS, (2023) Investigation of the Biofidelity of Human Body Models and ATD Models in Sled Test Conditions, 27th International Technical Conference on the Enhanced Safety of Vehicles (ESV), 2023, Yokohama, Japan
- Wang Z.J., Hu G. (2024) Investigation of Injury Risk Functions of THOR-AV Percentile Male Dummy. Stapp Car Crash Journal, Vol. 68. 2024.
- Liu C., Wang Z. (2024) Dummy Positioning at Reclined Seating Position before Impact Testing, Proceedings of SAE World Congress, 2024. DOI: https://doi.org/10.4271/2024-01-2490
- Albert D., Chan H., Gayzik S., Kemper A.(2024) Comparison of THOR-AV and Volunteer Kinematics during Low-Speed Frontal and Frontal-Oblique Sled Tests. Proceedings of IRCOBI Conference, 2024, Stockholm, Sweden.
- Wang J., Hu G., (2024) Investigation of Pressure-based Abdomen Injury Risk Function with Postmortem Human Subject and Porcine Data for THOR-AV 50M Dummy. Proceedings of IRCOBI Conference, 2024, Stockholm, Sweden.
- Fei J., Wang P., Yang X. Li Z., Wang Q., Wan X. (2024), Comparison of Responses Between Human Body Model and Anthropomorphic Test Device Model in Reclined Postures. Proceedings of IRCOBI Conference, 2024, Stockholm, Sweden.
- Wang Z.J., Richard O., Lebarbe M., Uriot J. (2025) Biofidelity Evaluation of THOR-AV 50th Percentile Male Dummy with A 60° Reclined Semi-rigid Seat. Proceedings of IRCOBI Conference, 2025 (submitted)
- Wang Z.J. Hu G. (2025) Neck Injury Risk Curve Development for THOR-AV 50th Percentile Male Dummy. Proceedings of IRCOBI Conference, 2025 (submitted)

Thank you!

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