

# THUMS

# Overview and Application

**IWG-DPPS 7<sup>th</sup> Meeting**  
**September, 2020**

Hiroshi Miyazaki  
TOYOTA MOTOR CORPORATION

# Contents

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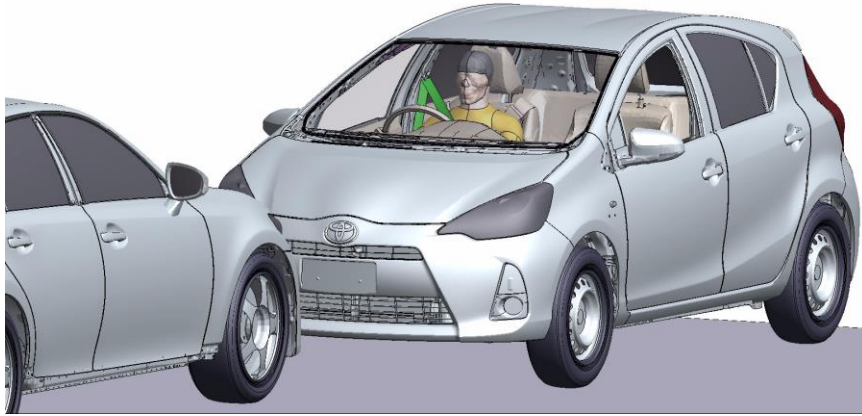
- 1. Overview of THUMS**
- 2. Application of THUMS**
- 3. THUMS Announcement**
- 4. Conclusions**

# Contents

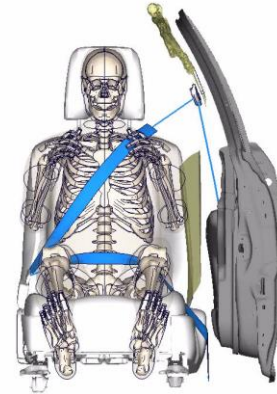
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- 1. Overview of THUMS**
2. Application of THUMS
3. THUMS Announcement
4. Conclusions

# 1-1. Overview THUMS



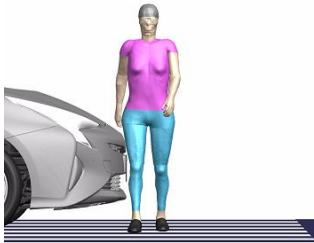
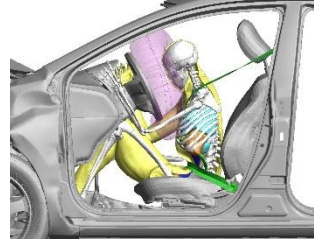
Frontal collision



Side collision

# 1-2. What is THUMS ?

- A computer model representing human body
- Use of crash test dummy in vehicle crash tests
- Durable dummy while vulnerable human body
- THUMS to simulate injuries for real-life safety research



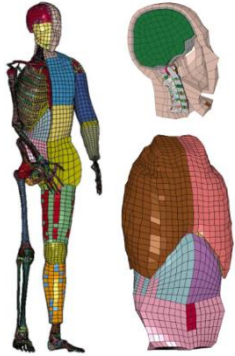
**Crash Test Dummy**

**THUMS**

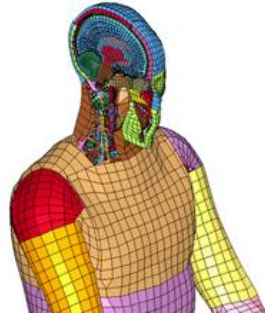
THUMS... Total Human Model for Safety  
Jointly developed with Toyota Central  
Research and Development, Inc.

# 1-3. Evolution of THUMS

- Improvement of biofidelity to better represent human body



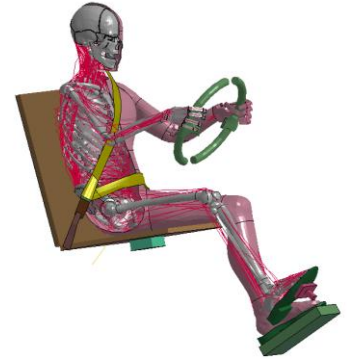
Version 1-2 (Bones)



Version 3 (+Brain)



Version 4 (+Internal Organs)

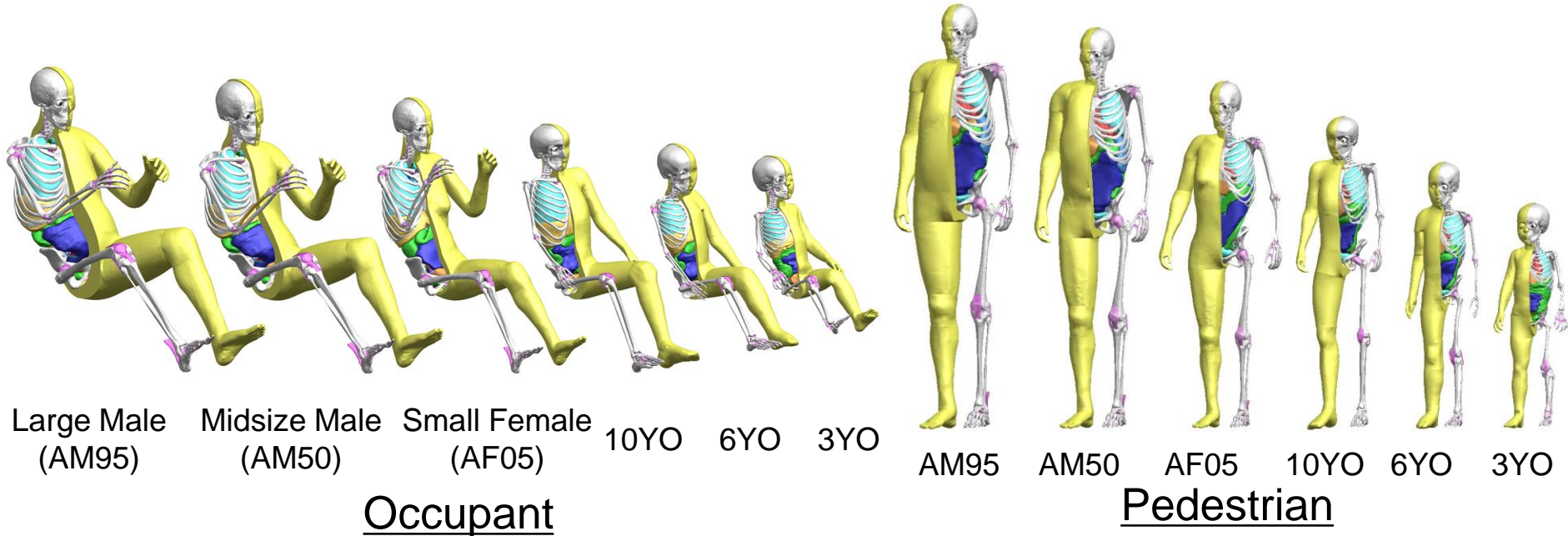


Version 5-6 (+Muscles)

Injury / Biological Response		Version 1-2 (2000)	Version 3 (2008)	Version 4 (2010)	Version 5-6 (2015)
Minor Injury	Bone Fracture	Y	Y	Y	Y
Severe / Fatal Injury	Brain Injury	N	Y	Y	Y
	Organ Injury	N	N	Y	Y
Biological Response	Muscle Effect	N	N	N	Y

# 1-4. Posture of THUMS

- Six physique occupant and pedestrian models



## THUMS Version 4 Family

# 1-5. Development of THUMS

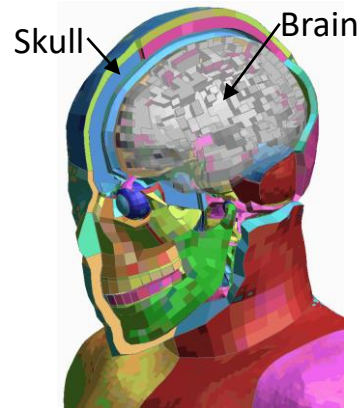
- High resolution CT scan of living human subject
- Finite element (FE) modeling of body parts
- Integration into whole body model (connections, contacts)
- Definition of material property for each body part



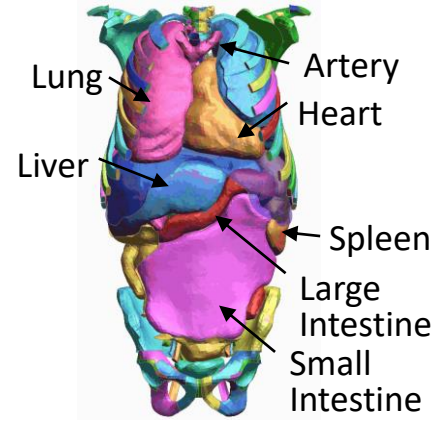
Human Subject



CT Scan Image



Head FE Model

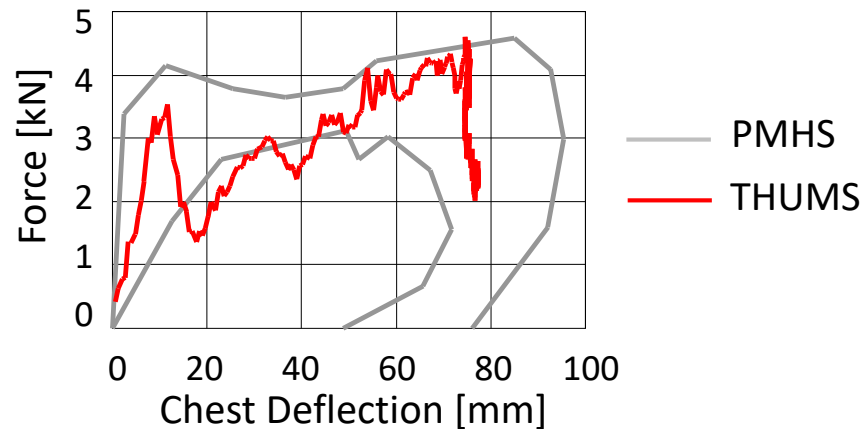
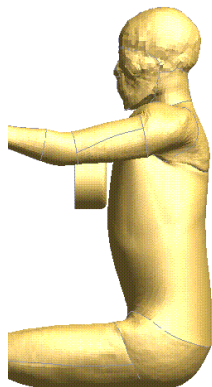


Internal Organ FE Model



# 1-6. Validation of Mechanical Response

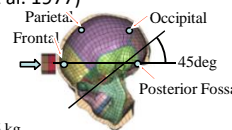
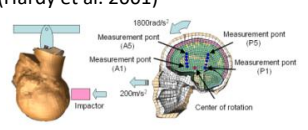
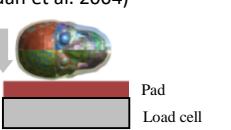
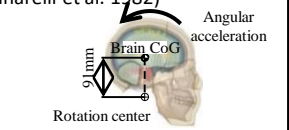
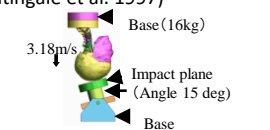
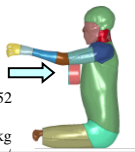
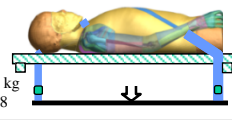
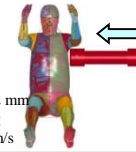

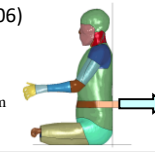
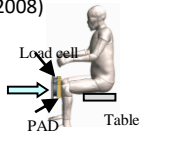
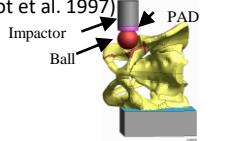
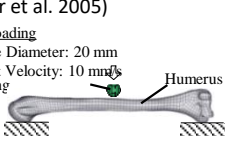
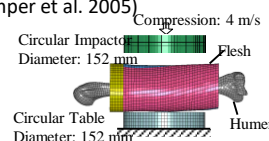
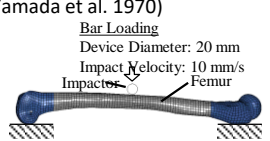
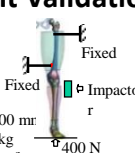
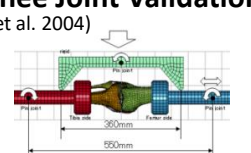
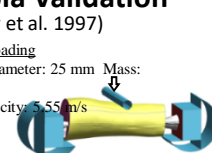
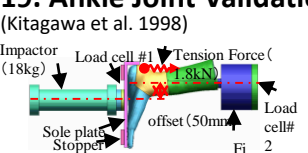
- Literature survey on impact biomechanics
- Loading tests on post mortem human subject (PMHS)
- Simulations of loading tests using THUMS
- Correlations in mechanical responses (force-deflection)



**Example: Anterior Thorax Loading**      **Comparison of Force Deflection Curves**

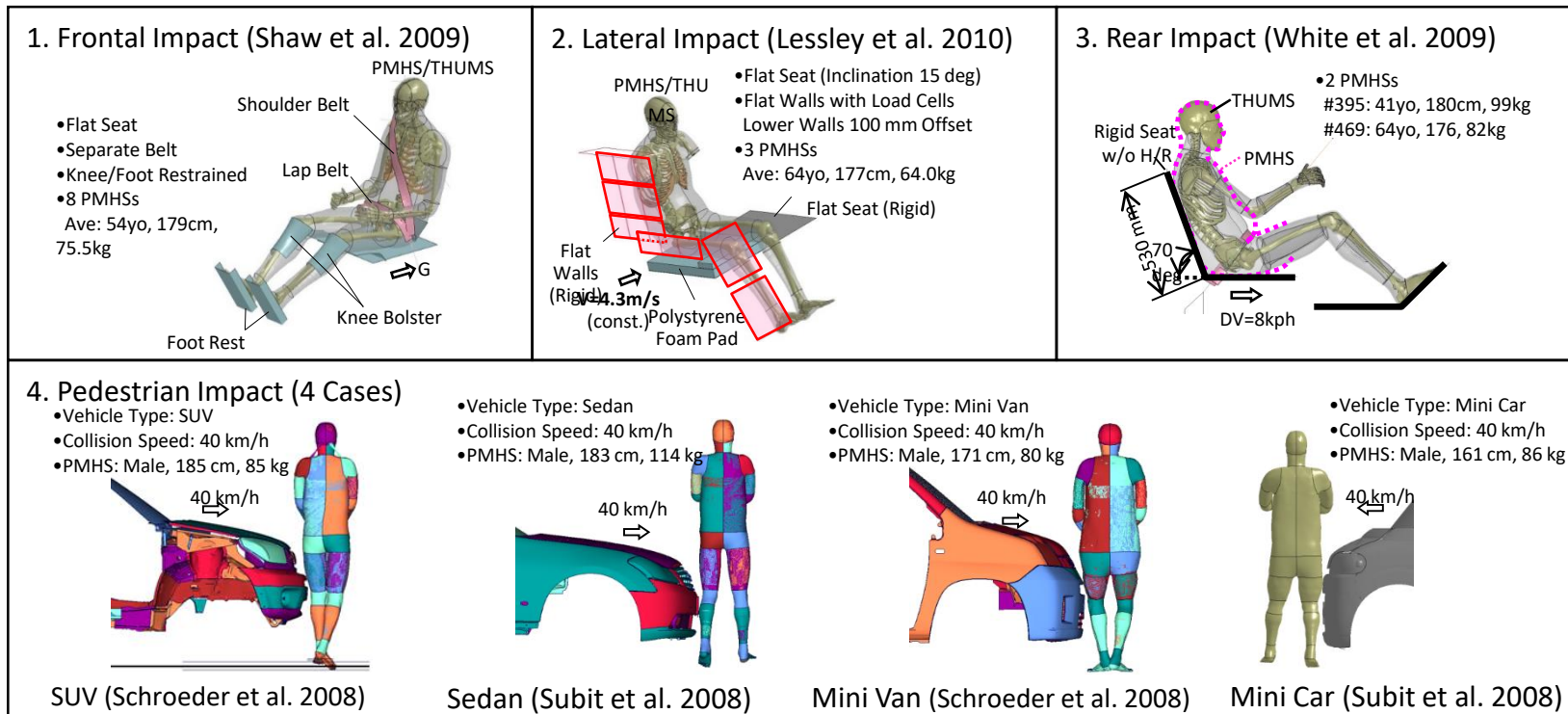
# 1-7. Component Validations

## • Verification of mechanical response from head to foot

<p><b>1. Head Validation</b> (Nahum et al. 1977)</p>  <p>Cylindrical Impactor Weight: 5.6 kg Velocity: 6.3 m/s</p>	<p><b>2. Head Validation</b> (Hardy et al. 2001)</p>  <p>1000rad/s Measurement point (A1) Measurement point (A2) Measurement point (P1) Measurement point (P2) Center of rotation</p>	<p><b>3. Head Validation</b> (Yoganandan et al. 2004)</p>  <p>Free fall Pad Load cell</p>	<p><b>4. Head Validation</b> (Gennarelli et al. 1982)</p>  <p>Angular acceleration Brain CoG 91mm Rotation center</p>	<p><b>5. Neck Validation</b> (Nightingale et al. 1997)</p>  <p>Base (16kg) 3.18m/s Impact plane (Angle 15 deg) Base</p>
<p><b>6. Thorax Validation</b> (Kroell et al. 1974)</p>  <p>Cylindrical Impact Impactor Diameter: 152 mm Impactor Weight: 23 kg Impact Velocity: 7.2 m/s</p>	<p><b>7. Thorax Validation</b> (Cesari et al. 1990)</p>  <p>Belt Loading Weight: 22.4 kg Velocity: 7.78 m/s</p>	<p><b>8. Thorax Validation</b> (Shaw et al. 2006)</p>  <p>Cylindrical Impact Impactor Diameter: 152 mm Impactor Weight: 23 kg Impact Velocity: 2.76 m/s</p>	<p><b>9. Abdomen Validation</b> (Cavanaugh et al. 1986)</p>  <p>Bar Impact Impactor Diameter: 25 mm Impactor Weight: 32 kg Impact Velocity: 6.1 m/s</p>	<p><b>10. Abdomen Validation</b> (Foster et al. 2006)</p>  <p>Belt Loading Width: 50 mm Velocity: 6.9 m/s</p>
<p><b>11. Waist Validation</b> (Rupp et al. 2008)</p>  <p>Load cell PAD Table</p>	<p><b>12. Waist Validation</b> (Guillemot et al. 1997)</p>  <p>PAD Impactor Ball</p>	<p><b>13. Humerus Validation</b> (Kemper et al. 2005)</p>  <p>Bar Loading Device Diameter: 20 mm Impact Velocity: 10 mm/s Loading Head Humerus</p>	<p><b>14. Humerus Validation</b> (Kemper et al. 2005)</p>  <p>Compression: 4 m/s Circular Impactor Diameter: 152 mm Flesh Humerus Circular Table Diameter: 152 mm</p>	<p><b>15. Femur Validation</b> (Yamada et al. 1970)</p>  <p>Bar Loading Device Diameter: 20 mm Impact Velocity: 10 mm/s Impactor Femur</p>
<p><b>16. Knee Joint Validation</b> (Kajzer et al. 1997)</p>  <p>Fixed Fixed Impactor 400 N</p> <p>Impactor Loading Impactor Diameter: 100 mm Impactor Mass: 6.25 kg Impact Velocity: 40 km/h</p>	<p><b>17. Knee Joint Validation</b> (Bose et al. 2004)</p>  <p>300mm 500mm</p>	<p><b>18. Tibia Validation</b> (Schreiber et al. 1997)</p>  <p>Impactor Loading Impactor Diameter: 25 mm Mass: 9.48 kg Impact Velocity: 5.55 m/s</p>	<p><b>19. Ankle Joint Validation</b> (Kitagawa et al. 1998)</p>  <p>Impactor (18kg) Load cell #1 Tension Force (8KN) Load cell #2 offset (50mm) Sole plate Stopper Fi</p>	

# 1-8. Whole body Validations

- Verification of mechanical response at whole body level



# Contents

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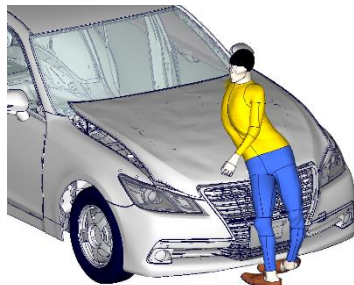
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# 2-1. Application of THUMS

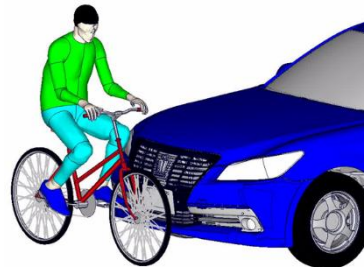
- THUMS is currently used in vehicle safety research and comfort



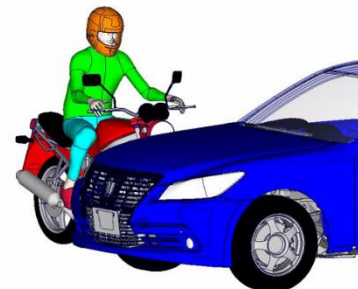
Occupant



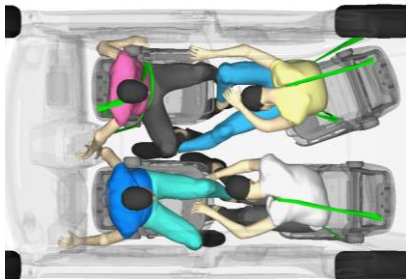
Pedestrian



Cyclist

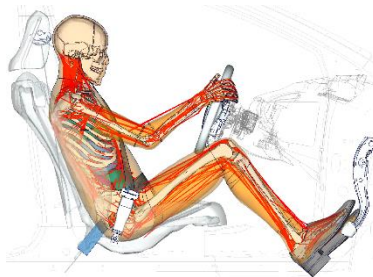


Motorcyclist



Note: Not Product Vehicle Interior

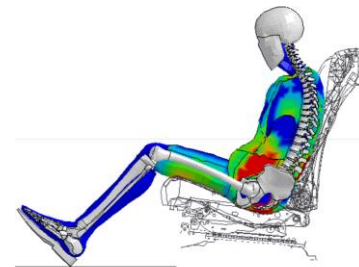
Research of  
Autonomous Vehicle



Pre-Collision Safety



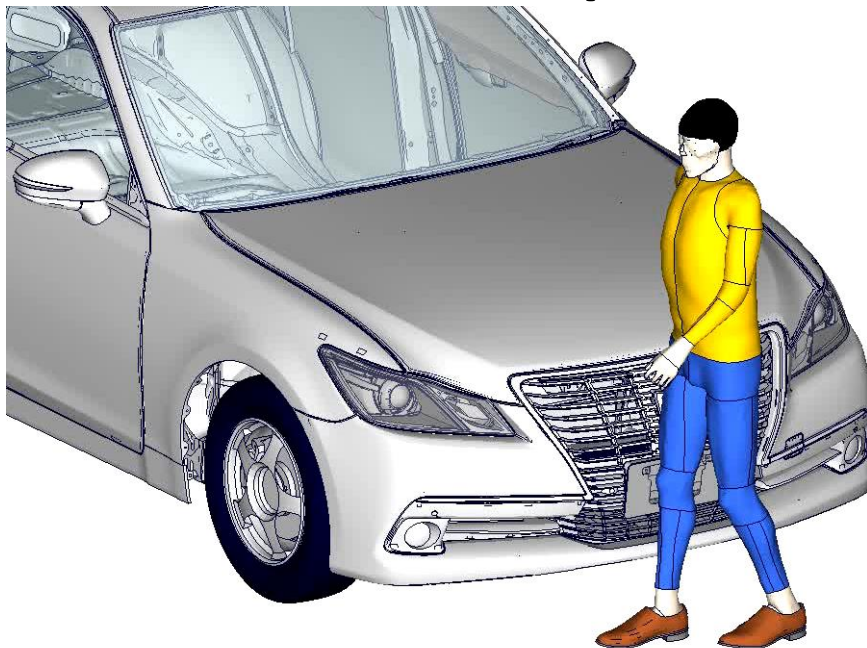
Slalom Driving



Ride Comfort

# 2-1. Application of THUMS (Cont.)

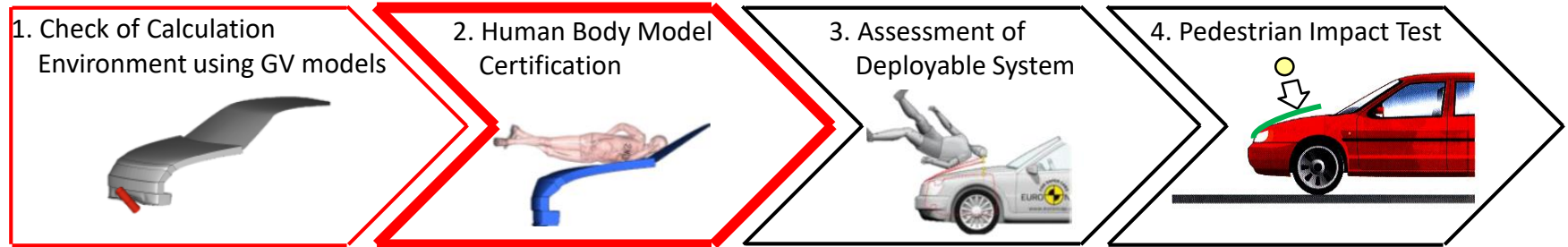
## Pedestrian (Active bonnet)



# 2-2. ENCAP Pedestrian Testing Protocol

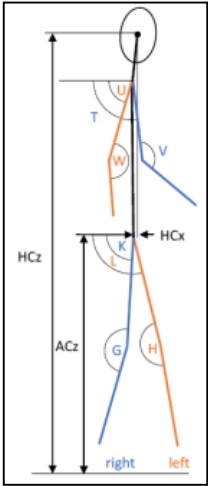
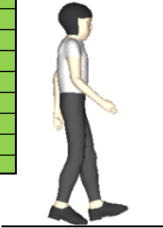
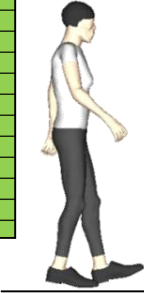


1. Check of Calculation Environment using GV models
2. Human Body Model Certification
3. Assessment of Deployable System
4. Pedestrian Impact Test

Technical Bulletin 024  
(TB024)



# 2-3. Size and Posture

- THUMSs (6YO/AF05/AM50/AM95) size and posture were modified for TB024.
- All modified THUMSs meet the certification requirements.

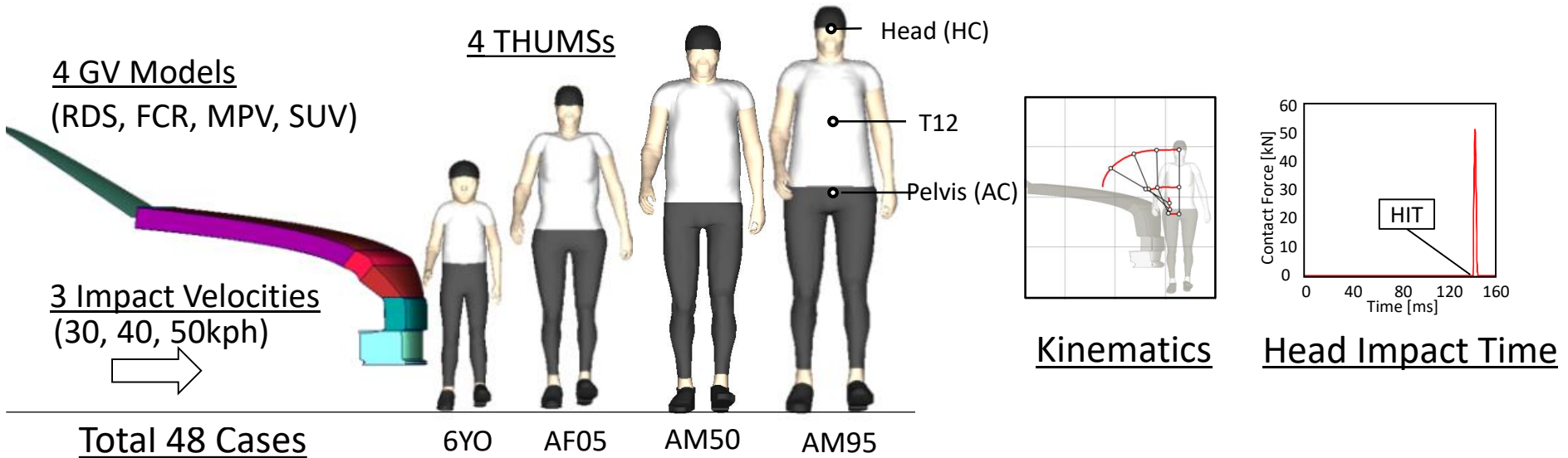
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	THUMS 6YO V4	THUMS AF05 V4.02	THUMS AM50 V4.02	THUMS AM95 V4.02																																																																																																																																																																								
	<table border="1"> <thead> <tr> <th></th> <th>Actual</th> <th>Check</th> </tr> </thead> <tbody> <tr><td>Px</td><td>202</td><td>OK</td></tr> <tr><td>Py</td><td>151</td><td>OK</td></tr> <tr><td>ACz</td><td>640</td><td>OK</td></tr> <tr><td>K</td><td>90.1</td><td>OK</td></tr> <tr><td>L</td><td>102.2</td><td>OK</td></tr> <tr><td>G</td><td>165.3</td><td>OK</td></tr> <tr><td>H</td><td>178.4</td><td>OK</td></tr> <tr><td>T</td><td>97.5</td><td>OK</td></tr> <tr><td>U</td><td>69.8</td><td>OK</td></tr> <tr><td>V</td><td>140.7</td><td>OK</td></tr> <tr><td>W</td><td>164.9</td><td>OK</td></tr> <tr><td>HCx</td><td>6</td><td>OK</td></tr> <tr><td>HCz</td><td>1117</td><td>OK</td></tr> </tbody> </table> 		Actual	Check	Px	202	OK	Py	151	OK	ACz	640	OK	K	90.1	OK	L	102.2	OK	G	165.3	OK	H	178.4	OK	T	97.5	OK	U	69.8	OK	V	140.7	OK	W	164.9	OK	HCx	6	OK	HCz	1117	OK	<table border="1"> <thead> <tr> <th></th> <th>Actual</th> <th>Check</th> </tr> </thead> <tbody> <tr><td>Px</td><td>236</td><td>OK</td></tr> <tr><td>Py</td><td>152</td><td>OK</td></tr> <tr><td>ACz</td><td>831</td><td>OK</td></tr> <tr><td>K</td><td>91.1</td><td>OK</td></tr> <tr><td>L</td><td>103.9</td><td>OK</td></tr> <tr><td>G</td><td>166.0</td><td>OK</td></tr> <tr><td>H</td><td>177.0</td><td>OK</td></tr> <tr><td>T</td><td>96.9</td><td>OK</td></tr> <tr><td>U</td><td>70.8</td><td>OK</td></tr> <tr><td>V</td><td>139.0</td><td>OK</td></tr> <tr><td>W</td><td>164.7</td><td>OK</td></tr> <tr><td>HCx</td><td>27</td><td>OK</td></tr> <tr><td>HCz</td><td>1473</td><td>OK</td></tr> </tbody> </table> 		Actual	Check	Px	236	OK	Py	152	OK	ACz	831	OK	K	91.1	OK	L	103.9	OK	G	166.0	OK	H	177.0	OK	T	96.9	OK	U	70.8	OK	V	139.0	OK	W	164.7	OK	HCx	27	OK	HCz	1473	OK	<table border="1"> <thead> <tr> <th></th> <th>Actual</th> <th>Check</th> </tr> </thead> <tbody> <tr><td>Px</td><td>298</td><td>OK</td></tr> <tr><td>Py</td><td>167</td><td>OK</td></tr> <tr><td>ACz</td><td>939</td><td>OK</td></tr> <tr><td>K</td><td>90.6</td><td>OK</td></tr> <tr><td>L</td><td>104.6</td><td>OK</td></tr> <tr><td>G</td><td>165.0</td><td>OK</td></tr> <tr><td>H</td><td>176.0</td><td>OK</td></tr> <tr><td>T</td><td>97.9</td><td>OK</td></tr> <tr><td>U</td><td>70.2</td><td>OK</td></tr> <tr><td>V</td><td>140.0</td><td>OK</td></tr> <tr><td>W</td><td>159.9</td><td>OK</td></tr> <tr><td>HCx</td><td>44</td><td>OK</td></tr> <tr><td>HCz</td><td>1682</td><td>OK</td></tr> </tbody> </table> 		Actual	Check	Px	298	OK	Py	167	OK	ACz	939	OK	K	90.6	OK	L	104.6	OK	G	165.0	OK	H	176.0	OK	T	97.9	OK	U	70.2	OK	V	140.0	OK	W	159.9	OK	HCx	44	OK	HCz	1682	OK	<table border="1"> <thead> <tr> <th></th> <th>Actual</th> <th>Check</th> </tr> </thead> <tbody> <tr><td>Px</td><td>335</td><td>OK</td></tr> <tr><td>Py</td><td>263</td><td>OK</td></tr> <tr><td>ACz</td><td>1043</td><td>OK</td></tr> <tr><td>K</td><td>87.9</td><td>OK</td></tr> <tr><td>L</td><td>102.2</td><td>OK</td></tr> <tr><td>G</td><td>164.5</td><td>OK</td></tr> <tr><td>H</td><td>176.1</td><td>OK</td></tr> <tr><td>T</td><td>97.5</td><td>OK</td></tr> <tr><td>U</td><td>71.2</td><td>OK</td></tr> <tr><td>V</td><td>140.8</td><td>OK</td></tr> <tr><td>W</td><td>164.5</td><td>OK</td></tr> <tr><td>HCx</td><td>16</td><td>OK</td></tr> <tr><td>HCz</td><td>1841</td><td>OK</td></tr> </tbody> </table> 		Actual	Check	Px	335	OK	Py	263	OK	ACz	1043	OK	K	87.9	OK	L	102.2	OK	G	164.5	OK	H	176.1	OK	T	97.5	OK	U	71.2	OK	V	140.8	OK	W	164.5	OK	HCx	16	OK	HCz	1841	OK
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HCz	1117	OK																																																																																																																																																																										
	Actual	Check																																																																																																																																																																										
Px	236	OK																																																																																																																																																																										
Py	152	OK																																																																																																																																																																										
ACz	831	OK																																																																																																																																																																										
K	91.1	OK																																																																																																																																																																										
L	103.9	OK																																																																																																																																																																										
G	166.0	OK																																																																																																																																																																										
H	177.0	OK																																																																																																																																																																										
T	96.9	OK																																																																																																																																																																										
U	70.8	OK																																																																																																																																																																										
V	139.0	OK																																																																																																																																																																										
W	164.7	OK																																																																																																																																																																										
HCx	27	OK																																																																																																																																																																										
HCz	1473	OK																																																																																																																																																																										
	Actual	Check																																																																																																																																																																										
Px	298	OK																																																																																																																																																																										
Py	167	OK																																																																																																																																																																										
ACz	939	OK																																																																																																																																																																										
K	90.6	OK																																																																																																																																																																										
L	104.6	OK																																																																																																																																																																										
G	165.0	OK																																																																																																																																																																										
H	176.0	OK																																																																																																																																																																										
T	97.9	OK																																																																																																																																																																										
U	70.2	OK																																																																																																																																																																										
V	140.0	OK																																																																																																																																																																										
W	159.9	OK																																																																																																																																																																										
HCx	44	OK																																																																																																																																																																										
HCz	1682	OK																																																																																																																																																																										
	Actual	Check																																																																																																																																																																										
Px	335	OK																																																																																																																																																																										
Py	263	OK																																																																																																																																																																										
ACz	1043	OK																																																																																																																																																																										
K	87.9	OK																																																																																																																																																																										
L	102.2	OK																																																																																																																																																																										
G	164.5	OK																																																																																																																																																																										
H	176.1	OK																																																																																																																																																																										
T	97.5	OK																																																																																																																																																																										
U	71.2	OK																																																																																																																																																																										
V	140.8	OK																																																																																																																																																																										
W	164.5	OK																																																																																																																																																																										
HCx	16	OK																																																																																																																																																																										
HCz	1841	OK																																																																																																																																																																										

Certification (Green/OK means “Certified”)



# 2-4. Impact Response

- Forty eight (48) vehicle-to-pedestrian collision simulations were conducted with the modified THUMSs (6YO, AF05, AM50, AM95) having their size and posture changed.
- Body kinematics (Head, T12 and Pelvis) and head impact time were calculated.



# 2-5. THUMS TB024 Summary

- Modified THUMS having size and posture changed meet TB024 certification requirements including impact response of THUMS AM50 and 6YO.
- Impact responses of THUMSs (AF05, AM95) can be simulated to head contact.

	Size and Posture	Impact Response (30, 40, 50kph)	
		kinematics	HIT
AM50	OK	OK	OK
6YO	OK	OK	OK
AF05	OK	Can be simulated	Can be simulated
AM95	OK	Can be simulated	Can be simulated

Certification (Green/OK means “Certified”)

# 2-6. THUMS Users

- THUMS is currently used in vehicle safety research by over 100 vehicle manufacturers, suppliers, research institutions, and others.



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# 3-1. Free Access to THUMS

- THUMS models freely available from January 2021.
- THUMS will help to improve the safety of cars and mobility.

June 16, 2020  
Toyota Motor Corporation

**Toyota Offers Free Access to THUMS Virtual Human Body Model Software**

Greater use of THUMS for analysis of vehicle collision-related injuries to enhance vehicle safety

Toyota City, Japan, June 16, 2020—Toyota Motor Corporation (Toyota) announced today that it will make its Total Human Model for Safety (THUMS) software freely available from January 2021 as part of its efforts toward a safe mobility society. THUMS is a virtual human body model software program for computer analysis of human body injuries caused in vehicle collisions. Free access to THUMS, and subsequent use by a wider variety of users, is expected to enhance vehicle safety.

Designed to aid vehicle safety technologies' research and development, and developed in cooperation with Toyota Central R&D Labs., Inc. THUMS was the world's first virtual human body model software when it launched in 2000. It enabled simulation and analysis of injuries caused in vehicle collisions. Since then, and up until the latest version 6 was released last year, it has continually evolved to add a range of models with different genders, ages and physiques that include skeletal structures, brains, internal organs, and muscles. Compared to the physical crash dummies commonly used in vehicle collision tests, THUMS is able to analyze collision-related injuries in more detail, because it precisely models the shapes and durability of human bodies. Conducting simulations on computers also enables repeated analysis of a range of different collision patterns, while it can dramatically reduce development lead times and costs associated with collision testing.

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Evolution of THUMS

**Detailed Modeling of Human Tissues**

**Muscle Modeling**

THUMS is currently used in vehicle safety research by over 100 vehicle manufacturers, suppliers, universities, research institutions and others, in Japan and overseas. It is being used to research and develop many different safety technologies, such as seatbelts, airbags, and vehicle structures that help reduce injury risks in vehicle collisions with pedestrians. Vehicle safety assessment organizations are also currently considering the use of THUMS for virtual testing in their future assessment plans.

Making THUMS freely available is expected not only to enable a greater number of people to use it in their vehicle safety research, but to also improve the usability of the software, as users make improvements to the model themselves and share the results with others.

Sergo Kuzumaki, Fellow at Advanced R&D and Engineering Company, offered the following comment about free access to THUMS: "Since the very first launch of THUMS in 2000, we've been making ongoing improvements and avidly working to better reproduce the human anatomy and expand the variations of models. It has now become indispensable technology to Toyota's efforts in developing safety technologies and vehicles. We decided to make the software freely available to have more people use it, to further enhance vehicle safety across the entire automotive industry, and to help reduce traffic injuries and fatalities to create a safer society. We look forward to seeing it applied broadly in development sites and others, envisaging a mobility society with automated vehicles and other technologies, moving forward."

Software license sales through JSOL Corporation (Tokyo) and ESI Group (Paris) will come to an end during 2020, with the start of free access to THUMS.

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**THUMS Version 4: Models**

Models include detailed human anatomy (skeletal structures, brains, internal organs, etc.) in a range of genders, ages, physiques, and postures.

Note: Versions 4, 5, and 6 will be made available for free.

**History of THUMS**

Year	Progress	Details
1997	Toyota begins developing THUMS together with Toyota Central R&D Labs., Inc.	
2000	Version 1 released	Detailed modeling of bones added
2005	Version 2 released	Detailed modeling of faces added
2008	Version 3 released	Detailed modeling of the brain added
2010	Version 4 released	Detailed modeling of internal organs added
2011	A variety of different physiques added to Version 4	Small female, large male models added
2015	Version 5 released	Modeling of all body muscles added
2016	Child models added to Version 4	Child models aged 3, 6, and 10 years old added
2019	Version 6 released	Modeling of muscles added to modeling of internal organs
2020	Free access will be offered	Current release

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Toyota news release: <https://global.toyota/en/newsroom/corporate/32665896.html>

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# Conclusions

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1. THUMS was modeled with CT data of living human subject and has been validated for components and whole body kinematics.
2. THUMS is currently used in vehicle safety research by over 100 users. And THUMS pedestrian models meeting TB024 certification are available.
3. THUMS will be available free access from next year.

**Thank you for  
your attention!**



**THUMS Version 4 Family**