TOYOTA

Sensitivity of hardware testing variability on injury outcomes of THOR-50M in frontal impact

16.10.2024

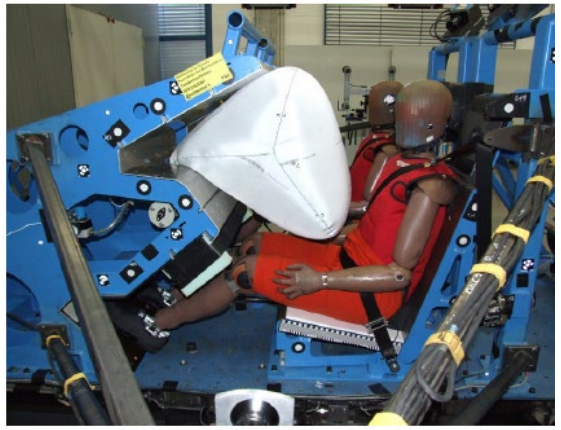
German LS-DYNA Forum 2024

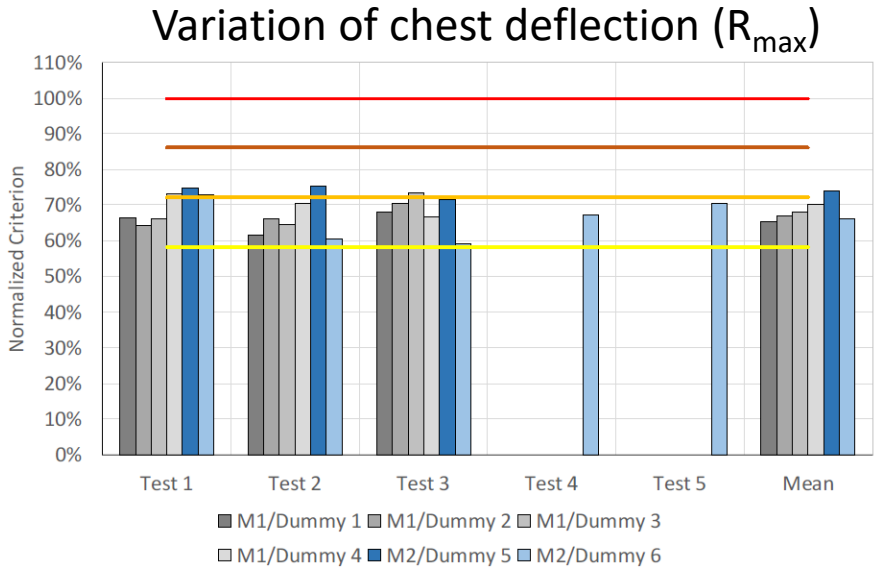
Daiki Furukawa | Toyota Motor Corporation
Dr. Andre Eggers | BASt

Contents

Background

- Hardware test scatter in MPDB test with THOR dummy leads to variation in test results(i.e. injury values and rating)
- This scatter effect might be higher than the differences resulting from different safety systems (e.g. improved advanced restraint system)





C. Gehre, THOR 50-M R&R compared to current consumer rating schemes First Results - Update, 2019

Objective

Identify and quantify influence on test results (injury values, rating) of hardware test scatter resulting from test boundary condition and restraint system

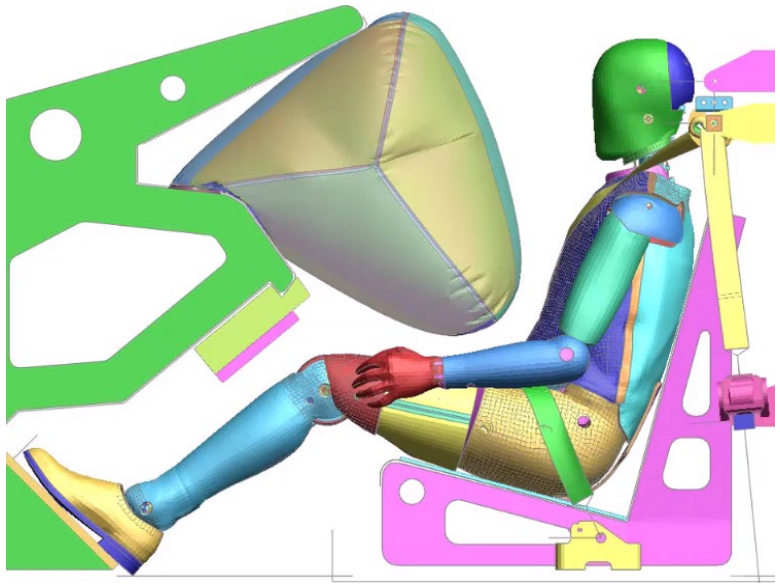
Method -Investigation Flow-

- Step1
  - Setup of a simulation environment (baseline condition)
  - Define parameters and their range of variation
- Step2
  - Simulations with changing parameters (one parameter in each simulation)
- Step3
  - Analyze the variation influence on injury outcomes (Head, Thorax)

Method -Simulation Environment-

- Vehicle environment: Generic rigid seat setup (developed by PDB*1)
- Restraint system: 3pt. belt with pretensioner and load limiter, Airbag, Knee bolster

  *2: The simulation model was provided by PDB and parameters of the restraint system were updated based on the sled tests data conducted in BASt (35kph FRB, N=4) and validated with these hardware test results
- Load case: 50km/h MPDB generic pulse (Euro NCAP knee mapping sled class-B*3, 0 degree sled)
- Occupant: THOR-50M Euro (Humanetics v1.9.2*4)
- Assessment criteria: Head(HIC15, DAMAGE) and Thorax(R_{max}, PC Score, TIC-NFR)*5



Criteria	Definition
R_{max}	$R_{max} = \max(UL_{max}, UR_{max}, LL_{max}, LR_{max})$
PC Score	$PC\ Score = 0.486\left(\frac{up_{tot}}{17.439}\right) + 0.492\left(\frac{low_{tot}}{14.735}\right) + 0.496\left(\frac{up_{dif}}{9.672}\right) + 0.526\left(\frac{low_{dif}}{12.384}\right)$ $up_{tot} = \lvert UL\rvert_{max} + \lvert UR\rvert_{max}\ ,\ up_{dif} = \lvert UL - UR\rvert_{max}$ $low_{tot} = \lvert LL\rvert_{max} + \lvert LR\rvert_{max}\ ,\ low_{dif} = \lvert LL - LR\rvert_{max}$
TIC-NFR	$TIC_{NRF} = Rmax + 1.66\ up_{dif}$

*1: Wernicke, P. et al.: "Repeatability and reproducibility of the Q10 child dummy with upgrade kit", International Conference Protection of Children in Cars, 2022
*3: Euro NCAP: "Sled Test Procedure for Assessing Knee Impact Areas", Version 4.1, 2020
*4: Humanetics Innovative Solutions: " THOR-50M Euro NCAP Dummy LS-DYNA FE Model Release Version 1.9.2 Technical Report and User's Manual", 2024
*5: ISO 19222:2020(E), Road Vehicle – THOR dummy Injury Risk Curves

Method -Parameters-

- Single parameter was changed in each simulation
- Total of 15 simulations including baseline condition
- Range of parameter was assumed based on Euro NCAP protocol* or realistic test scatter (next page)

Boundary condition	Restraint system
➢ Dummy initial posture ➢ Belt routing ➢ Vehicle pulse	➢ Load limiter force ➢ Pretensioner timing ➢ Airbag vent property ➢ Knee bolster stiffness

*Euro NCAP: "MPDB FRONTAL IMPACT TESTING PROTOCOL Version 1.1.4", 2023

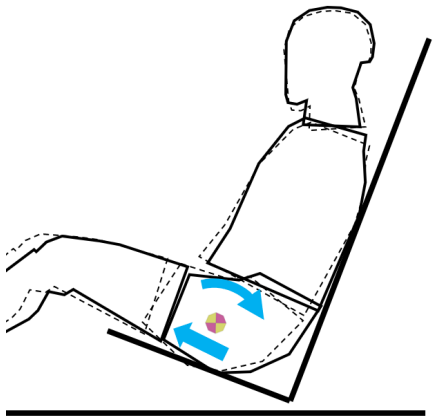
Method -Boundary Condition Parameters-

Dummy initial posture

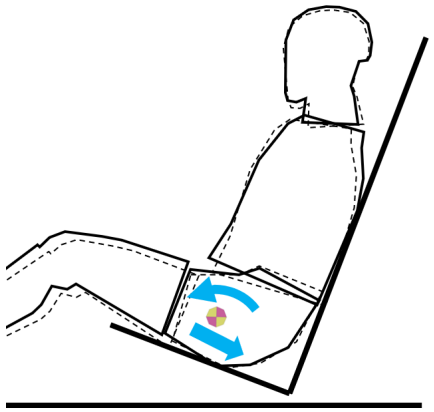
Posture	H-point (X/Z)	Pelvis angle(Y)	Knee-IP distance
Baseline	-	32.2	72
Forward	-13/+3	35.5(=33+2.5)	52
Rearward	+13/-3	30.5(=33-2.5)	87

Neck/T1 angle and heel positon were set as close as baseline posture

Forward

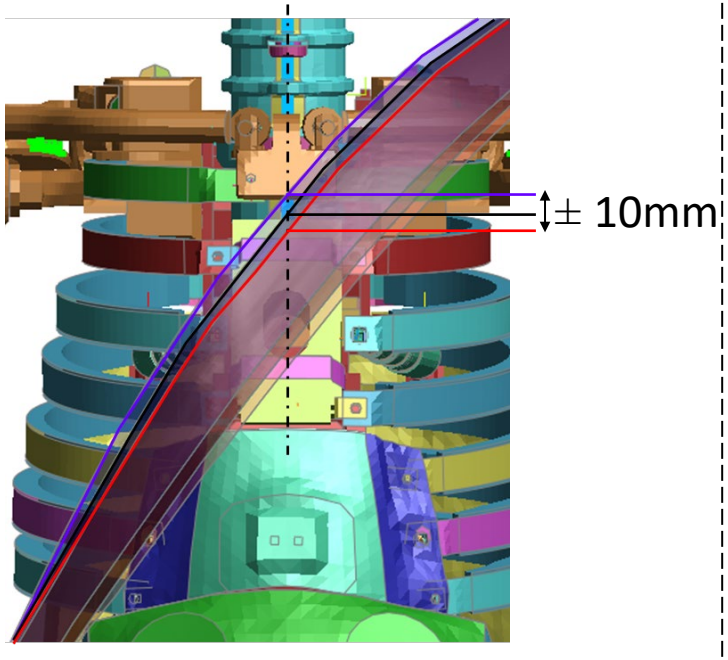


Rearward



*The range of H-point and pelvis angle were defined based on Euro NCAP protocol: "MPDB FRONTAL IMPACT TESTING PROTOCOL Version 1.1.4", 2023

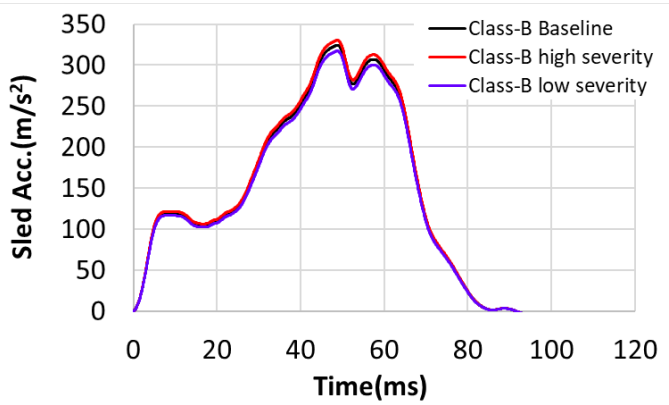
Diagonal belt routing



Vehicle pulse

Pulse	OLC
Baseline	25.5
High severity	26.1
Low severity	24.8

± 2.5%

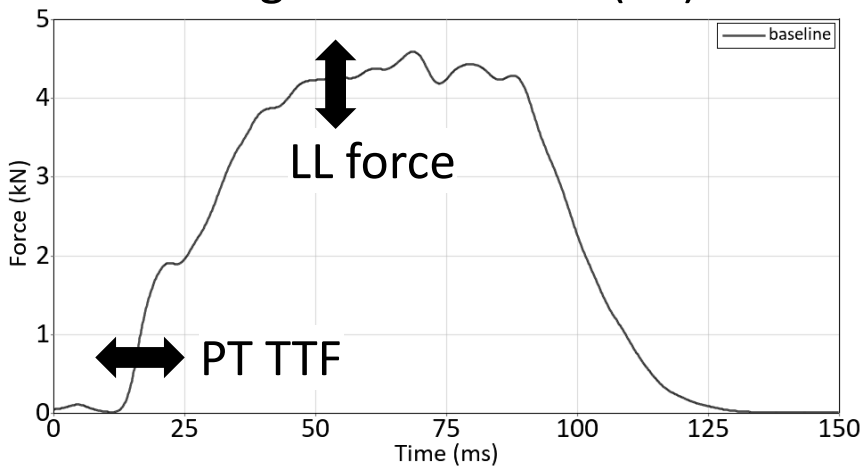


Method -Restraint System Parameters-

Seatbelt

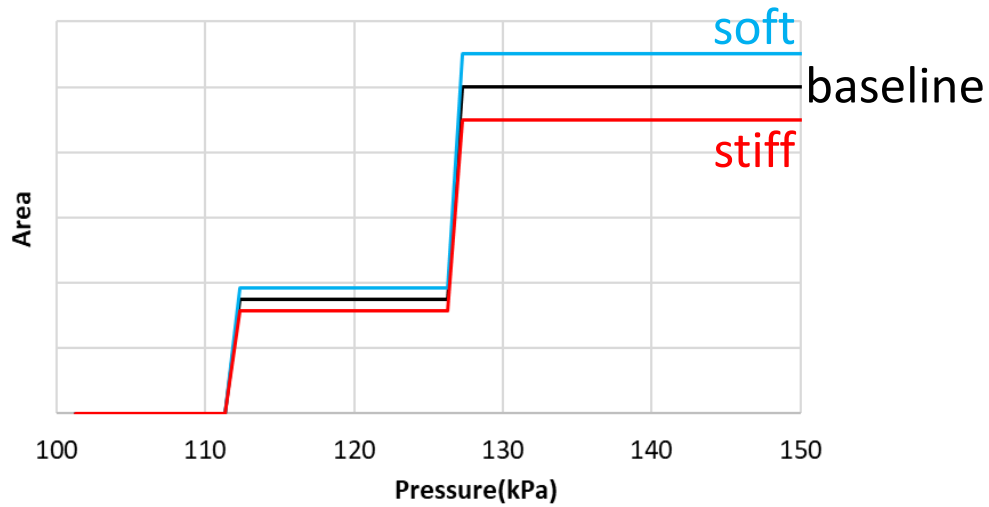
Parameter	Range
Load Limiter force (LL force)	Baseline± 7.5%
Pretensioner time to fire (PT TTF)	Baseline± 3ms

Diagonal belt force (B3)



Airbag & Knee bolster

Parameter	Range
Airbag(AB) vent property	Baseline± 10%
Knee bolster(KB) stiffness	Baseline± 10%



Result -Variation of Head Injury Criteria-

- DAMAGE was more sensitive to seatbelt parameters than others
- Variation of HIC15 was smaller than DAMAGE in most cases (less than 1%)

Variation*1 of injury probability*2, 3

	Boundary condition			Restraint system			
	Dummy posture	Belt routing	Vehicle pulse	LL force	PT TTF	AB vent	KB
HIC15(AIS3+)	0.4	0.3	0.6	0.1	0.2	0.1	0.0
DAMAGE(AIS2+)	6.6	4.8	4.8	9.6	7.0	0.0	2.3

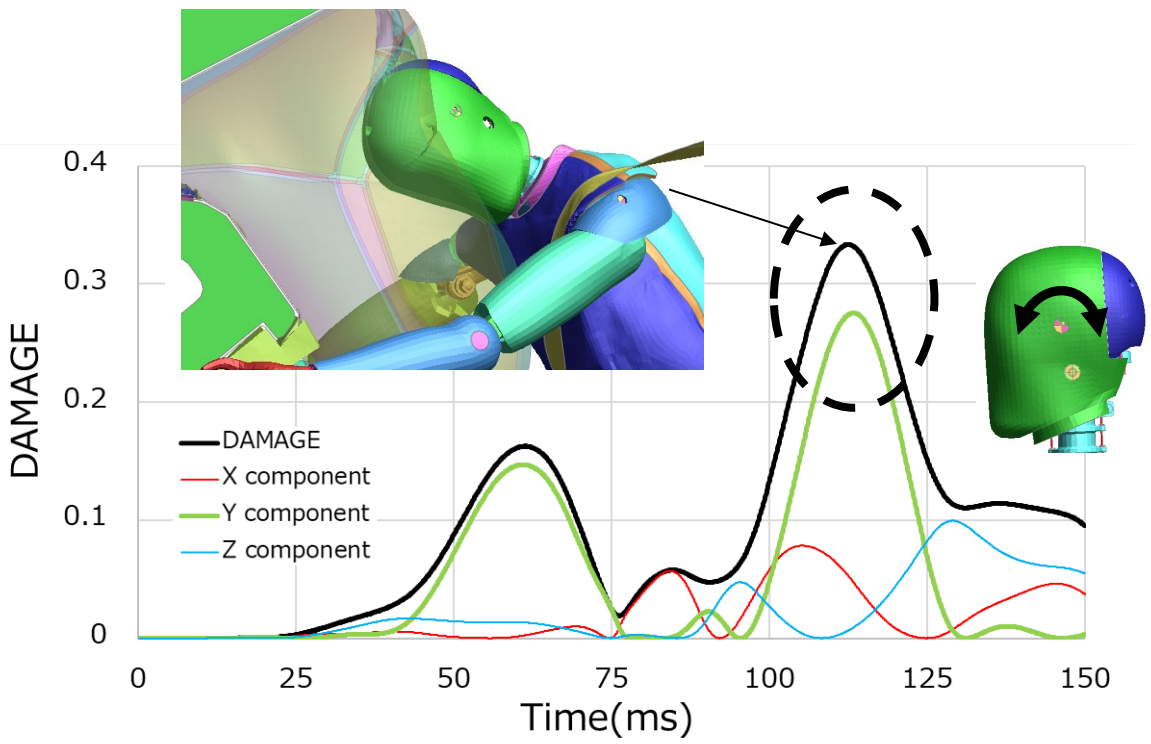
*1 : $Variation\ of\ injury\ probability[\%] = Max.P(Baseline,\ Upper,\ Lower) - Min.P(Baseline,\ Upper,\ Lower)$

*2: NHTSA, Injury Criteria for the THOR 50th Male ATD, 2020
*3: ISO 19222:2020(E), Road Vehicle – THOR dummy Injury Risk Curves

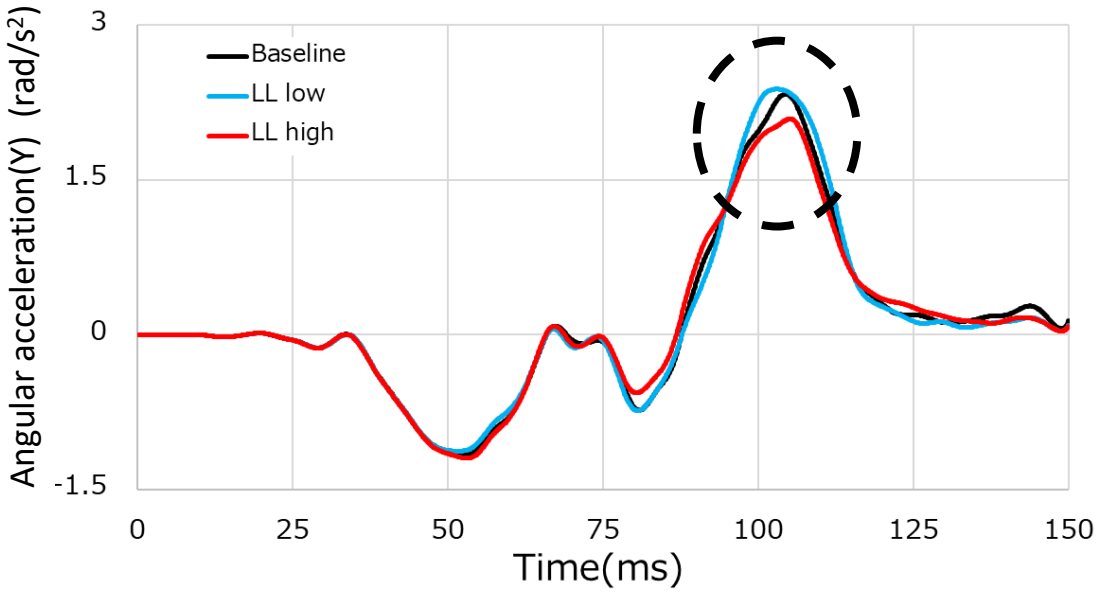
Discussion -Variation of DAMAGE-

- DAMAGE was highly dependent on Y axis rotation kinematics when beginning of head rebounding from airbag
- DAMAGE may be affected by contact position with airbag or thorax kinematics

Axial component of DAMAGE (Baseline)

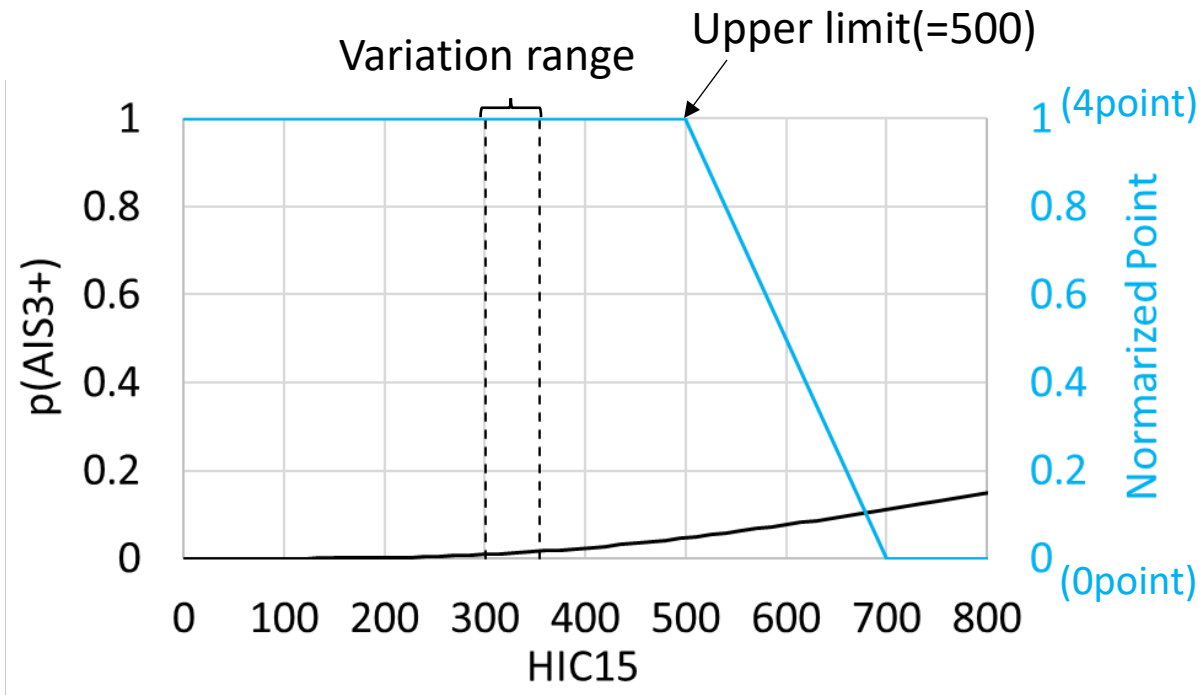


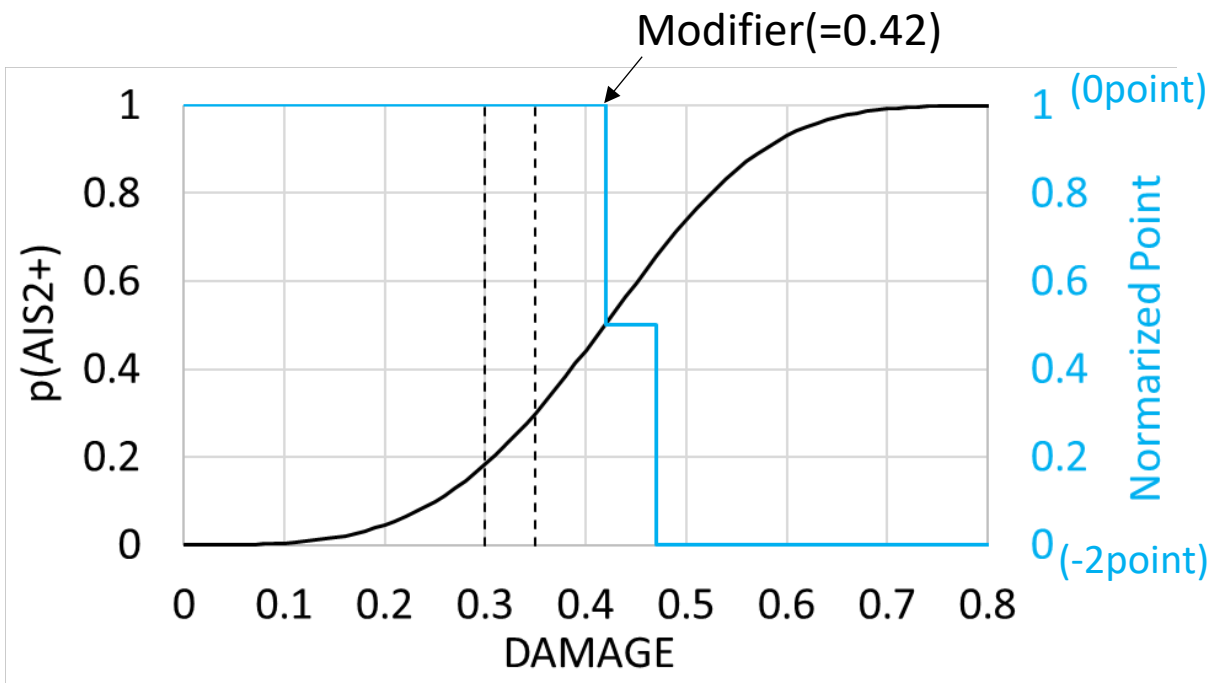
Y axis angular acceleration
(LL force parameter)



Discussion -Comparison with current Euro NCAP rating-

- The variation range of head criteria were under upper limit or modifier (Rating result of head region are not affected in this condition)





*Euro NCAP: „Assessment protocol Adult Occupant Protection Version 9.3", 2023

Result -Variation of Thorax Injury Criteria-

- R_{max} and PC Score were more sensitive to dummy posture and LL force than other parameters
- Variation of TIC-NFR was up to 4.4% and showed different tendency compare to Rmax & PC Score

Variation*1 of injury probability*2-4

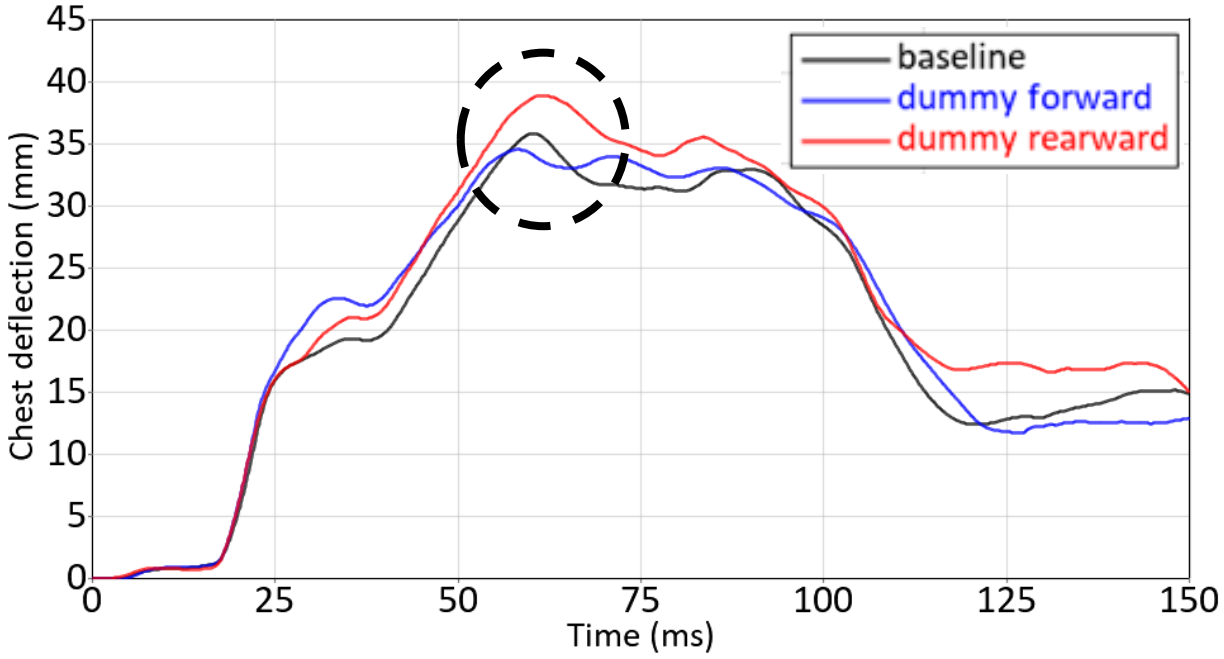
	Boundary condition			Restraint system			
	Dummy posture	Belt routing	Vehicle pulse	LL force	PT TTF	AB vent	KB
R_{max}	8.3	1.2	0.7	5.6	2.4	0.0	0.5
PC Score	5.9	0.7	0.7	3.5	1.4	0.1	0.4
TIC-NFR	3.3	4.4	0.9	1.2	2.6	0.1	0.3

*1: $Variation\ of\ injury\ probability[\%] = Max.P(Baseline,\ Upper,\ Lower) - Min.P(Baseline,\ Upper,\ Lower)$
*2: Injury probability of AIS3+(NFR3+) was calculated as occupant of 45 years old
*3: NHTSA, Injury Criteria for the THOR 50th Male ATD, 2020
*4: ISO 19222:2020(E), Road Vehicle – THOR dummy Injury Risk Curves

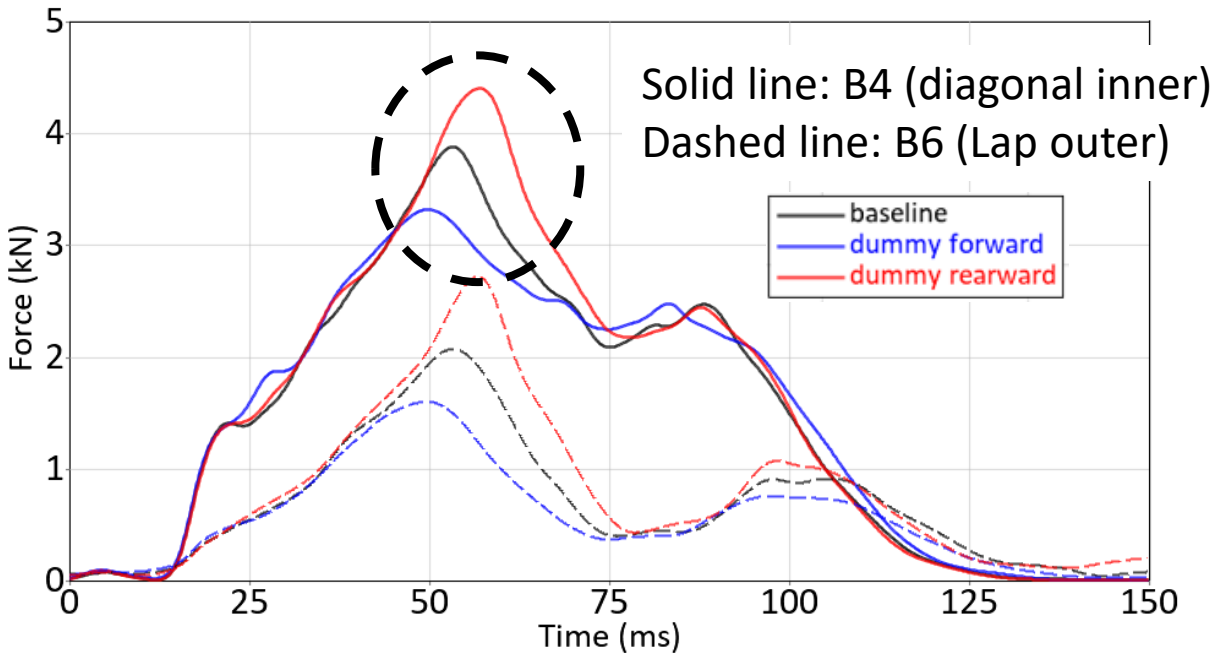
Discussion -Variation of Chest Deflection-

- Chest deflection increaced as initial pelvis location became more rearward
- Seatbelt force (B4&B6) were affected by pelvis kinematics (knee restraint timing)

Chest Deflection (Upper Right)



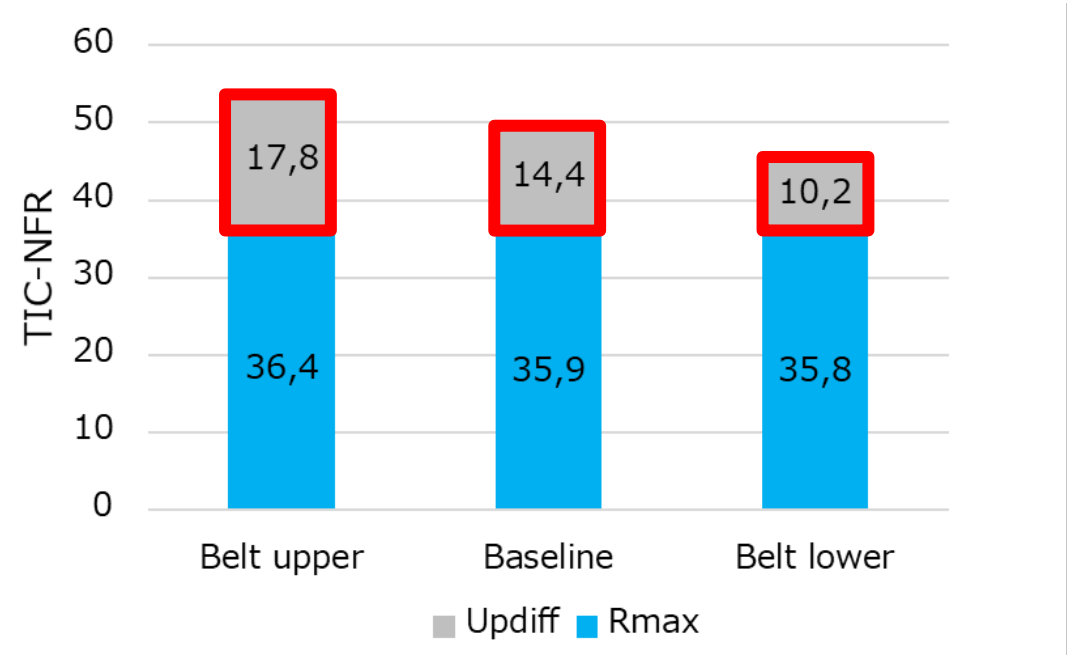
Seatbelt force

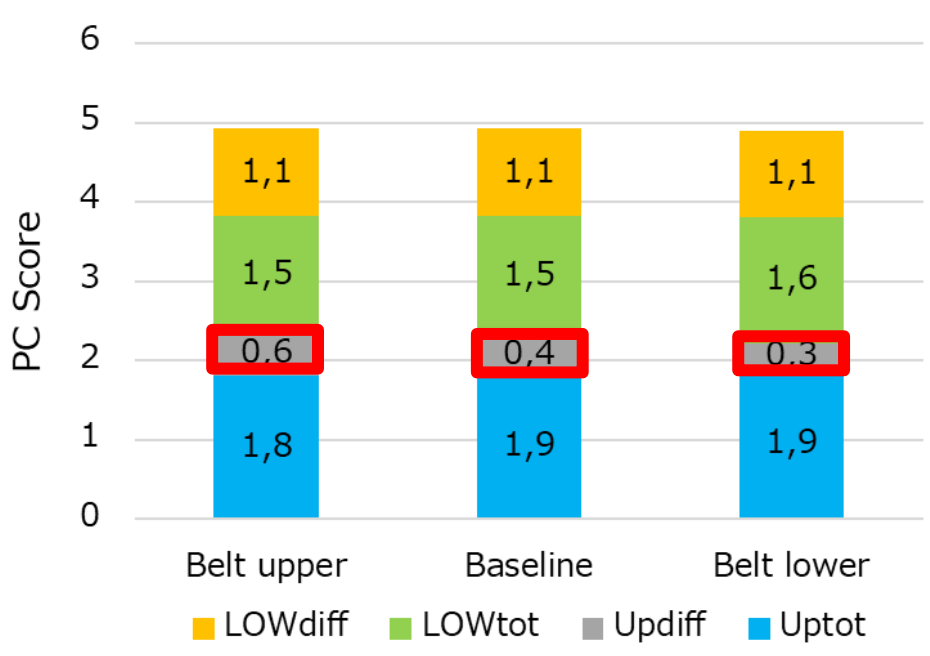


Discussion -Thorax Injury Criteria-

- Contribution of upper deflection term of TIC-NFR was larger than PC Score (i.e. TIC-NFR was more sensitive to upper deflection difference)

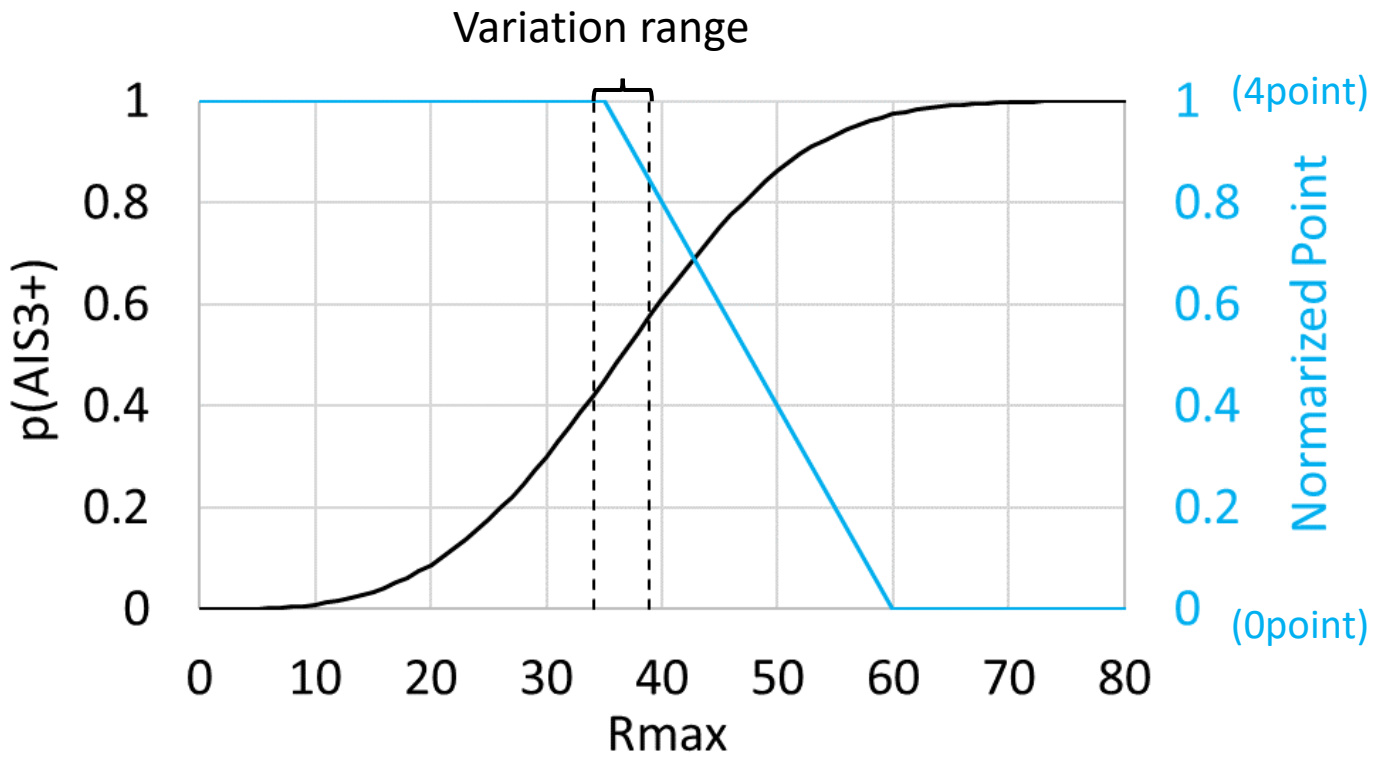
Criteria	Definition
PC Score	$PC\ Score = 0.486\left(\frac{up_{tot}}{17.439}\right) + 0.492\left(\frac{low_{tot}}{14.735}\right) + 0.496\left(\frac{up_{dif}}{9.672}\right) + 0.526\left(\frac{low_{dif}}{12.384}\right)$ $up_{tot} = \lvert UL\rvert_{max} + \lvert UR\rvert_{max}\ ,\ up_{dif} = \lvert UL - UR\rvert_{max}$ $low_{tot} = \lvert LL\rvert_{max} + \lvert LR\rvert_{max}\ ,\ low_{dif} = \lvert LL - LR\rvert_{max}$
TIC-NFR	$TIC_{NRF} = Rmax + 1.66\ up_{dif}$





Discussion -Comparison with Euro NCAP rating (Thorax)-

- Rating result of thorax region could be affected resulting from the variation of boundary condition or restraint system



Summary

- Simulation-based investigation to clarify the influence of boundary condition and restraint system variability on injury outcomes were conducted

- **This study suggests that controlling of the initial dummy posture is important to mitigate the thorax assessment variation**
  - Maximum 8.3% variation of R_{max} and 5.9% of PC Score resulting from variation of dummy posture
  - The variation of TIC-NFR was up to 4.4% and different tendency of sensitivity was seen compared to the other thorax criteria
  - The variation range of head criteria were under upper limit or modifier

Limitation and Outlook

- Limitation
  - These findings were based on small number of simulations and interaction of parameters were not considered
  - The simulations were conducted in a generic sled (0 degree) environment

- Outlook
  - Sensitivity analysis of THOR-50M parts was conducted
    (presented at Humanetics Safety Summit EU 2024)
  - Sensitivity analysis of relevant parameters by DOE study
  - Investigation of boundary conditions and restraint system by HBM simulations
    (will be presented at carhs Human Modeling and Simulation Symposium in November)

Achknowledgement

We would like to thank Partnership for Dummy Technology and Biomechanics (PDB) for providing the baseline simulation model and related test data

Thank you for your attention!