中国汽车工程研究院股份有限公司
China Automotive Engineering Research Institute Co., Ltd.

Research on Occupant Response and Injuries of Reclined Seat

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1.1 Products

1.2 Accidents

1.3 Injuries

1.4 Protocols

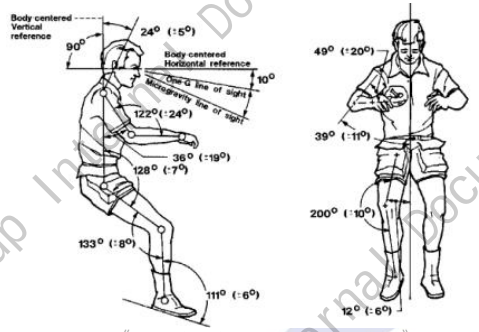
Why We Do

1.1 Products- Autonomous Driving and Zero-gravity Seats

Occupant non-driving activities, unconventional positions

Polular Zero-gravity Seat (Reclined Seat) in market

More comfort and less safety



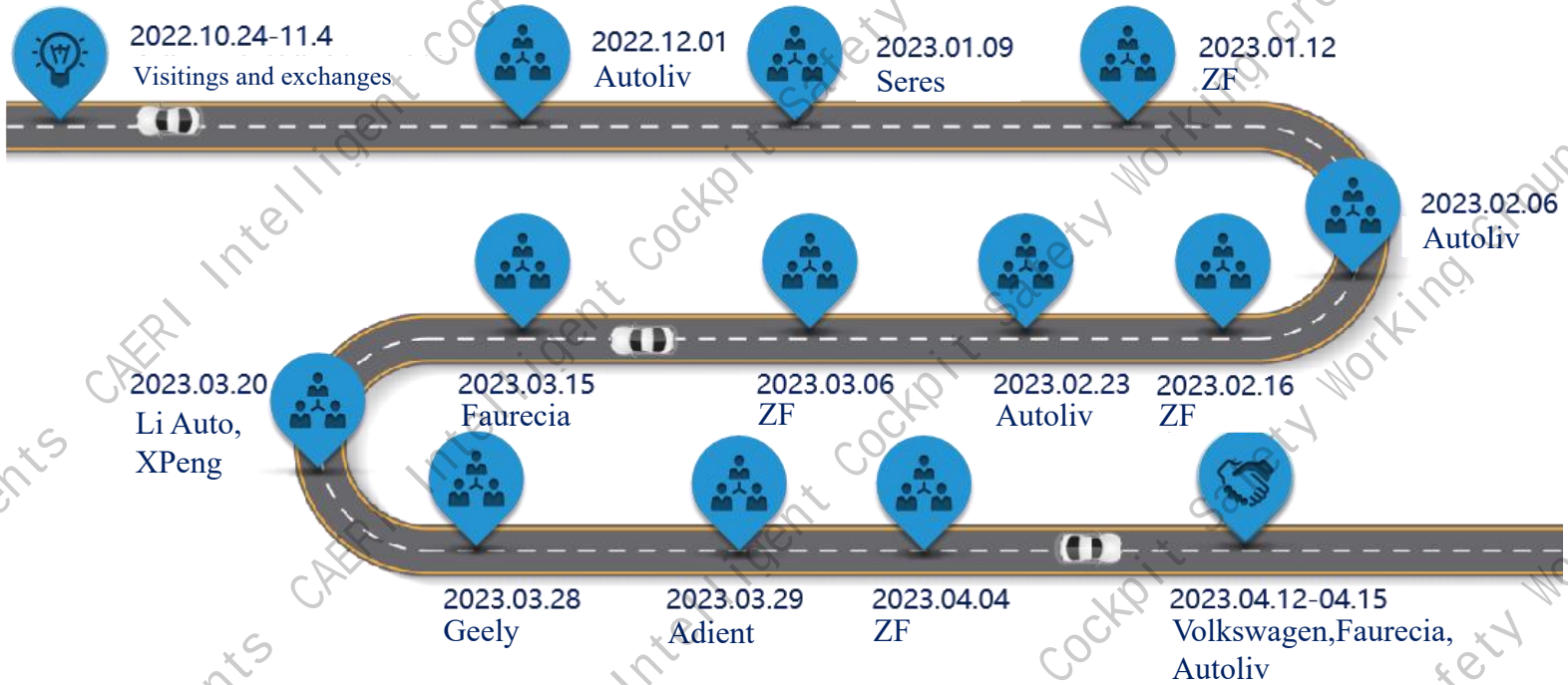
NASA《Neutral Body Posture in Spaceflight》

A Zero-gravity Seat

In the future there will be more space for occupants, but the safety have to be improved!

Why We Do

1.1 Products - Market Research



Technical Exchanges

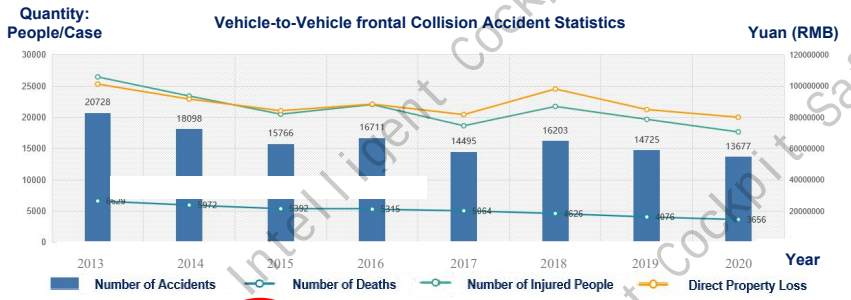
Product Research

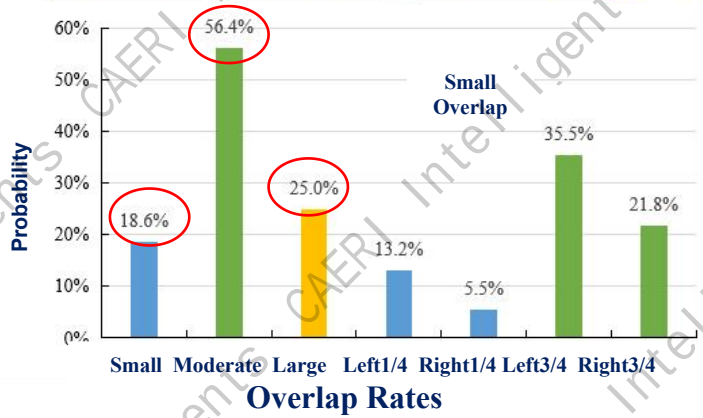
Surveyed the current status and research plans of new products of 21 OEMs and 4 suppliers, confirming the urgency of the research.

Why We Do

1.2 Accidents - Traffic Accident Data over the World

✓ Frontal Collision Accidents - Related Data



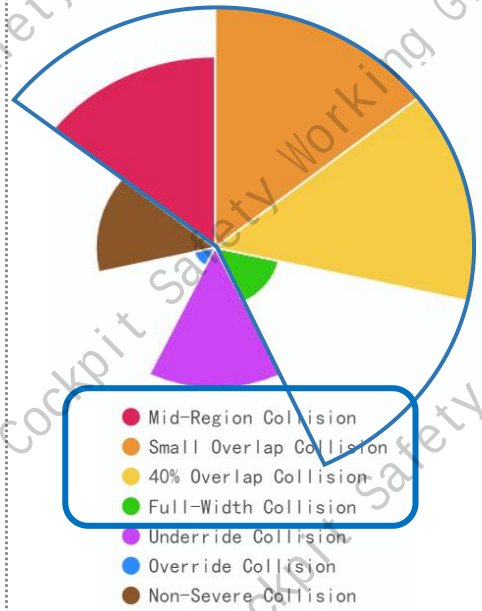


Overlap Rates

According to the Traffic Management Bureau of the Ministry of Public Security and the FASS Database:

Statistics of Frontal Collision Accident Types

✓ Proportions of Injuries in Frontal Collision Accident Data under Different Collision Scenarios and Overlap Rates



According to IIHS:

Frontal Collision Scenario Type Distribution Chart

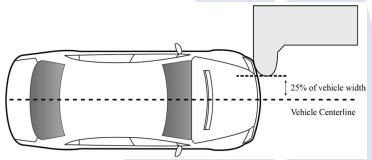
Overlap	AIS1+	AIS 3+	Fatality
1-10	6	4.9	5.2
11-20	13.8	9	-
21-30	19.9	16	12
31-40	13	24	18
41-50	10.5	9.5	5.5
51-60	7	9	11.5
61-70	4.8	4.8	6
71-80	7	4.9	5.1
81-90	1	4.9	11.5
91-100	11.5	14	24

Occupant Injury Proportion in Frontal Collisions with Different Overlap Rates

✓ FRB/MPDB/SOB tests are representative

Full-Width Frontal Impact (FRB test)

Moderate Overlap (50% Offset) Frontal Impact (MPDB test)



Small Overlap (25% Offset) Frontal Impact (SOB test)

In all frontal collision accidents, FRB, MPDB, and SOB are the most representative test conditions, and they account for a large proportion of severe injuries and fatalities.

Why We Do

1.2 Accidents - Traffic Accident Data over the World

✓ Risks to Occupants in a Reclined Posture

Table 4 Mortality Risk With Full or Partial Recline, Compared With Occupants in the Upright Position

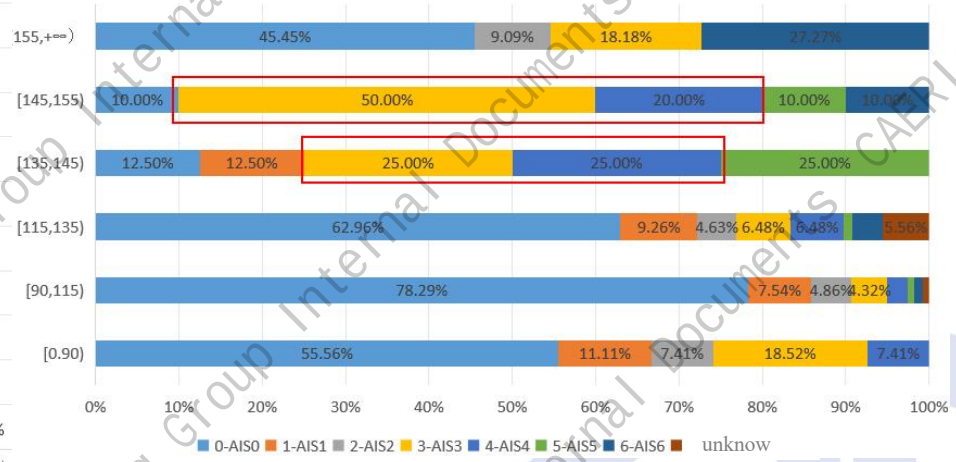
Seat Position	Adjusted Odds Ratio for Mortality	95% CI
Partial reclined	1.15	1.05–1.26
Fully reclined	1.77	1.09–2.88

- In the NASS-CDS data of 90,412 frontal crash accidents from 1995 to 2005, 50% of the occupants are partially reclined, resulting in a **15%** higher **mortality rate** compared to the normal upright sitting position, while 0.3% of the occupants were fully reclined, with a **mortality rate 77%** higher than that of the normal.[1]
- In frontal crash accidents from 2000 to 2015, the risk for **MAIS2+** increased by **21%** (with seat belts fastened) and the risk for **MAIS3+** increased by **69%** for reclined occupants.[2]

✓ FASS database shows a significant increase in the risk of AIS3+ in reclined posture.

Future mobile traffic Accident Scenario Study(FASS) database from 2018 to 2022.

N=3270, occupants of passenger cars.



- The Chinese FASS database has compiled statistics on the distribution of recline angles and injury of occupants (with seat belts fastened) in passenger cars from 2018 to 2022: Although the proportion of seat cushion and backrest angles greater than 115° is only **4.19%**, the risk for AIS3+ injuries is **4.4 times** that of others, and the risk for AIS4+ injuries is **5.2 times** that of others. In particular, the AIS3+ proportion is the highest when the seat back angle is within the range of approximately **55° -65°** .

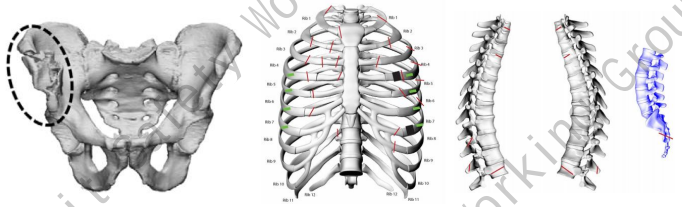
The casualty rate of occupants in traffic accidents in reclined postures is much higher than that in a normal sitting position.

[1] Letarte, Peter B. , et al. "The effect of reclined seats on mortality in motor vehicle collisions - Discussion." The Journal of trauma 64.3(2008):627-628.
[2] Mcmurry, Timothy L. , et al. "Crash safety concerns for out-of-position occupant postures: A look toward safety in highly automated vehicles." Traffic injury prevention 19.6(2018):582-587.

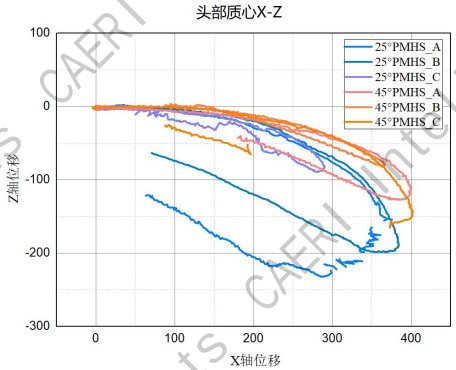
Why We Do

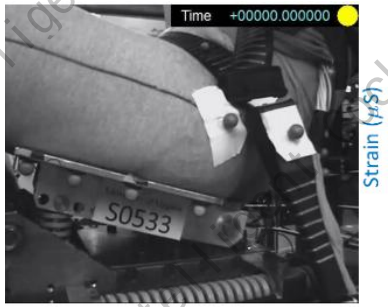
1.3 Injuries - New Occupants' Injuries

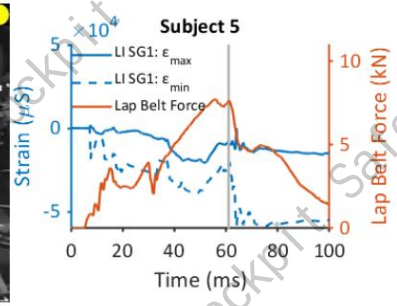
	Injury	25°	45°
Chest	Highest AIS level in the left	3	5
	Highest AIS level in the right	3	5
Spine	Highest AIS level	3	3



- **New injuries in pelvic and spine,** higher AIS level



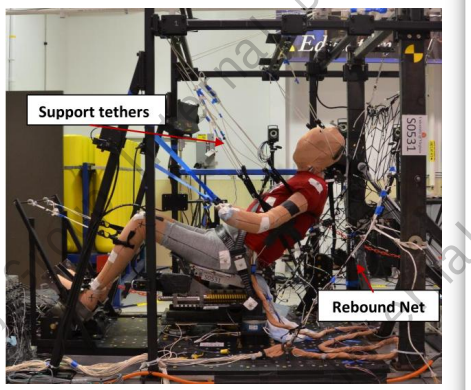




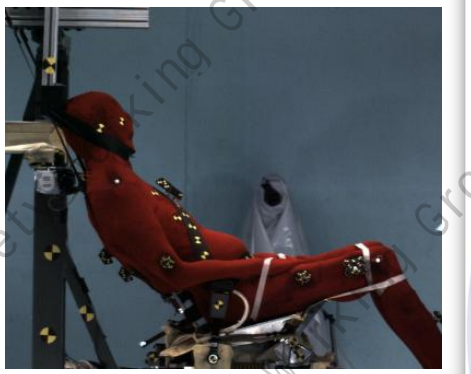
- **New kinematic response,** higher head displacement, spine acceleration, risk of submarining

PMHS tests

UMTRI 45° recline



UVA 50° recline



Pre-research tests

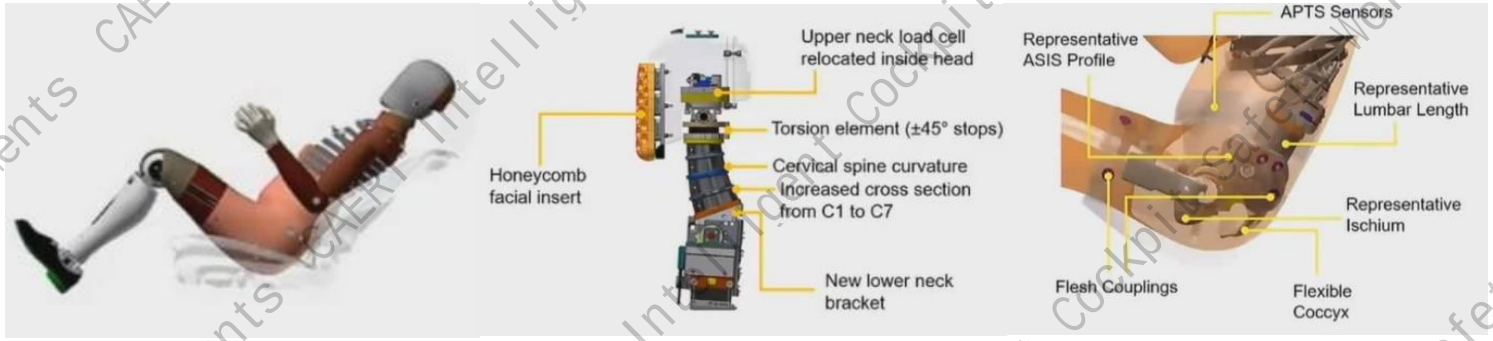
CAERI≤50° recline

Through research on studies of occupant injuries in reclined seats, it has been found that occupants in reclined postures face new injury risks, and the risks are higher.

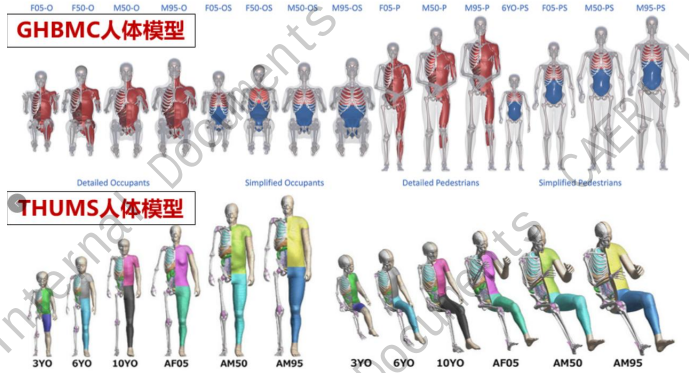
Why We Do

1.4 Protocols - No Existing Protocols

➢ **Limitations of ATDs -** large gaps between head and shoulder, pelvis and sternum.



➢ **THOR-AV&THOR-RS -** the pelvis is more flexible and adapted.



AC-HUMS

➢ **HBM used for VT -** detailed anatomical characteristics, advanced injury prediction.

RS and AV are more suitable for the physical test and assessment of reclined posture occupants, while HBM is used for predicting human injury.

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Why We Do

Objective

This study aims to study the injury mechanisms of occupants in a reclined posture, based on which, we will establish the test and rating protocols for occupants in reclined seats in frontal crash scenarios. It is expected to lead the development of automotive safety testing technology and promote the development of intelligent occupant protection systems.

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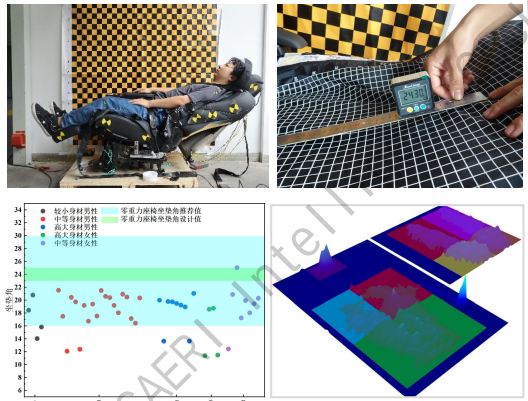
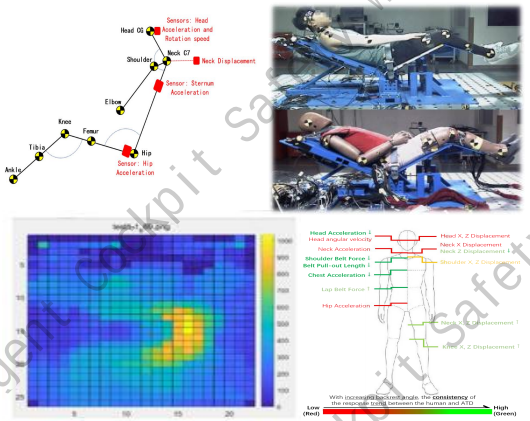
What we do

Our Research - Overall research approach

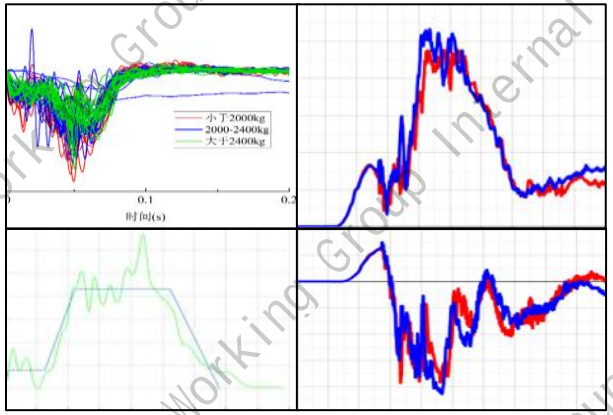
Comfort Analysis



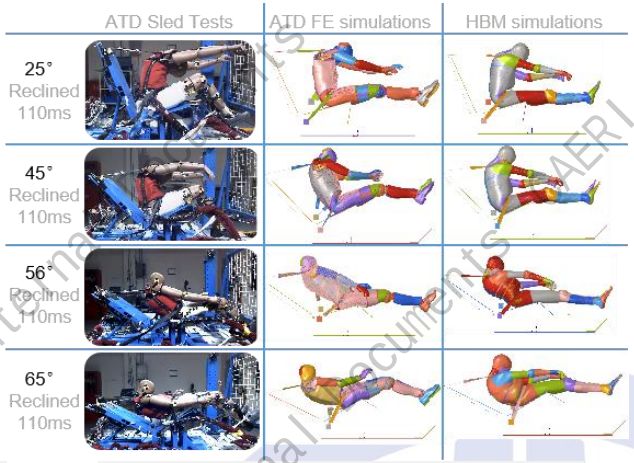
Volunteer & ATD Low-speed Sled Tests



Pulse Simplification and Validation

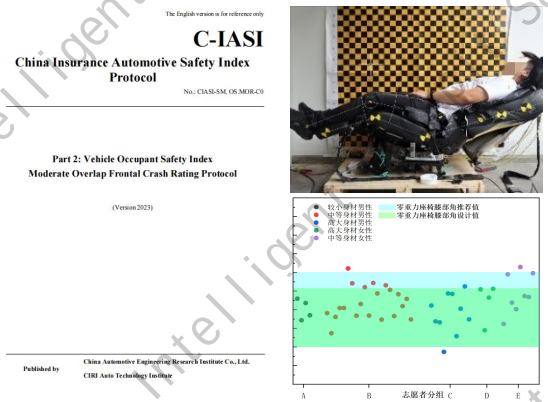


High-Speed (MPDB and SOB) Testing and FE Simulation Analysis



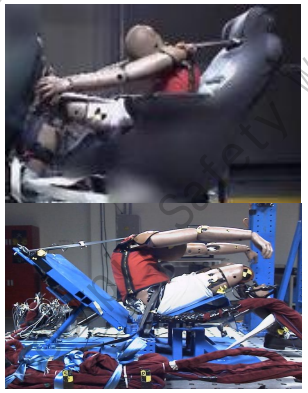
Typical Kinematic and Injury Response

Draft Test and Assessment Protocol and Survey on Protection Measures

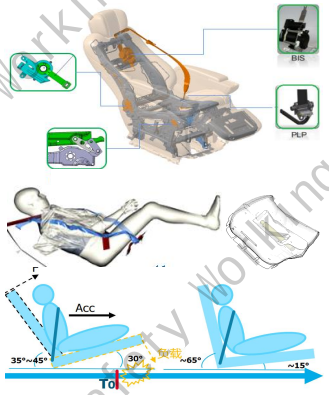


①Based on the Criteria in Existing Protocols

②Considering Occupant Comfort



③Considering the Typical Types of Injuries in the Test



④Considering the Effectiveness of Countermeasures

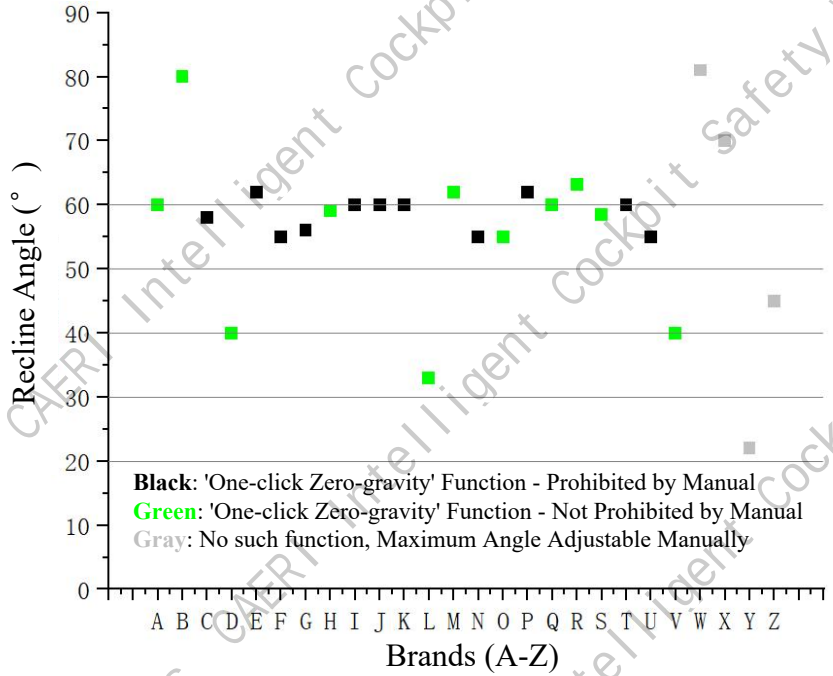
Dimensions of Assessment

- Restraints and Dummy Kinematics
- Injury Rating
- Overall Rating

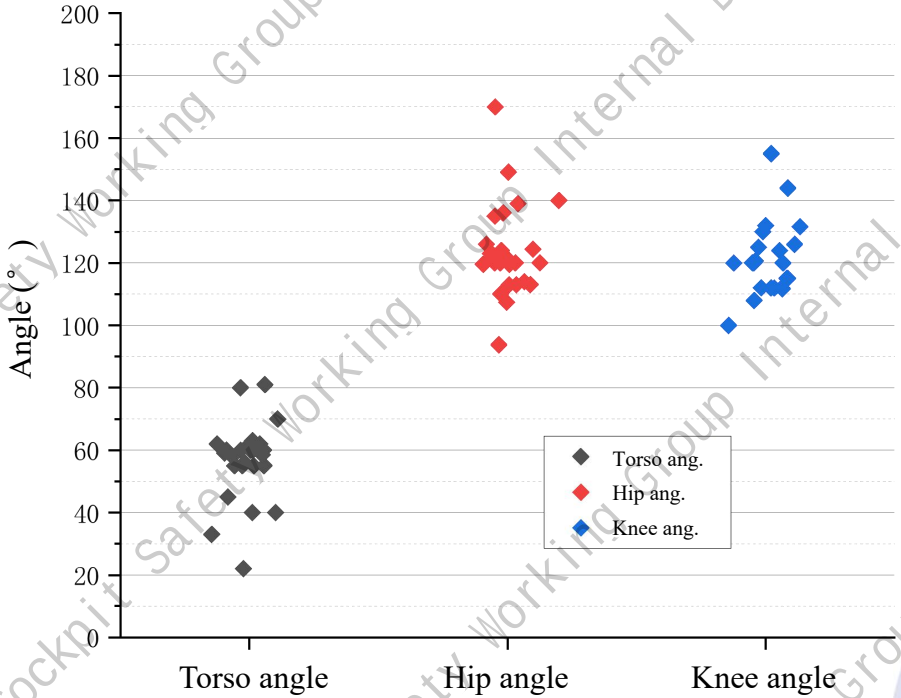
What we do

2.1 Our Research - Comfort Analysis

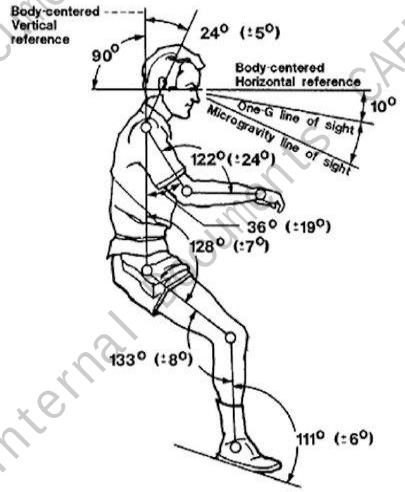
- Research on 26 Different Vehicle Reclined Seats in the Market



- On the market, the function like 'one-click zero-gravity' will adjust the seatback angles to 50° - 70° as a design feature,
- Without explicit prohibition in the manual, there is a safer situation where the "one-click zero-gravity" seatback angle is set within 40°.



- The backrest angle (torso angle) is predominantly within the range of 50° to 70°,
- The hip angle and knee angle are predominantly within the range of 110° to 140°.



Source：NASA

NASA Neutral Body Posture(NBP)
Hip Angle：128° ±7°
Knee Angle：133° ±8°

By the end of 2023: most companies are still researching the range of angles that are compatible with both comfort and safety, which is currently close to NBP.

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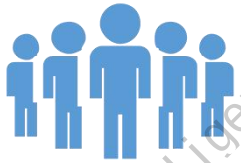
What We Do

2.2.1 Our Research - Comfort Analysis

✓ Recruit volunteers to collect comfort angle data for vehicle reclined seats (zero-gravity seats)

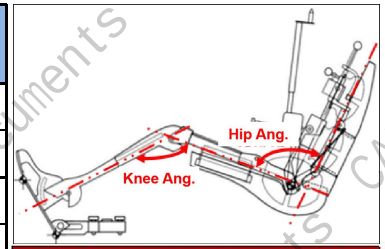


Choose body size from QCCT55, GB/T 10000

Number of Volunteers	
Small size males and females	4
Mid size males and females	29
Big size males and females	14

✓ The data is obtained by marker point image recognition, angle sensor, and goniometer measurement

Name	Volunteer	NBP	T/CESS 12—2023
Seatback Ang.	61° ±8°		
Torso Ang.	60° ±6°		56° ±8°
Legrest Ang.	23° ±5°		
Leg Ang.	29° ±6°		34° ±15°
Cushion Ang.	18° ±3°		
Thigh Ang.	10° ±4°		25° ±8°
Knee Ang.	142° ±5°	133° ±8°	119° ±12°
Hip Ang.	141° ±5°	128° ±7°	121° ±9°



Preliminary recommended test recline seatback angle as		
Torso Ang.	Thigh Ang.	Calf Ang.
50°	10°±4°	29°±6°
Calculation	Hip Ang.	142°±5°
	130°±4°	141°±10°

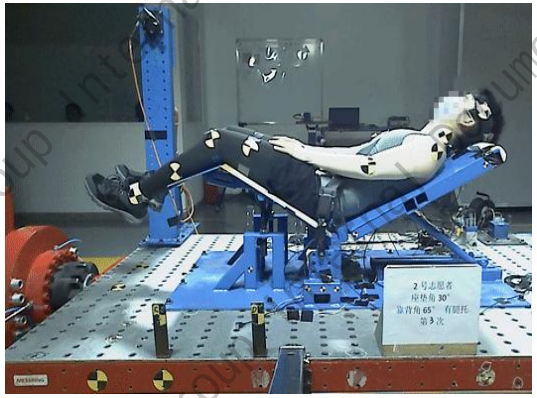
- 47 volunteers were recruited: covering male and female occupants with different sizes;
- Considering the current research on the comfort and occupant safety of reclined seat, the recommended test angles in the table are proposed to provide data support for the follow-up test of dummy and seat positioning.

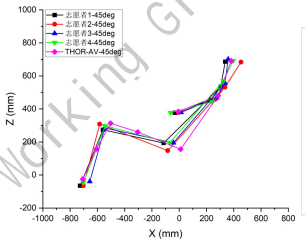
What We Do

2.2 ATD & Volunteer sled tests at low-speed

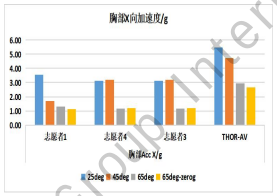
Design Rigid Seat

Invention patent(Submitted): a zero-gravity characteristic of automobile crash test rigid seat

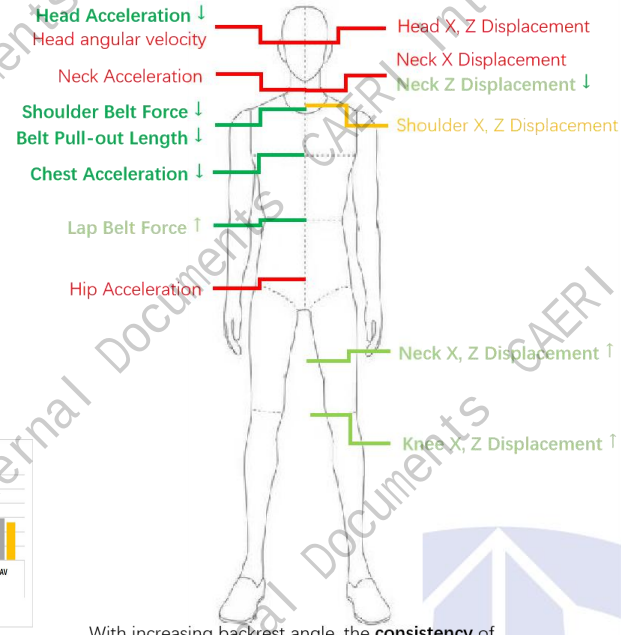




Comparison of static sitting postures



Comparison of sensor's data



With increasing backrest angle, the **consistency** of the response trend between the human and ATD

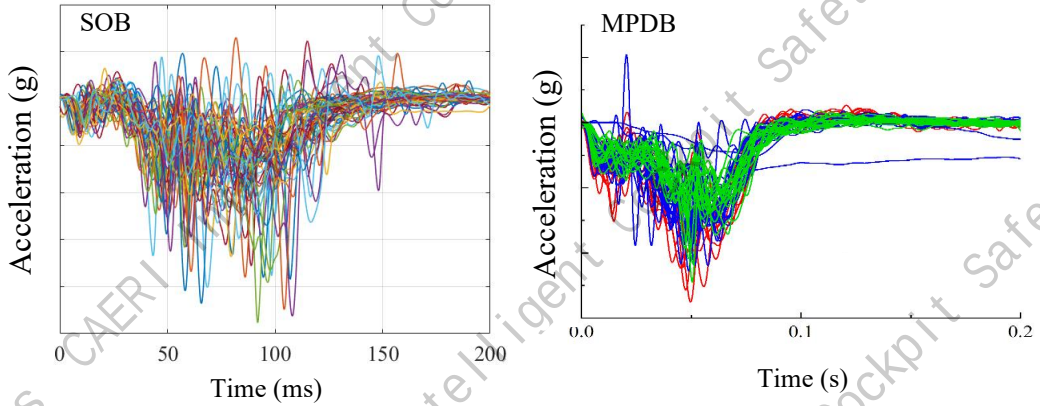
Low (Red) → High (Green)

- **Total 50 tests were conducted with 4 volunteers: A, B, and D are close to the average male size (177 cm, 76.7 kg), while C is close to China average male size (168.6 cm, 67.5 kg).**
- **With the increasing seatback angle, the response of the body except the head and neck changes the same trend. so ATD can reflect the motion response of a real human body to a certain extent.**

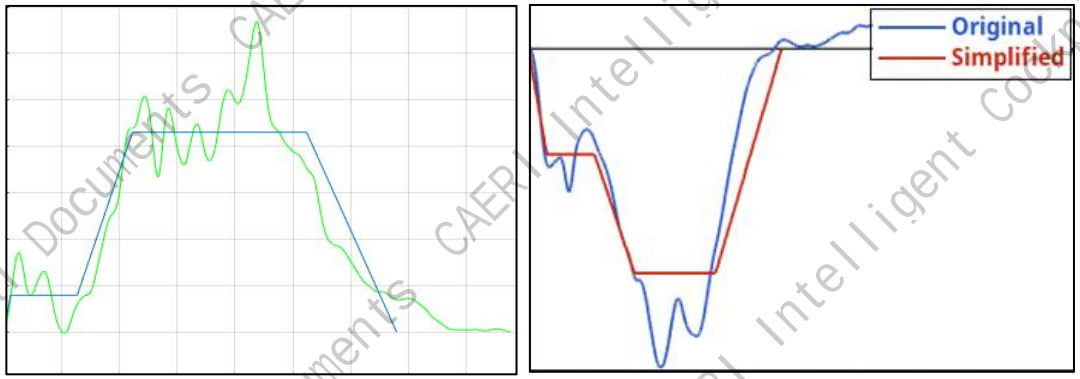
What We Do

2.3 Our Research - Pulse Simplification and Injury Comparison Before and After Simplification

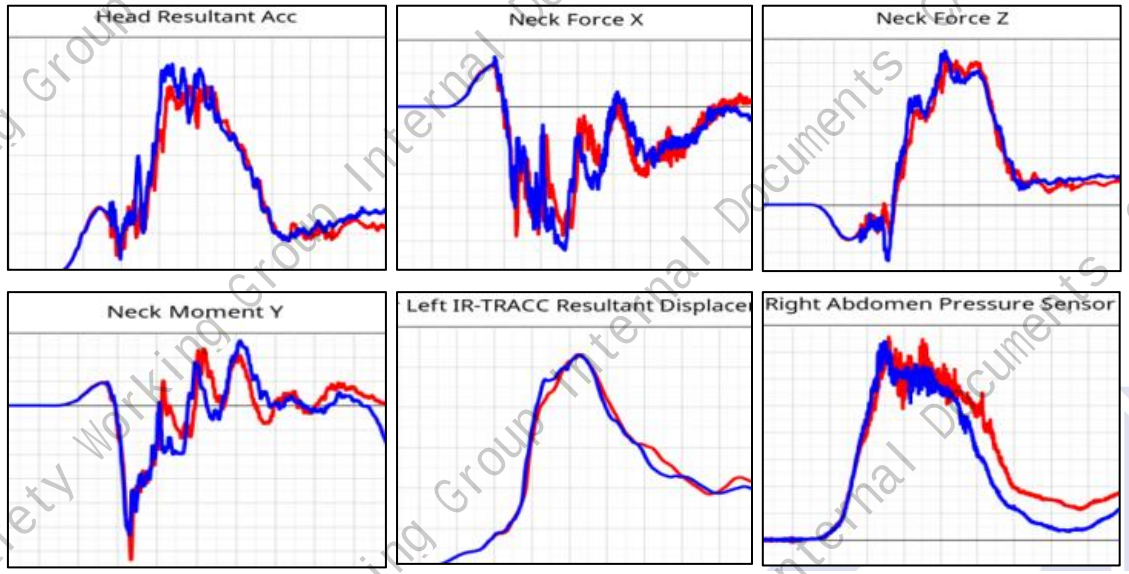
✓ The pulse data of the tested vehicles in the past five years were selected for analysis.



✓ Based on the peak and valley values of the pulse, a standard double trapezoidal pulse is constructed



Reference invention patent: a deceleration pulse analysis method for vehicle SOB crash test

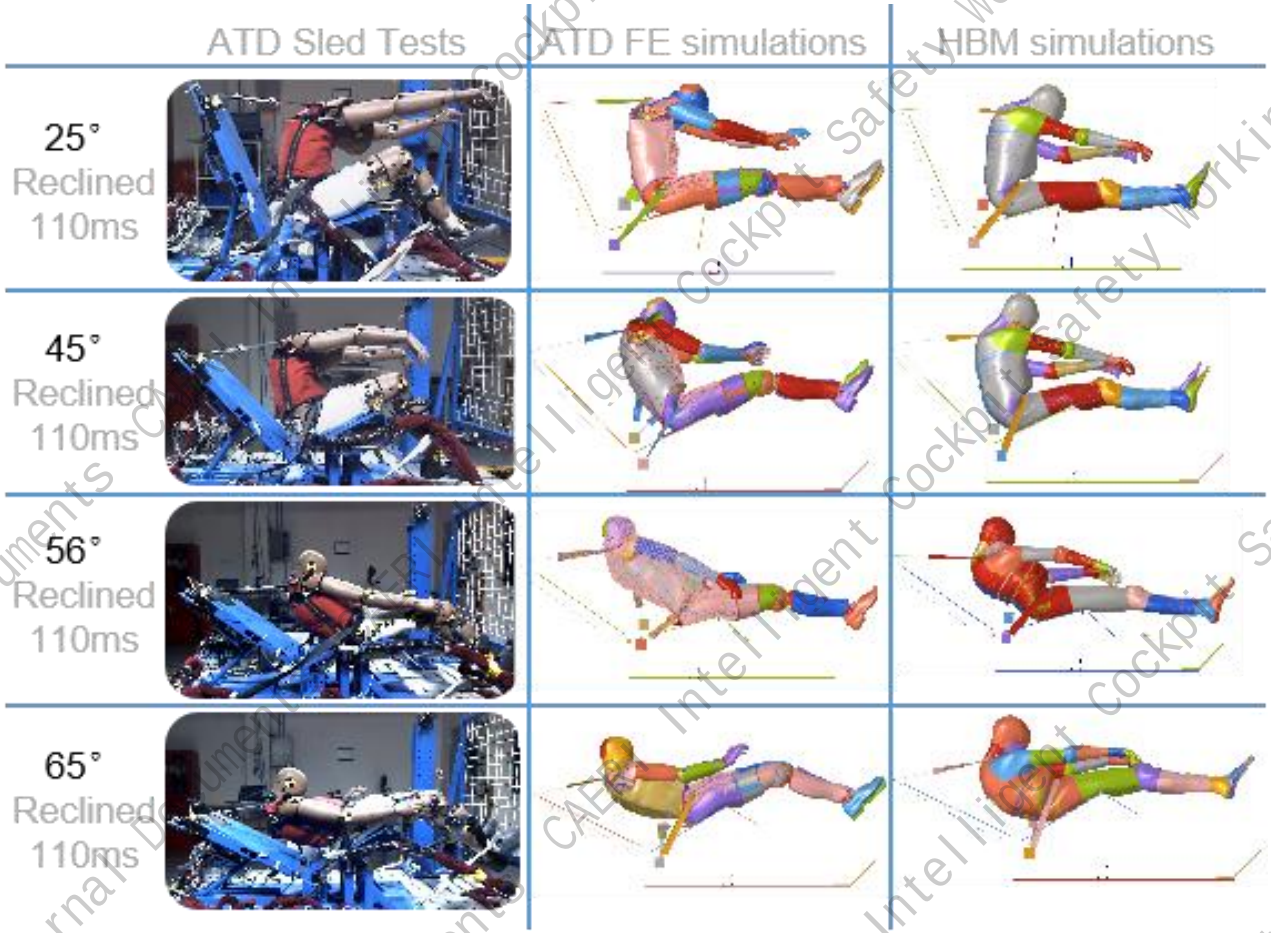


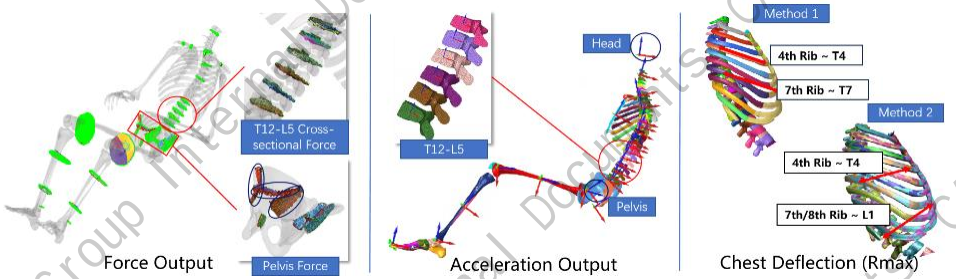
Comparison Before and After Simplification

- **131 groups acceleration curves were selected for SOB and 59 groups were selected for MPDB,**
- **By simulating and comparing the input original pulse with the double trapezoidal pulse, it is found that the simplified method has little impact on the kinematic and injury of the dummy.**

2.4 Our Research - High-Speed (MPDB and SOB) Testing and FE Simulation Analysis

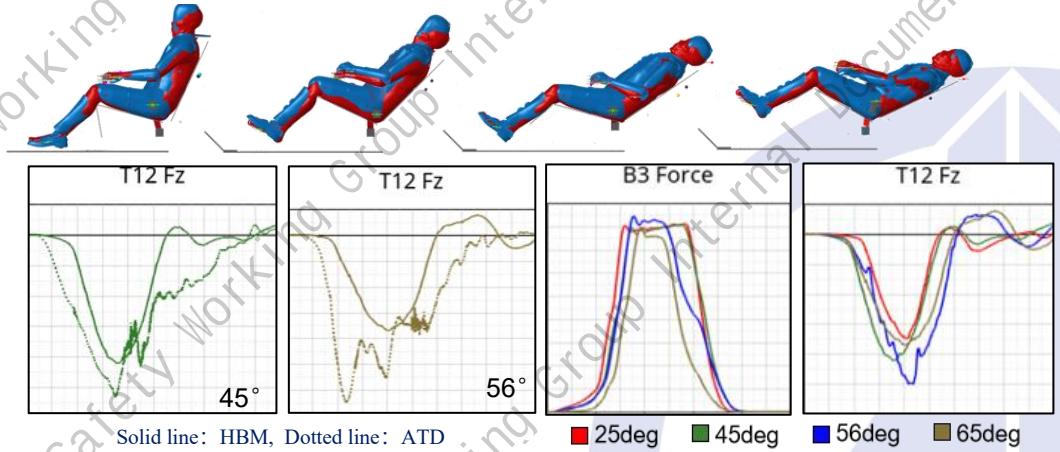
✓ With the same boundary conditions as ATD, we run HBM (THUMS) simulations.





Force output settings

Acceleration output settings



- 46 sled tests of vehicle seats and rigid seats under different backrest angles were carried out,
- Comparison between ATD and HBM: after kinematic and injury comparison, the overall injury of the dummy under different backrest angles is greater than that of the human body model.

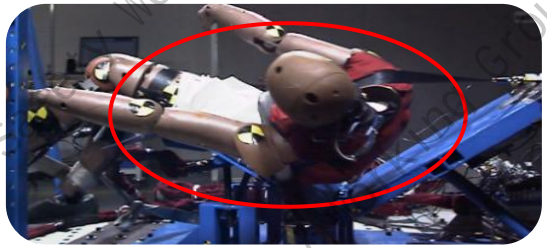
Paper(Submitted, unpublished): Acquisition and Application of Chinese MPDB Test Condition Characteristic Waveform Based on Characteristic Parameter Analysis

What We Do

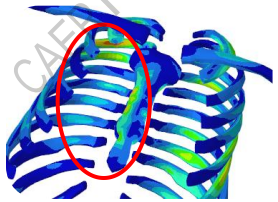
2.5 Our Research - Typical Injuries Study

①Belt rubbing neck

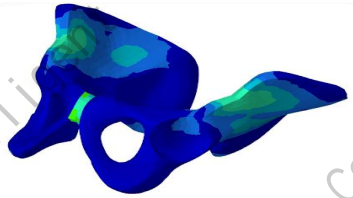
②Submarining



③Torso deflection to side

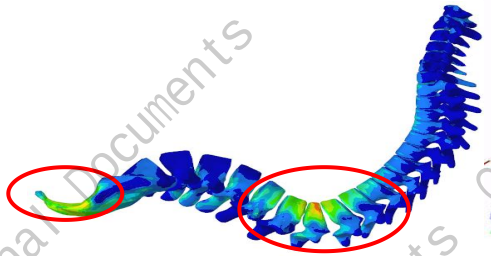


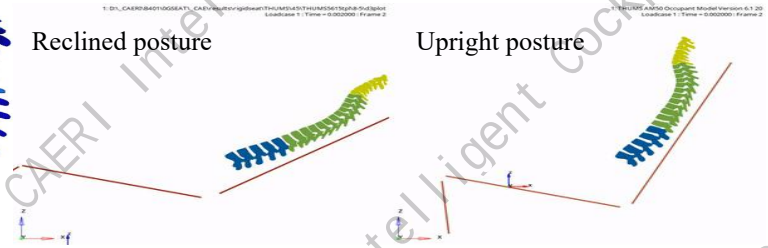
④High chest deflection/ Ribs fracture



⑤High ATD acetabulum force/
Risk of pelvis injury

⑥High abdomen pressure /
Risk of visceral organ injury





⑦High lumbar compression force and bending moment / Risk of lumbar fracture

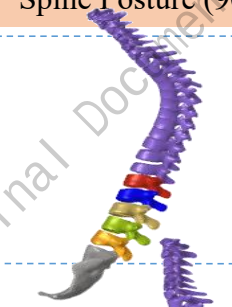
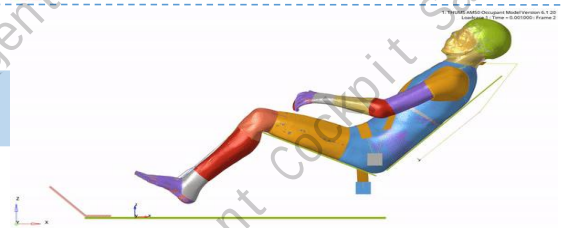
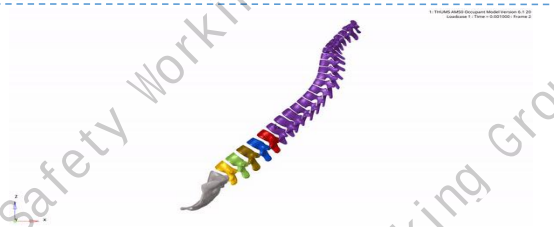
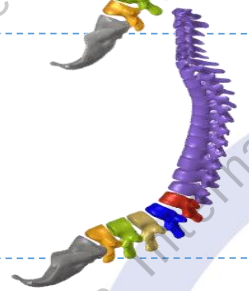
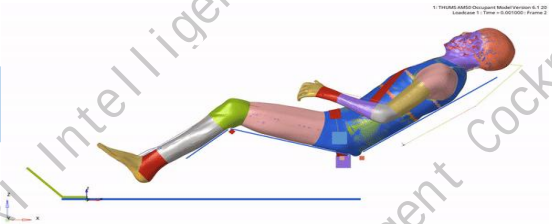
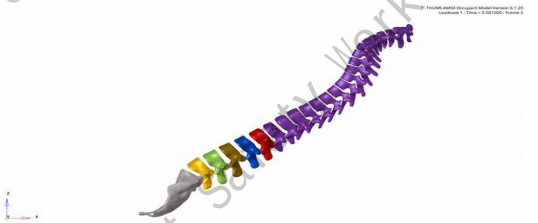
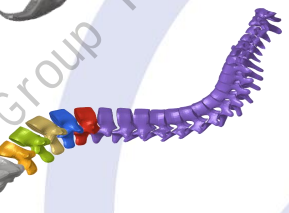
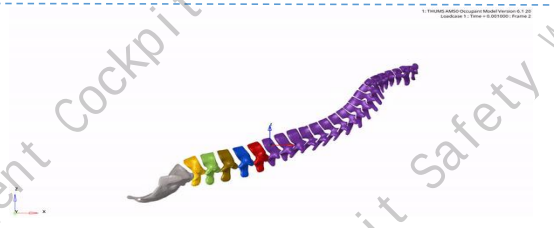
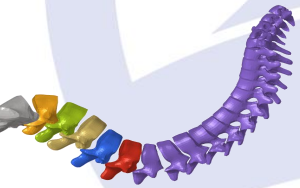
By ATD/HBM simulations and comparisons, 3 typical dummy kinematic responses and 4 typical injury responses are listed.

$$L_{fx}(t) = (1-\alpha)\frac{F(t)}{CSA} + \alpha\frac{M(t)}{CSA^{3/2}}$$

Introduce New Lumbar Spine Injury Criteria -- 'Lij' into the Protocol

2.5 Our Research - Typical Injuries Study

✓ The form of lumbar spine injury in THUMS simulation was analyzed.

MPDB	Overall Animation	Spine Animation	Spine Posture (90ms)
01 25° upright posture **No submarining**			
02 45° reclined posture **No submarining**			
03 56° reclined posture **Submarining**			
04 65° reclined posture **Submarining**			

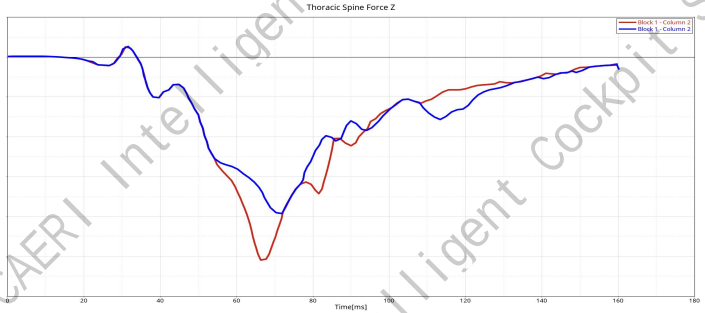
What We Do

2.6 Our Research - Research on Occupant Protection Countermeasures

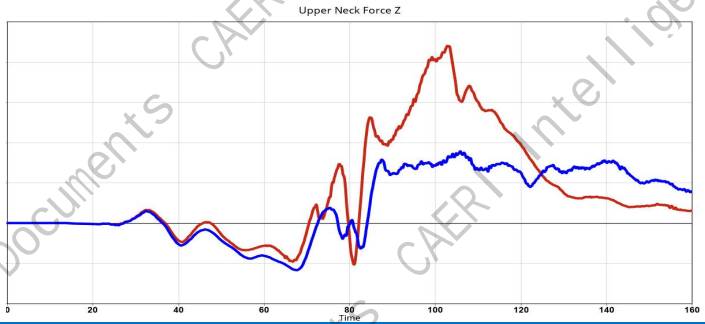
✓ The effect of different protection measures for occupants in reclined seats

Base Take measures

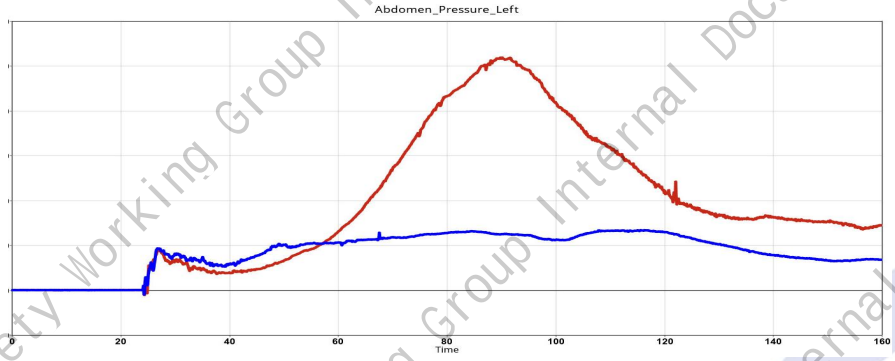
➢ Reducing the Fz on the lumbar spine by energy absorption through the seat cushion

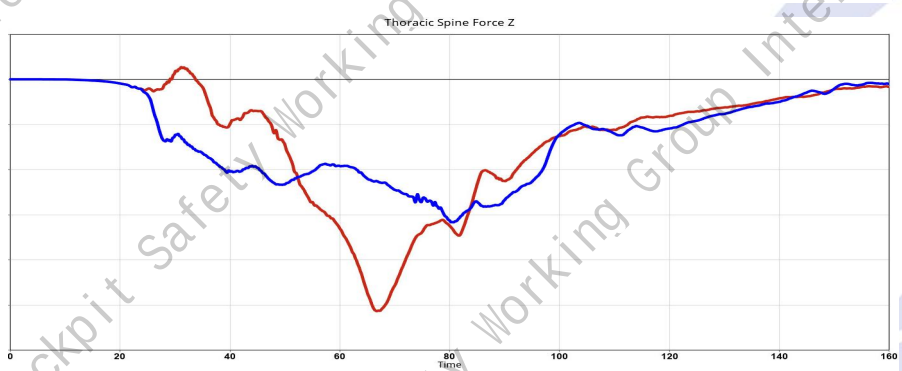


➢ Reducing the axial force Fz on the neck by force-limiting mechanism in the backrest



➢ Reducing the submarining risk through seat cushion airbags, thereby decreasing abdominal pressure and Fz on the lumbar spine





OEMs can use different technical measures to reduce the risk of injury to different body parts

What We Do

2.7 Our Research - Working Group Meetings

Held 3 working group meetings, over 80 point-to-point communications, and maintained continuous communication with international organizations and universities.


[2023.03.14] The First Working Group Meeting in Chongqing


[20230803] The Working Group Stage Meeting in Qingdao


[2024.04.10] The Working Group Stage Meeting in Guangzhou


RCCADS exchange


Virginia(UVA) exchange


Chalmers exchange

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CONTENTS

In the Future

- Using HBM and ATD simulations for comparative analysis, combined with ATD tests and cadaver tests at different crash speeds, to analyze the mapping relationship between HBM and ATD, then obtain the injury risk curve for ATD dummies,
- Taking the initial test and rating protocol for occupant safety injury in reclined seats as the basis, and refining the protocols in conjunction with vehicle seat sled tests,
- Research on the safety protection of occupants with different physical characteristics in various seating postures under multiple crash conditions, while simultaneously using AC-HUMS for virtual testing studies.

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