ZF LIFETEC

PIONEERING AUTOMOTIVE SAFETY

RESTRAINT ANALYSIS ON HYDRA®

TO FOSTER REAL-LIFE SAFETY

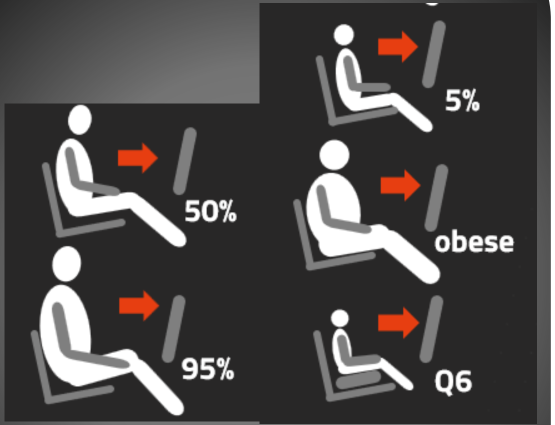
26.09.2024 | Humanetics Safety Summit 24 | K.-U. Machens

AGENDA

THE NORMAL IS WHAT YOU FIND BUT RARELY …

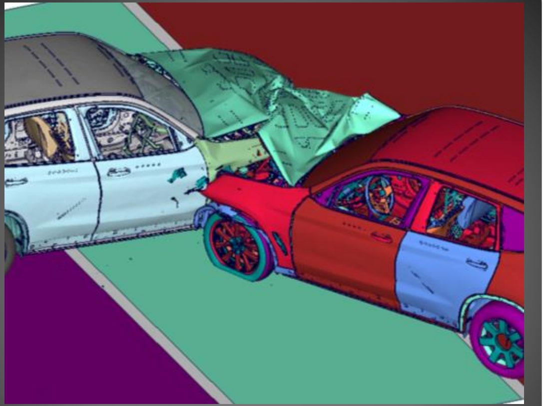
IN REAL-LIFE

… in body shape



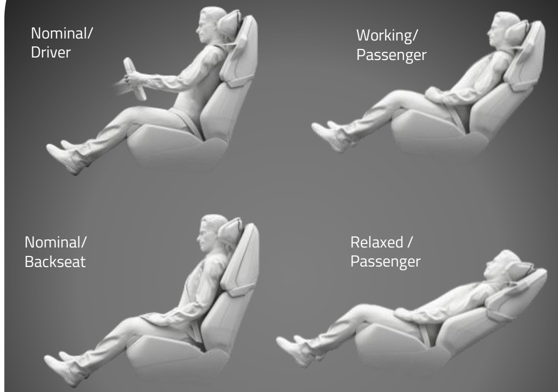
- Mass/ body-fat (slack) distribution
- Skeleton (kinematics)
- Posture (slouching)
- Muscle activation (pre-crash)

… in crash pulse



- Crashworthiness
- Delta velocity
- Crash scenario
- Pre-crash action

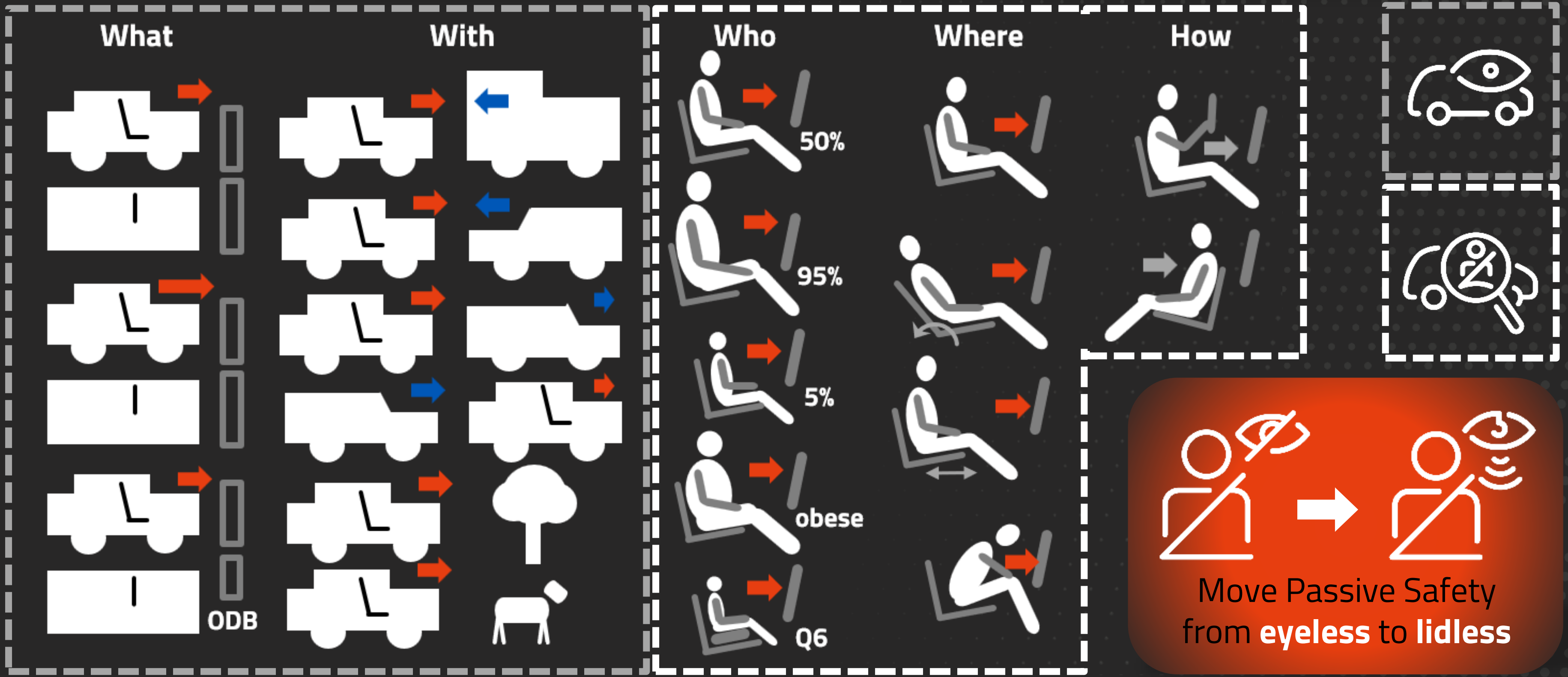
… in seating position



- Seat position / orientation
- Seat geometry/ compliance
- SBS fixation points

ADAPTIVE SAFETY TO COME ...

... CALLS FOR VIRTUAL CRASH-SAFETY VALIDATION

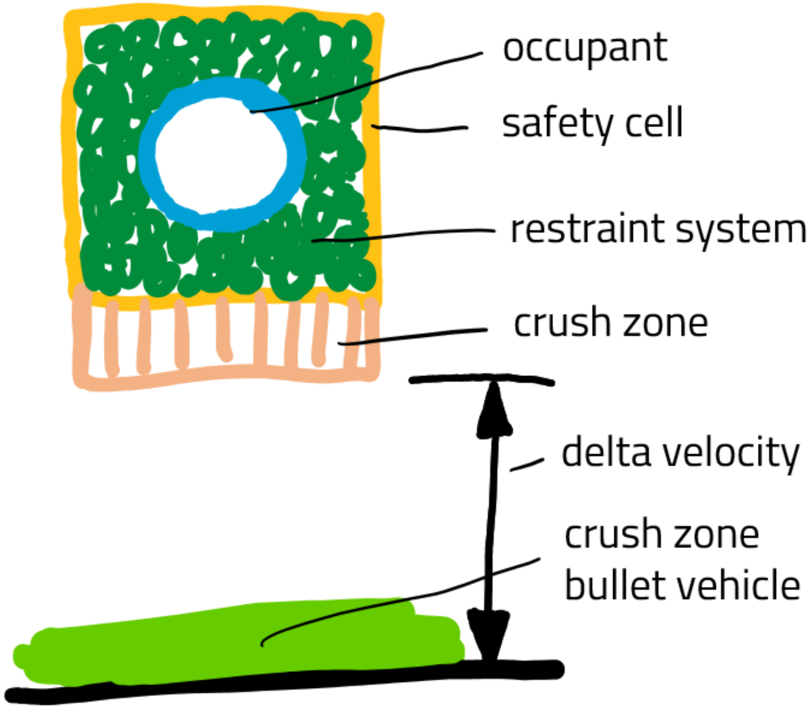


AGENDA

CRASH INJURY RISK FACTORS

VISUALIZED AS PADDED GOODS IN A MOVING BOX

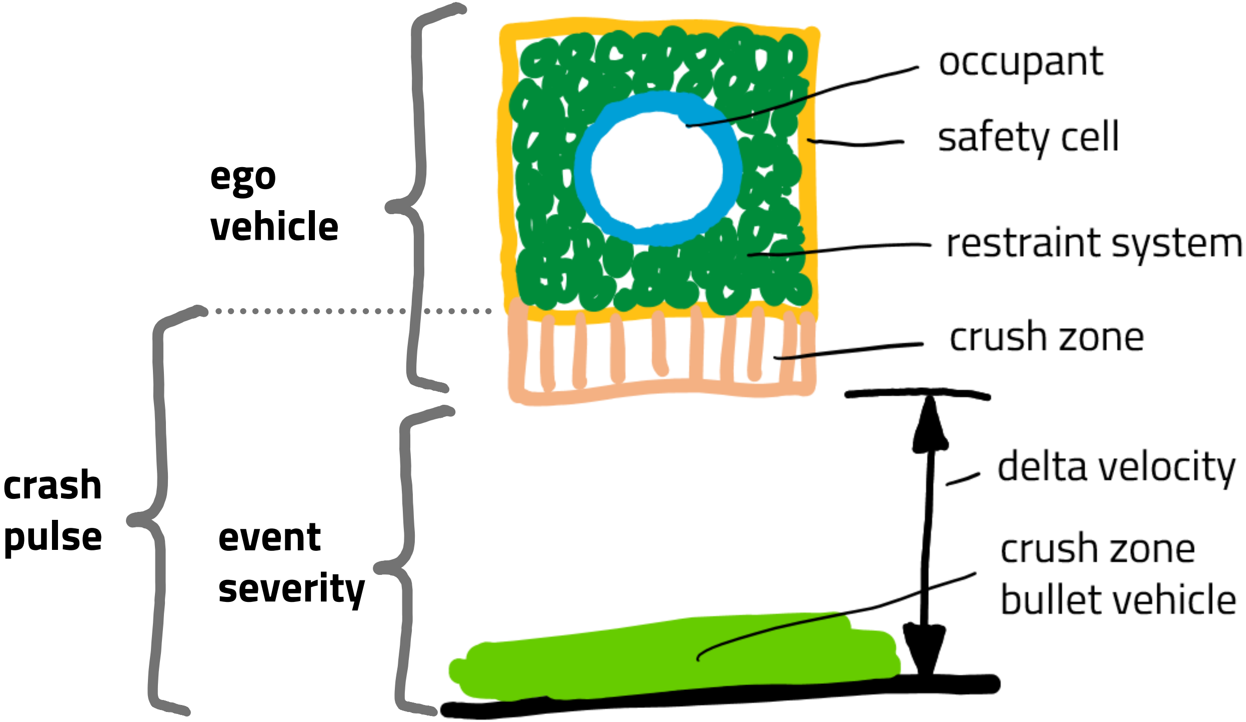
Imagine goods (occupant) bubble wrapped (restraint system) in a box (safety cell) with bottom as a bumper zone (crush zone).



Here, dropping height and floor composition (carpet present?) represent delta velocity and crush zone bullet vehicle.

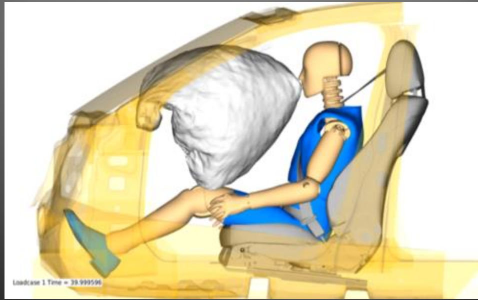
CRASH INJURY RISK FACTORS

VISUALIZED AS PADDED GOODS IN A MOVING BOX



SBS load case

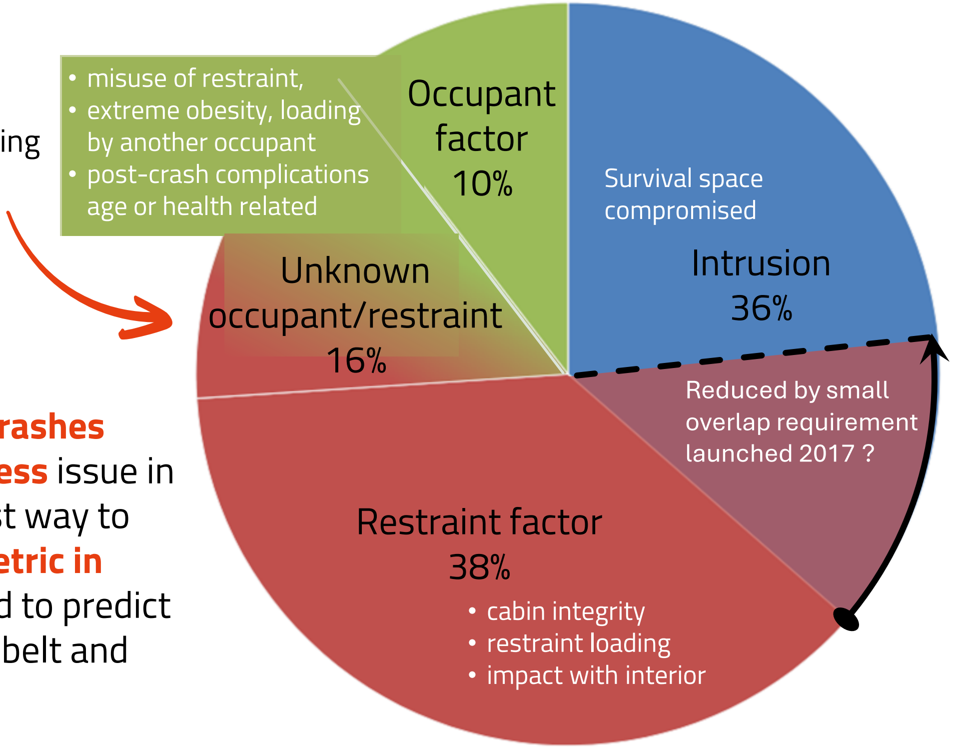
- Crash pulse acting on cell
- Safety cell not compromised
- Vehicle configuration (geometry)
- Occupant



FINDINGS OF IIHS AND NTHSA

2000-06 DATA FROM NASS-CDS

- Analysis of real-world cases with serious injuries resulting from frontal crashes of vehicles rated good for frontal crash protection.[2] (2000-06 data from NASS-CDS)
- Further restraint system improvements may require technologies that adapt to occupant and crash circumstances.[2]



Improved **thoracic injury protection in frontal crashes may be the single most pressing crashworthiness** issue in the passenger vehicle fleet. Perhaps the quickest way to make gains in this area would be the use of a **metric in crash test rating** programs that is demonstrated to predict **field injury risk for drivers restrained** by a seat belt and airbag.[1]

[1] Brumbelow ML, et. al. (2022) Predicting Real-World Thoracic Injury Using THOR and Hybrid III Crash Tests. Proceedings of IRCOBI Conference, 2022, Porto, Portugal

[2] Brumbelow ML., Zuby DS. Impact and injury patterns in frontal crashes of vehicles with good ratings for frontal crash protection. Proceedings of 21st Intl Tech Conf on the Enhanced Safety of Vehicles, 2009

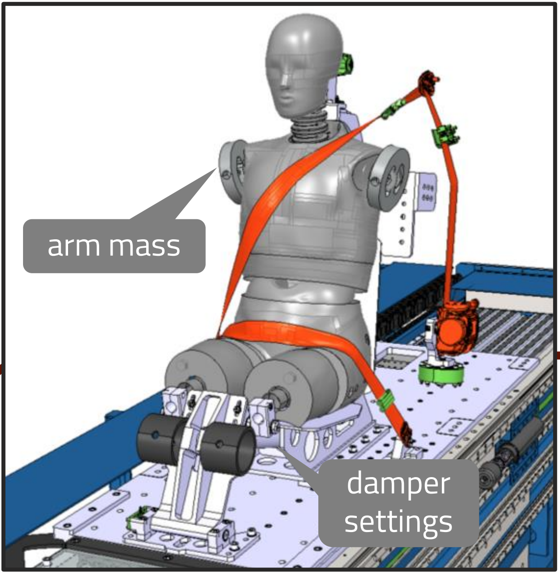
AGENDA

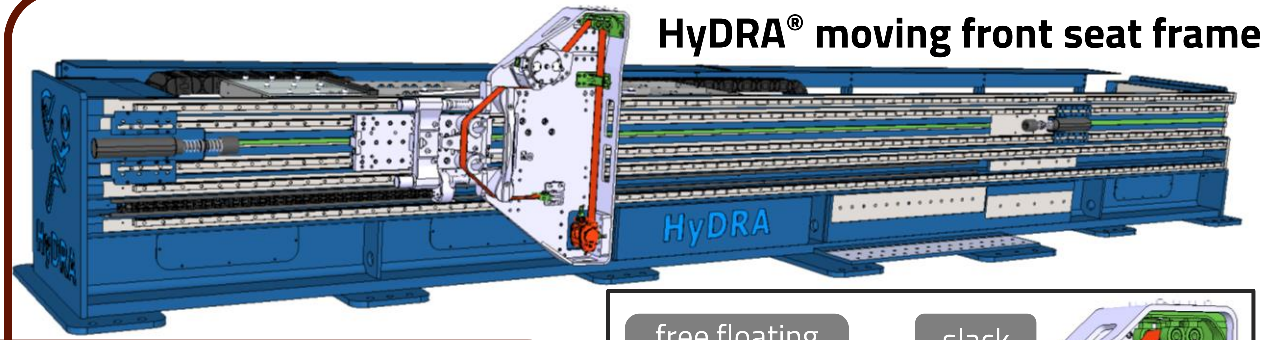
HYDRA® - HYPER DYNAMIC RESPONSE ACTUATOR

ENABLING TECHNOLOGY FOR NEXT GEN. PRE-CRASH ACTIVATED & ADAPTIVE SAFETY

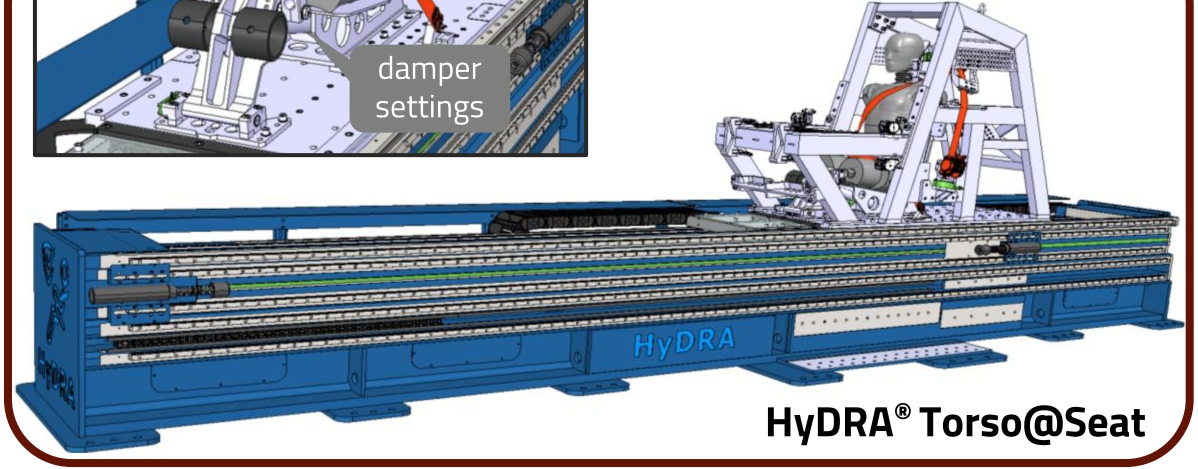
[HyDRA - ZF LIFETEC (zf-lifetec.com)](https://www.zf-lifetec.com)

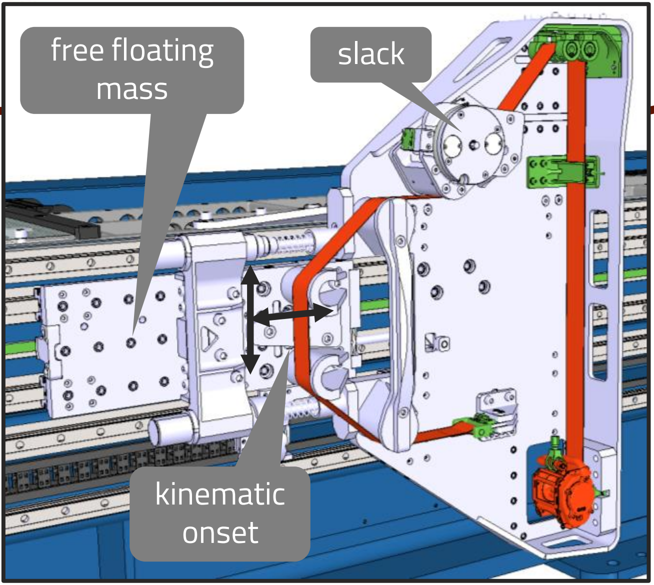
DYNAMIC HIGH PRECISION SETUPS TO IDENTIFY SBS FUNCTIONALITY





Pulse / TTF (PT, LL)

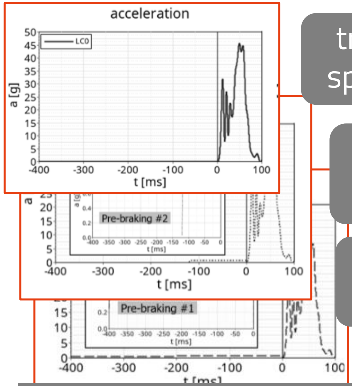




SBS: Seat Belt System
PT: Pretensioning
LL: Load Limiting
TTF: Time-To-Fire
T@S: Torso @ Seat

SBS FUNCTIONAL MODEL WITH THIRD PARTY SIGN OFF

Pulse input specification

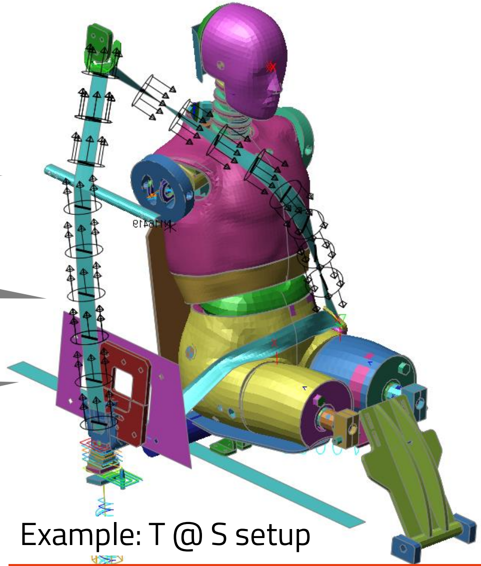


trunk mass specification

pelvis mass specification

pelvis slack specification

Crash sensory system = Time-To-Fire requirement



Example: T @ S setup

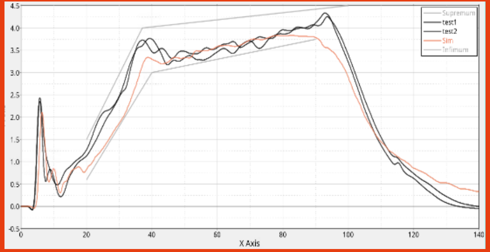
0 LOAD CASE SPECIFICATION by
- Pulse input
- TTF
- …

1 VIRTUAL PREDICTION of
- shoulder force time sequence
- pelvis forward displacement
- …

3RD PARTY TESTED

3rd party:
1. selects input parameters
2. receives virtual prediction
3. witness compliances of physical test results of chosen scenario
4. Compliances: Measured time sequence within a defined corridor around virtual prediction

2 PHYSICAL TEST



SBS: Seat Belt System
TTF: Time-To-Fire
T@S: Torso @ Seat

AGENDA

SEATBELT RESTRAINT PERFORMANCE

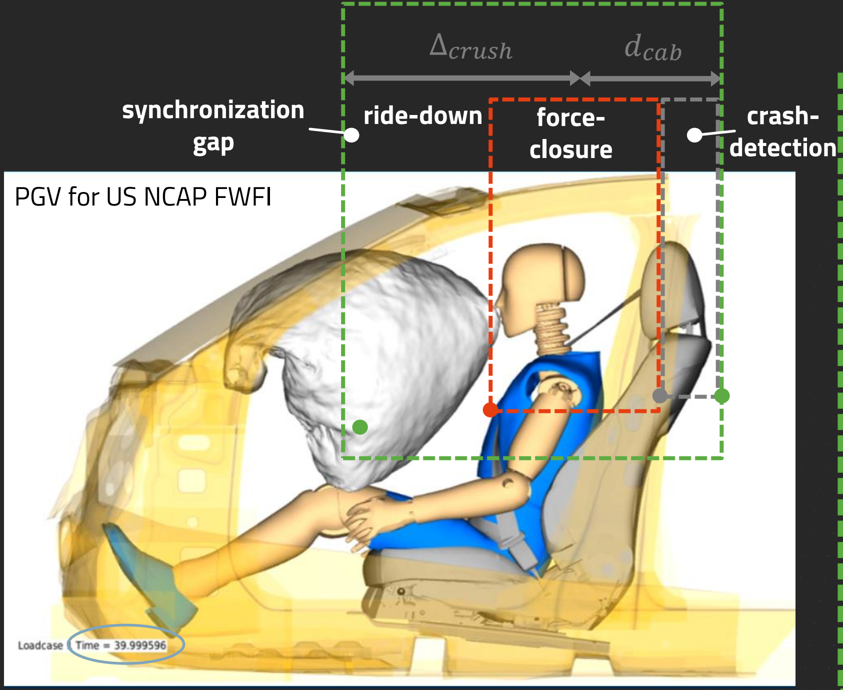
Function	**Metric**
Occupant coupling to vehicle:	
Effective Force Closure	**CFL** (Char. Shoulder Belt Force Level)
Pretensioning Force Limit	**MPF** (Maximal Pretensioning Force)
Limit Pelvis Displacement	**MPD** (Maximal Pelvis Displacement)
Ride-down Contribution	
Limit Chest Displacement	**MCD** (Maximal Chest Displacement)
Limit Neck Nij-Value	**MNij** (Maximal Neck Nij)
Stability of Load Limiting Characteristics	

CFL-Metric:

- Quantification of SBS restraint performance
- Evaluation of contributing factors

DOMINANT FACTORS AS A FUNCTION OF IN-CRASH PHASES

PGV: FRONT PASSENGER US NCAP FWFI (FIVE STAR RATED MIDSIZE SEDAN)



Occupant Protection

Until ***ride-down*** completion
Based on Integral Scenario

1. **Seat Belt System**
2. **Crash Scenario**
3. **Vehicle Sensory System**
4. **Occupant**
5. **Vehicle**
6. **Seat & Environment**
7. **Airbag System**

SBS Performance

Force-closure generation
Based on **"The Big 8"**

1. **Vehicle pulse**
2. **Time-to-Fire delay**
3. **ATD**
4. **SBS fixation points**
5. **Initial Torso inclination**
6. **Pelvis damper force**
7. **System slack**
8. **Available safety space**

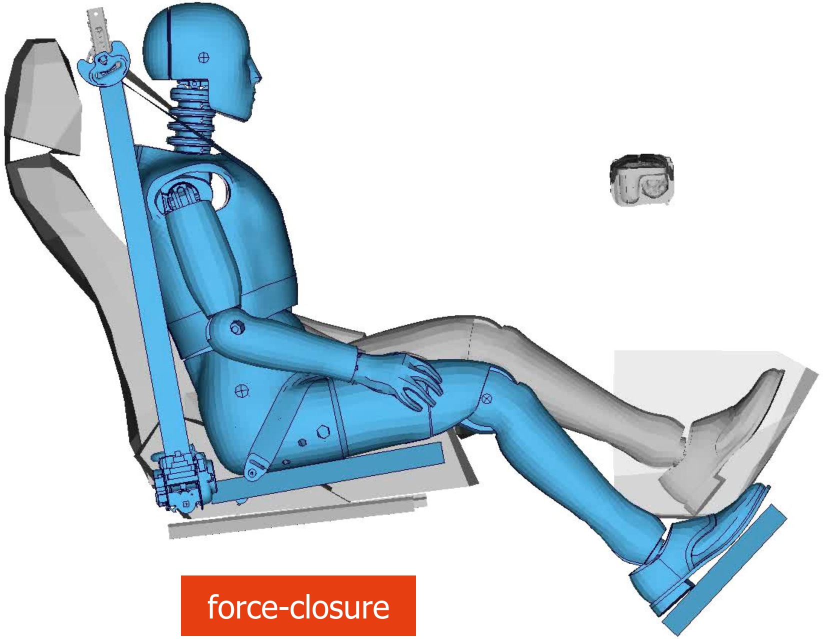
Ride-down contribution

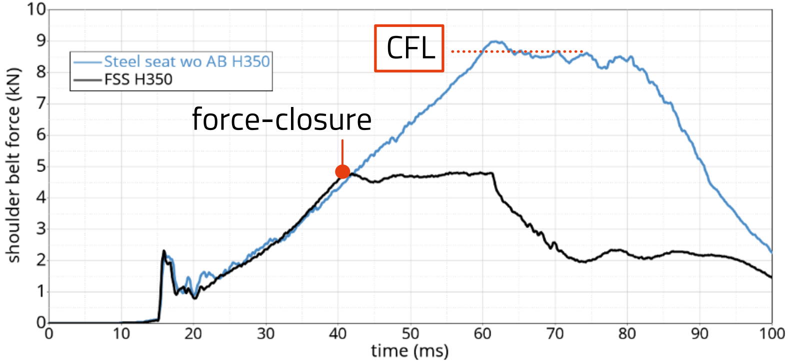
A. **SBS-energy management**
B. **Stop (hard, soft)**

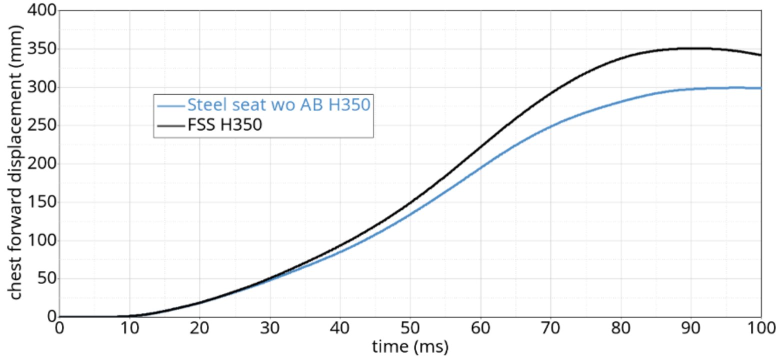
SBS Task: Establish early & efficient force-closure and contribute to ride-down.
Airbag System and Seat & Environment do **not** interact with occupant in **force-closure** phase.

230119_ESV27_paper_Pre-Crash-Approach.docx (zf-lifetec.com)

CHARACTERISTIC SHOULDER BELT FORCE LEVEL (CFL)

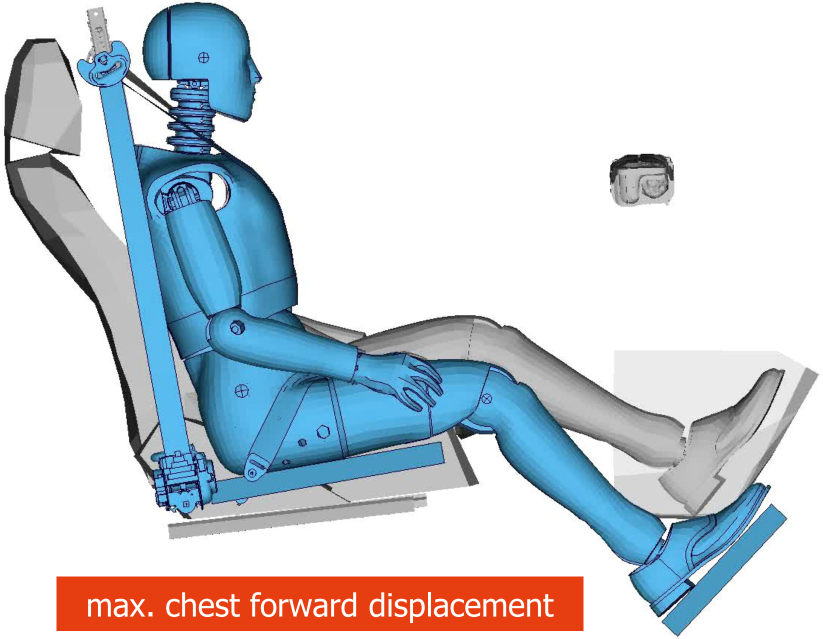


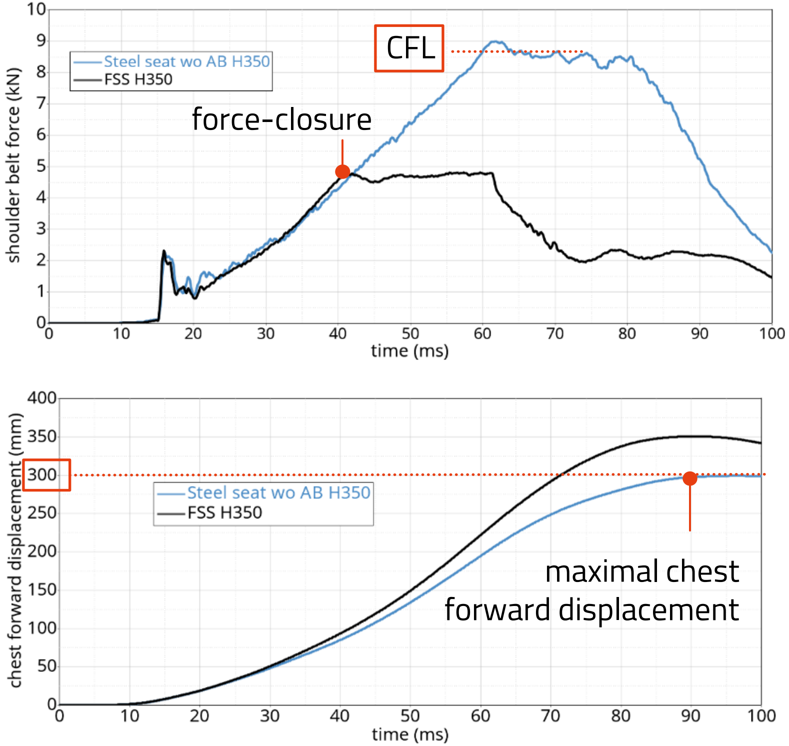




CFD: Chest Forward Displacement
CFL: Characteristic Shoulder Belt Force Level
CLL: Constant Load Limiter
AB: Air Bag

CHARACTERISTIC SHOULDER BELT FORCE LEVEL (CFL)

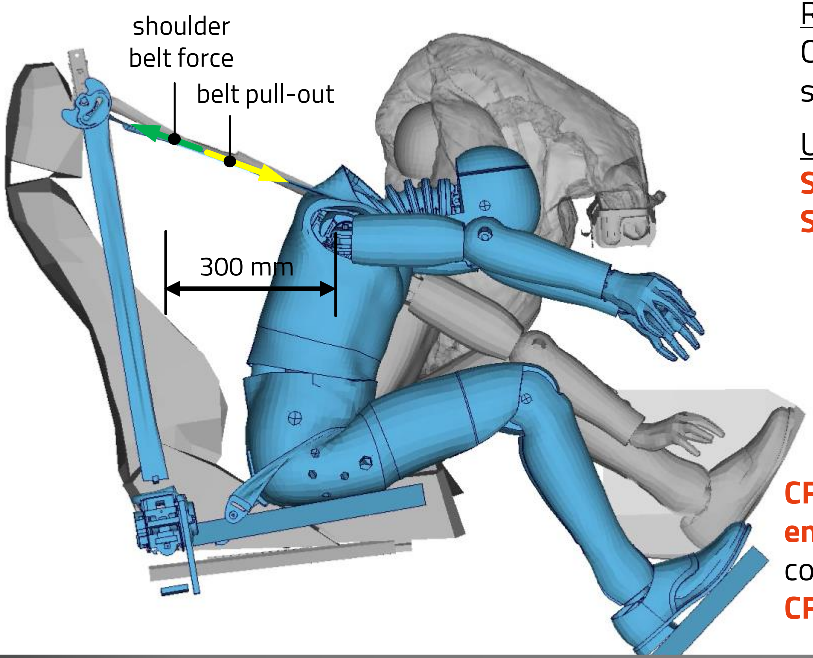




CFD: Chest Forward Displacement
CFL: Characteristic Shoulder Belt Force Level
CLL: Constant Load Limiter
AB: Air Bag

CHARACTERISTIC SHOULDER BELT FORCE LEVEL (CFL)[3][4]

230119_ESV27_paper_Pre-Crash-Approach.docx (zf-lifetec.com)



Ride-down w. **CFL as CLL-level**:
CFL defined as CLL-level to stop chest forward displacement on simplified T@S setup at 300 mm $\pm 1.5\ mm$.

Until force-closure:
Steal seat and **T@S** setup behavior **corresponds** to **Full Safety System** config. for identical "The Big 8" parameter set.

CFL is higher

1.) if consumed distance is larger or

2.) if dissipated kinetic energy is lower

CFL combines shoulder belt force (~ chest deflection) **with rest energy dissipation** (work = belt force * belt displacement) therefore considering both important factors in a single value.
CFL assumes ride-down with **minimal** (=constant) belt **force**

CFL (the lower the better) serves as **single value metric** to quantify the **restraint performance** in a specific load case.

[3] Machens KU, Kübler L. Dynamic testing with pre-crash activation to design adaptive safety systems. Proceedings 27th Conference on the Enhanced Safety of Vehicles, Yokohama, 2023
[4] Schöneburg R. Integrale Sicherheit von Kraftfahrzeugen, ISSN 2628-104X ISSN 2628-1058 (electronic) ATZ/MTZ-Fachbuch ISBN 978-3-658-42805-1 ISBN 978-3-658-42806-8 (eBook) https://doi.org/10.1007/978-3-658-42806-8, 2023

CFD: Chest Forward Displacement
CFL: Characteristic Shoulder Belt Force Level
CLL: Constant Load Limiter
T@S: Torso @ Seat

AGENDA

QUANTIFICATION OF RESTRAINT PERFORMANCE

BY REFERENCING TO A STATE-OF-THE-ART CONFIG. (PGV, PGS, PGO) IN A REF. LOAD CASE

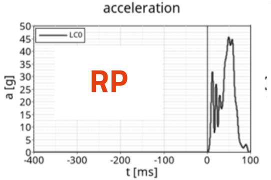
Pretty Good Seatbelt System (PGS):
SPR8-Retractor, full metal pilar loop, pure locking tongue, System Test Belt

Pretty Good Vehicle (PGV):
Fixation points, Seat Orientation, Seat Friction, WOS 900 mm

Pretty Good Occupant (PGO):
H350-ATD -> Torso@Seat (T@S)

Reference Pulse (RP):
PGV under US NCAP FWFI 56 kmph

Reference TTF (RTTF):
10 ms



The **relative deviation** from **CFL** obtained for (PGV,PGS,PGO, RP, RTTF)

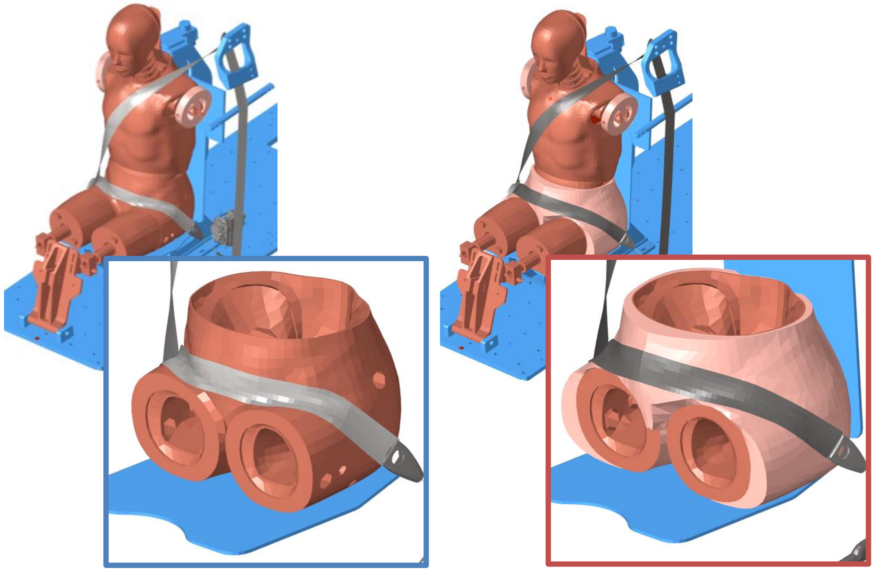
- by using a vehicle specific pulse is defined as **Pulse Severity (PS)** (Pulse & TTF for specific crash event & pre-crash dynamics)
- by using a specific occupant is defined as **Occupant Handicap (OH)**
- by using a specific vehicle configuration is defined as **V-Configuration Handicap (VCH)**
- by using a specific seatbelt system is defined as **SBS Thoracic Load (STL)**

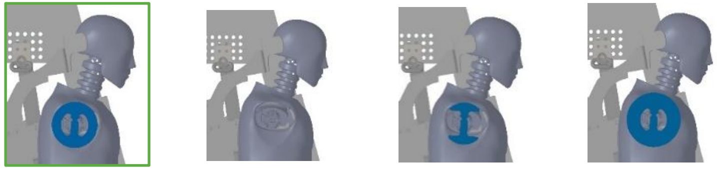
To assess a different **event severities** a typical pulse is selected as new reference and “specific” joins the name.
Load Case Severity (LC-S) links this pulse to **RP & RTTF** by applying both on PGV,PGS, PGO and calculating their relative CFL.

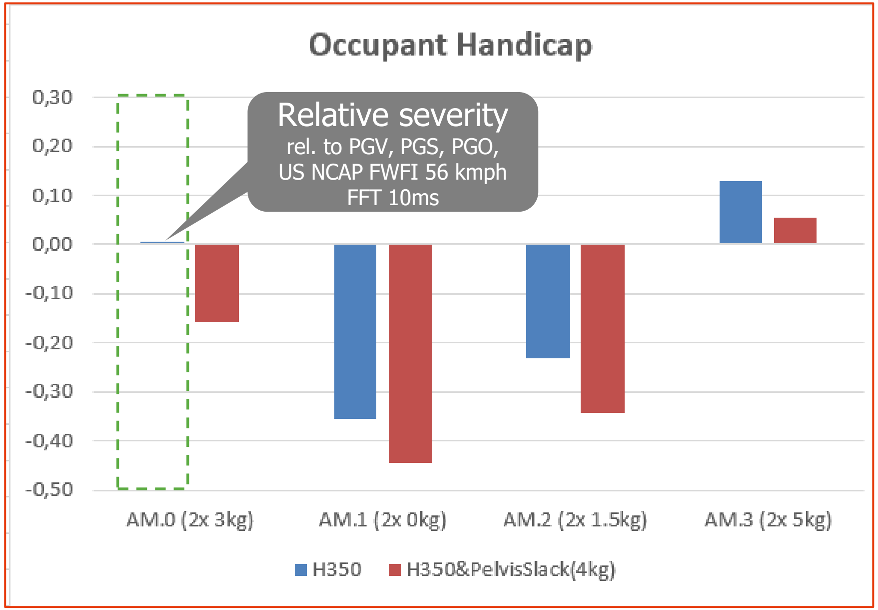
OCCUPANT HANDICAP RATING WITH CFL

REFERENCE PULSE & TTF (PGV, PGS)

INSPIRED BY [5]





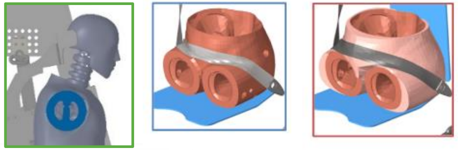


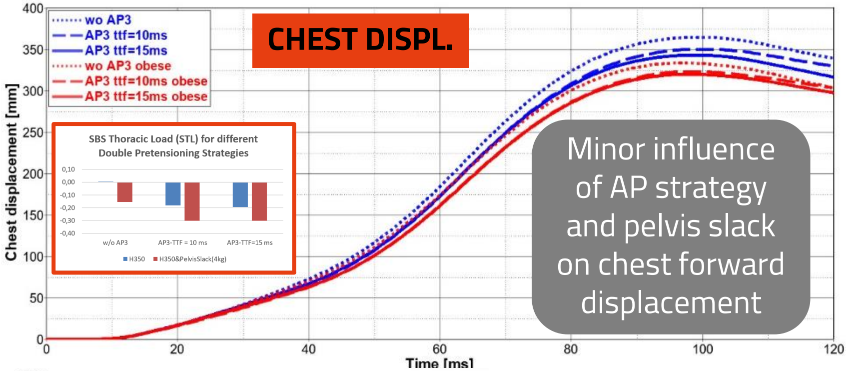
- **Occupant Handicap** grows by added mass at shoulder (0-10 kg) from **-35% to 12%**
- **Pelvis obesity** lowers CFL **by 9-16%**

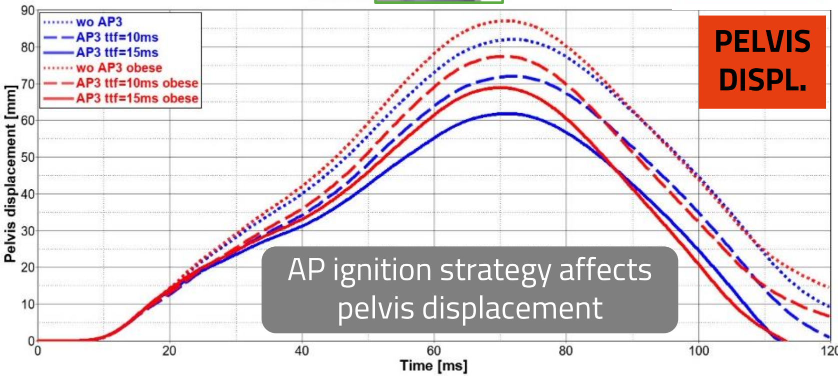
[5] Andreas Schäuble et al., Impact Kinematics and Dynamics of an Obese ATD in Comparison with an Elderly Female, the HIII 50th Male and the HIII 5th Female ATDs as Drivers and Front Passengers in Full-width Frontal Impacts. Proceedings of IRCOBI Conference, 2023, Cambridge, United Kingdom

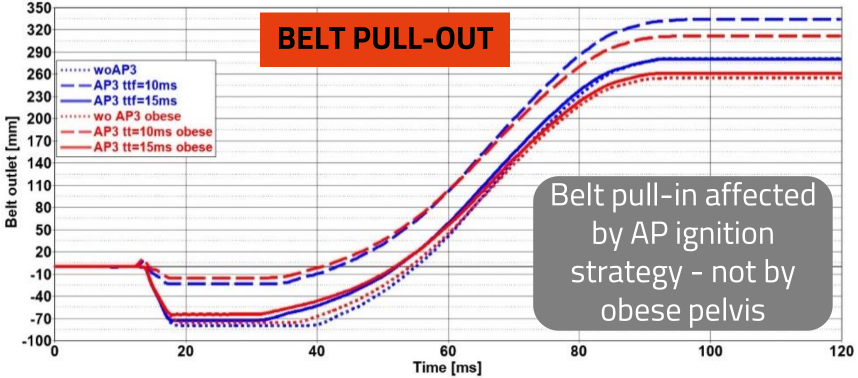
DOUBLE PRETENSIONING / OBESE PELVIS

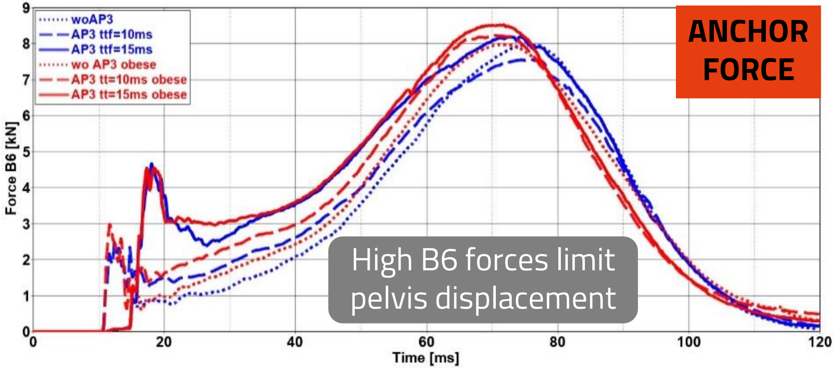
REFERENCE PULSE & TTF (PGV, PGS)







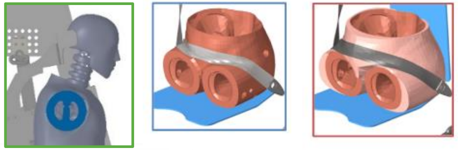


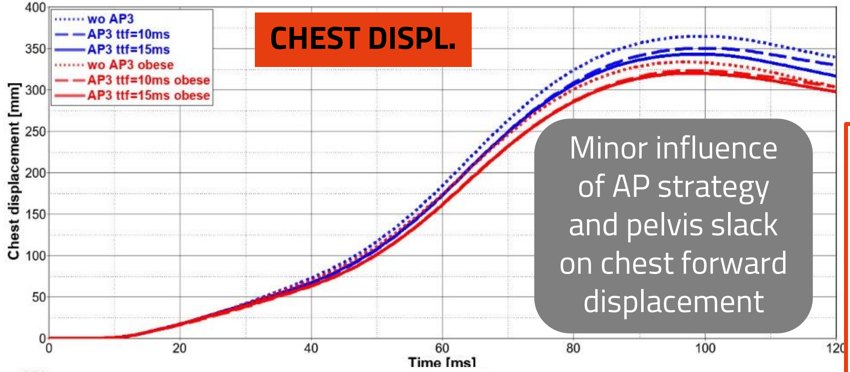


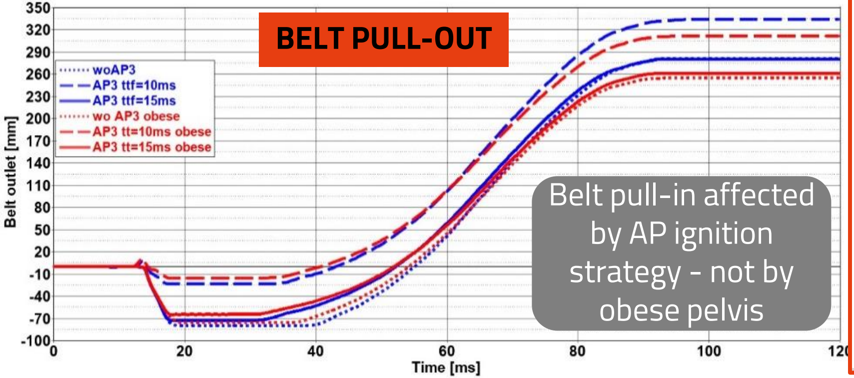
Double pretensioning affects ATD kinematic and is supposed to diminish submarining effect.

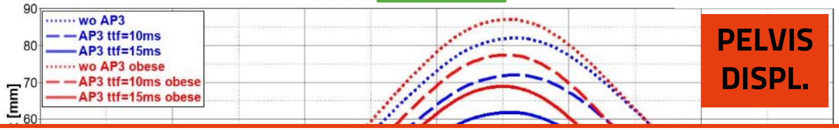
DOUBLE PRETENSIONING / OBESE PELVIS

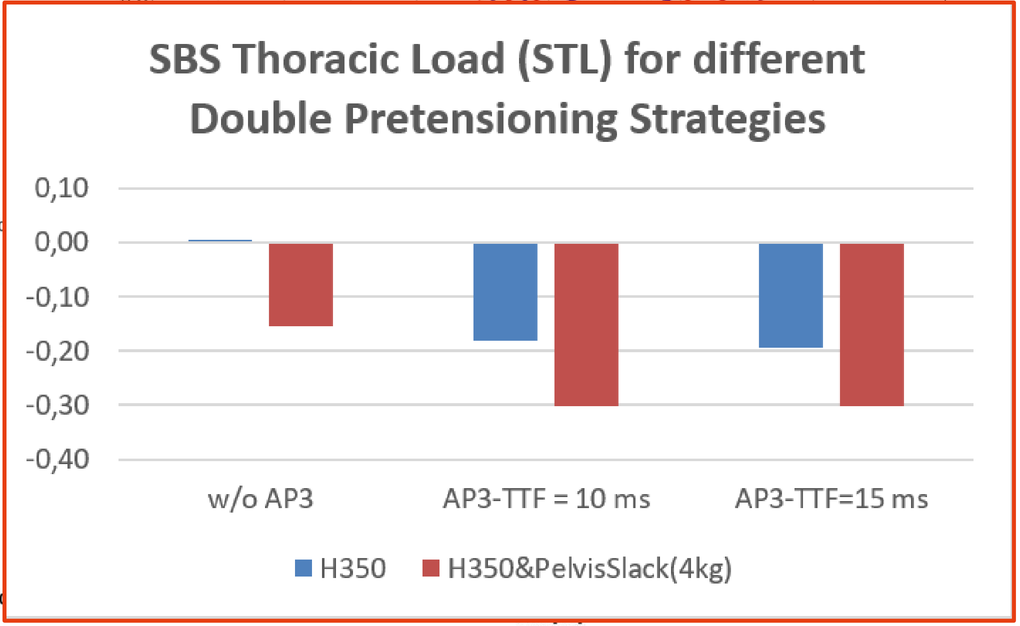
REFERENCE PULSE & TTF (PGV, PGS)







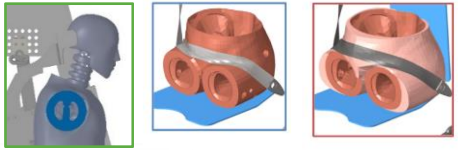


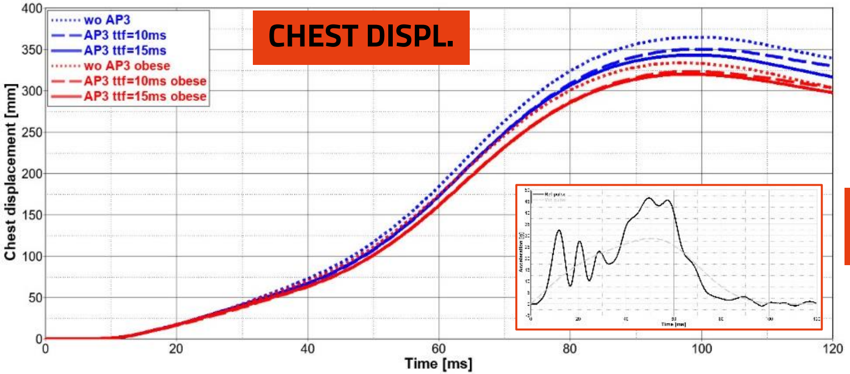


Double pretensioning affects ATD kinematic and is supposed to diminish submarining effect.

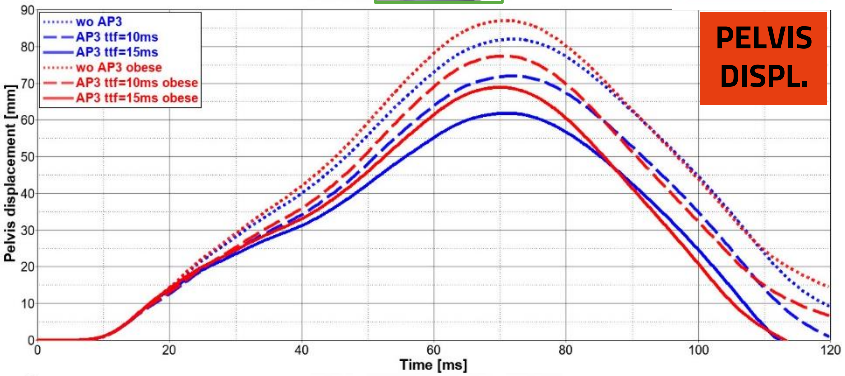
DOUBLE PRETENSIONING / OBESE PELVIS

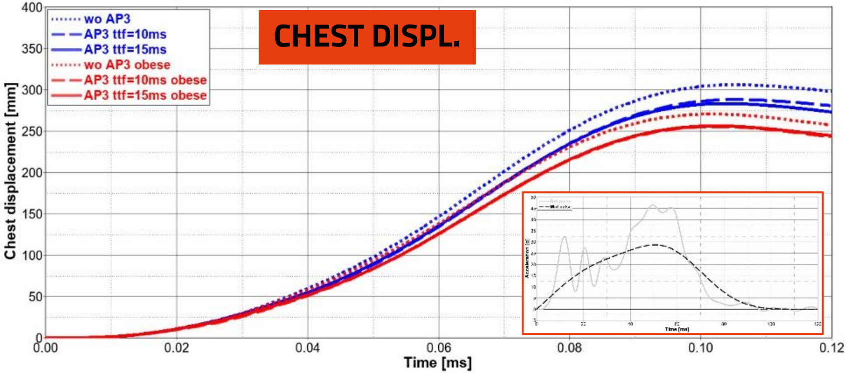
REFERENCE PULSE & TTF / MID-PULSE & TTF (PGV, PGS)



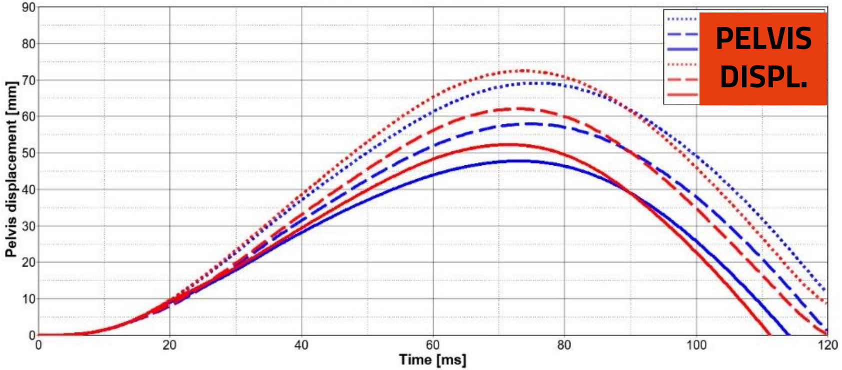


REF.-PULSE





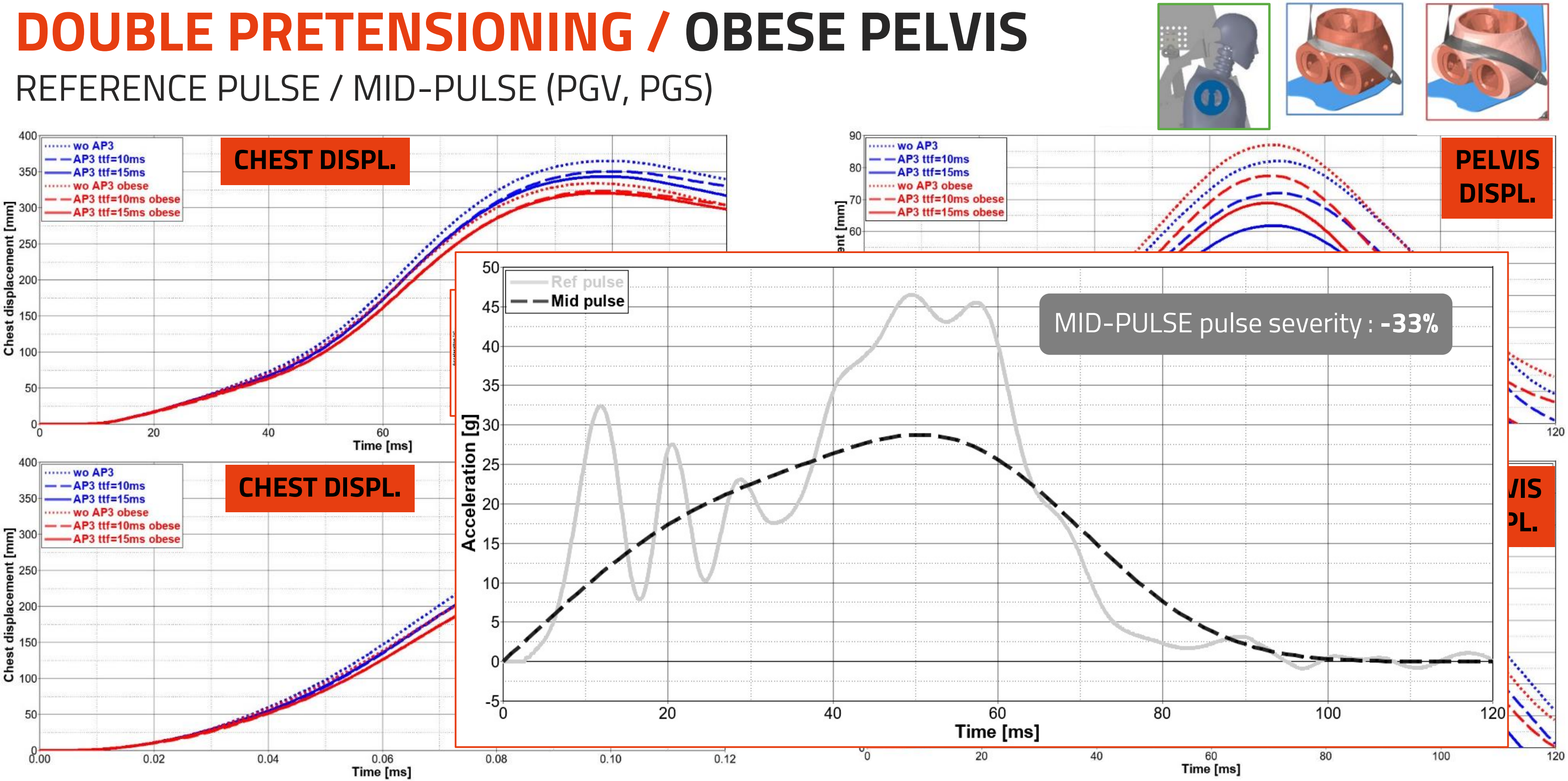
MID-PULSE



Max chest/pelvis displacement different! Effect of double pretensioning strategie similar

DOUBLE PRETENSIONING / OBESE PELVIS

REFERENCE PULSE / MID-PULSE (PGV, PGS)



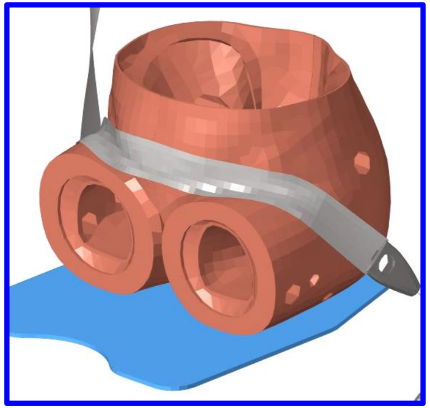
Max chest/pelvis displacement different! Effect of double pretensioning strategie similar

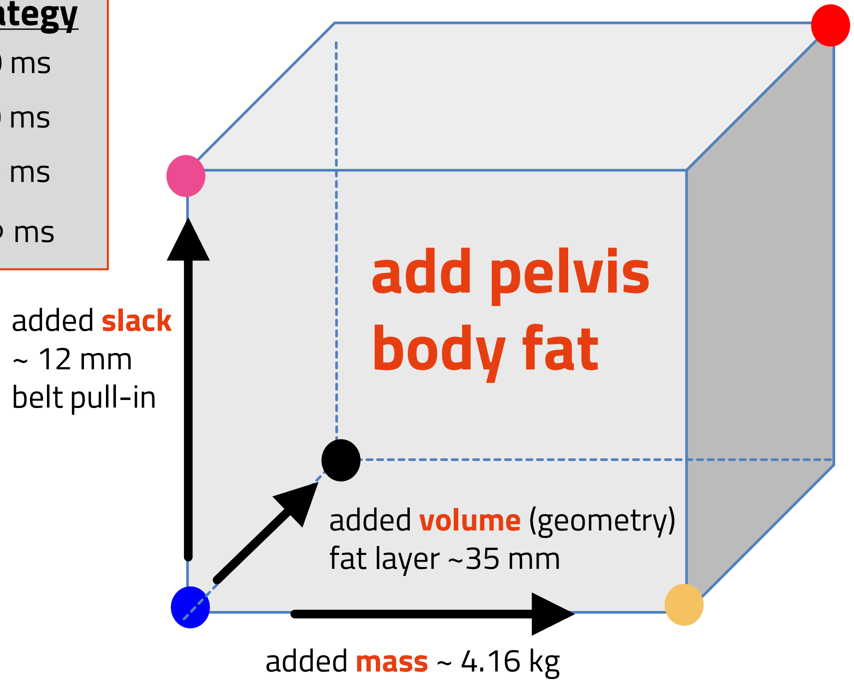
ADDED PELVIS BODY FAT ON H350

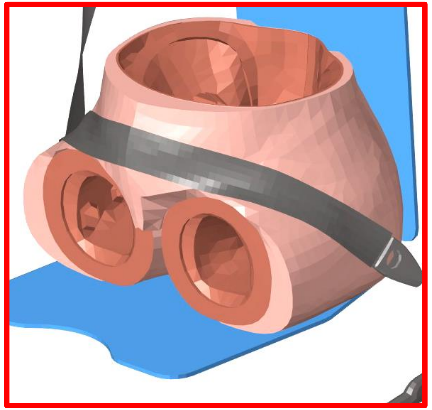
FUNCTIONALLY CLUSTERED IN MECHANICAL EFFECTS

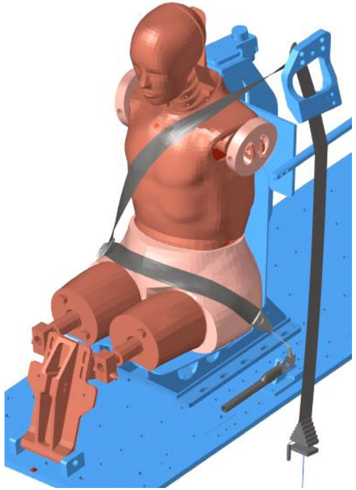
Double pretensioning strategy

	RP-TTF = 10 ms
– – – – ·	AP-TTF = 10 ms
———	AP-TTF = 15 ms
··············	AP-TTF = ∞ ms





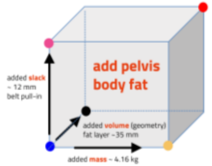


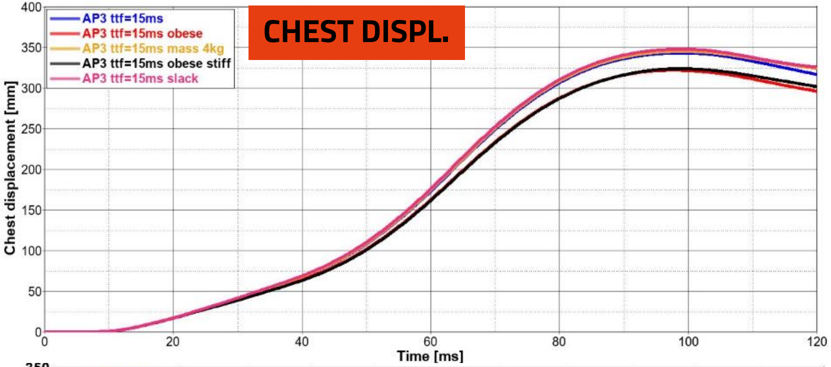


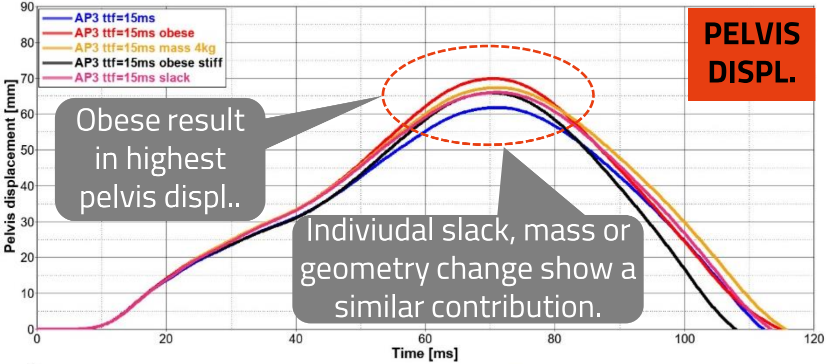
activation under reference pulse

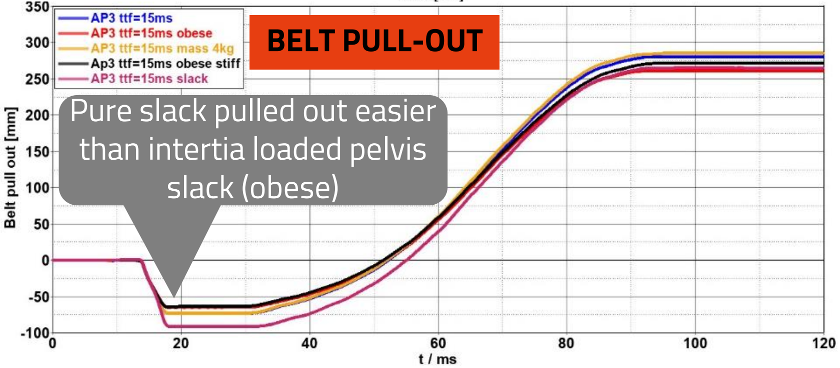
DOUBLE PRETENSIONING / OBESE PELVIS

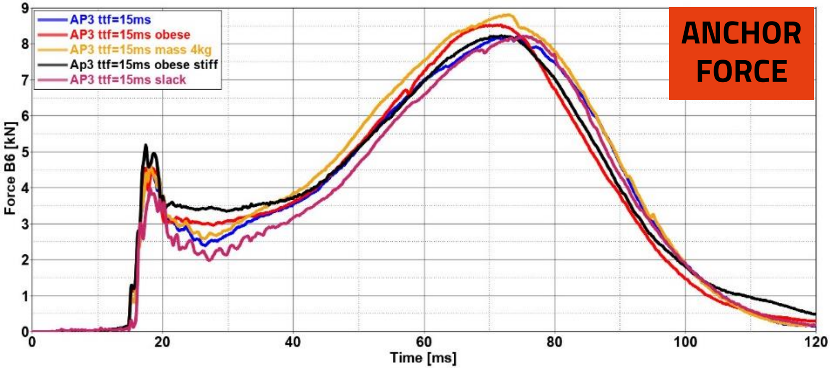
REFERENCE PULSE / MID-PULSE (PGV, PGS)











Obese pelvis contributes by additional slack, mass and geometry to restraint performance. All three show similar contribution.

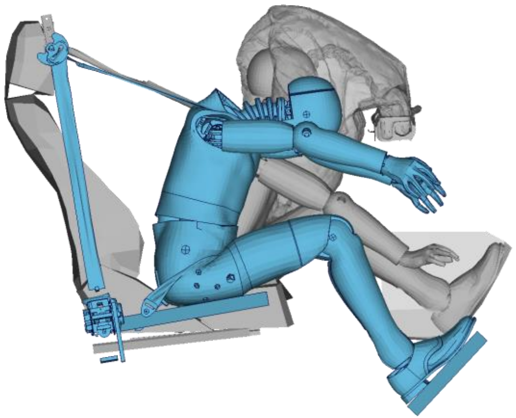
AGENDA

SUMMARY AND OUTLOOK

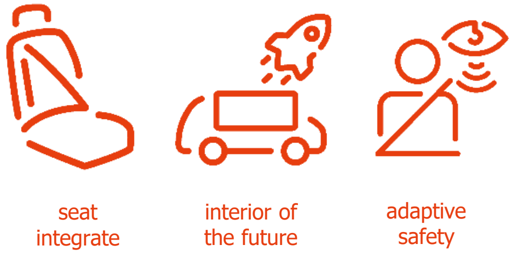
Matthiew Brumbelow, Jesssica S. Jermakian (IIHS)

"Improved **thoracic injury protection in frontal crashes may be the single most pressing crashworthiness issue** in the passenger vehicle fleet. Perhaps the quickest way to make gains in this area would be the use of **a metric in crash test rating** programs that is demonstrated to predict field injury risk for **drivers restrained by a seat belt and airbag**." **[1]**

[1] Brumbelow ML, et. al. (2022) Predicting Real-World Thoracic Injury Using THOR and Hybrid III Crash Tests. Proceedings of IRCOBI Conference, 2022, Porto, Portugal



1. **Characteristic shoulder belt force level (CFL)** is a potential metric to **predict SBS Thoracic Load** (Correlation to field injury risk pending).
2. **Adaptive restraint systems** regarded as important step towards **equity in occupant real-life safety**.
3. **HyDRA®** bench **enabler** to cross link **virtual functional SBS models** to **physical** testing.



LOTS OF THOUGHTS NOT MUCH ROOM HERE …

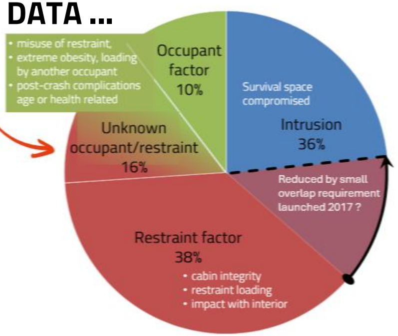
https://www.linkedin.com/feed/update/urn:li:ugcPost:7225877679147741185?commentUrn=urn%3Ali%3Acomment%3A%28ugcPost%3A7225877679147741185%2C7228753889645191169%29&dashCommentUrn=urn%3Ali%3Afsd_comment%3A%287228753889645191169%2Curn%3Ali%3AugcPost%3A7225877679147741185%29

WHEN TESTING DEVICE IS MORE SOPHISTICATED THAN THE INJURY CRITERIA …

High precision testing **speeds up product development and validation** as functional product design changes can be safely verified with a minimum of test sample size. **No averaging needed** to reduce measurement noise in testing.

WE HAVE TO DEPEND ON FIELD DATA …

IIHS requests improvement of **thoracic injury protection in frontal crashes** based on field data analysis.



Greg Bayley • 2.

3 Wochen •••

Actively pursuing application of safety technology to marine environments

When the testing device is more sophisticated than the injury criteria how does a system designer know how to select product characteristics that provides the widest attenuation of injury causation loading. Take the example of bone deformation in high severity impacts. University of Wisconsin created instrumentation for the human rib cage over 30 years ago. It never caught on as a part of the FMVSS 208 injury criteria even though there was field data showing related types of injury. At the time, I think the biomechanics community felt that the current measuring devices and criteria would would provide the greatest benefit for the investment. Without more realistic injury tolerance limits for the different shapes, sizes and ages of occupants the fall back position is usually scaling of occupant injury criteria that were established in the 1960s - 1980s and directed at the mid sized male and scaled up or down for other sizes. We have to depend on field data to tell us if scaling has resulted in improvements protection for non 50%tile. Lots of thoughts not much room here.

ZF LIFETEC

PIONEERING AUTOMOTIVE SAFETY

CONTACT

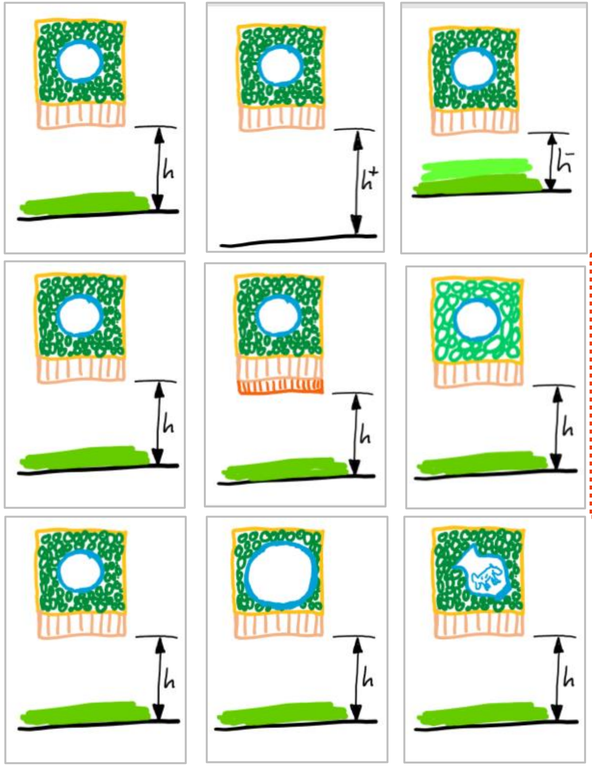
DR.-ING. KAI-ULRICH MACHENS
MANAGER SEATBELT SYSTEMS ENGINEERING
FUNCTION TEST METHODOLOGY, MATERIALS & ACOUSTICS
+49-7172-3022286
KAI-ULRICH.MACHENS@ZF-LIFETEC.COM

DR.-ING. LARS KÜBLER
DIRECTOR SEATBELT SYSTEMS ENGINEERING
+49-7172-3022230
LARS.KUEBLER@ZF-LIFETEC.COM

ZF LIFETEC
ZF Automotive Germany GmbH
Industriestrasse 20
D-73553 Alfdorf Germany

CRASH INJURY RISK FACTORS

VISUALIZED AS PADDED GOODS IN A MOVING BOX



Event severity

fuzzy, uncontrollable, outside

- delta velocity
- crashworthiness bullet vehicle / obstacle
- compatibility
- mass distribution …

Restraint performance

- crash detection (TTF)
- crashworthiness ego vehicle
- vehicle configuration
- force-closure performance SBS
- ride-down performance

controlled subsystem

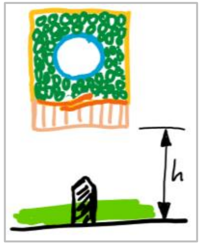
Occupant factor

- obese,
- large
- vulnerable
- seat adjustment …

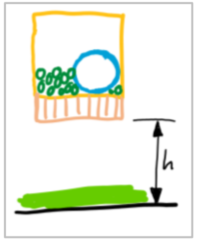
fuzzy, uncontrollable, outside

Out of scope

- intrusion
- multiple impact



- misuse
- out of position
- (unbelted)



- extreme obesity
- post crash complications (age or heart related)

In-Crash Phases for Passive & Integrated Safety

Passive Safety: phases in-crash

Phase 1	Phase 2	Phase 3
crash detection	**force closure**	**ride-down**
first contact – TTF	TTF – LL-level reached	LL-level reached – occupant at rest
task: reliable crash detection	task: fast coupling build up belt forces	task: ride-down occupant with controlled (minimal) forces

Irreversible SBS activation

Integrated Safety: phases in-crash

Phase 1	Phase 2	Phase 3
pre-crash preparation	**force closure**	**ride-down**
... – collision imminent signal (TTF)	TTF – LL-level reached	LL-level reached – occupant at rest
task: pre-crash activity reliable crash detection	task: fast coupling build up belt forces	task: ride-down occupant with controlled (minimal) forces

Reversible SBS activation → ***Irreversible*** SBS activation

Efficient coupling of occupant to vehicle major task of Seat Belt Systems & SBS pre-crash activation.
In **Integrated Safety** *pre-crash* and *in-crash* phase need to be evaluated together.

LL: Load Limiting
TTF: Time To Fire
SBS: Seat Belt System

Findings of IIHS and NTHSA

From National Automotive Sampling SystemCrashworthiness Data System (NASS-CDS)

- NTHSA reports that about 50% of all passenger vehicle occupants killed in 2020 were unrestrained.[1]
- Frontal non-rollover crashes accounted for 50% of fatalities of belted passenger-vehicle occupant in 2019 [1]. This proportion is highest for the newest vehicles (Fig.1),...[2]
- The estimated risk of a thoracic injury was greater than the risk of any other non-extremity injury for the two oldest age groups at all delta-Vs, with a larger difference for the oldest group.[3]

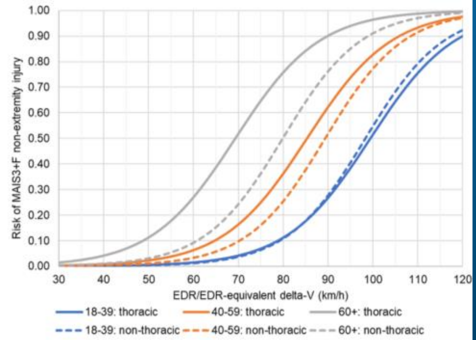


Fig. 4. Thoracic vs. non-thoracic (non-extremity) injury risk by delta-V and driver age in large overlap, moderate overlap and center impact crashes

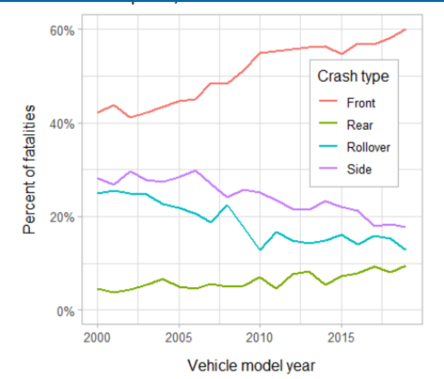


Fig. 1. 2018–2019 US fatalities of belted passenger-vehicle occupants by model year and crash type.

Improved thoracic injury protection in frontal crashes may be the single most pressing crashworthiness issue in the passenger vehicle fleet. Perhaps the quickest way to make gains in this area would be the use of a metric in crash test rating programs that is demonstrated to predict field injury risk for drivers restrained by a seat belt and airbag.[2]

[1] National Highway Traffic Safety Administration (2020) Fatality Analysis Reporting System

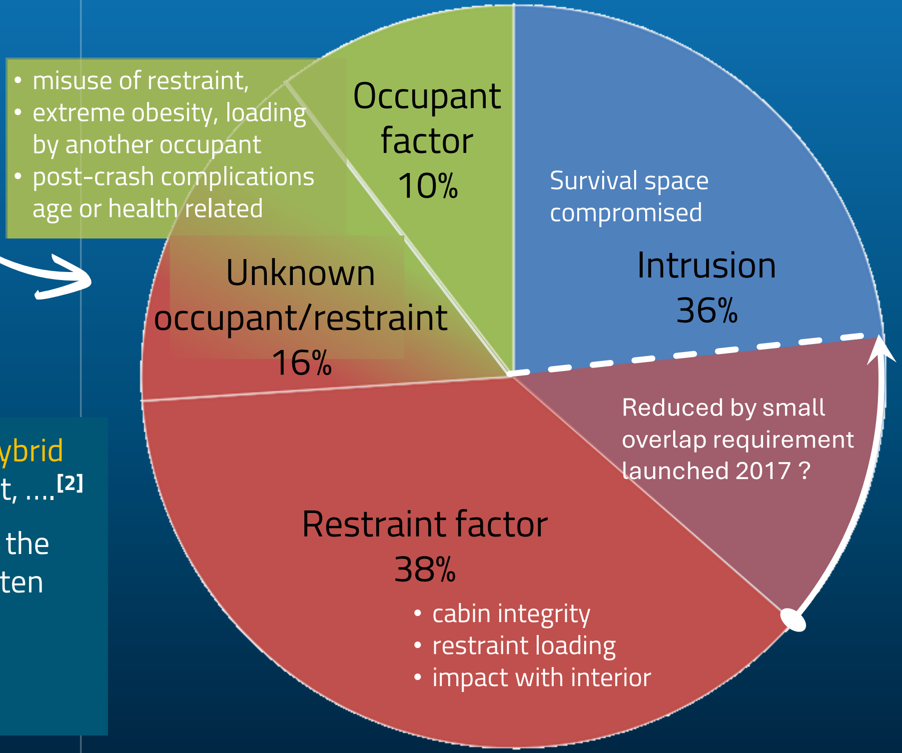
[2] Brumbelow ML, et. al. (2022) Predicting Real-World Thoracic Injury Using THOR and Hybrid III Crash Tests. Proceedings of IRCOBI Conference, 2022, Porto, Portugal..

[3] Brumbelow ML (2019) Front crash injury risks for restrained drivers in good-rated vehicles by age, impact configuration, and EDR-based delta V. Proceedings of IRCOBI Conference, 2019, Florence, Italy.

Findings of IIHS and NTHSA

From National Automotive Sampling SystemCrashworthiness Data System (NASS-CDS)

- Analysis of real-world cases with serious injuries resulting from frontal crashes of vehicles rated good for frontal crash protection.[4] (2000-06 data from NASS-CDS)
- Further restraint system improvements may require technologies that adapt to occupant and crash circumstances.[4]



- The high levels of real-world injury risk are not predicted by Hybrid III (HIII) measurements taken in the IIHS moderate overlap test, ….[2]
- … shoulder-belt force, vehicle bumper-to-firewall distance, or the ratio between sternum deflection and thoracic acceleration often performed better in predicting injury outcomes than sternum deflection alone.[2]

[2] Brumbelow ML, et. al. (2022) Predicting Real-World Thoracic Injury Using THOR and Hybrid III Crash Tests. Proceedings of IRCOBI Conference, 2022, Porto, Portugal

[4] Brumbelow ML., Zuby DS. Impact and injury patterns in frontal crashes of vehicles with good ratings for frontal crash protection. Proceedings of 21st Intl Tech Conf on the Enhanced Safety of Vehicles, 2009

ODB: **O**ffset **D**eformable **B**arrier

HYDRA® TORSO@SEAT

B-PILLAR CONFIGURATION

Test objectives:

- 3PGA test with focus on pretensioning and load limiting
- Relevant system resistance is considered by dummy interaction

Loading parameter and settings:

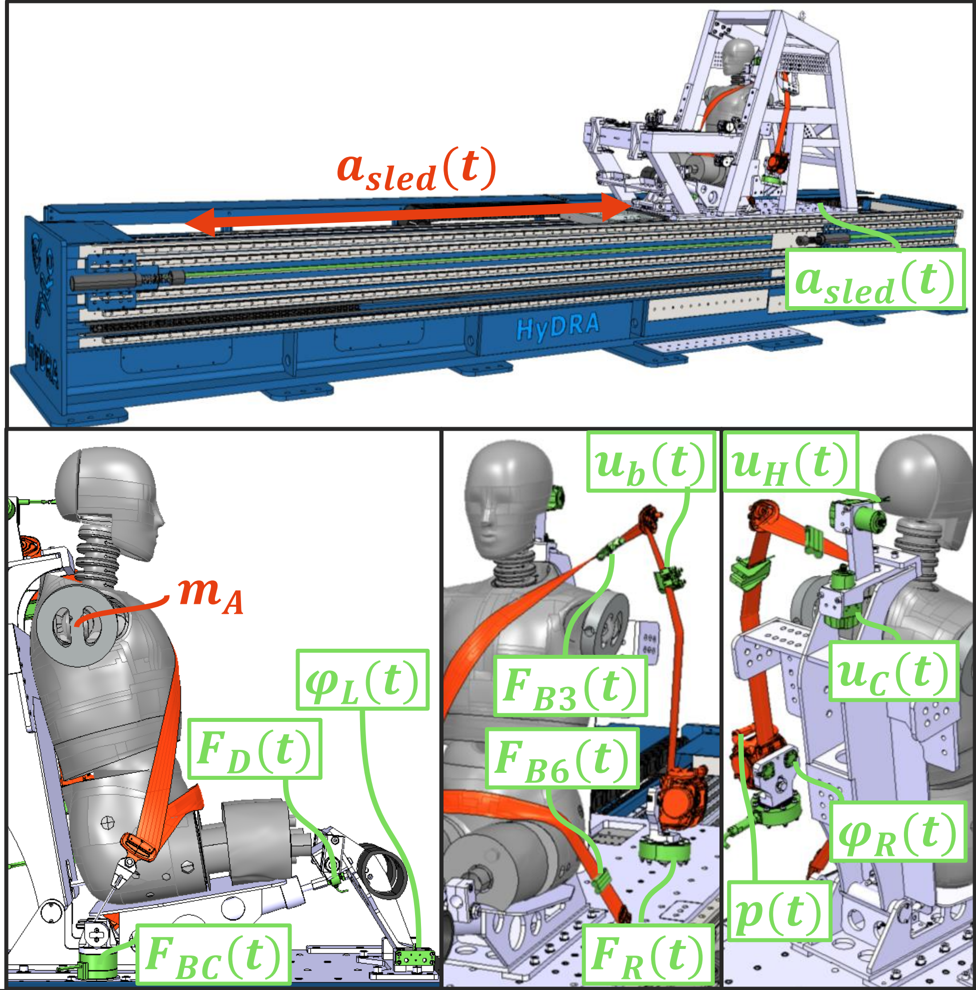
- Crash pulse $a_{Sled}(t)$
- Arm masses m_A
- Damper settings (1-8)

Component settings:

- Webbing on spool (WOS)

Measurements:

- Belt forces $F_{B3}(t)$ and $F_{B6}(t)$
- Buckle forces $F_{BC}(t)$
- Retractor force $F_R(t)$
- Belt displacement $u_b(t)$
- Chest and head displacement $u_H(t)$ and $u_C(t)$
- Damper force $F_D(t)$
- Leg rotation angle $\varphi_L(t)$
- Sled acceleration $a_{sled}(t)$
- Optional: Retractor tube pressure $p(t)$ and spool rotation $\varphi_R(t)$
- Retractor and load limiter current



HYDRA® MOVING FRONT SEAT FRAME

GENERIC LOOPED

Test objectives:

- Retractor test with focus on pretensioning and load limiting
- System resistance simulated by setup parameter to achieve similar belt pull-in and pull-out characteristics

Loading parameter and settings:

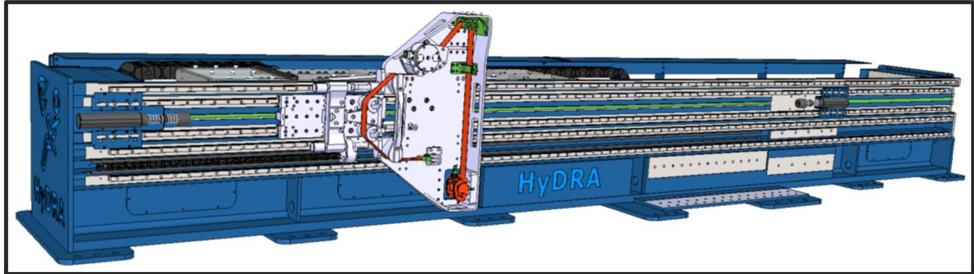
- Crash pulse $a_F(t)$
- Free floating mass m_m
- Kinematic onset

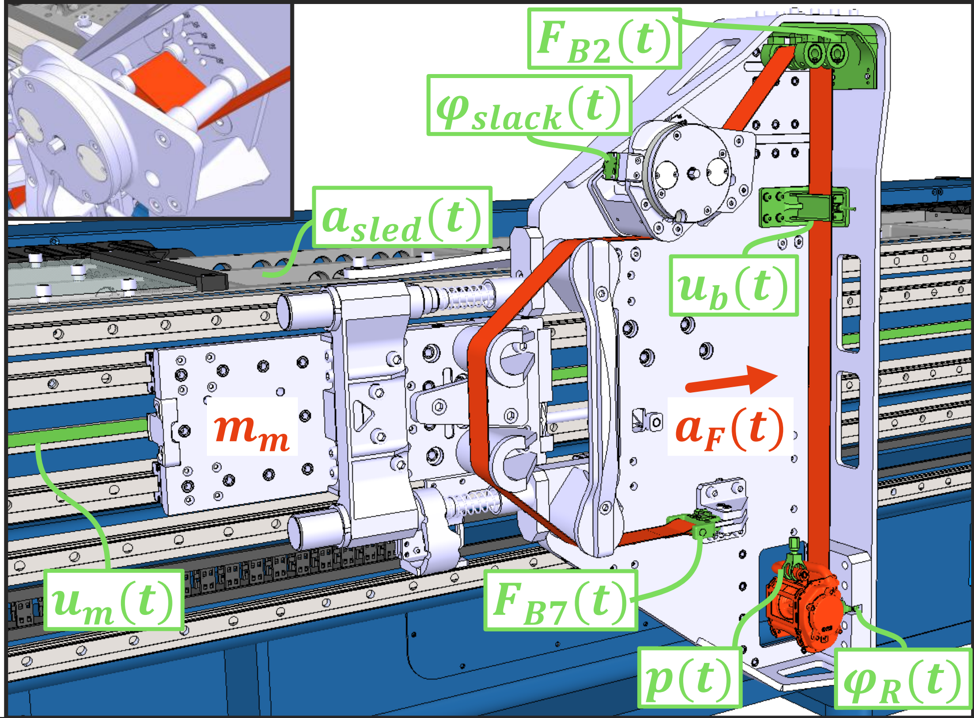
Component settings:

- Webbing on spool (WOS)

Measurements:

- Belt forces $F_{B2}(t)$ and $F_{B7}(t)$
- Belt displacement $u_b(t)$
- Mass displacement $u_m(t)$
- Sled acceleration $a_{sled}(t)$
- Slack rotation $\varphi_{slack}(t)$
- Optional: Retractor tube pressure $p(t)$ and spool rotation $\varphi_R(t)$
- Retractor and load limiter current





REAL-LIFE SAFETY – FOCUS OF FUTURE NCAP & INSURANCE TESTING

USA – NTHSA[1] / IIHS[2]

Frontal non-rollover crashes accounted for 50% of fatalities of belted passenger-vehicle occupant in 2019 [1]. This pro-portion is highest for the newest vehicles (Fig.1),…[2]

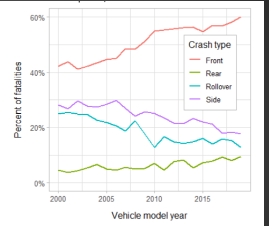


Fig. 1. 2018–2019 US fatalities of belted passenger-vehicle occupants by model year and crash type.

Improved thoracic injury protection in frontal crashes may be the single most pressing crashworthiness issue in the passenger vehicle fleet. [2]

EU - NCAP

Roadmap 2030

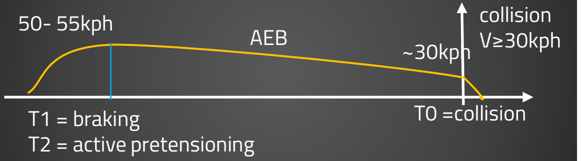
Starting 2026

- Consider elderly
- Wider range required: 5%ile 35 kmph, 95%ile, 56 kmph
- female dummy bio fidelity, THOR 5%ile
- Virtual testing (real-life safety)

China - CNCAP / CIASI

2024 Protocol

- Active Restraints
- ACR bonus point – performance in pre-braked sled test (CATARC)



- Comfort seating „0-Gravity" draft

Adaptivity / Virtual Testing / Digital Twin / Reversible Pretensioning / Pre-Crash Validation

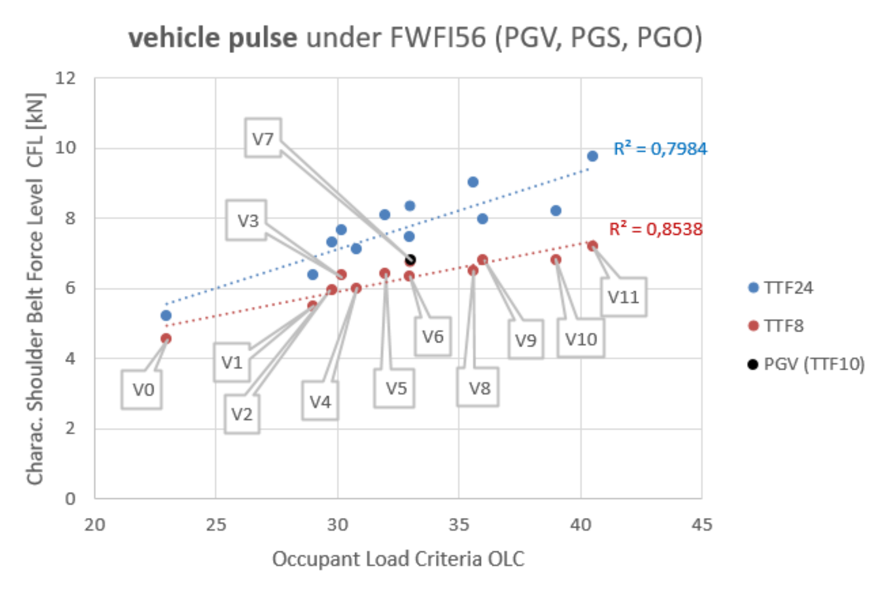
06

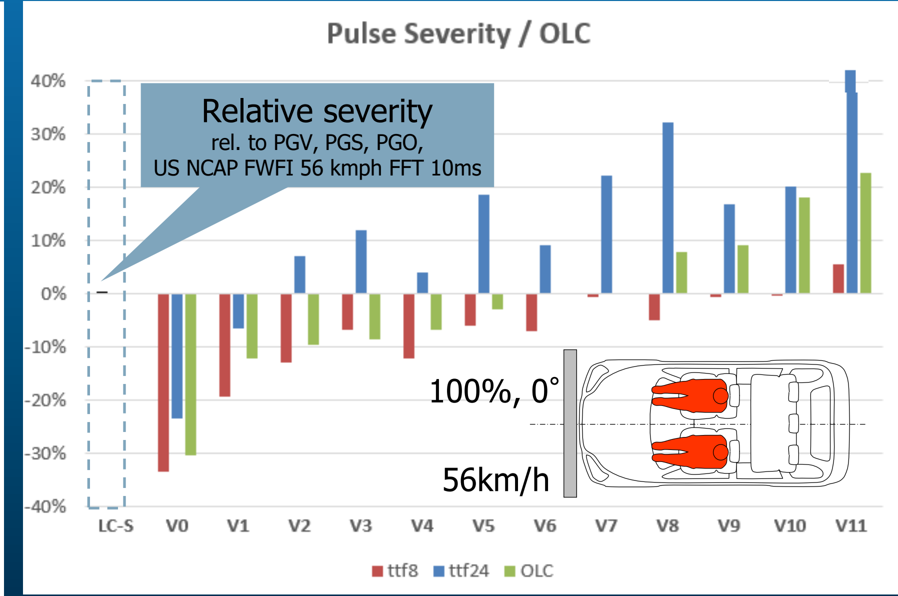
Quantification of restraint performance including factor benchmarking

Pulse Severity (Crashworthiness)
Occupant Handicap
V-Configuration Handicap
SBS Thoracic Load
specific SBS Thoracic Load (with Pre-crash activation)

SBS: **S**eat **B**elt **S**ystem

Pulse Severity (Crashworthiness rating) with CFL
Vehicle pulses under US NCAP FWFI (PGV config., PGS (TTF8, TTF24), PGO)



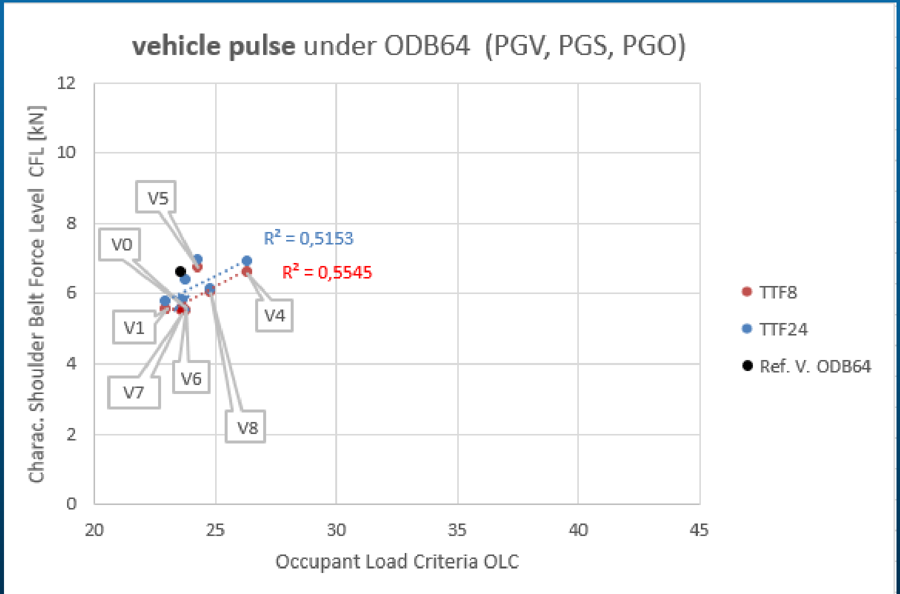


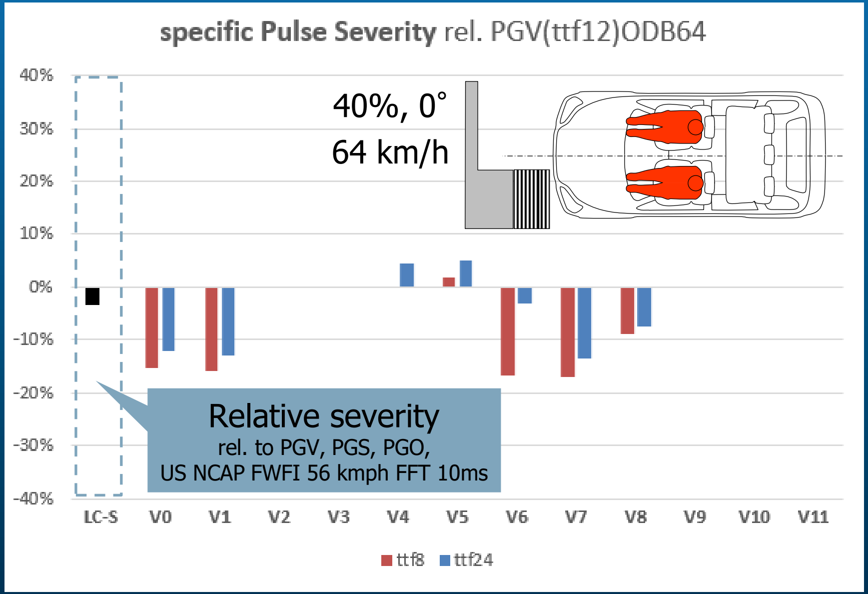
- Rough correlation between **Pulse Severity with CFL** (TTF 8ms) and pulse criterion **OLC**.
- **CFL is enriched** by ATD kinematic, TTF information and uses the **dynamic characteristics of a typical SBS** which replaces the generic assumptions used in **OLC.** Higher calculation effort results in **improved effect separation**.

OLC: Occupant Load Criterium
CFL: Characteristic Shoulder Belt Force Level
SBS: Seat Belt System
TTF: Time To Fire

Specific Pulse Severity (Crashworthiness rating) with CFL

Vehicle pulses under EU NCAP ODB (PGV config., PGS (TTF8, TTF24), PGO)



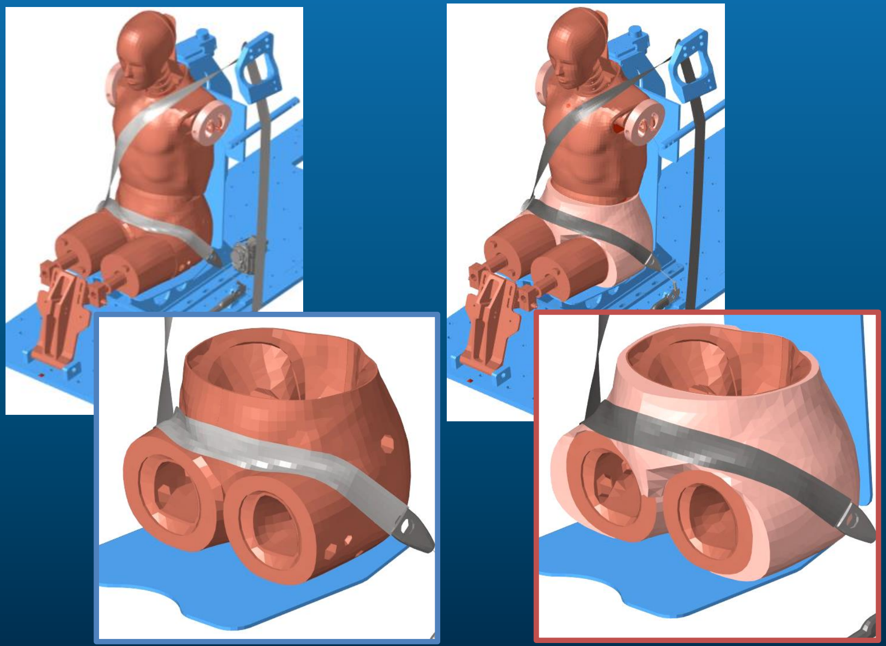


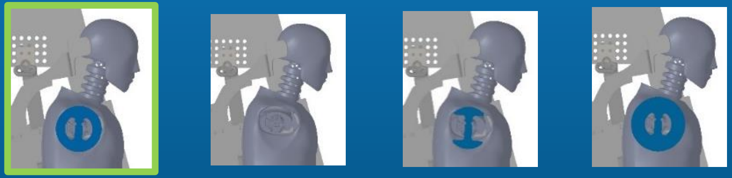
- Deformable Barrier (=crashworthiness bullet vehicle) **reduces vehicle pulse differences** in CFL and OLC metric.
- CFL for PGV FWFI56(TTF10) and ODB64(TTF12) differs only by 3%
- **LC-S:** Average CFL under FWFI56 and ODB64 similar for **TTF8**: 6.3 /6.1 (**3%**), different for **TTF24**: 7.7 / 6.4 (**20%**)

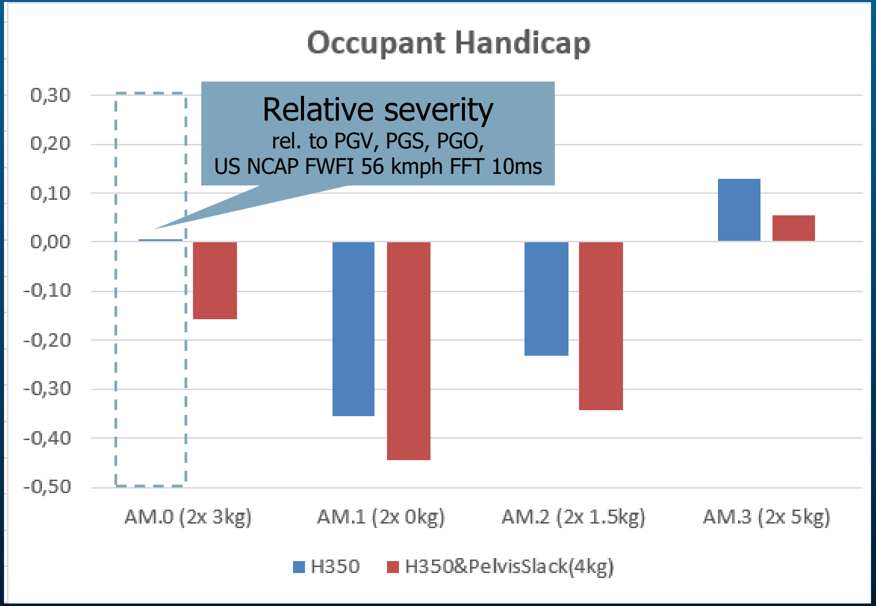
PGS: Pretty Good System
CFL: Characteristic Shoulder Belt Force Level
PGV: Pretty Good Vehicle
TTF: Time To Fire

Occupant Handicap rating with CFL

Pulse & TTF from PGV under US NCAP FWFI 56kmph for (PGV, PGS)



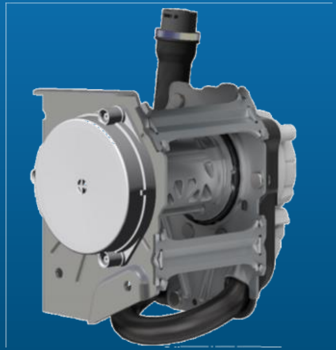




- **Occupant Handicap** grows by added mass at shoulder (0-10 kg) from **-35% to 12%**
- **Pelvis slack** (+4 kg) lowers CFL **by 9-16%**

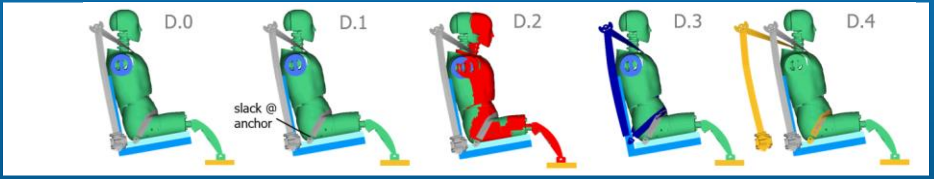
V-Configuration Handicap / SBS Thoracic Load rating with CFL

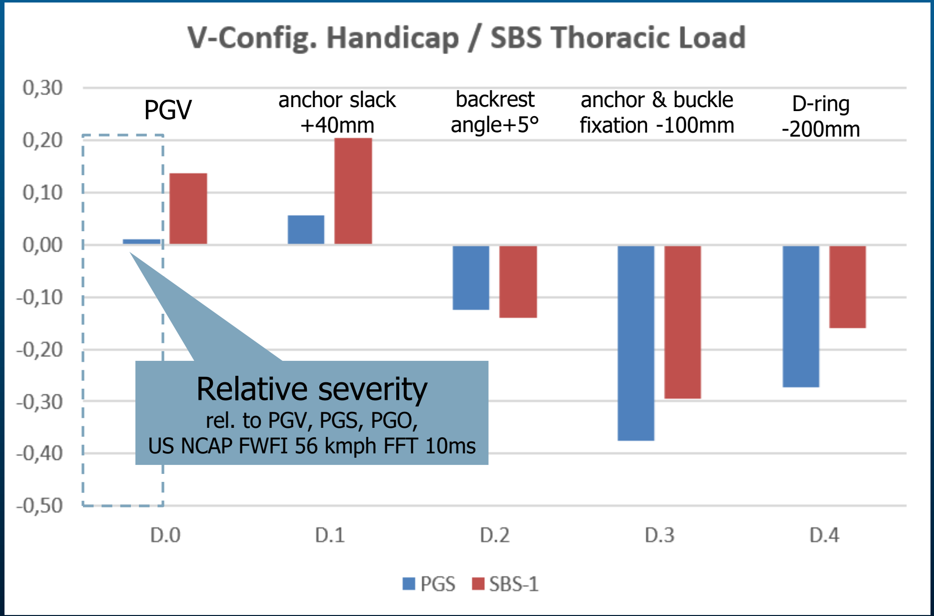
Pulse & TTF from PGV under US NCAP FWFI 56kmph for (PGS, PGO)



PGS

SBS-1



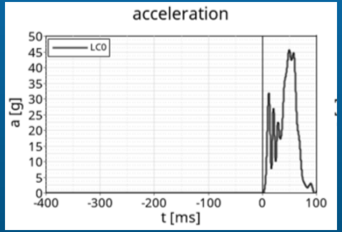


- **SBS-1** raises CFL **by 14%** (SBS-1 less effiicient)
- **40 mm anchor slack** raises CFL **by 6%**
- **Backrest angle +5°** lowers CFL **by 13%/14%**
- **Anchor & buckle fixation 100mm backwards** lowers CFL **by 38%**
- **D-ring fixation 200mm backwards** lowers CFL **by 27%/26%**

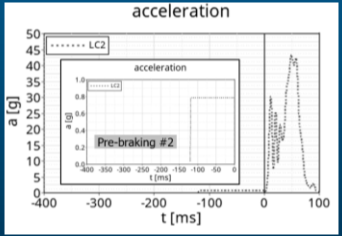
PGS: Pretty Good System
CFL: Characteristic Shoulder Belt Force Level
PGV: Pretty Good Vehicle
TTF: Time To Fire

Specific SBS Thoracic Load w. pre-crash dynamics
Example: Variations of PGS activation

Load Case scenario

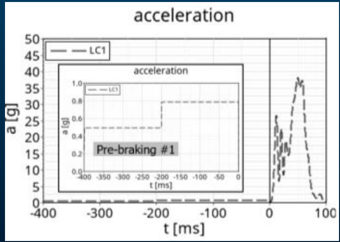


LC0



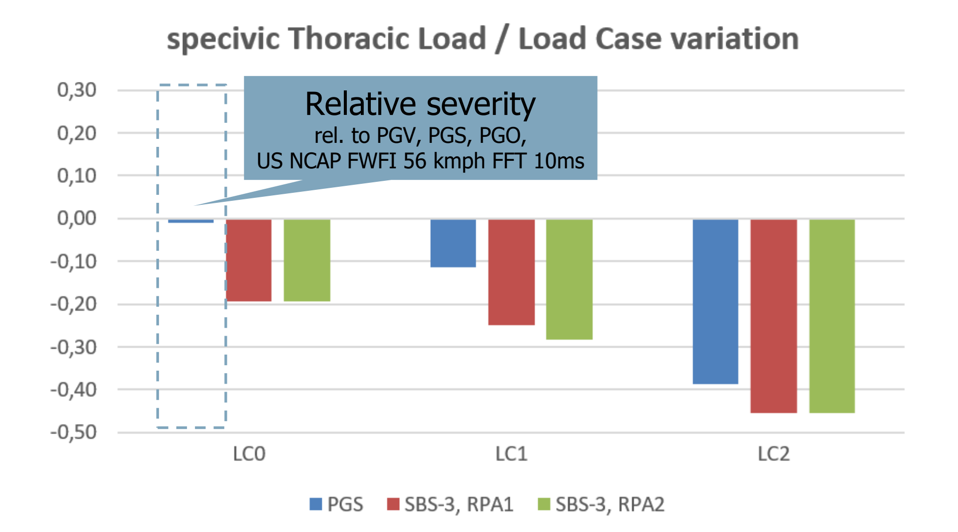
LC1

Scaling factor: 0.94



LC2

Scaling factor: 0.833



SBS activation

- ACR activation reduces CFL by **19% w/o braking.**
- **Pure braking** beneficial by **11%/39%.** (the longer the better)
- ACR activation reduced CFL up to **11%/14% in addition to** the effect of **short braking** and 6% in addition to long braking
- **ACR & Braking amount to 45% CFL** reduction about the effect of maximal vehicle pulse differences in the field.

PGS: Pretty Good System
CFL: Characteristic Shoulder Belt Force Level
SBS: Seat Belt System
ACR: Active Control Retractor