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DEFEATING THE THREAT™

Survivability Evaluation of Blast Mitigation Seats for Armored Vehicles

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OUTLINE

- **Survivability Evaluation Methods for Blast Mitigation Seats**
  - *Field blast-off tests*
  - *Laboratory blast simulation tests (drop-tower and sled)*
- **Seating system analysis**
  - *Analytical modeling*
  - *LS-Dyna FEA analysis*
- **Discussions**

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Platform Survivability ≠ Crew Survivability

- **Existing military vehicles retrofitted with add-on ballistic panels**
- **Objective is to defeat emerging threat**
  - IEDs (underbelly, roadside)
  - EFPs, etc.

Vehicle armor

- **Threat of penetrating vehicle hull has been reduced**
- **Occupant injuries persist**
  - *High-speed impact generates high acceleration on the occupants.*

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Blast Mitigation Seats for Armored Vehicles

Floor Mounted	Wall Mounted	Ceiling Mounted
		

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Injury Criteria and Tolerance Levels

	Injury Criteria	Tolerance Level	Signification	Specification
Thoraco-Lumbar spine	**Dynamic Response Index (DRIz)**	**17.7**	10% risk of AIS 2+	Based on H3 pelvis vertical acceleration
Lower leg	**Peak lower tibia compression force (-Fz)**	**5.4 kN**	10% risk of AIS 2+	Lower leg position straight upward
Neck	**Compression force (-Fz)**	**4 kN @ 0 ms** **1.1 kN @ 30 ms**	Serious (AIS 3) injuries unlikely below tolerance level	Measured at the H3 upper neck
	Peak flexion bending moment (+My)	**190 N-m**	Significant (AIS 2+) injuries unlikely below tolerance level	Measured at the H3 upper neck
	Peak extension bending moment (-My)	**57 N-m**	Significant (AIS 2+) injuries unlikely below tolerance level	Measured at the H3 upper neck
Non-auditory internal organs	**Chest wall velocity predictor (CWVP)**	**3.6 m/s**	No injury	Based on reflection pressure measurement

— AEP-55 Vol. 2 and NATO/RTO HFM-090/TG-25, April 2007

Note: 1) Injury criteria and tolerance levels based on 50th Hybrid III mannequin (occupant) safety
2) Seating can address everything except tibia and chest

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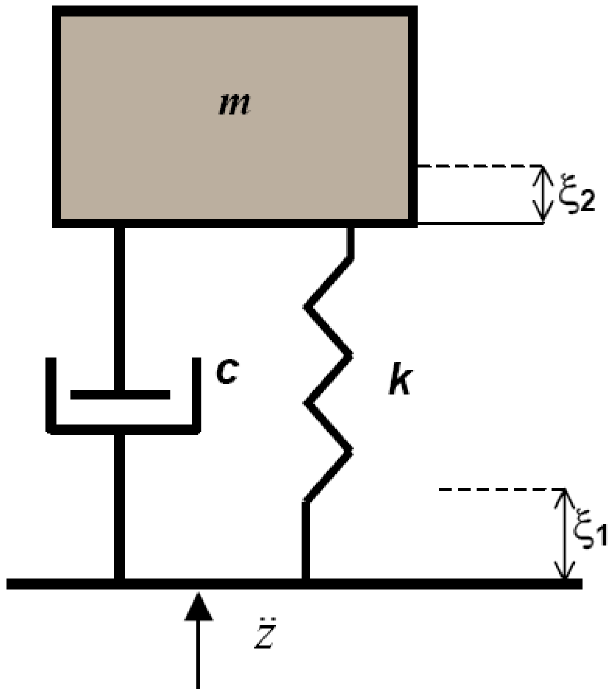
Dynamic Response Index (DRI)

$$\zeta = \frac{c}{2m\omega_n} = 0.224$$

$$\omega_n = \sqrt{\frac{k}{m}} = 52.9\ rad/s$$



$$\delta(t) = \xi_1 - \xi_2$$

$$\ddot{Z}(t) = \ddot{\delta}(t) + 2\zeta\omega_n\dot{\delta}(t) + \omega_n^2\delta(t)$$

$$DRI_z = \frac{\omega_n^2\ \delta_{\max}}{g} < 17.7 \quad or \quad \delta_{\max} < 62\,\mathrm{mm}$$

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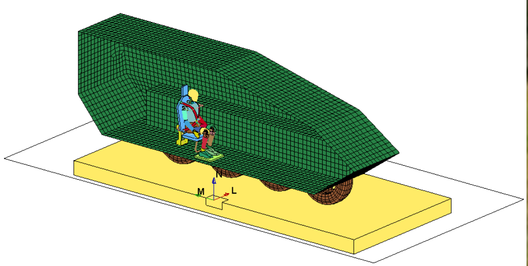
Seat Evaluation — Field Blast-Off Tests



Full-Size Vehicle

Surrogate Vehicle Hull

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Seat Evaluation — Laboratory Impact Tests

Drop-tower

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Various Test Methodologies

	Field Blast Tests		Laboratory Impact Tests	
	Full-size	Surrogate	Drop-Tower	Sled
Objective	Vehicle platform and crew survivability against IEDs of a specific threat level		Seat performance evaluation against a specific acceleration impact pulse	
Closeness to reality	Excellent	Fair	Poor	Poor
Repeatability	Poor	Poor	Good	Good
Seat potential	Poor	Poor	Good	Good
Accel pulse representative	Excellent	Good	(Depending)	Poor
Vehicle Response	Included	Surrogate-dependent	Not included	Not included
Cost	High	Median	Low	Low

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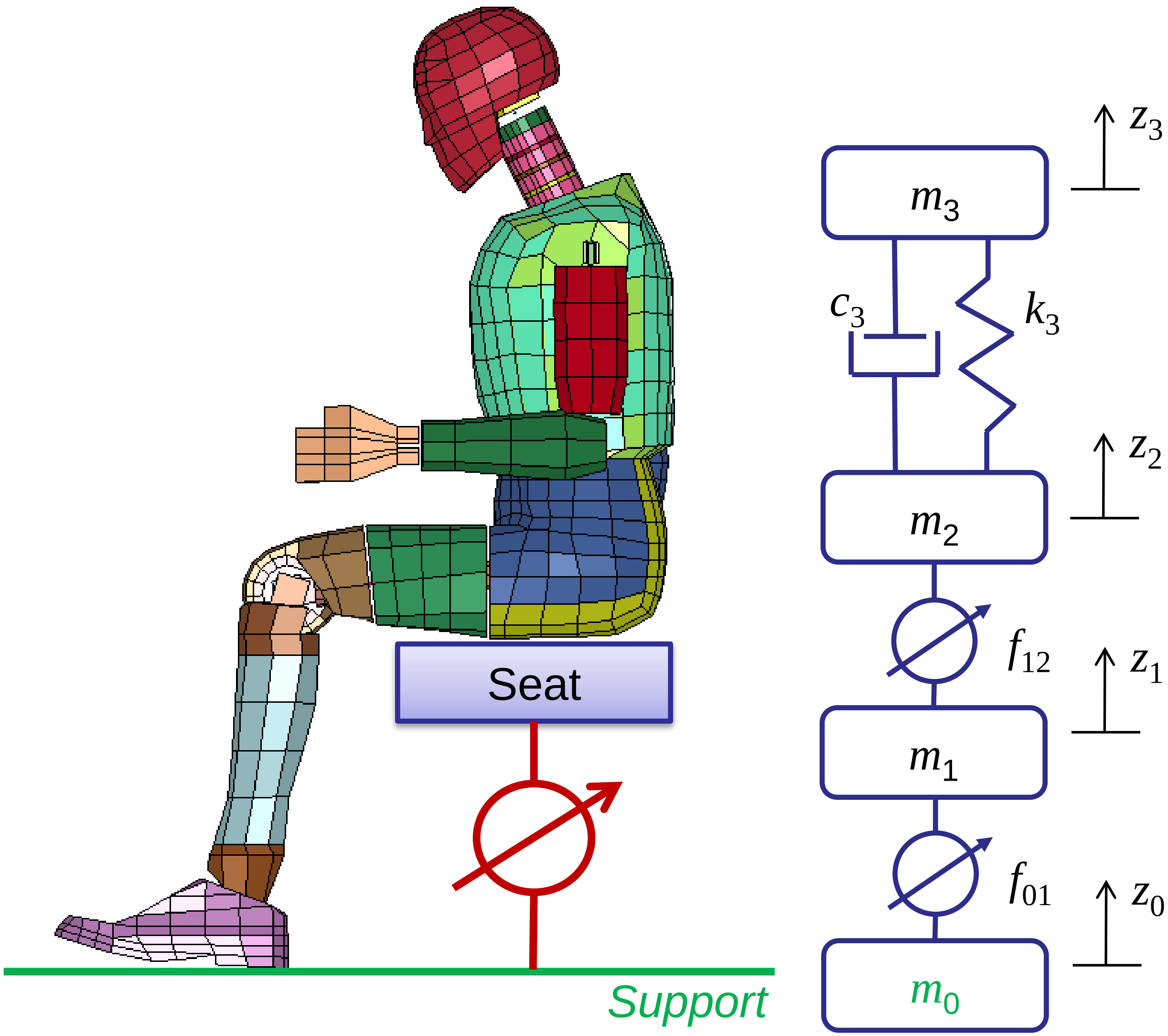
Seating System Modeling



DRI model
(AEP-55 V2, STANAG 4569)

$$\omega_n = \sqrt{\frac{k_3}{m_3}} = 52.9 \text{ rad/s}$$

$$\zeta = \frac{c_3}{2 \cdot m_3 \cdot \omega_n} = 0.224$$

Lower portion
of the mannequin

Cushion contact

Shock Attenuation
Mechanism

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Mass of the Support (m_0)

Test Type	Support	Mass (kg)	Direction of Motion
Field blast-off tests	Full-size vehicle	3,000 ~ 50,000	Vertical (Up)
	Surrogate	500 ~ 2,000	Vertical (Up)
Laboratory simulation tests	Sled	200 ~ 2,000	Horizontal
	Tower carriage	100 ~ 300	Vertical (Down & Up)

The mass of the support has a significant influence on the test results

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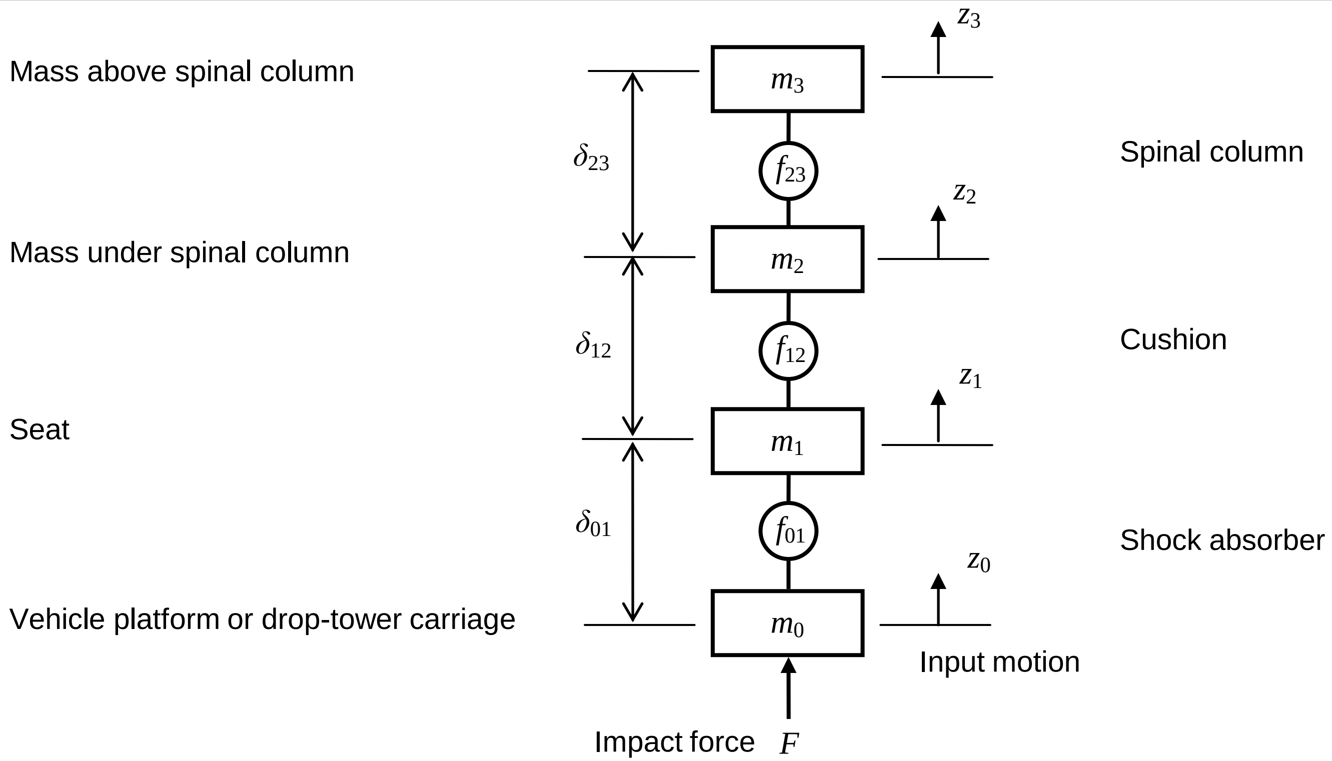
Analytical Modeling of Seating System



Control Forces

$$f_{ij} = f_{ij} \ \delta_j , \quad \dot{\delta}_j$$

Equation of Motion

$$\begin{Bmatrix} \ddot{\delta}_{01} \\ \ddot{\delta}_{12} \\ \ddot{\delta}_{23} \end{Bmatrix} + \begin{bmatrix} m_1 & & \\ & m_2 & \\ & & m_3 \end{bmatrix}^{-1} \begin{Bmatrix} f_{01} - f_{12} \\ f_{12} - f_{23} \\ f_{23} \end{Bmatrix} = -\ddot{z}_0 \begin{Bmatrix} 1 \\ 1 \\ 1 \end{Bmatrix}$$

Note:
Same or close enough initial conditions can be achieved for different test methods.

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Initial Conditions for Different Test Methods

Variables	Blast-Off	Drop-Tower	Sled
F	Explosion	Ground impact	Piston impact
f_{01}	Compressed	Decompressed	Decompressed
f_{12}	Compressed	Decompressed or decoupled	Decompressed or decoupled
f_{23}	Compressed	Decompressed	Decompressed
f_{34}	Compressed	Decompressed	Decompressed
δ_{01}	0	> 0	> 0
δ_{12}	0	> 0	> 0
δ_{23}	0	> 0	> 0
$d\delta_{01}/dt$	0	0	0
$d\delta_{12}/dt$	0	0	0
$d\delta_{23}/dt$	0	0	0

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Can Drop-Tower Test Simulate Blast Test?

- **Drop-tower test can simulate the blast test if**
  - the base acceleration $\ddot{z}_0$ is controlled to be the same
  - the influence of the decompressions is small or compensated

- **However, in practice**
  - base acceleration $\ddot{z}_0$ is only controlled within the impact pulse duration
  - after the pulse duration, it depends on the mass of tower carriage and the characteristics of the shock attenuation mechanism.

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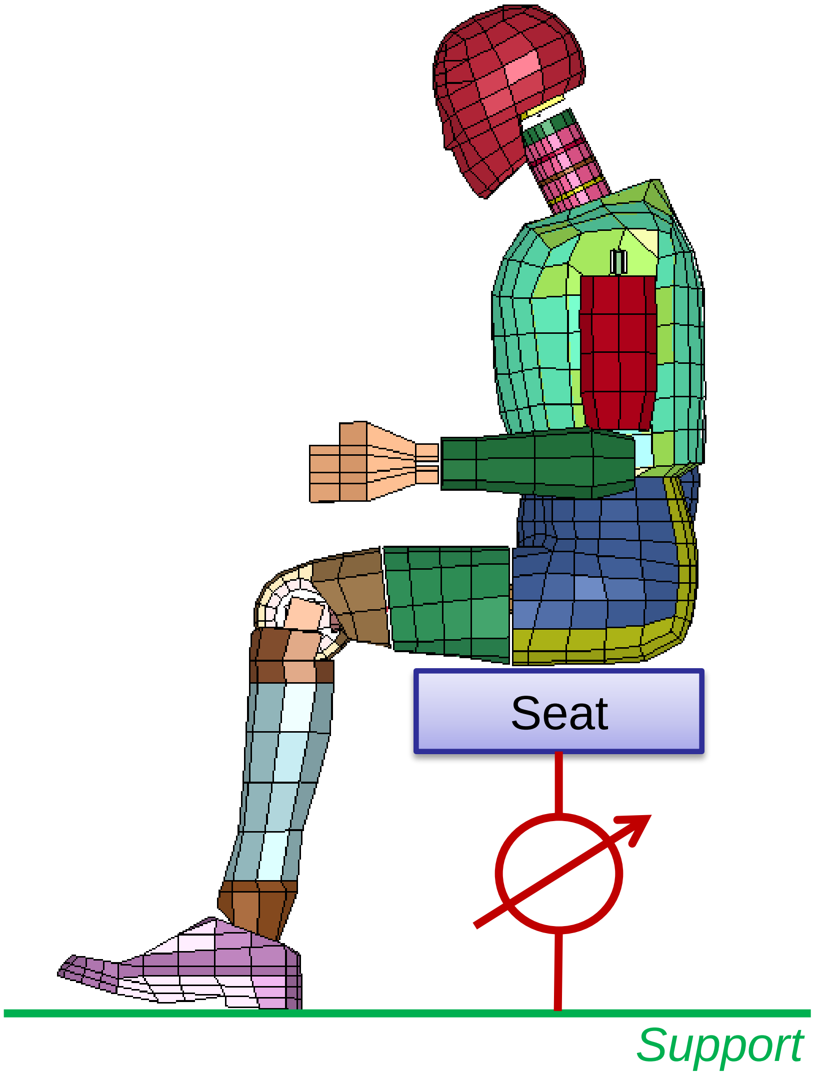
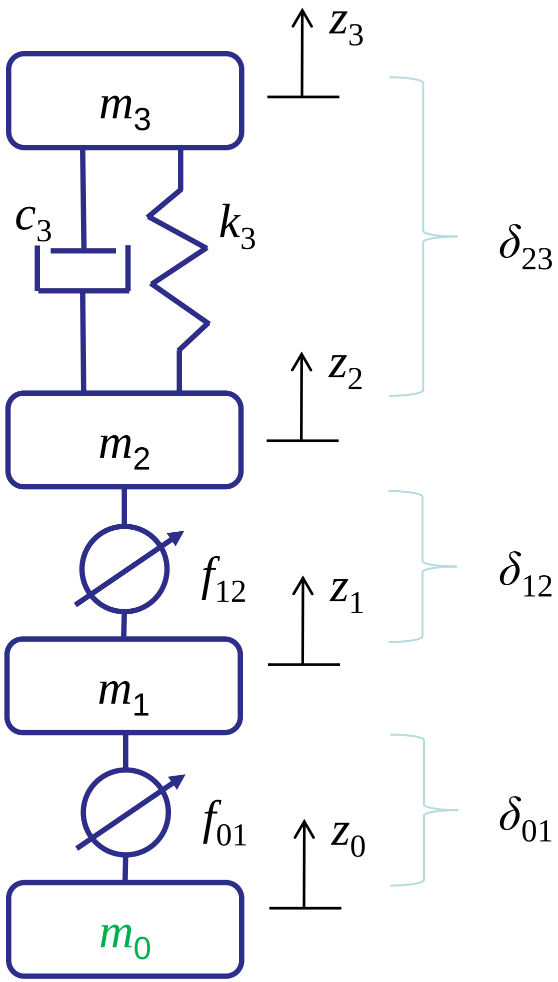
Seating System Modeling





$$\ddot{z}_0(t) = \frac{F}{m_0} + \frac{f_{01}}{m_0}$$

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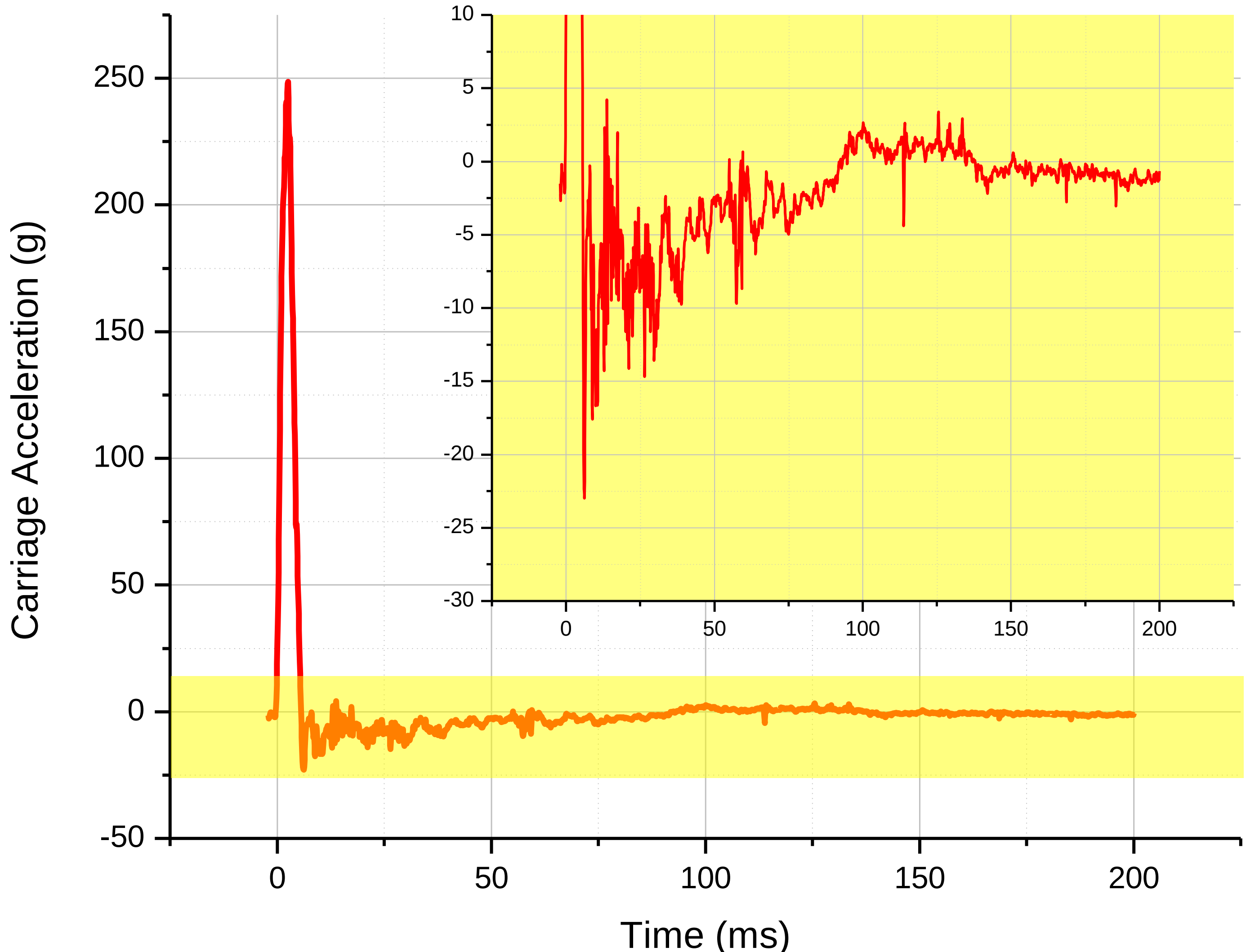
Typical Drop-Tower Carriage Signal



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Pelvis Acceleration From Different Test Methods

$$\ddot{Z}_2^{\text{blast-off}}(\;) = \ddot{\delta}_{01}^{\text{blast-off}}(\;) + \ddot{\delta}_{12}^{\text{blast-off}}(\;) + \frac{F^{\text{blast-off}}}{m_0^{\text{blast-off}}} + \frac{f_{01}^{\text{blast-off}}}{m_0^{\text{blast-off}}}$$

$$\ddot{Z}_2^{\text{drop-tower}}(\;) = \ddot{\delta}_{01}^{\text{drop-tower}}(\;) + \ddot{\delta}_{12}^{\text{drop-tower}}(\;) + \frac{F^{\text{drop-tower}}}{m_0^{\text{drop-tower}}} + \frac{f_{01}^{\text{drop-tower}}}{m_0^{\text{drop-tower}}}$$

<u>In the case of using a drop-tower test to simulate the blast-off test:</u>

$$\ddot{Z}_2^{\text{blast-off}}(\;) \cong \ddot{Z}_2^{\text{drop-tower}}(\;) + \frac{f_{01}^{\text{drop-tower}}}{m_0^{\text{drop-tower}}}\left(1 - \frac{m_0^{\text{drop-tower}}}{m_0^{\text{blast-off}}}\right)$$

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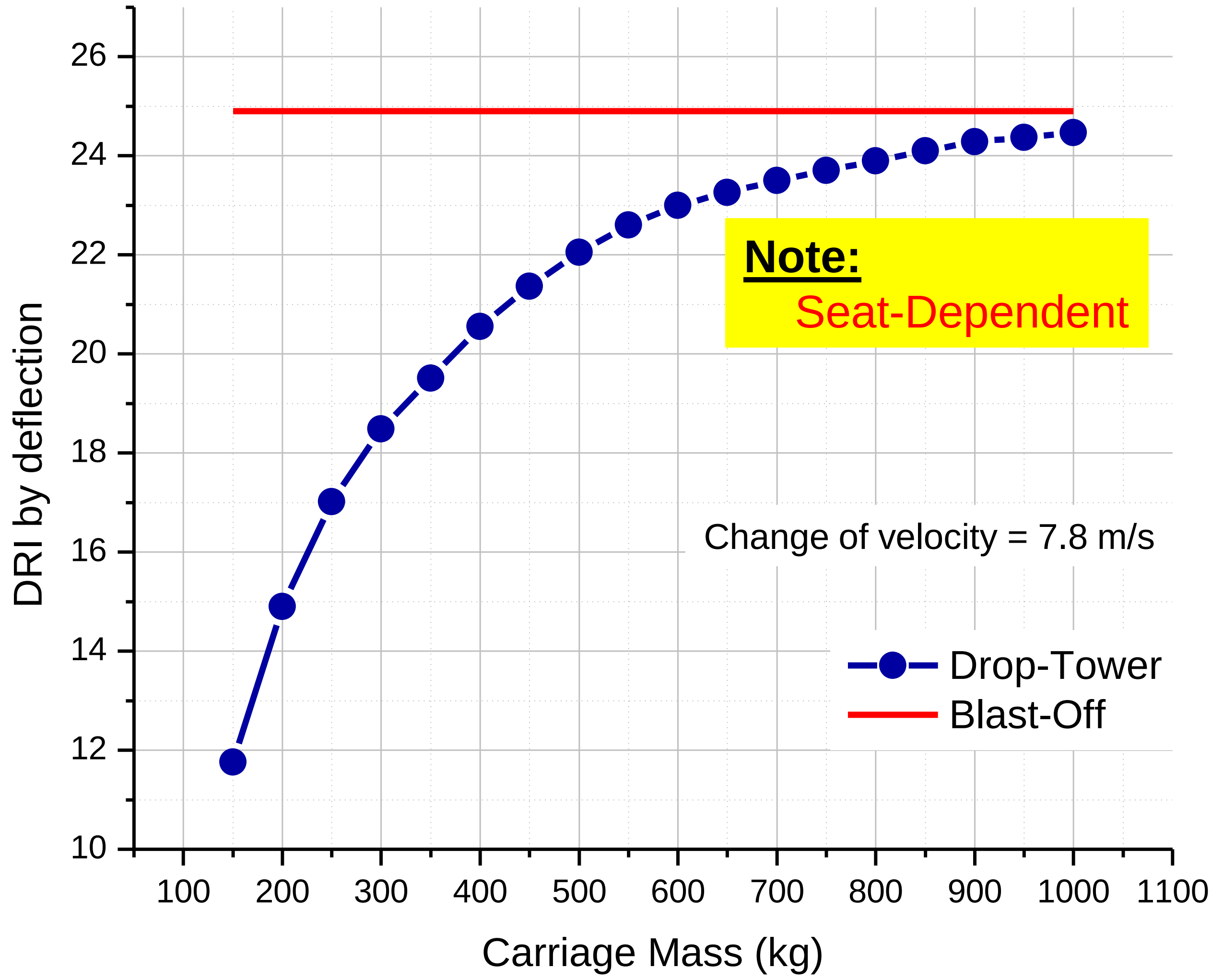
Effects of Carriage Mass on DRI



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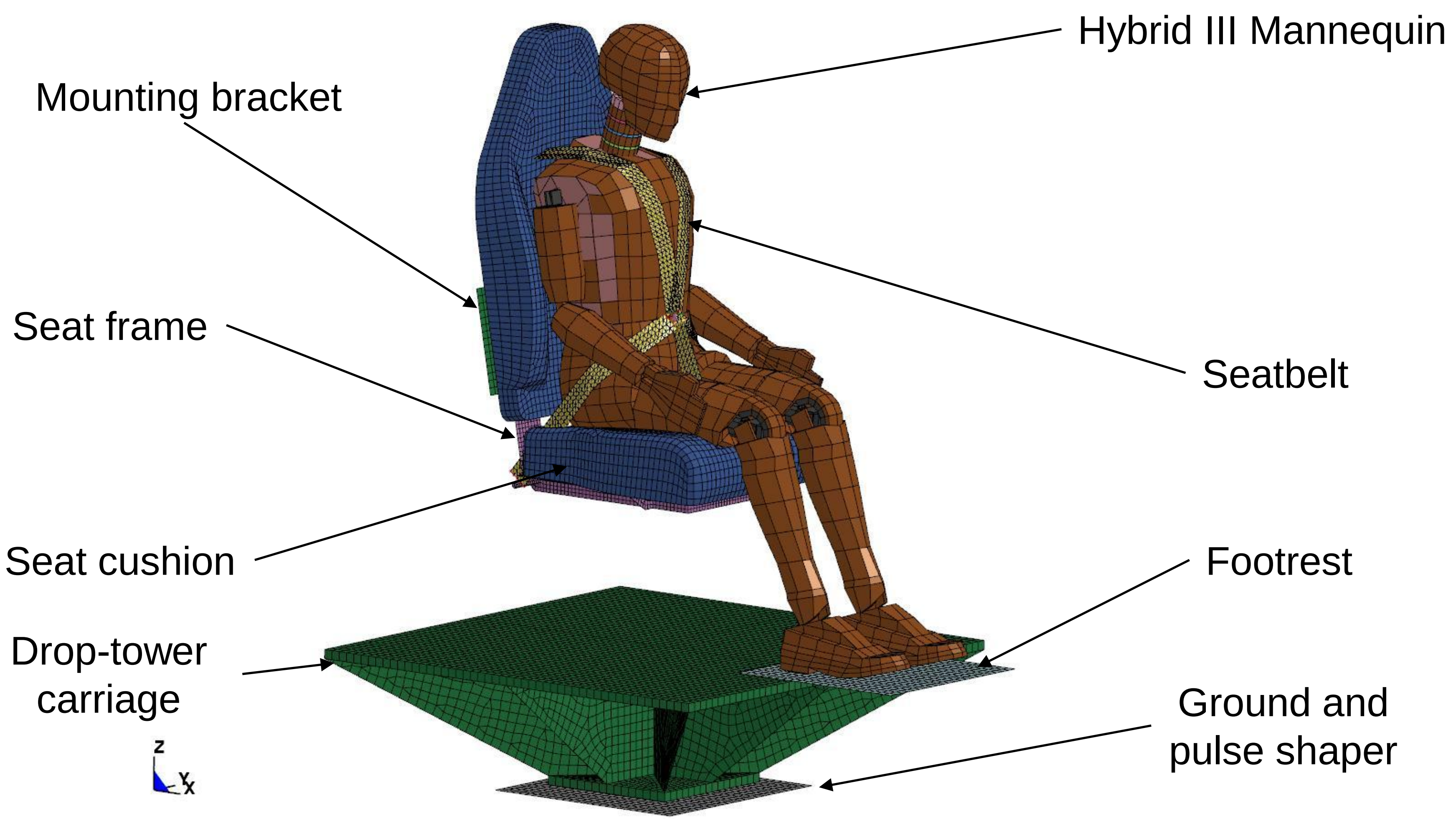
LS-Dyna Model for Simulating Drop-Tower Tests



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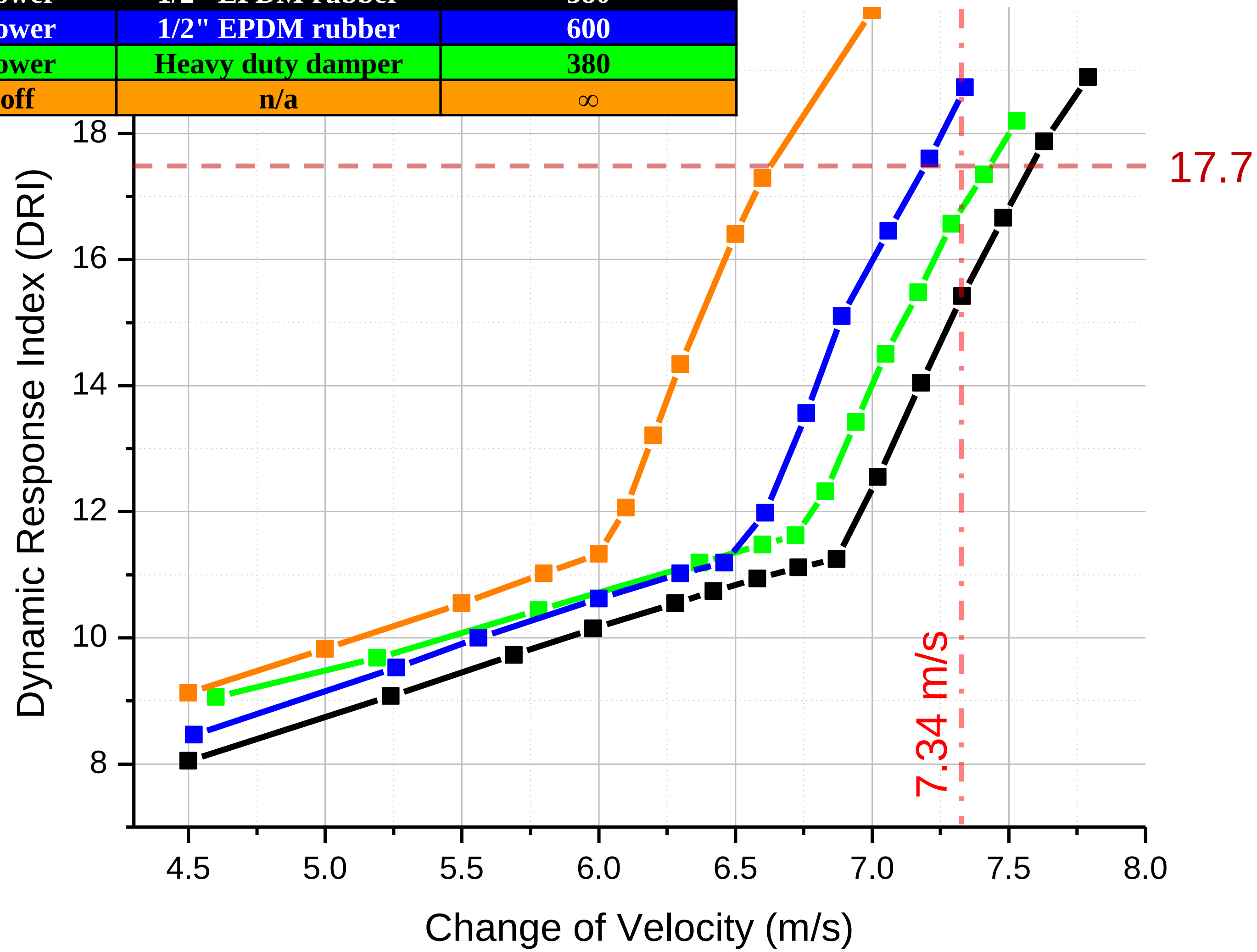
Drop-Tower Tests — Simulation Results

Config.	Impact Type	Pulse Shaper	Carriage Weight (kg)
1	Drop Tower	1/2" EPDM rubber	380
2	Drop Tower	1/2" EPDM rubber	600
3	Drop Tower	Heavy duty damper	380
4	Blast-off	n/a	∞



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Discussion

- **When using drop-tower test to simulate blast-off test, result interpretation must be careful.**
  - **Differences in the mass and motion of the support (vehicle or carriage)**
  - **Differences in initial conditions**
    - ***Initial distances between masses, especially the one between seat pan and buttocks where there is a recoverable cushion***
    - ***Different contact forces, especially between feet and floor***
    - ***Different mannequin postures***

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Discussion

- **When using drop-tower tests for seat performance analysis, a good understanding of the whole system is necessary.**
  - **The motion of the carriage depends not only on the impact force, but also on the force of the shock attenuation mechanism.**

$$\ddot{z}_0(t) = \underbrace{\frac{F}{m_0}}_{0<t<15\text{ ms}} + \underbrace{\frac{f_{01}}{m_0}}_{>50\text{ ms}}$$

  - **It is therefore hard to compare the performance of different seats using drop-tower test results**
  - ***Nevertheless, drop towers remain very useful for the purpose of research and product development***

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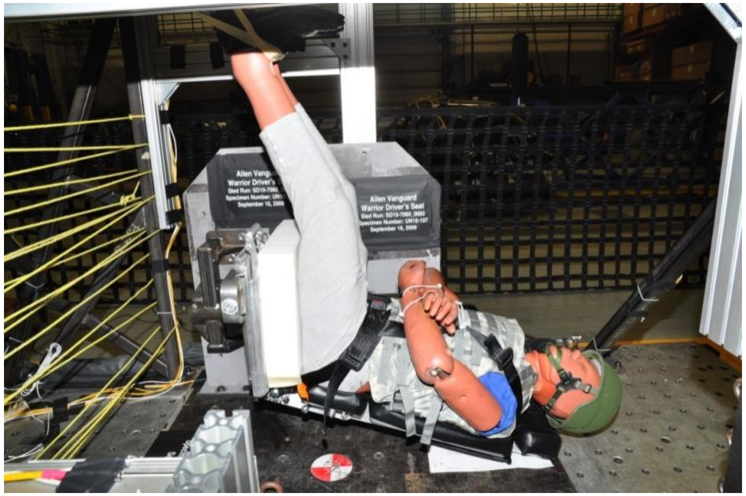
Discussion

- **The analysis presented so far can be extended to the sled test method with the same analysis procedure**



  - *The sled mass is usually much larger than that of the drop-tower carriage, resulting in higher pelvis acceleration and lower seat performance*
  - *Initial conditions are similar to those in drop-tower tests*
  - *Gravity is in transverse direction*

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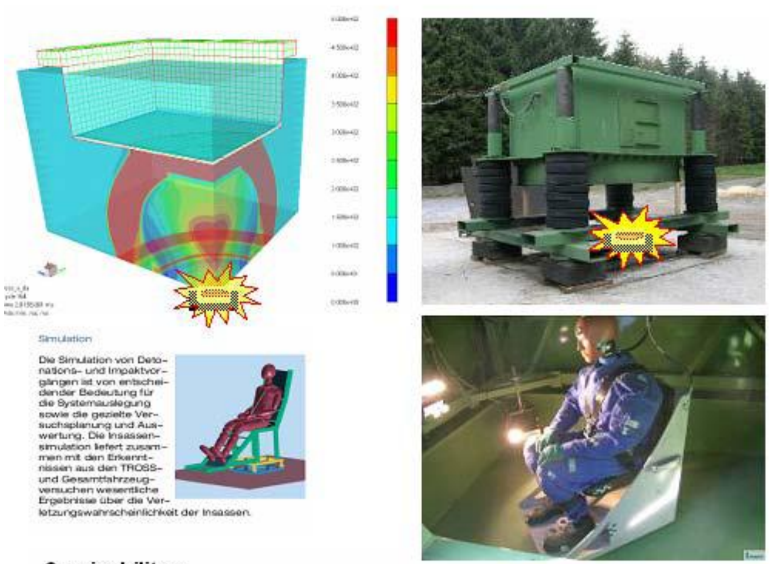
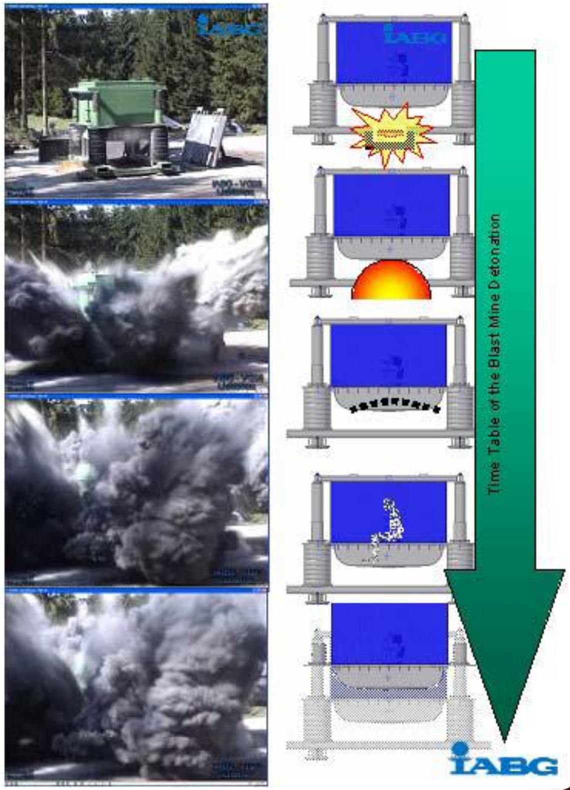
Discussion

- **Even for blast-off tests with a surrogate vehicle hull, the mass of the surrogate is still a problem. However, the deviation of the test results from full-size vehicle blast tests should not be significant,**



Survivability :

The internal dynamics within a protected vehicle are of essential importance in case of a mine detonation. All aspects of occupant protection in crew compartments can be analyzed in detail within TROSS Test rig configurations.



However, … …

- **The above discussion is based on an idealized acceleration pulse for blast impact on the vehicle**
  - *The actual pulse is the response of the vehicle at the seat mounting location*
  - *The actual pulse depends on the structure of the vehicle*
- **The validity of the above discussion needs further study based on actual signals measured on vehicles in full-size blast-off tests**
  - *Unfortunately, these signals are usually treated classified or confidential by most armor vehicle manufacturers, causing further study difficult.*

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