DUMMY Positioning for a Whiplash Load Case Using LS-DYNA Implicit

Andreas Hirth – RD/KSB
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Mercedes-Benz

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DUMMY Positioning Using LS-DYNA Implicit

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1. Why Use LS-DYNA Implicit?

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Motivation

- Normally the positioning of dummies in crash test simulations are described as a prescribed motion to a known position (H-point, torso inclination) in the seat. Adherence to **static equilibrium** between the seat and dummy have always been of subordinate importance. Dummy loading is calculated using LS-DYNA Explicit.
- Whiplash as a load case, measured in a classic vehicle crash, is a low-speed case (16 km/h – 24 km/h) involving almost exclusively elastic deformation.
- Load case analysis is performed using LS-DYNA Explicit.
  The preconditions for **static equilibrium** between the dummy and seat are of crucial importance. Minor adjustments to the position of the dummy in relation to the seat (H-point, distance from head to head restraint) trigger considerable changes to the force and moment characteristics of the dummies.

1. Why Use LS-DYNA Implicit?

Motivation

- In order to carry out a prediction of the dummy's H-point and dummy position based on calculation models it is necessary to adhere to static equilibrium.
- The preconditions required to maintain this equilibrium are provided by implicit solvers.
- At the same time, consistency throughout the crash load case evaluation must be assured by using:
  - the same FE model for positioning and load case evaluation
  - the same pre- and post-processing technology independent of the process
  - resource-saving processes (number of processors and calculating time)
  - the same solver, in order to be able to transfer implicitly initialized pre-tensions to the explicitly subsequent load case calculation directly and without taking a roundabout way

→ LS-DYNA Implicit

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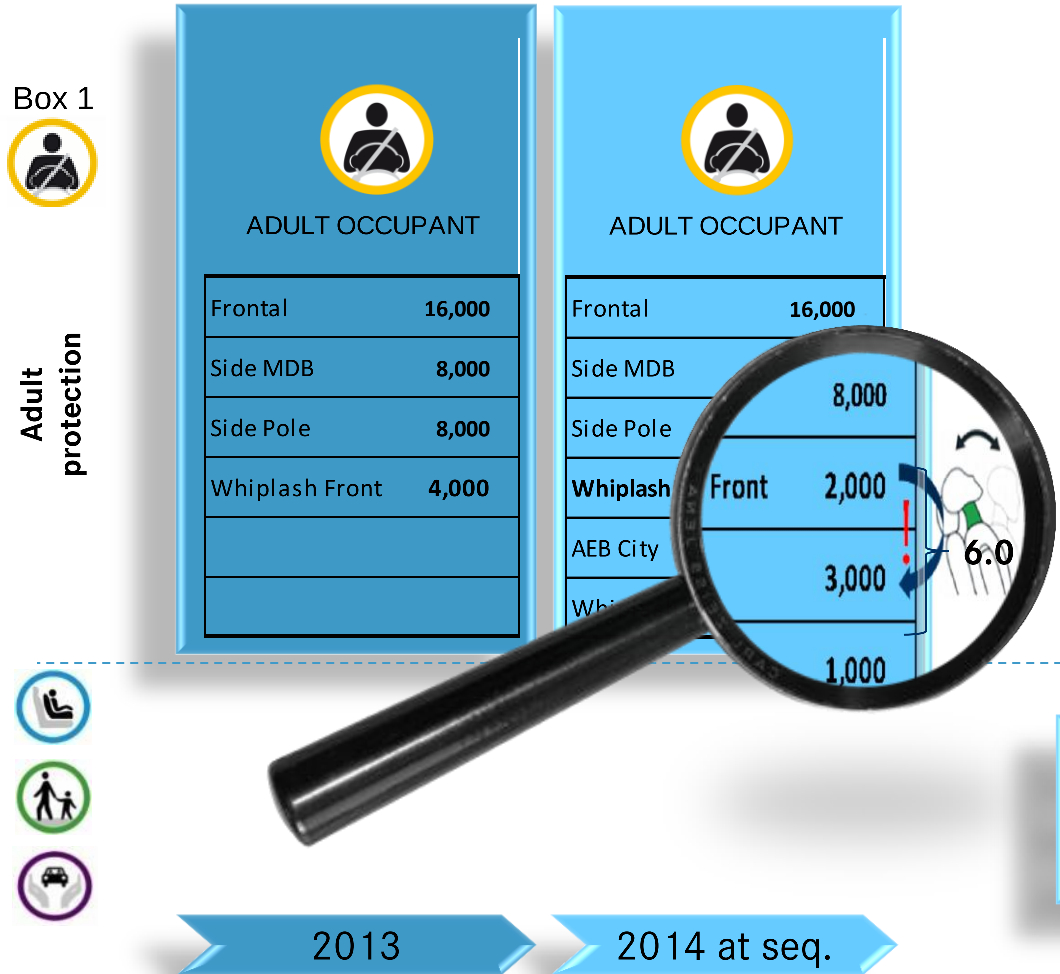
2. Whiplash Load Case – Description

Integral part of vehicle rating
e.g. EuroNCAP - Whiplash front test



Front whiplash - neck color coding

1.500 - 2.000	GOOD
0.750 - 1.499	MARGINAL
0.000 - 0.749	POOR

Static evaluation:

Head restraint height "height"

Head restraint X distance "backset"

Dynamic evaluation:

3 sled tests
with varying pulses

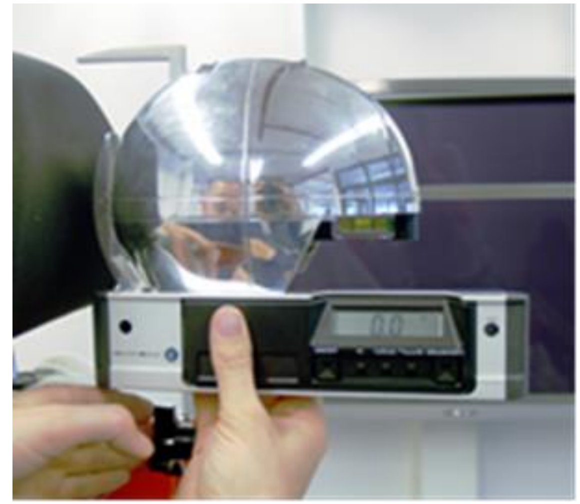
Switch for AEB city:
Whiplash front > 1.5 pt.
AEB city 0/3 pt.

2. Whiplash Load Case – Description

Integral part of vehicle rating
e.g. EuroNCAP - Whiplash front test

- Static evaluation using HPM
  - Head restraint height Z-distance "height"
  - Head restraint X distance "backset"

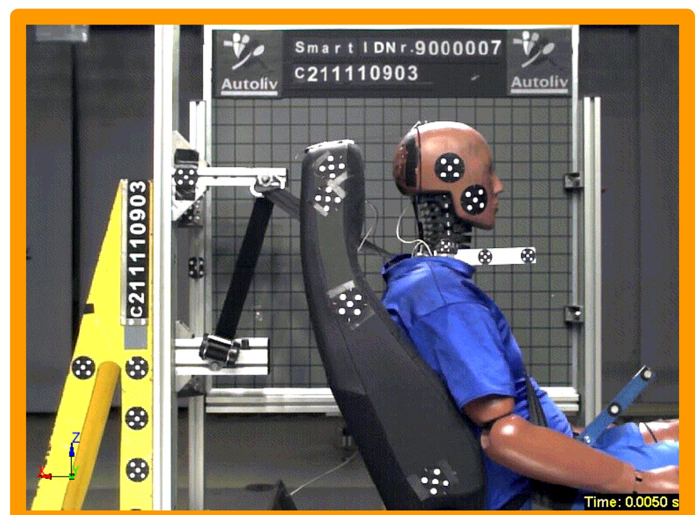
→ LS-DYNA Implicit (positioning)



- Dynamic evaluation using BioRID model

→ LS-DYNA Implicit (positioning)

→ LS-DYNA Explicit (load case evaluation)



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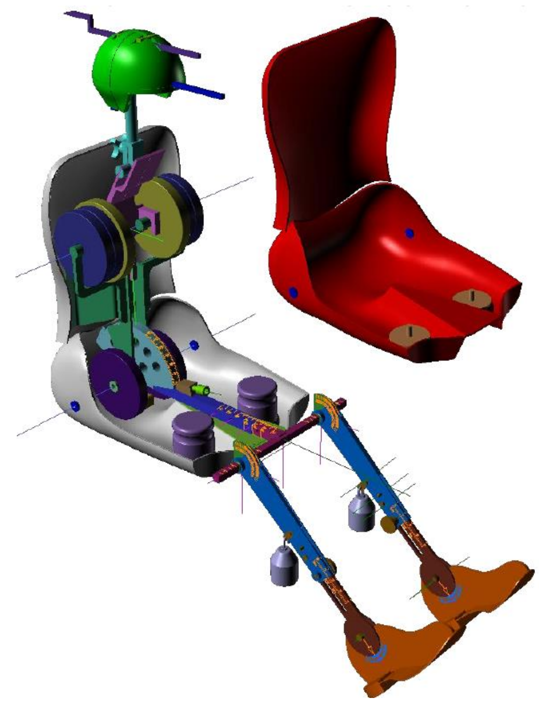
3. Dummy Positioning During the Test

I. Adjusting Seatback Tilt

- The measuring equipment used for setting seatback inclination and for determining the H-point and static quantities *height* and *backset* is the "*H-point manikin*" (**HPM**) fitted with a special head attachment, the "*Head Restraint Measuring Device*" (**HRMD**).

- According to Euro NCAP, the seatback must be set in such a way that the inclination of the torso of the HPM is 25° ±1.0°, as determined through a prescribed process. That process consists of 22 individual steps.



3. Dummy Positioning During the Test

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I. Adjusting Seatback Tilt

- Procedure for positioning the HPM

  (Euro NCAP whiplash test protocol v3.2)

1. The seat shall be covered with a cotton cloth large enough to cover both cushions and seatback.
2. The cloth shall be tucked into the seat joint by an amount sufficient to prevent hammocking of the material.
3. The H-point manikin shall be installed in the seat.
4. The lower legs shall be adjusted to the 50th percentile leg length setting, and the upper legs shall be adjusted to the 10th percentile leg length setting; these are the HPM settings closest to the Euro NCAP front and side impact protocol settings.
5. The legs shall be attached to the HPM and set to the 5th position (no.5) on the knee joint T-bar, which places the knees 250mm apart.
6. With the legs attached and the back pan tilted forward, the HPM shall be positioned in the seat such that its mid-sagittal plane coincides with the longitudinal centreline of the seat. The centreline of the seat may be defined from features such as the head restraint support tubes or seatback and seat pan side bolsters. Particular attention should be paid to seats with asymmetric design.

   .....

   .....

20. The 45 degree plane of the toe board should be moved toward the feet such that the tip of the toe lies between the 230mm and 270mm lines taking care not to disturb the position of the HPM. To facilitate easier setting of BioRID, the toe board should be moved such that the toes of the HPM feet are positioned nearer to the 230mm line.
21. When each foot is in its final position, the heel shall be in contact with the floor, and the sole of the foot shall be in contact with the 45 degree plane of the toe pan between the 230mm and 270mm lines.
22. If the HPM is not level after the feet have been repositioned, a sufficient load shall be applied to the top of the seat pan to level it on the vehicle seat. This may be verified using the bubble gauge fitted to the manikin or alternatively by verifying with CMM that the H-point positions on both sides of the machine are within ± 2.5mm of each other.

3. Dummy Positioning During the Test

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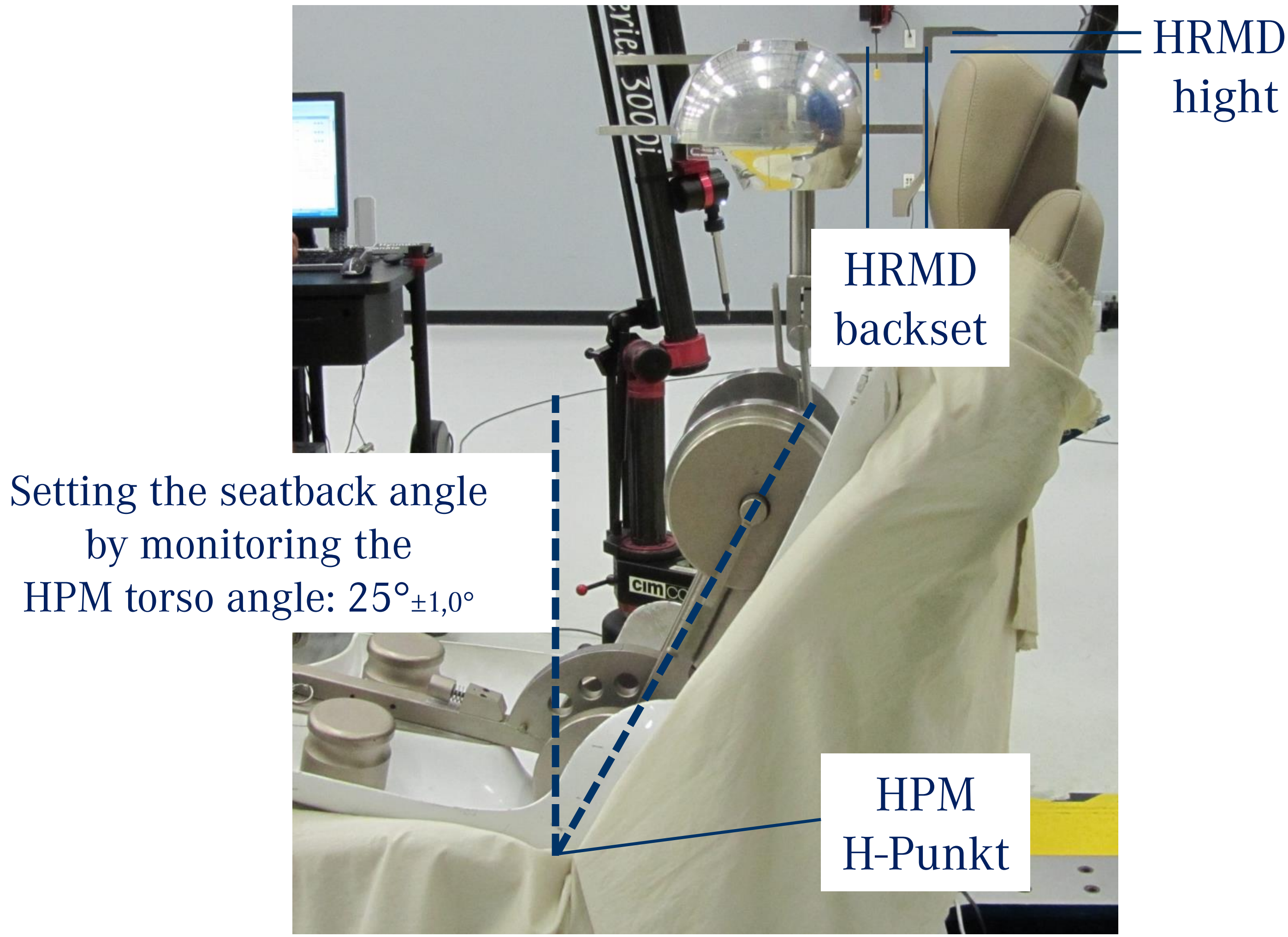
II. Measurement of Static Values on the HPM and HRMD



3. Dummy Positioning During the Test

III. Positioning the BioRID Dummy

- Procedure (15 steps) for positioning the BioRID model

  (EuroNCAP whiplash test protocol v3.2)

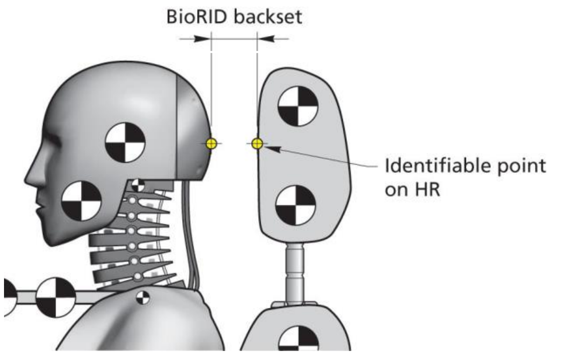
1. The seat should have already been set to give a torso angle of 25º ±1º measured on the H-point machine fitted with HRMD as described before. Allow the seat to recover for 15 minutes with nothing in it before installing the BioRID. Note, BioRID handling should only be undertaken using dedicated lifting tools and associated locations on the dummy following the BioRID manufacturer recommendations. Typically, during the installation of BioRID the H-point will initially be installed further rearward in the seat than is required. Therefore the pelvis should be moved forward to achieve the target set-up positioning.
2. Carefully place the seat belt across the dummy and lock as normal, ensure there is sufficient slack in the belt to allow positioning of BioRID.

   ......
   .....
   .....

14. Place one finger behind the diagonal section of the webbing at the height of the dummy sternum. Pull the webbing away from the chest horizontally forward and allow it to retract in the direction of the D-loop using only the force provided by the retractor mechanism. Repeat this step three times, only.
15. Once the belt is positioned the location of the belt should be marked across the dummy chest to ensure that no further adjustments are made. Mark also the belt at the

Location	Target Measure	Tolerance
H-point (X-axis)	+ 20mm forward*	± 10mm
H-point (Z-axis)	0mm*	± 10mm
Pelvis angle	26.5°	± 2.5°
Head plane angle	0° (level)	± 1°
Backset	15mm forward*	± 5mm

* Reference measurements taken using H-Point machine fitted with HRMD.



(EuroNCAP whiplash test protocol v3.2)

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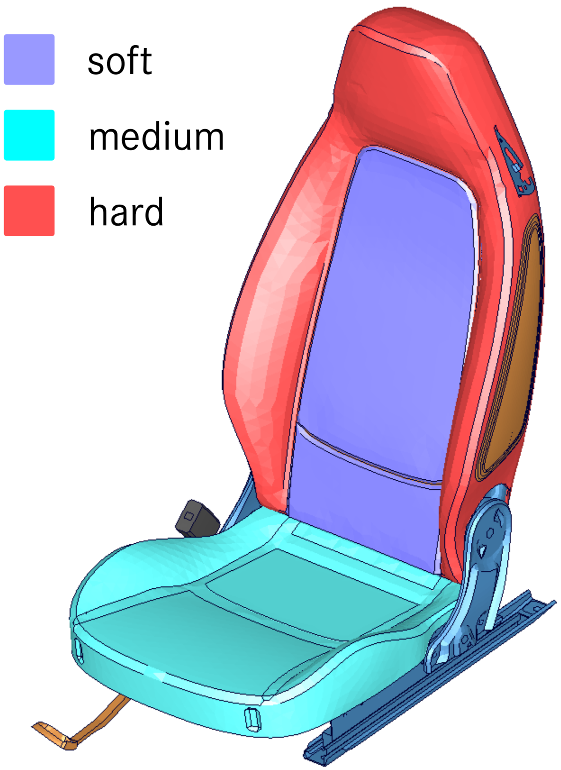
4. Seat Model Used

Series model from crash simulation

- Model used productively in a range of crash load cases for explicit calculations
- "Simple seat" with no comfort features and height adjustment
- Seatback lock
  – pivot angle 1.3°
- Different foam zones (soft/ medium/ hard)

Nodes	Beams	Shells	Solids	Parts	contacts
46600	1500	52000	52000	198	5



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5. Requirements for LS-DYNA Implicit Seat Models

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I. Preparing the Seat

- Basis: Production model of crash simulation for explicit calculations
- Requirements for the seat model for a <u>static</u> implicit calculation:
  - Absolutely no penetration
  - There must be no unsupported degree-of-freedom in the model structure
  - Specific model recommendations that work explicitly but are implicitly a problem, e.g.:
    - Young's modulus of parts which are involved in **CONTACT_TIED…* have to be in a physical reasonable range (e.g. **MAT_NULL* is used)
    - **MAT_123* replaced by **MAT_24* to improve convergence behavior
    - **CONTACT_SPOTWELD* replaced by **CONTACT_SPOTWELD_WITH_TORSION* to avoid drilling degree of freedom
    - Bending stiffness in **MAT_FABRIC*
    - …..

5. Requirements for LS-DYNA Implicit Seat Models

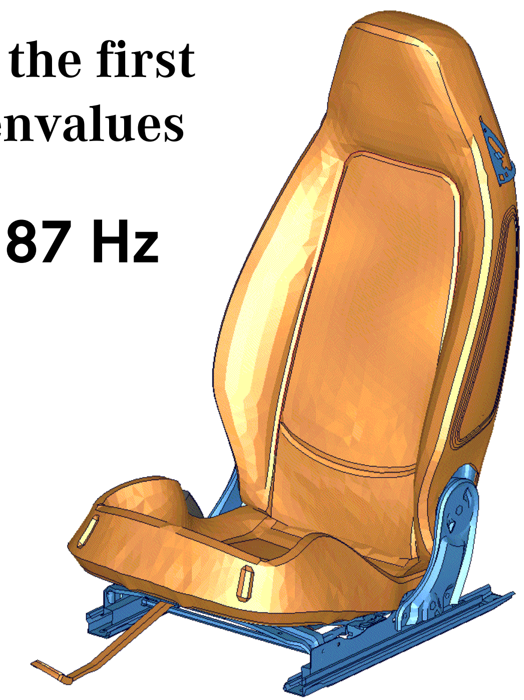
II. Implicit Test Calculations - Eigenvalue Analysis

- Testing stiffness matrix
- Model is considered linearly – e.g. non-linear materials are linearized internally by LS-DYNA
- All eigenvalues must be > 0 to make sense in a physical manner

Visualization of the first meaningful eigenvalues

36 Hz

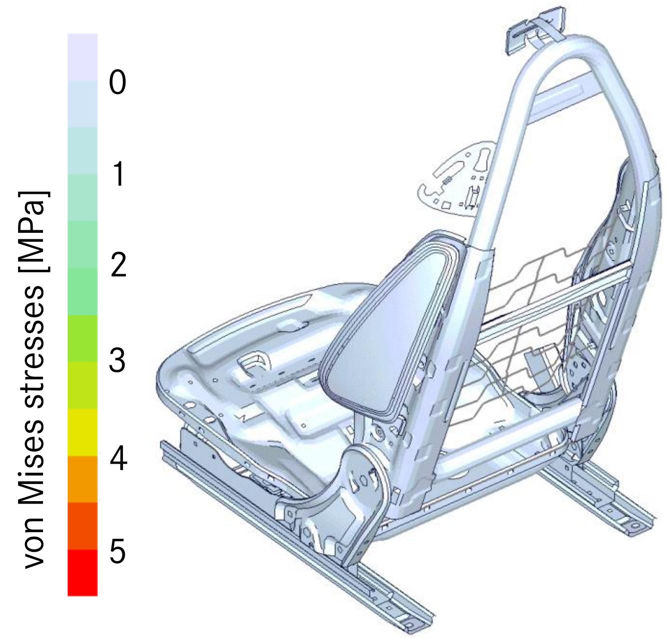
87 Hz



5. Requirements for LS-DYNA Implicit Seat Models

III. Implicit Test Calculations under Gravitational Load

- Consideration of the complete model (i.e. including all non-linear definitions)
- Final quality check of the model
- Targets:
  - `"Normal termination"`
  - Plausible results
  - Calculation within only a few minutes



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6. Requirements for BioRID LS-DYNA Implicit

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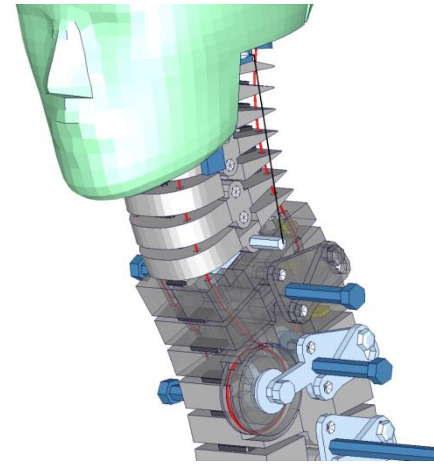
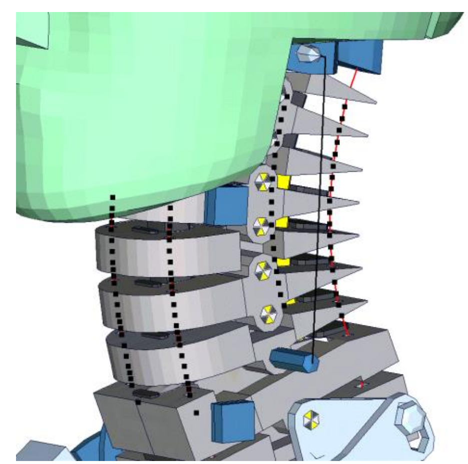
I. Further Development of the LS-DYNA



- Optimizations in foam and rubber material models (**MAT_FU_CHANG_FOAM* and **MAT_SIMPLIFIED_RUBBER*)
  - Convergence behaviour in implicit solutions
  - Consideration of the correct static material behaviour
  - Re-initialization of stresses
  - Unloading behaviour

- The Bowden cable in the BioRID model's spine is modelled with seatbelt elements. As a result of the lack of bending stiffness, they cannot be solved by a static implicit method.
  ➔ **MAT_SEATBELT* extended by bending stiffness (from Release R8.0)



- Bug fixes

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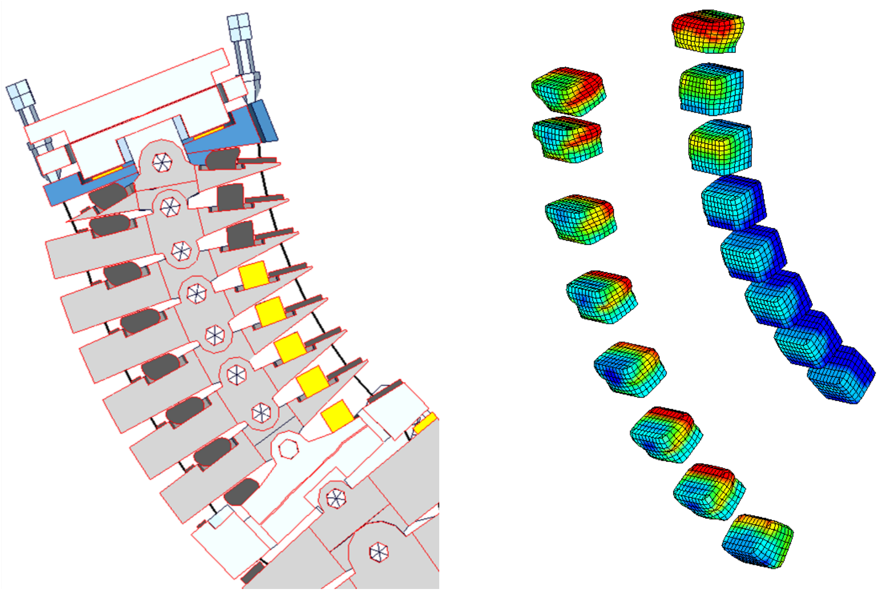
6. Requirements for BioRID LS-DYNA Implicit

II. Preparing the BioRID Model

- The BioRID model contains numerous components made of rubber and foam and has Bowden cables in its spine with pretension definitions. These pretensions, often of a high order of magnitude, cannot be initialized by a static implicit solver. The convergence criteria are not achieved.
- Initializing the pretensions through explicit dynamic relaxation with a subsequent implicit static analysis produced the required results

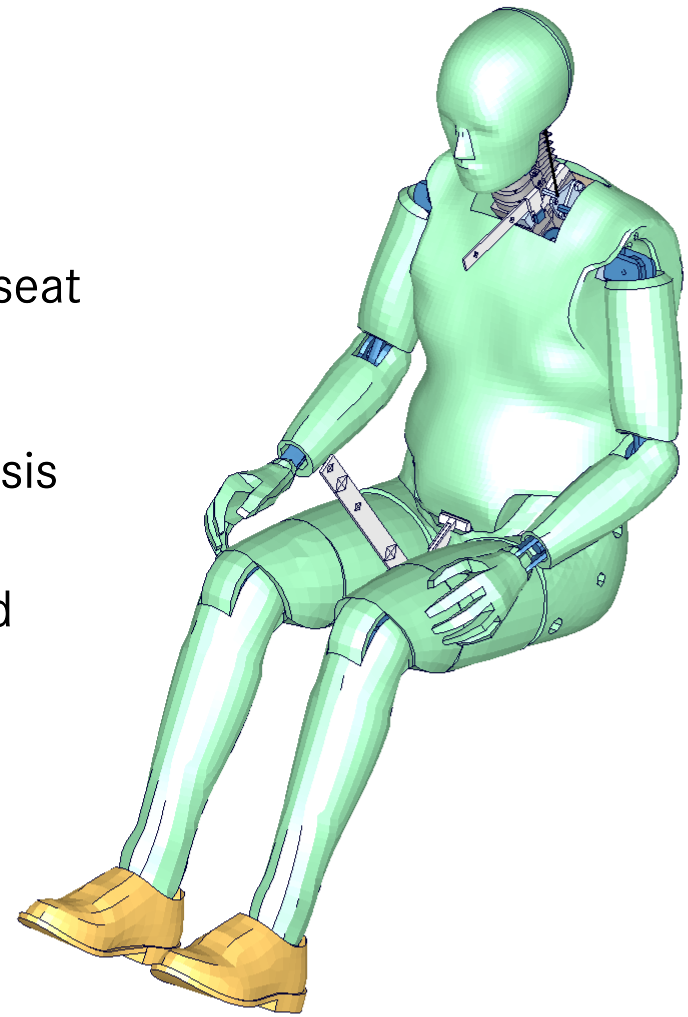


6. Requirements for BioRID LS-DYNA Implicit

III. Checking the BioRID Model

- Extension of the BioRID-2 v3.6 model for use in implicit simulations
  ➔ BioRID-2 v4.0 beta
- The procedure is in essence the same as for the seat model described

By analogy to 5.II.	Eigenvalue analysis
By analogy to 5.III.	Calculation with gravitational load



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7. Processes for Positioning the HPM

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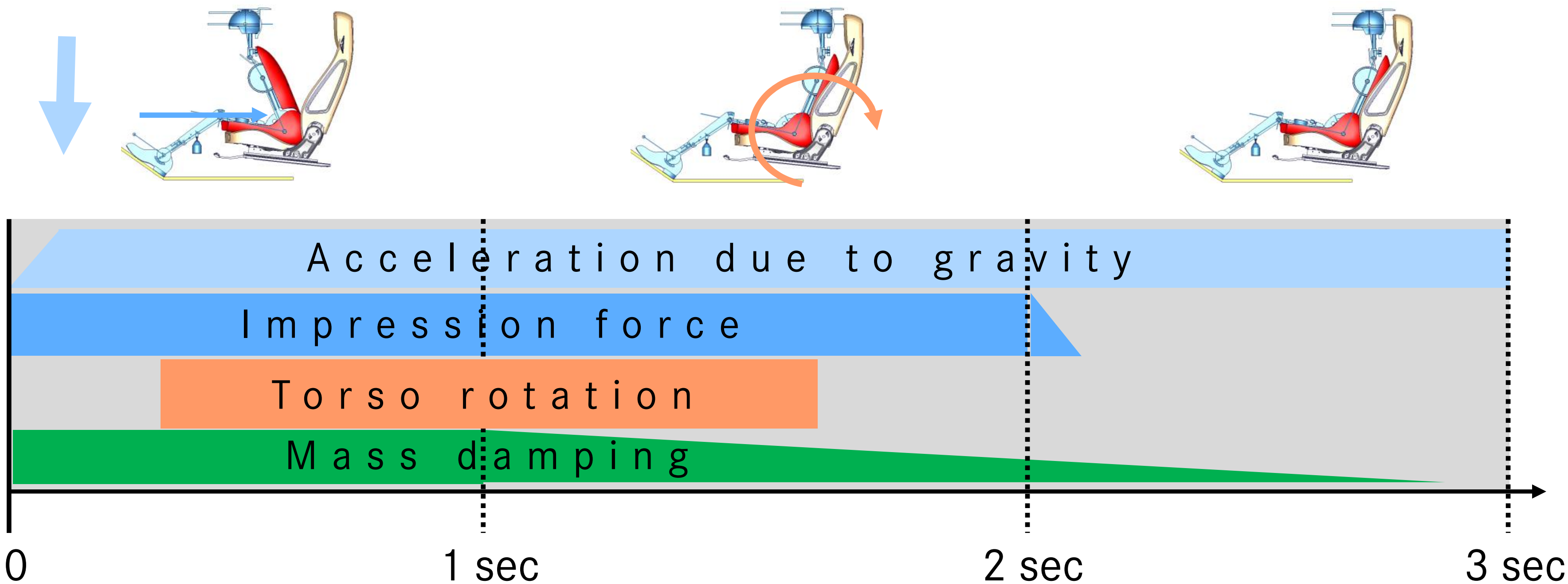
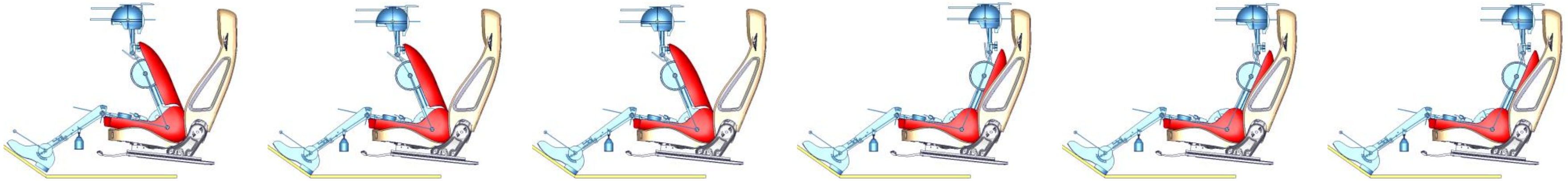
Explicit simulation: Existing process in 3 seconds real time

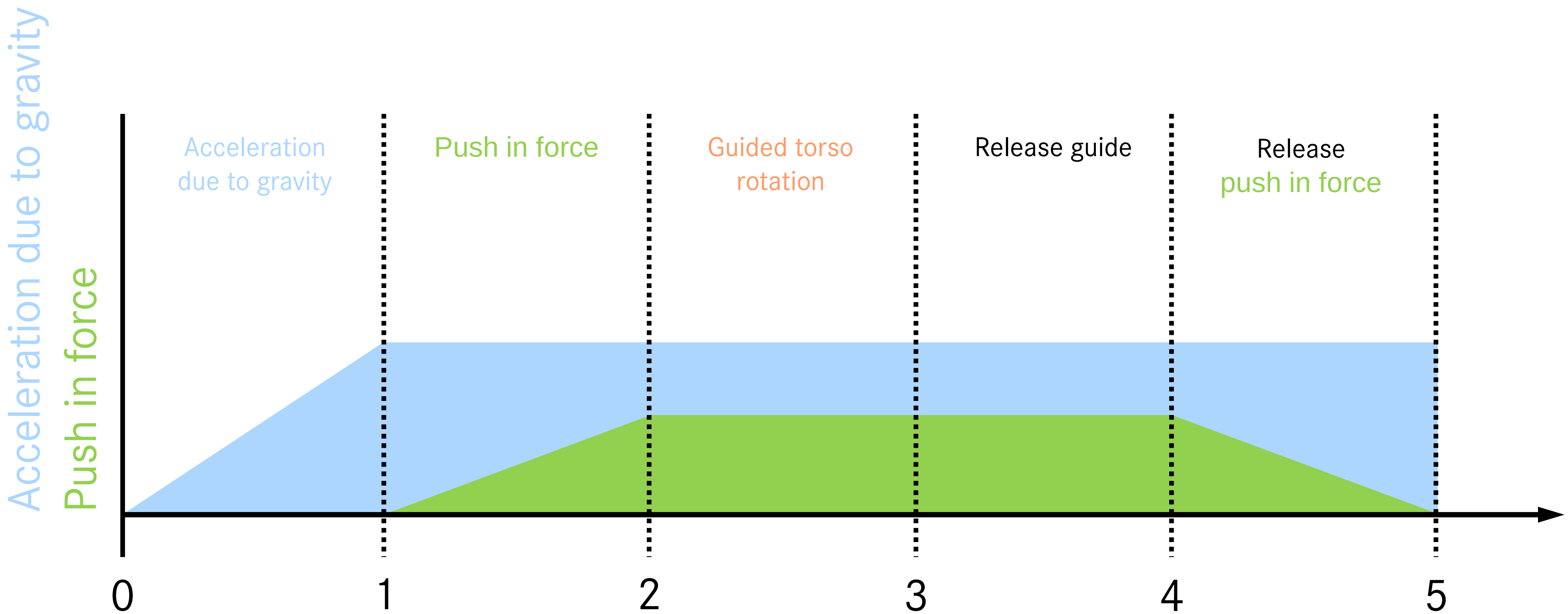
- Iterative positioning (seatback tilt) with relatively long simulation (user has to estimate) and response times
- Use of foam materials without strain rate dependency
- Apply initial damping and allow to fade out



7. Processes for Positioning the HPM

Implicit simulation: Static process in five load steps



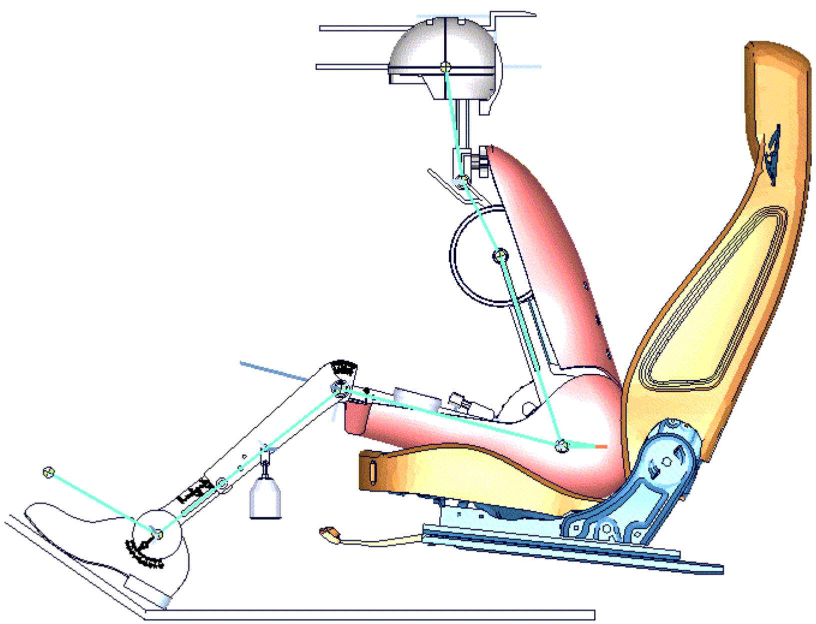


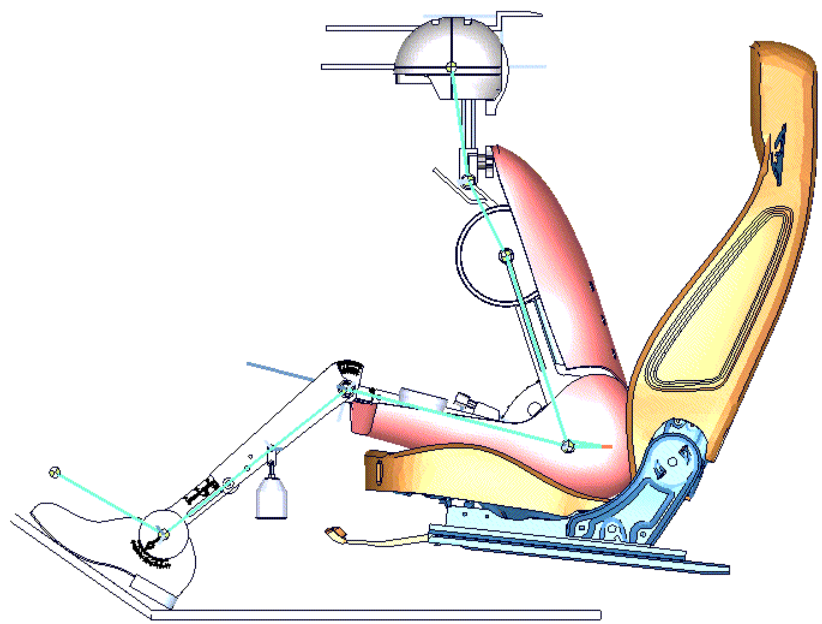
7. Processes for Positioning the HPM

Comparison of HPM positioning

Explicit	Implicit

Identical seat data record for explicit and implicit calculations

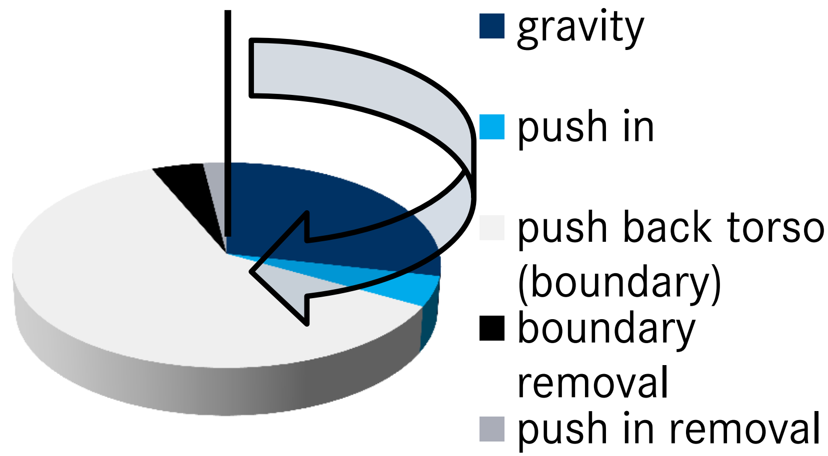




7. Processes for Positioning the HPM

Comparison of computing times and resources

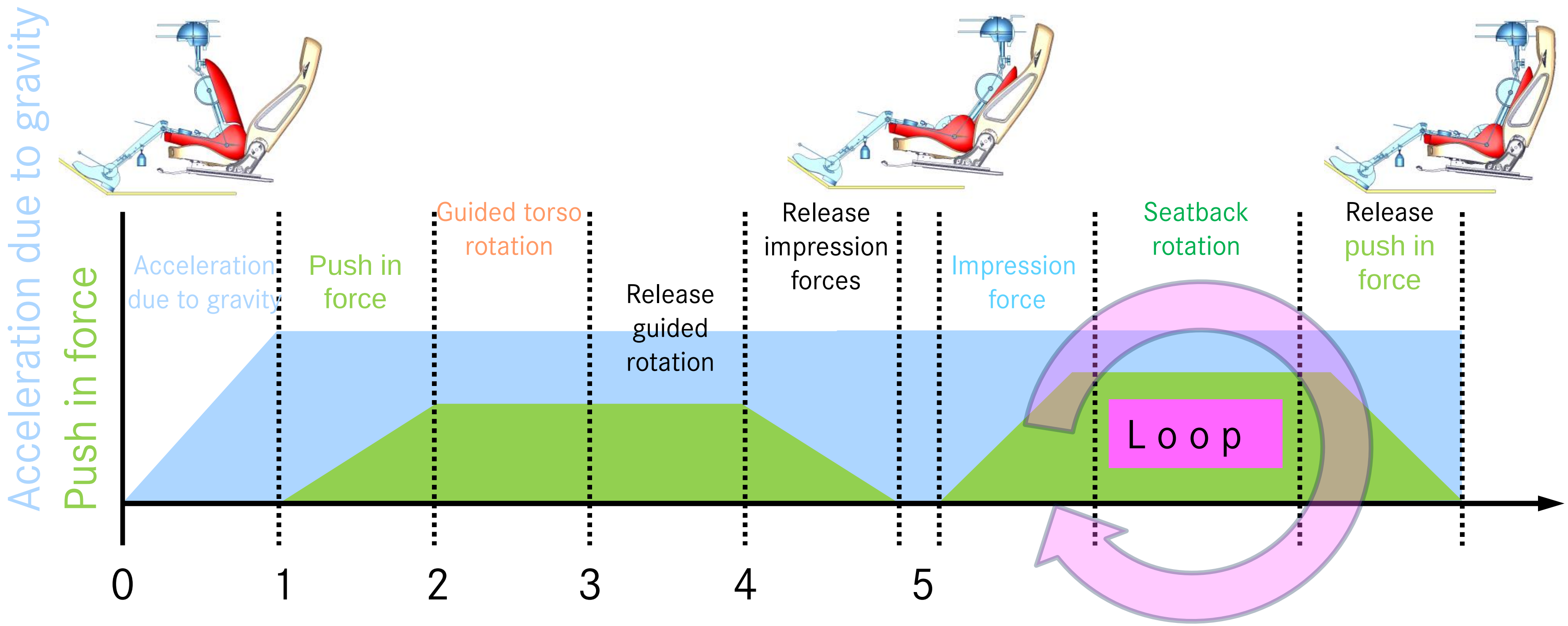
Explicit	Implicit
8 h 56 min	4 h 10 min
using 96 cores	using 8 cores
≈ 3,700,000 cycles (double precision)	88 steps



7. Processes for Positioning the HPM

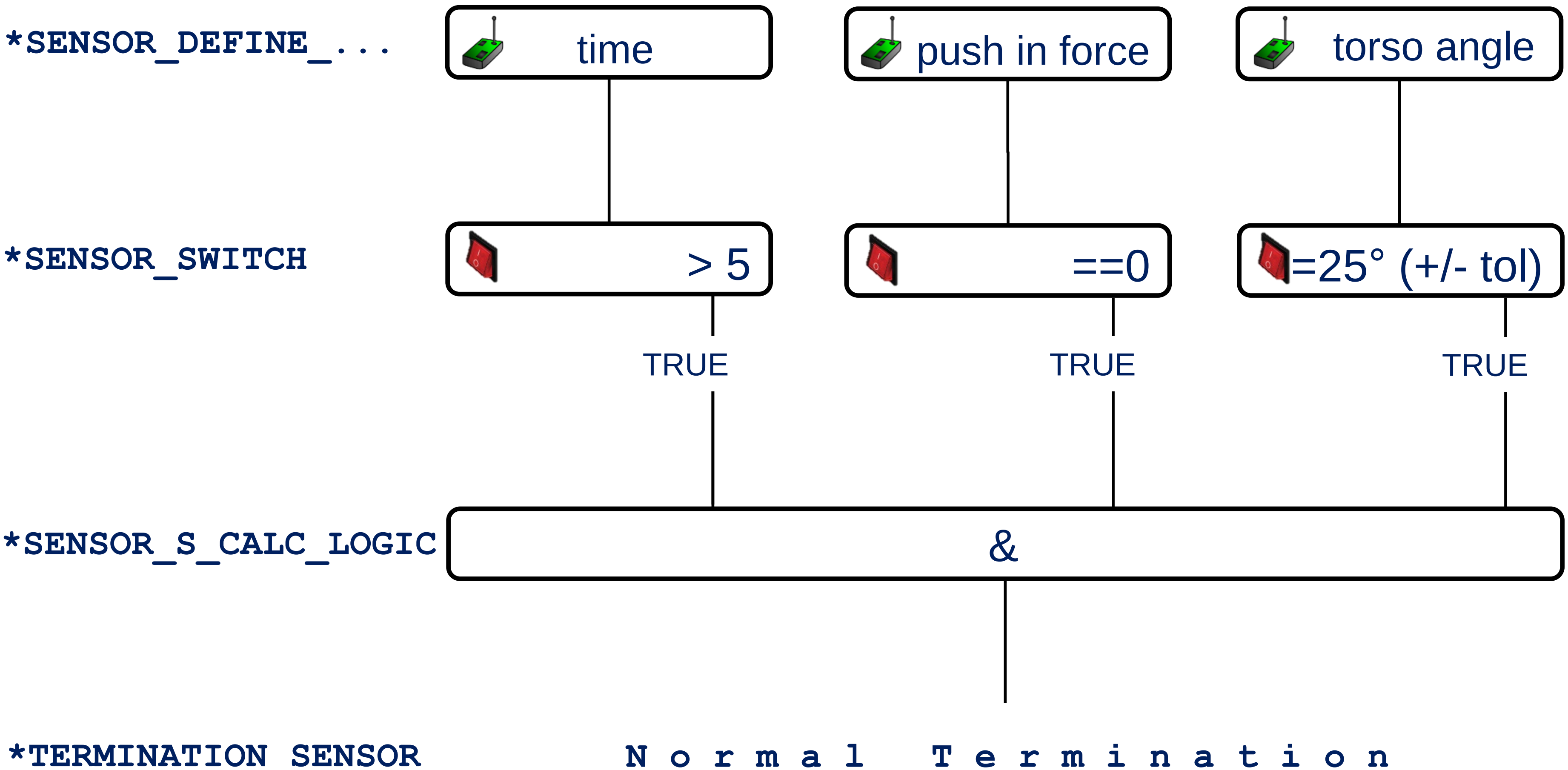
Automatic positioning of seatback tilt in accordance with EURO NCAP definition 25°

- Start: Seatback tilt lower than anticipated final position
- Adjust seatback "gradually" to upright position
- As soon as the target torso angle of 25° has been reached, "normal termination“



7. Processes for Positioning the HPM

Automated seatback positioning



7. Processes for Positioning the HPM

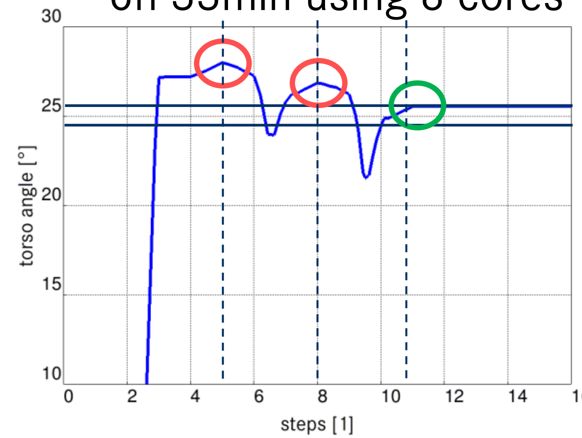
Automatic positioning of seatback tilt

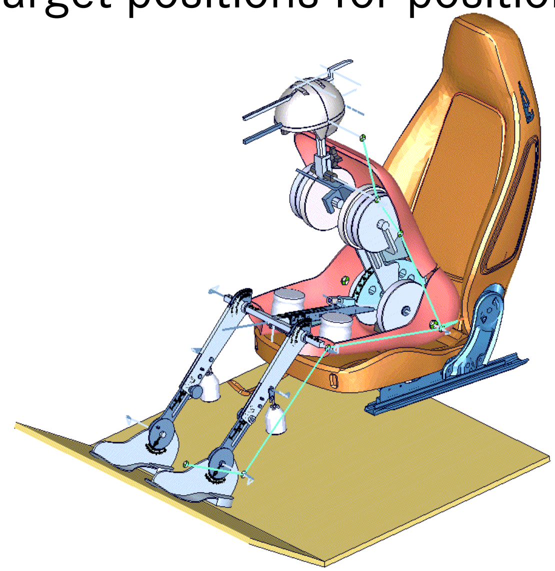
- Correction of seatback tilt by 2 notches to front during the automatic positioning

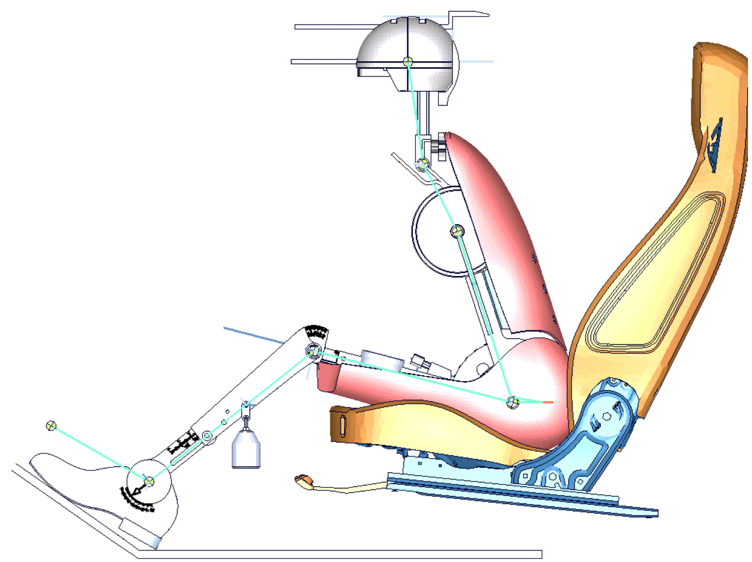
➢ The final seatback tilt used as start geometry for positioning the BIORID

➢ HPM reference points (H-point, backset) are the target positions for positioning the BioRID

6h 33min using 8 cores







7. Processes for Positioning the HPM

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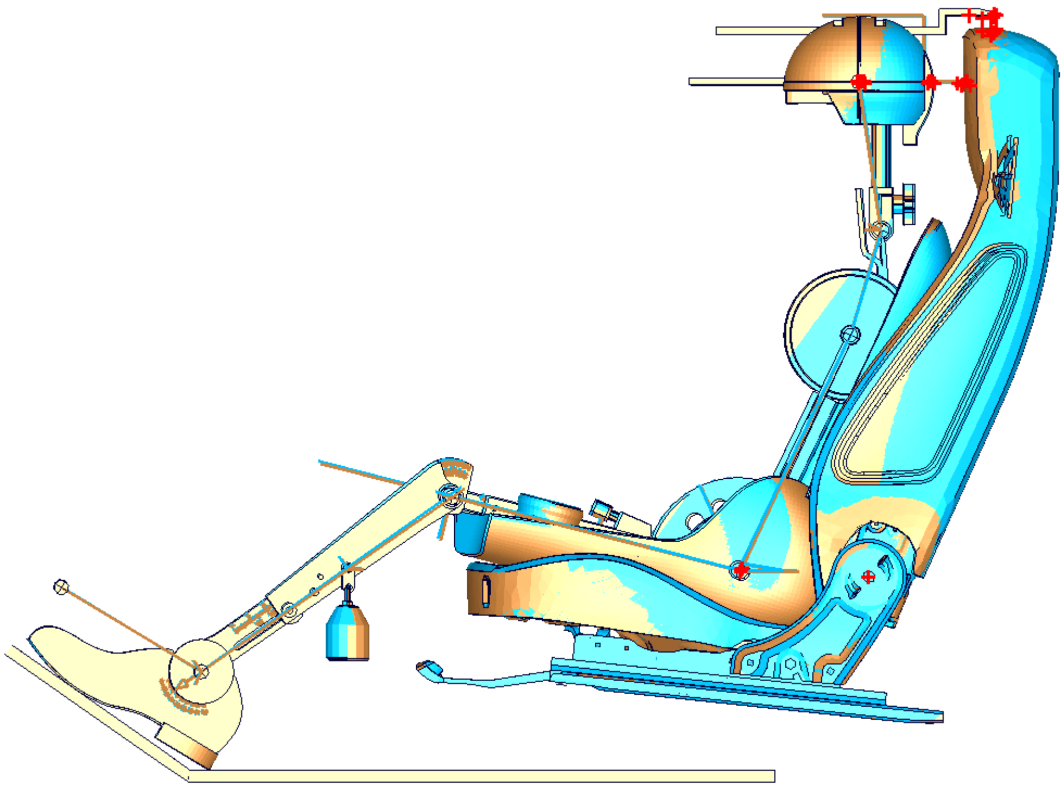
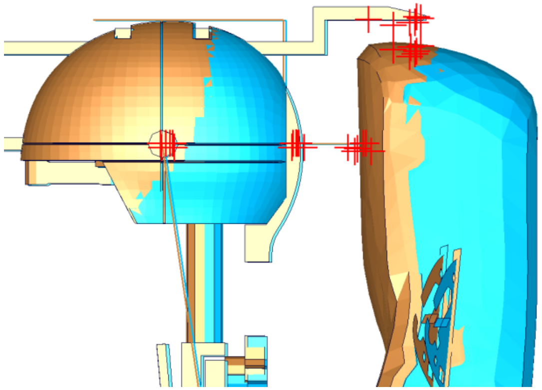
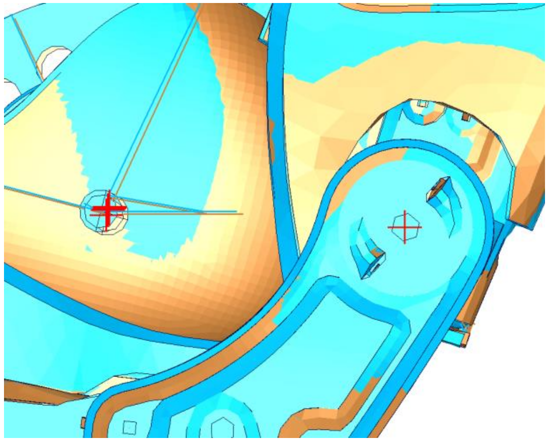
Comparison of final HPM positioning:

Explicit	vs.	Implicit	vs.	Target value







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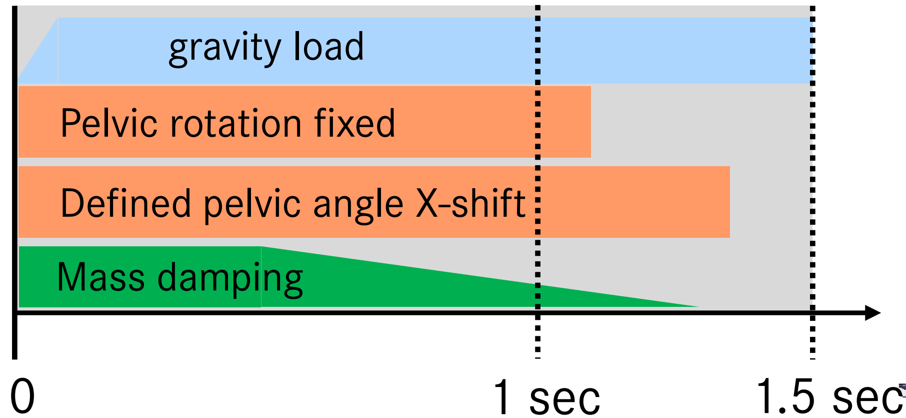
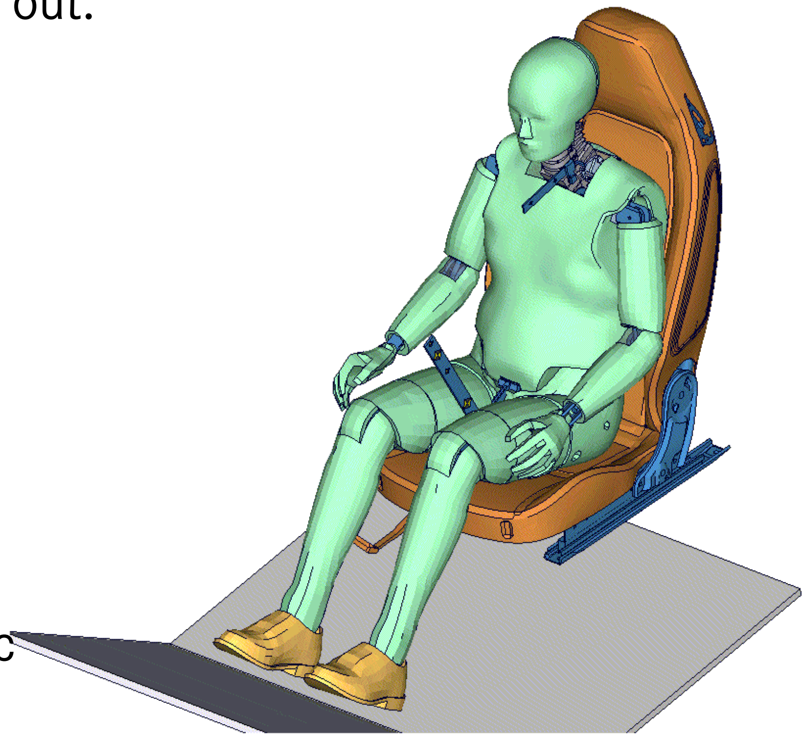
8. Simulation Process for Positioning the BioRID Model

Explicit simulation: Existing process in 1.5 seconds real time

- Use of foam materials without strain rate dependency
- Definition of boundary conditions for positioning (pelvic angle, H-point position, etc.) and releasing the boundaries
- Apply initial damping and allow to fade out.





8. Simulation Process for Positioning the BioRID Model

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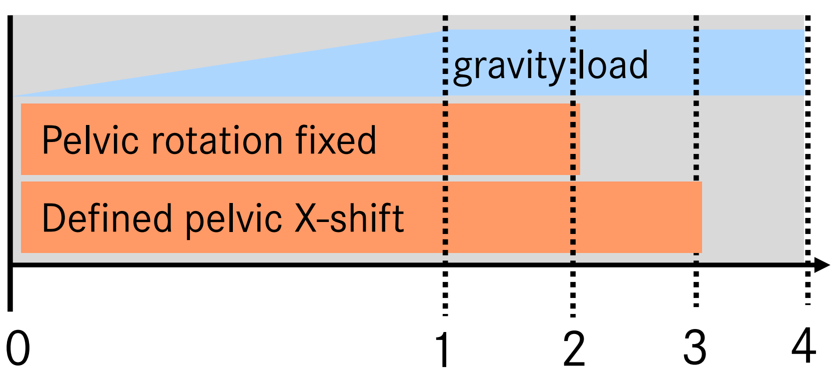
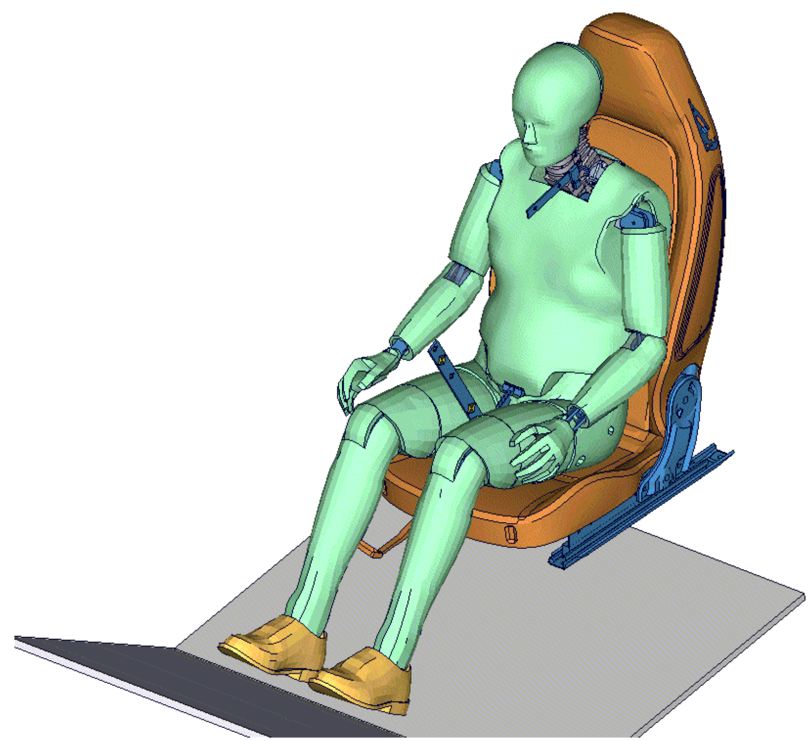
Implicit simulation: Static process in four load steps

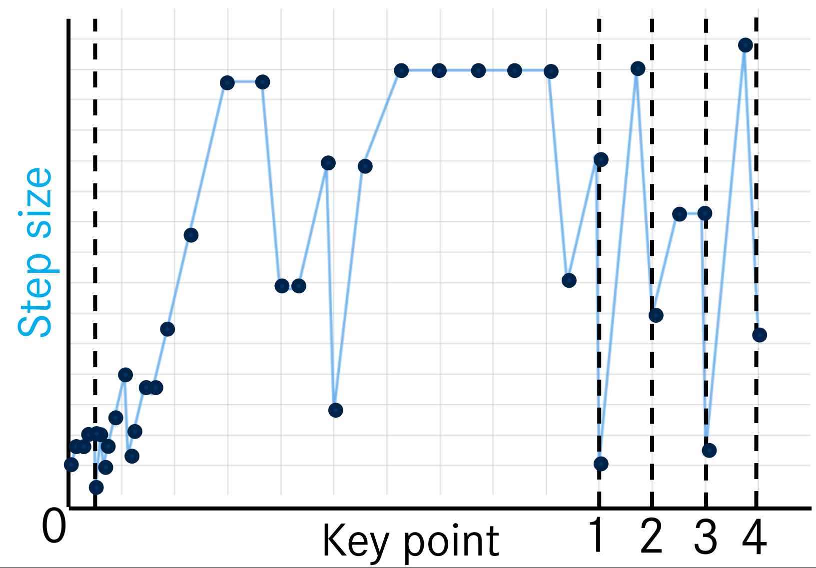
- Guided motion of the dummy's pelvis until it makes contact with the seat
- Apply gravitational load
- Then gradually release prescribed parameters





Comparison of computing times and resources

Explicit	Implicit
22 h 42 min	5 h 9 min
using 96 cores	using 8 cores
≈ 1,670,000 cycles (double precision)	41 steps



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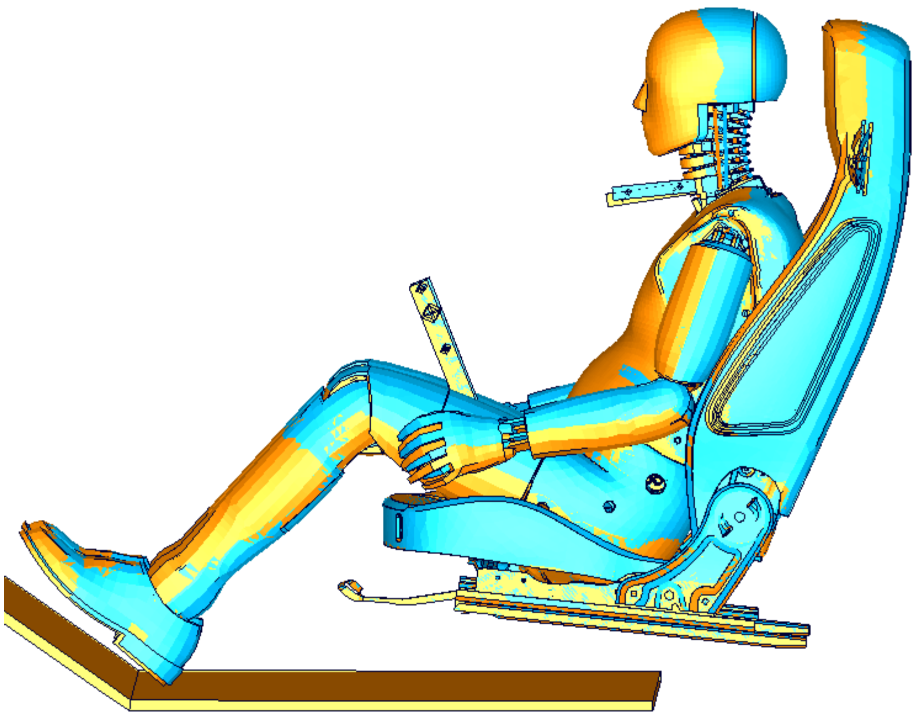
Comparison with BioRID final position

Target value vs. Explicit vs. Implicit



	Target value Take over from chapter 7: HPM positioning	Explicit	Implicit
H-Point x [mm]	1070 ± 10	1070	1071
H-Point z [mm]	391 ± 10	393	395
Pelvis angle [°]	26.5 ± 2.5	27.1	27.3
OC angle [°]	0 ± 1	1.6	0.3
Backset [mm]	66 ± 5	72	69

Deviation from target value – i.e. explicit application calculation has to be repeated.

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9. Summary and Outlook

Implicit simulation – status quo

- Considerable developments achieved in the last four years in the field of implicit capabilities available in LS-DYNA
- Implicit calculation is not a simple issue. It requires extensive experience in achieving convergent solutions.
- In terms of H-point predictions (HPM), use of LS-DYNA Implicit is a productive approach:
  - H-point predictions are statically possible
  - A meaningful basis for applying further explicit calculations
- Static seat comfort applications (resulting in seat pressure distribution) using the H-point manikin are robustly possible.
- The objective of simultaneously combining a "processor and resource saving procedure" with a static equilibrium solution has been achieved. The implicit result is a realistic static state of equilibrium.

9. Summary and Outlook

Implicit simulation – outlook at DAIMLER

- Development of a process for positioning the BioRID model (same as HPM coupled with sensor interrogation) still has to be achieved
- Transfer of the developed process to more complex seat models (for H-point manikin positioning, this has already been achieved)
- Extension of existing internal DAI modeling guidelines to take account of the requirements for implicit calculations
- Transfer of equilibrium state at the end of the implicit positioning calculation to explicit whiplash calculation

9. Summary and Outlook

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Implicit simulation – requirements for LSTC/ DYNAmore

- **"Explicit is handcraft - implicit is skill"**
  In order to take this striking description of the status quo up to the next level and promote distribution of the application, further development of LS-DYNA regarding fault messages and debugging options for non-robust problems is absolutely essential and a crucial precondition.
  ➔ LSTC
- Completion of the BioRID v4.0 model
  ➔ DYNAmore
- Establish a robust LS-DYNA production version based on R8
  ➔ DYNAmore + LSTC