LS-DYNA - from explicit to implicit simulation models

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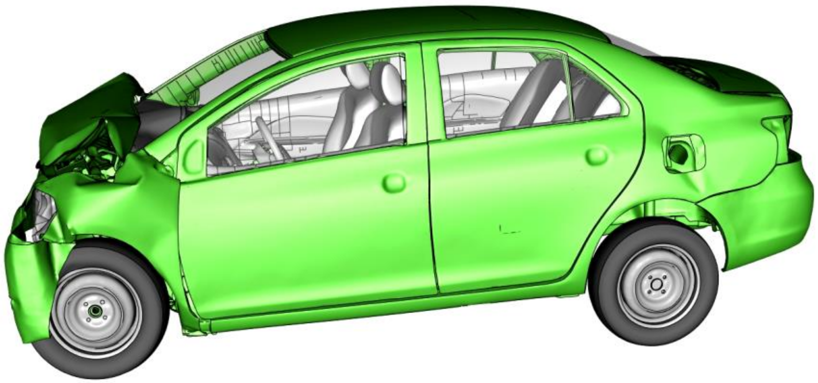


FROM EXPLICIT ...

TO IMPLICIT

LS-DYNA - from explicit to implicit simulation models

- Acknowledgement
- Background
- Workflow
  - Model build-up for implicit and explicit
  - Implicit set-up
- Conversion
  - From explicit to implicit
  - Modelling aspects
- Examples
- Summary

Acknowledgement

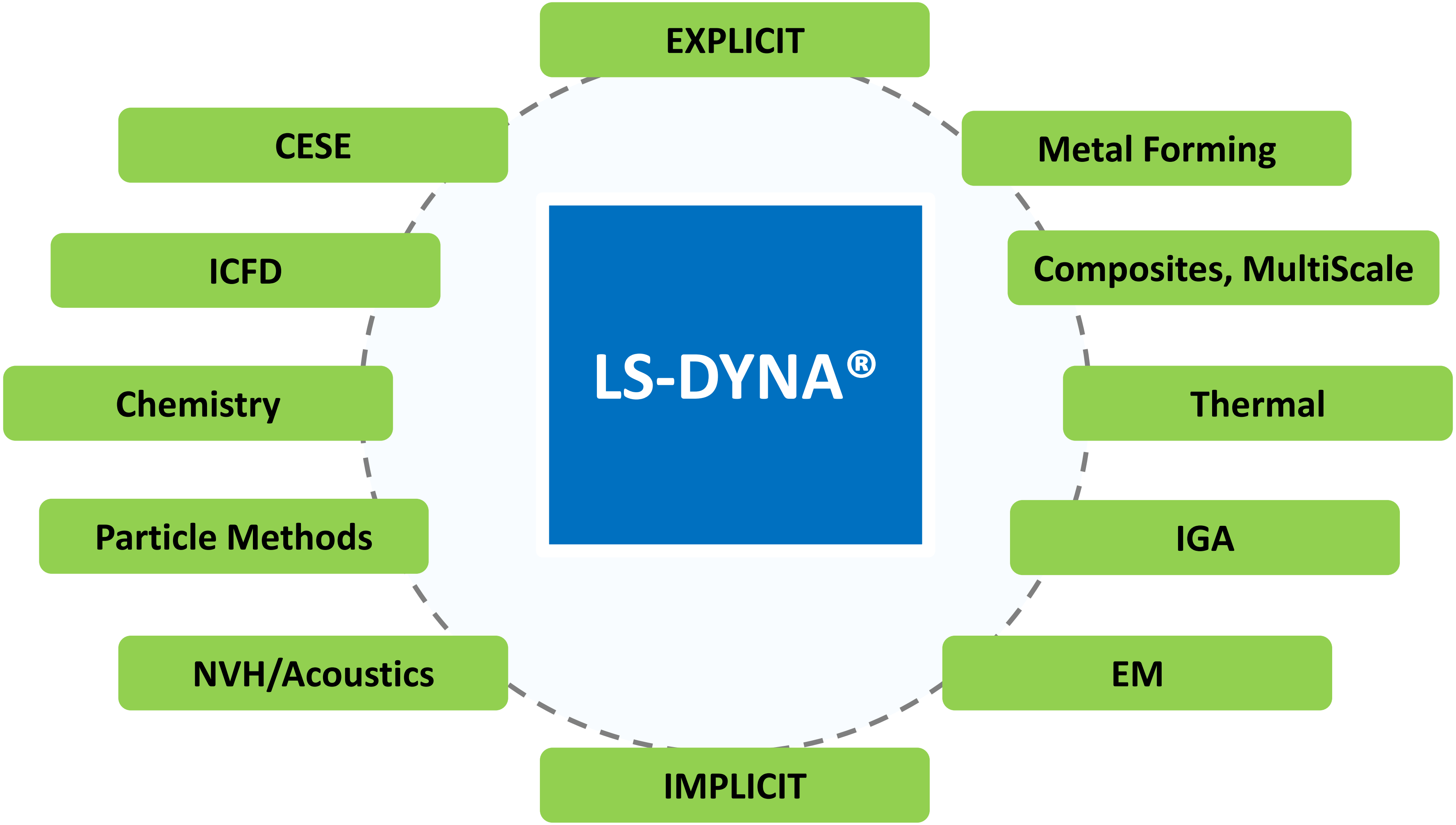
- This presentation contains examples based on the public FE-model:
- 2010-toyota-yaris-detailed-v2j.zip
- from The Center for Collision Safety and Analysis (CCSA) at the George Mason University (GMU) developed under a contract with the Federal Highway Administration (FHWA)
- The work of the CCSA at GMU is gratefully acknowledged.

- Also the public FE-model
- Oblique THOR Accord Model
- was used. It is developed by EDAG, Inc. under sponsorship from NHTSA

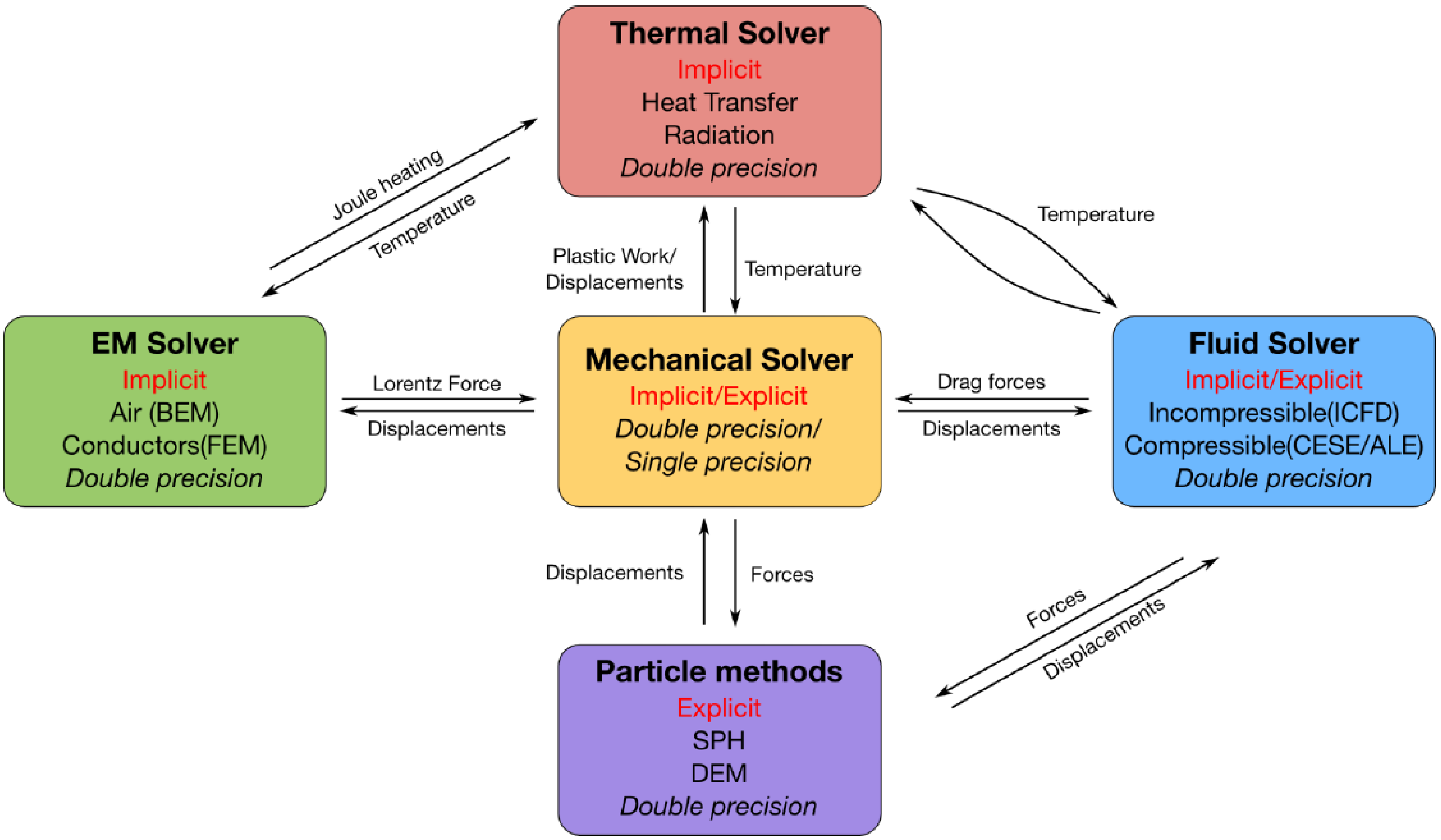
LS-DYNA Implicit

BACKGROUND

LS-DYNA is a versatile multi-physics solver package



LS-DYNA is a versatile multi-physics solver package

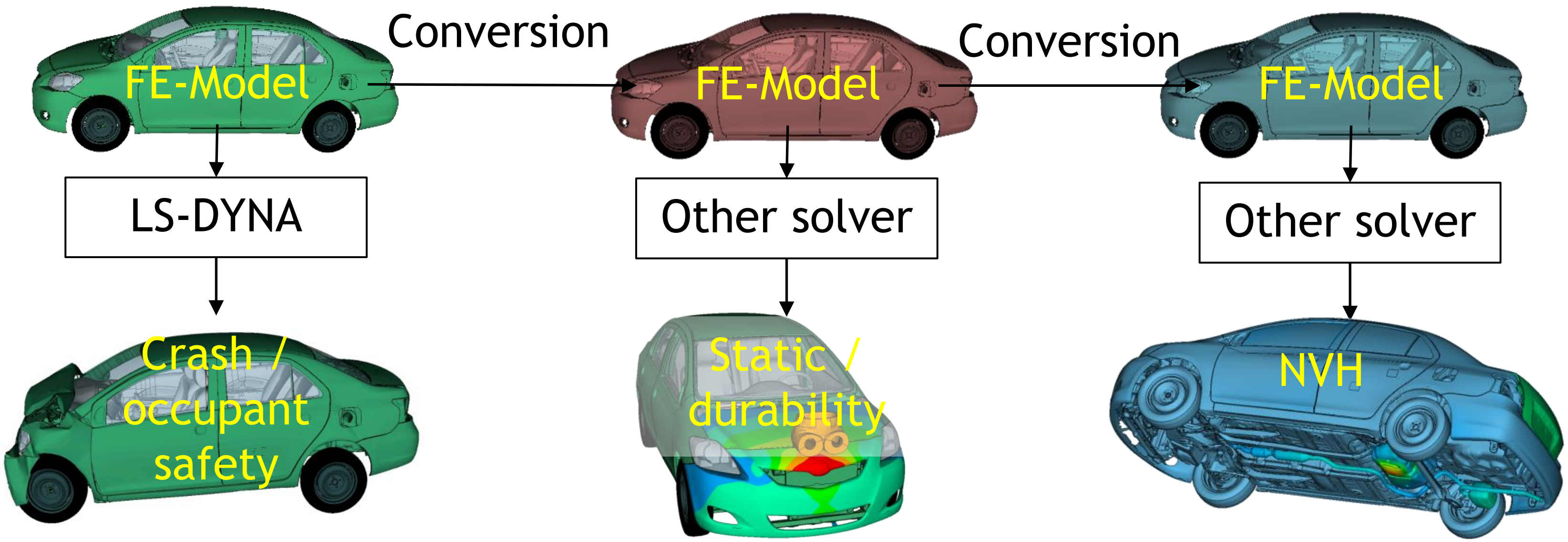


LS-DYNA Implicit

WORKFLOW

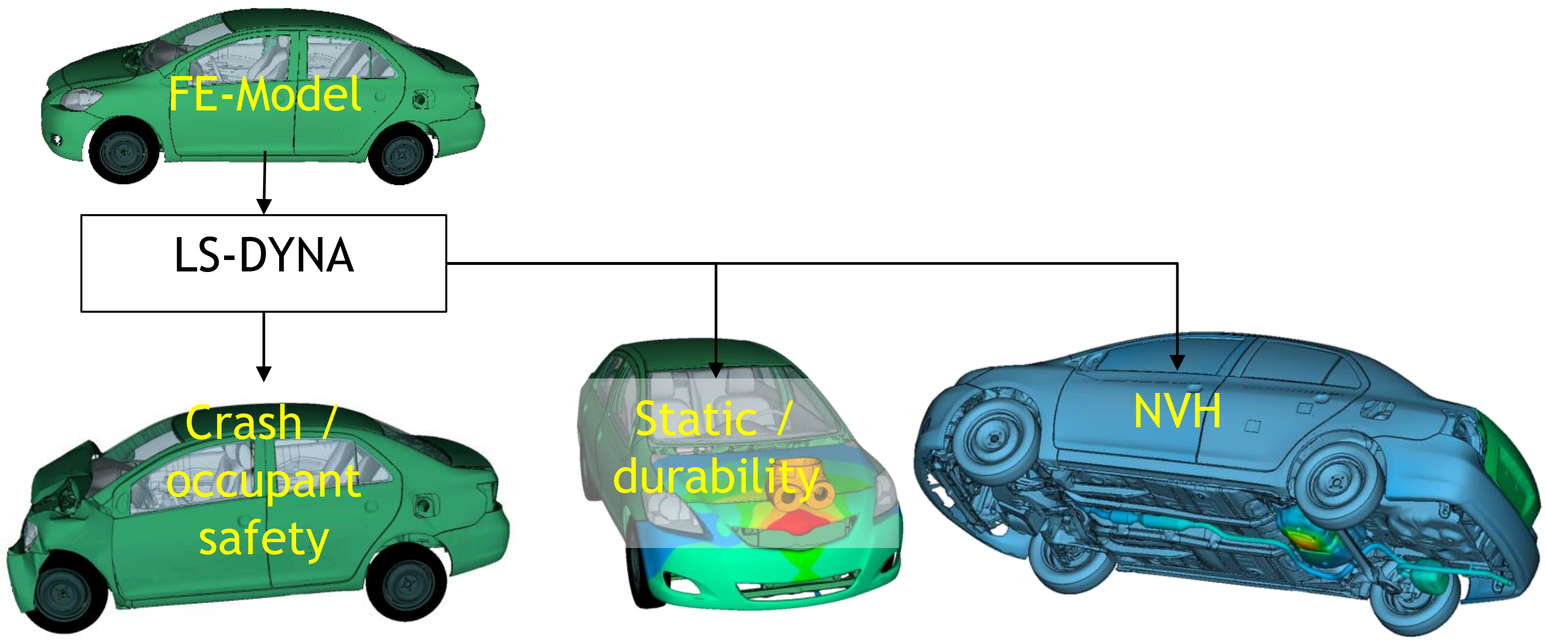
LS-DYNA implicit – Opening for new possibilities

- Traditional workflow for multi-disciplinary analyses



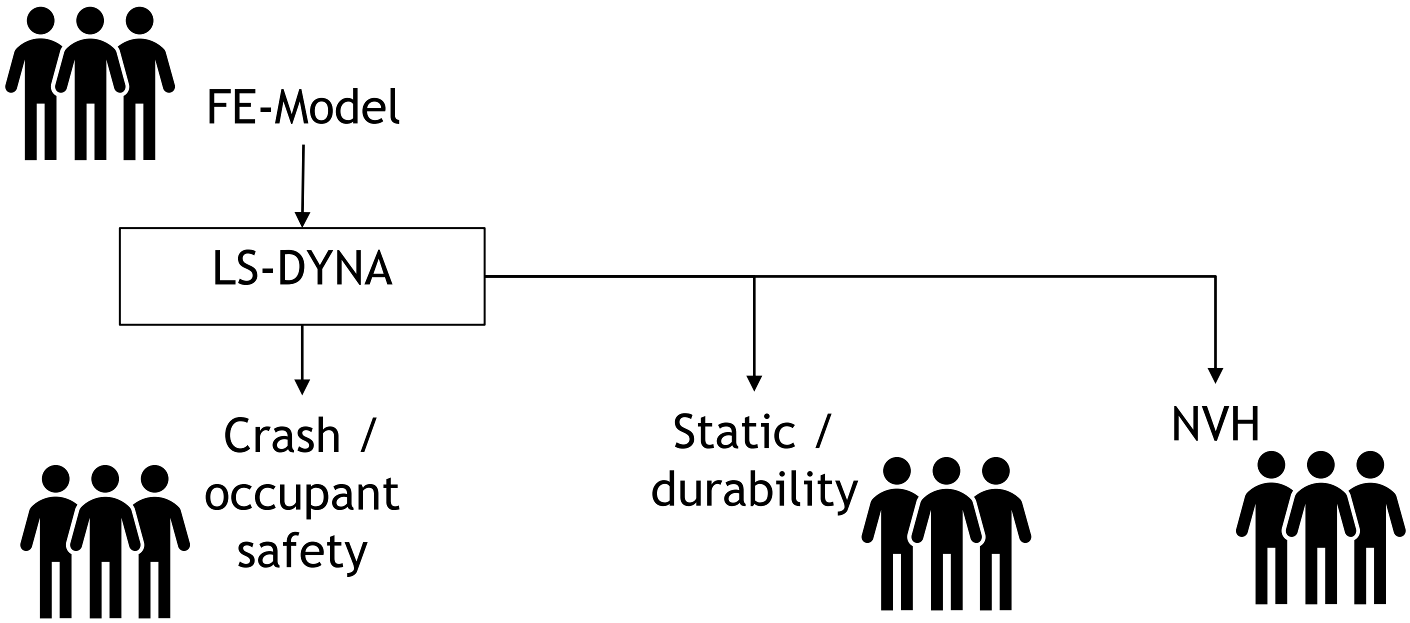
LS-DYNA implicit – Opening for new possibilities

- LS-DYNA One-code philosophy



LS-DYNA implicit – Opening for new possibilities

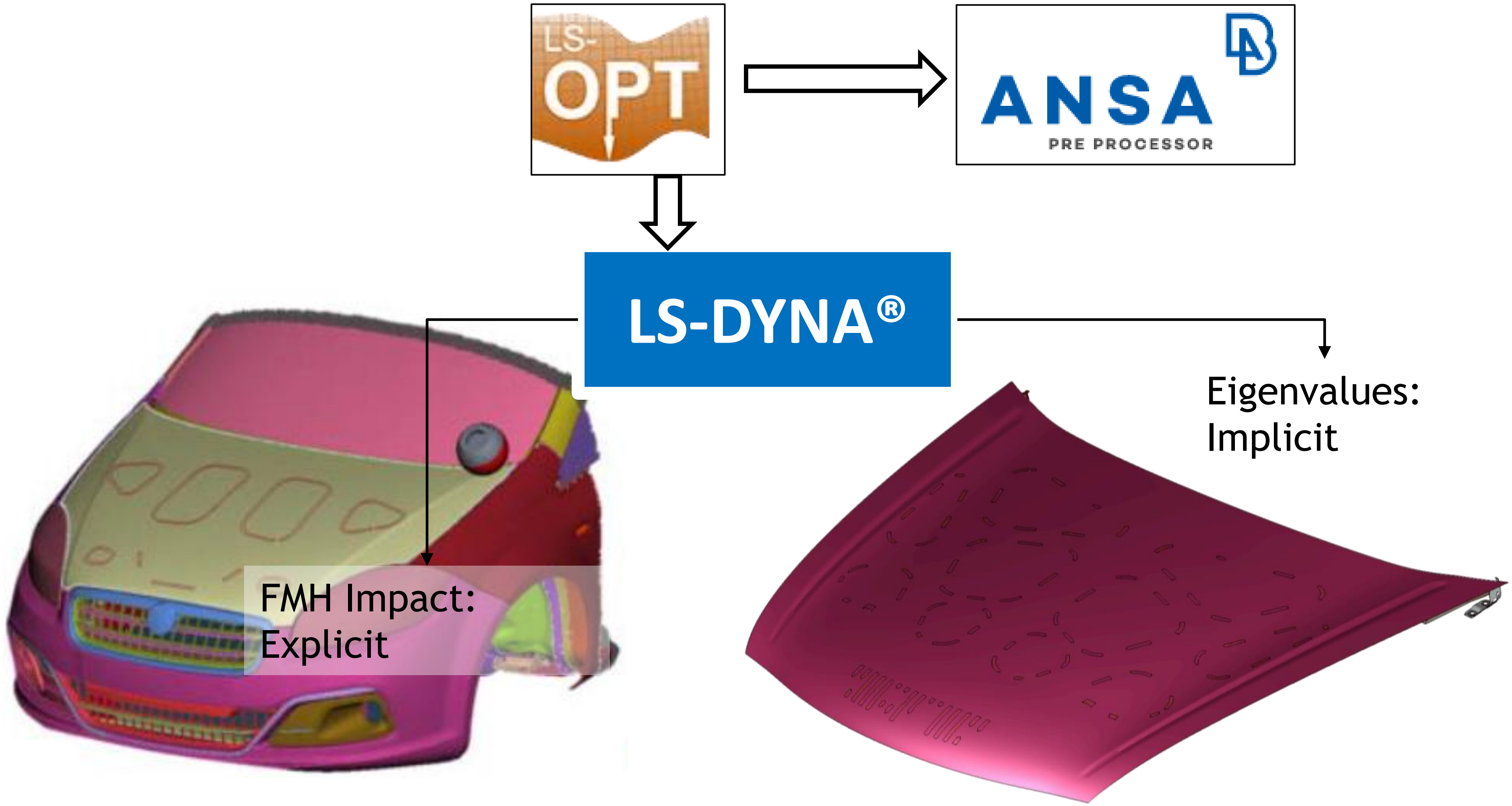
- LS-DYNA One-code philosophy



Using LS-DYNA for different disciplines makes it easier for simulation engineers from different groups to share information and experiences

LS-DYNA implicit – Opening for new possibilities

- Multi-disciplinary optimization of a hood

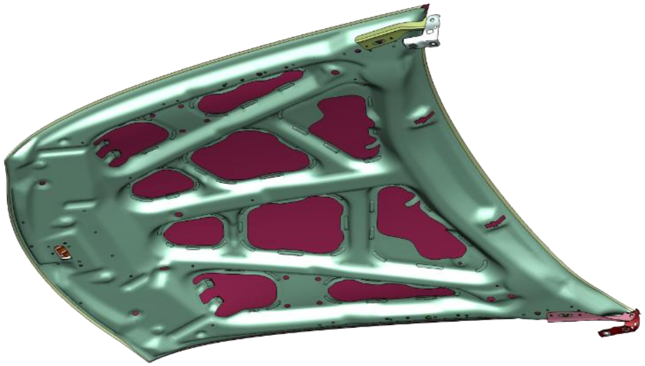


Workflow

- Modelling for explicit <u>and</u> implicit analyses

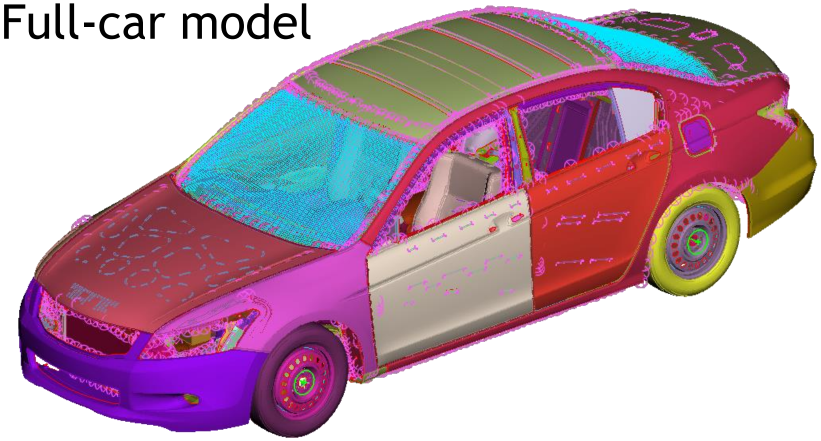
CAD → ANSA PRE PROCESSOR →

Automated meshing, assembly

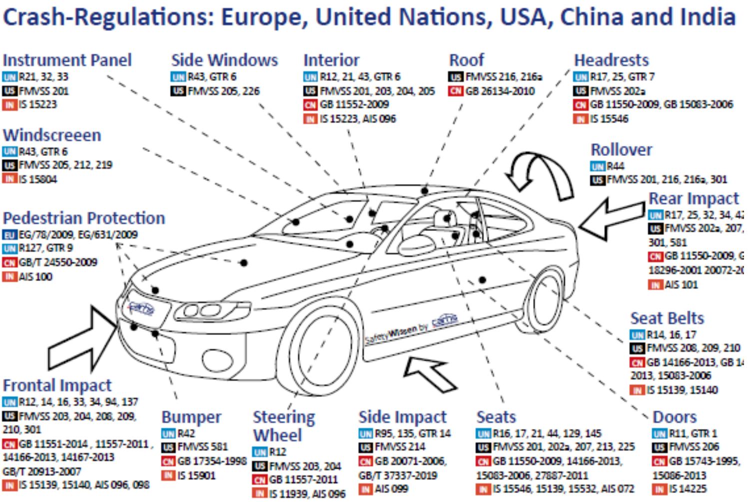


Sub-system verification

Full-car model



Crash load cases



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Workflow

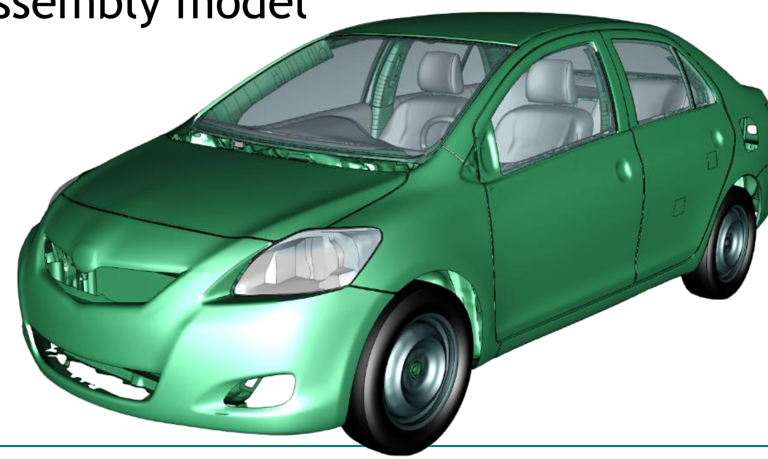
- Modelling for explicit <u>and</u> implicit analyses

CAD

Automated meshing, assembly

Sub-system verification

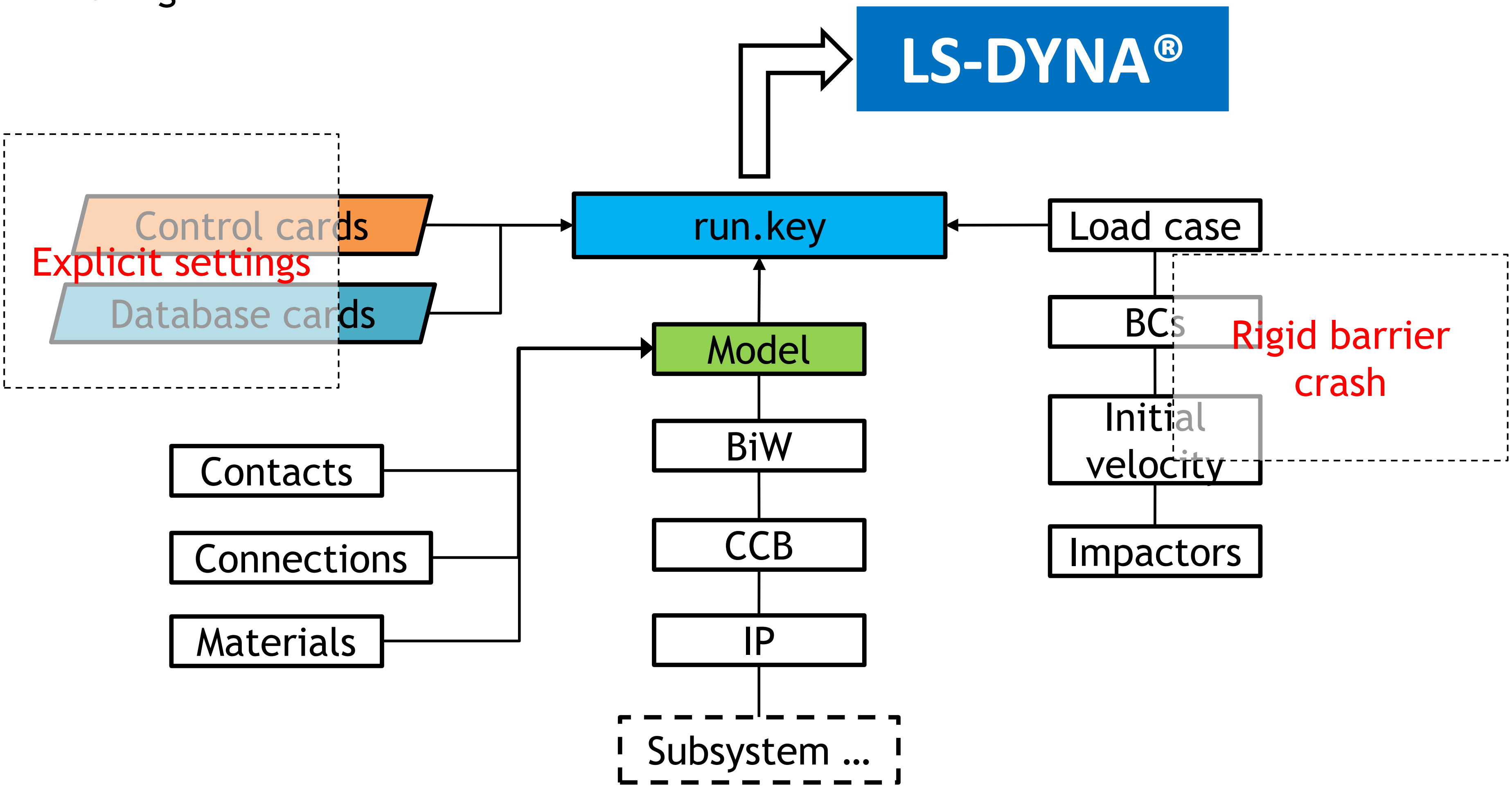
Assembly model



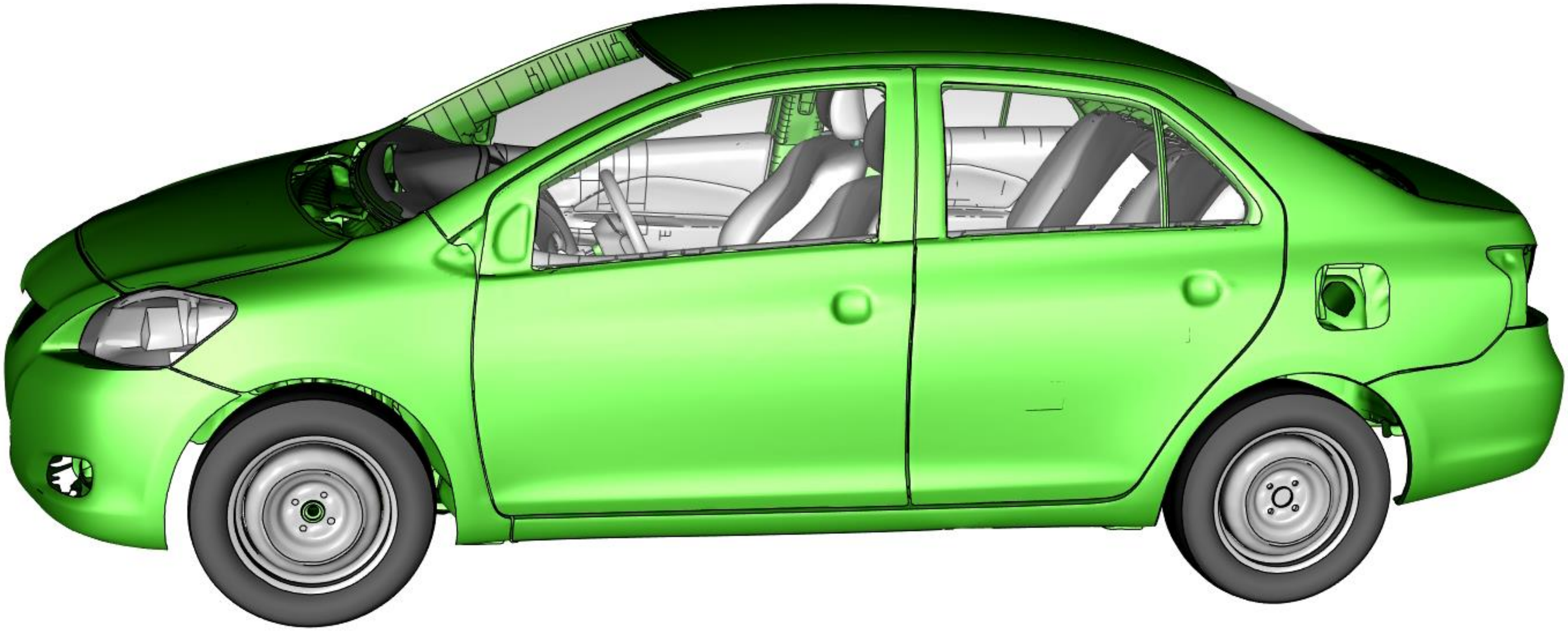
Durability load cases

Workflow and model organization

- Using an include file structure



Rigid barrier crash



Workflow and model organization

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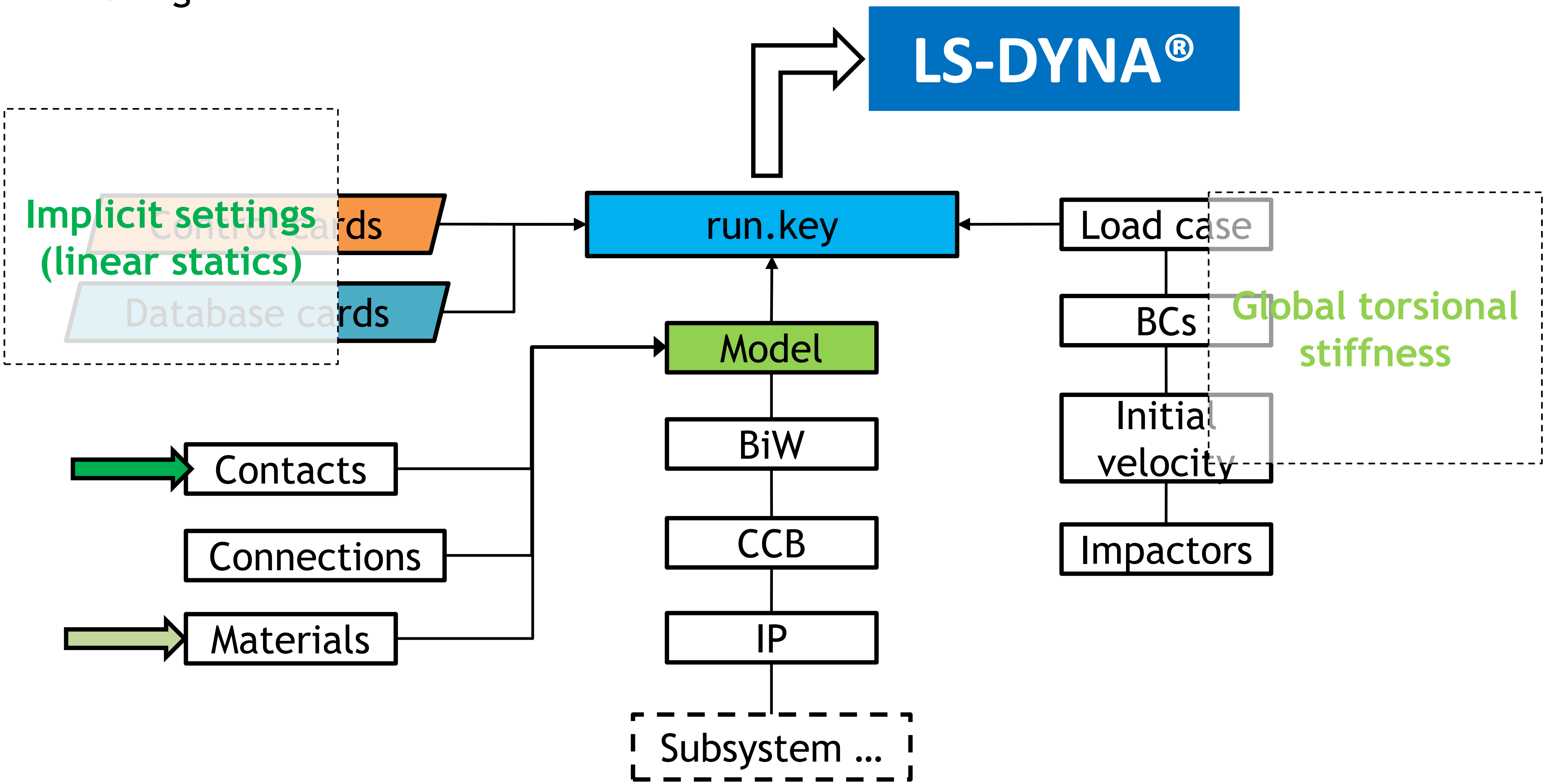


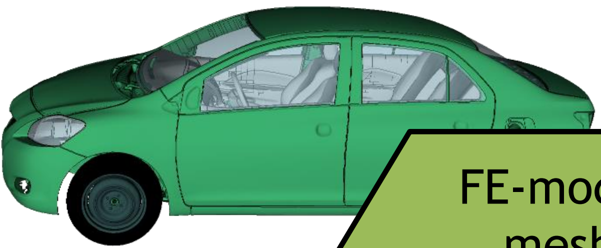
Torsional stiffness analysis

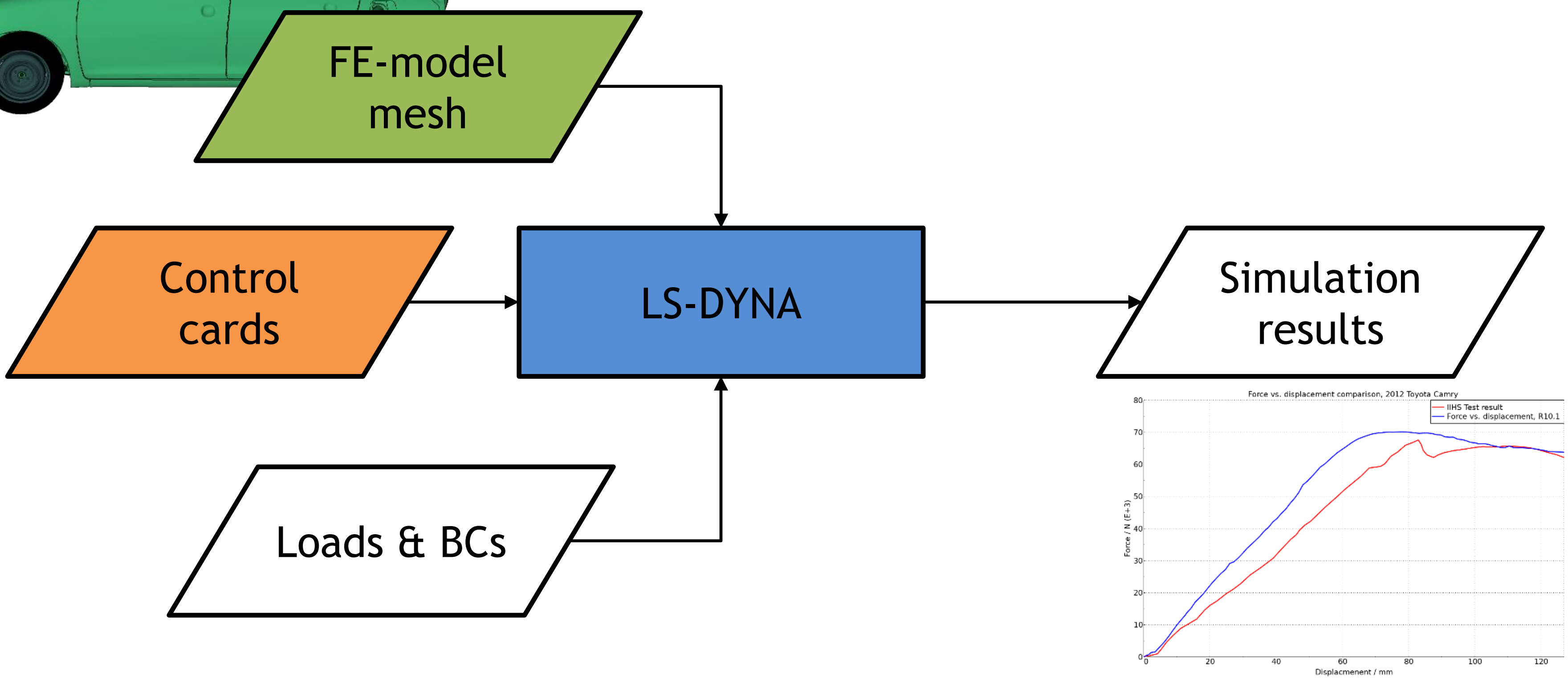
LS-DYNA Implicit

IMPLICIT SET-UP

Implicit set-up in LS-DYNA

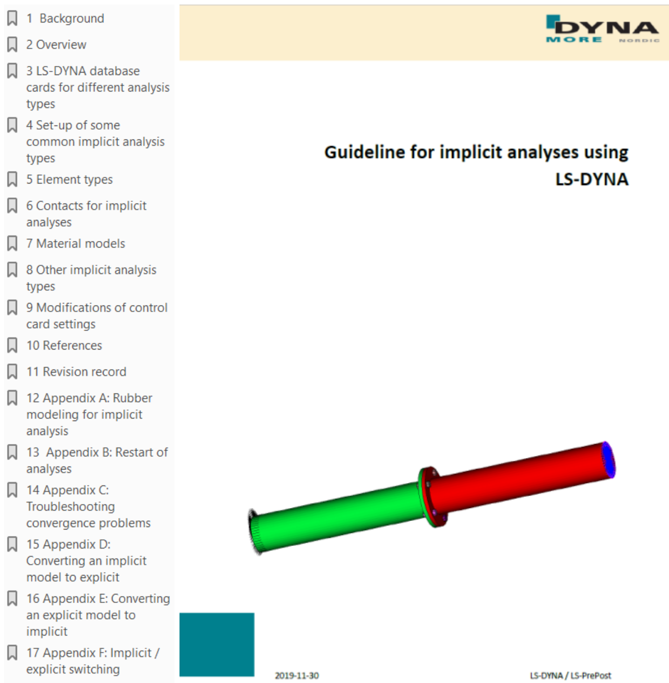
- Objective: to set-up a non-linear implicit analysis with minimal effort
- LS-DYNA is a versatile multi-physics solver. Many different analysis types are possible.

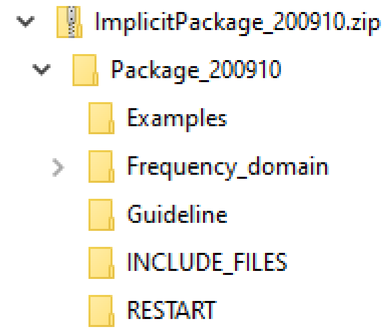




Implicit set-up in LS-DYNA

- In order to help the user getting started with Implicit analyses in LS-DYNA, the Guideline to implicit analysis was developed





- Available for DYNAmore Nordic customers from files.dynamore.se>ClientArea
- The focus of the “Guidelines for implicit analyses” is how to set up the analysis as such, and to guide in choice of elements, contacts, material models etc. Also provide a suggested starting point for control cards settings.

Implicit set-up in LS-DYNA – Control cards

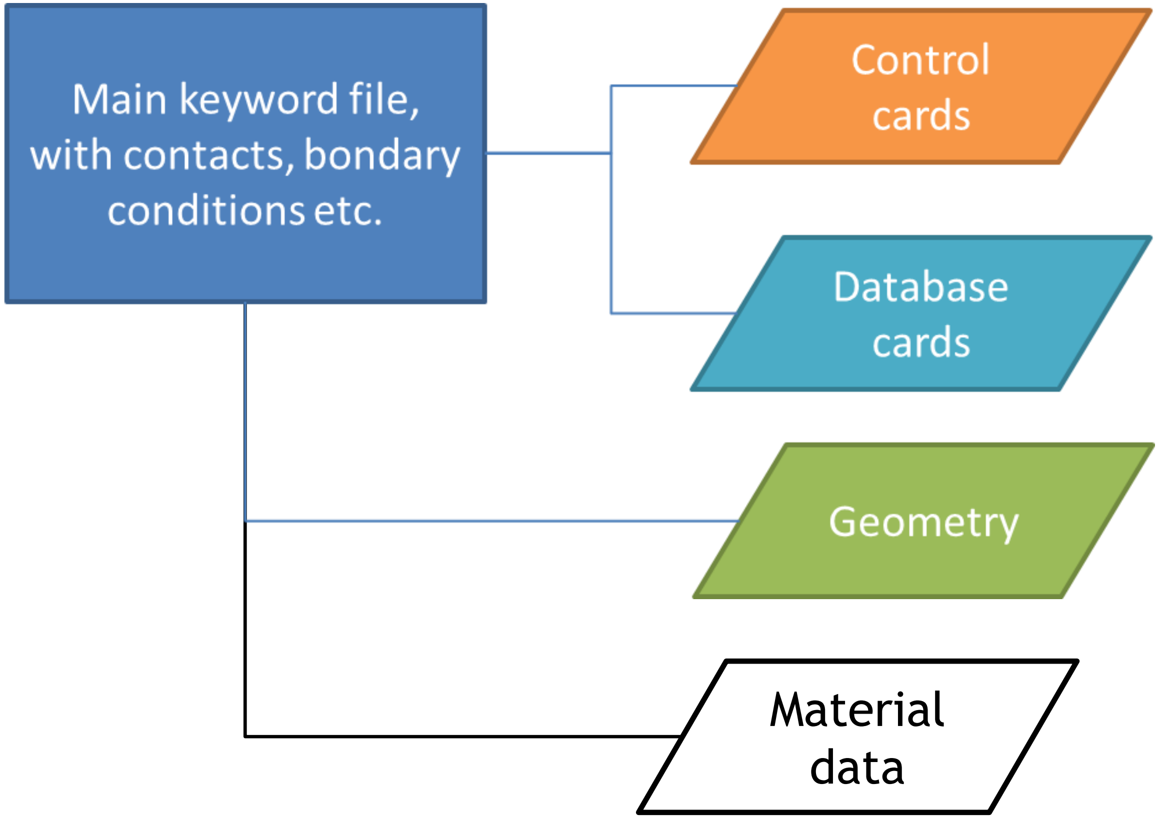
- Identify analysis type and select control card include file
  - In many cases, `*CONTROL_TERMINATION` is the only required additional control card
  - Note! LS-DYNA implicit is always either purely non-linear or purely linear!
- Use an include file structure! Then the control card include files from the Guideline may be used directly.

	Include files		Add keywords:(*)
Analysis type	control_cards_...	database_cards_...	*CONTROL_IMPLICIT_...
Linear static	linear.key	static.key	
Non-linear static	nonlin.key	static.key	
Linear buckling		(1) static.key	BUCKLE
Non-linear postbuckling	arc.key	static.key	
Eigenfrequency analysis		(1) static.key	EIGENVALUE
Linear transient modal dynamics	linear.key	dynamic.key	MODAL_DYNAMIC
Frequency domain analyses(2)	linear.key		
Non-linear implicit dynamics	nonlin.key	dynamic.key	DYNAMICS

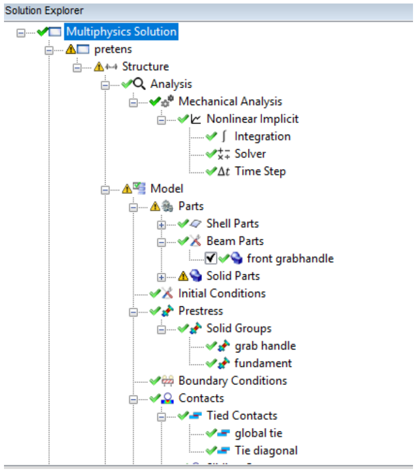
Notes: (*) `*CONTROL_TERMINATION` must always be added. (1) Can be part of both linear and non-linear analysis. (2) Frequency response functions, steady state dynamics etc.

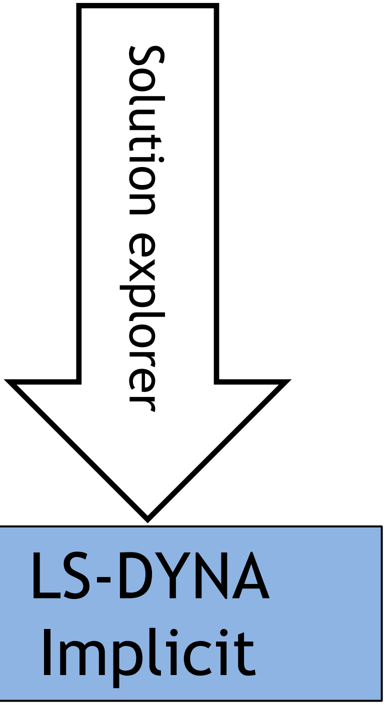
Implicit set-up in LS-DYNA – Control cards

- Identify analysis type and select appropriate control card include file.
  - In many cases, `*CONTROL_TERMINATION` is the only required additional control card.
- Use an include file structure! Then the control card include files of the Guideline may be used directly.



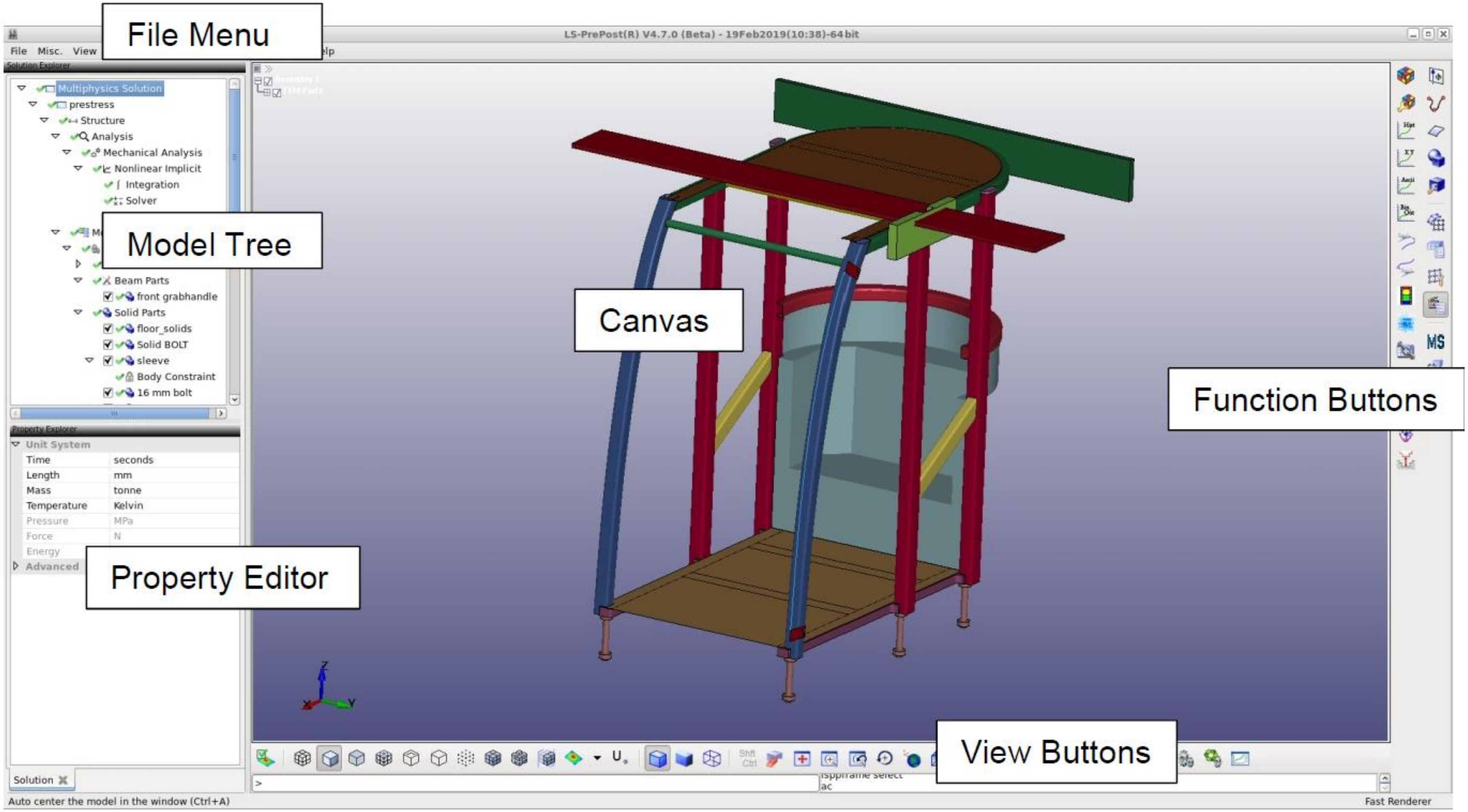
Different ways into the world of LS-DYNA implicit





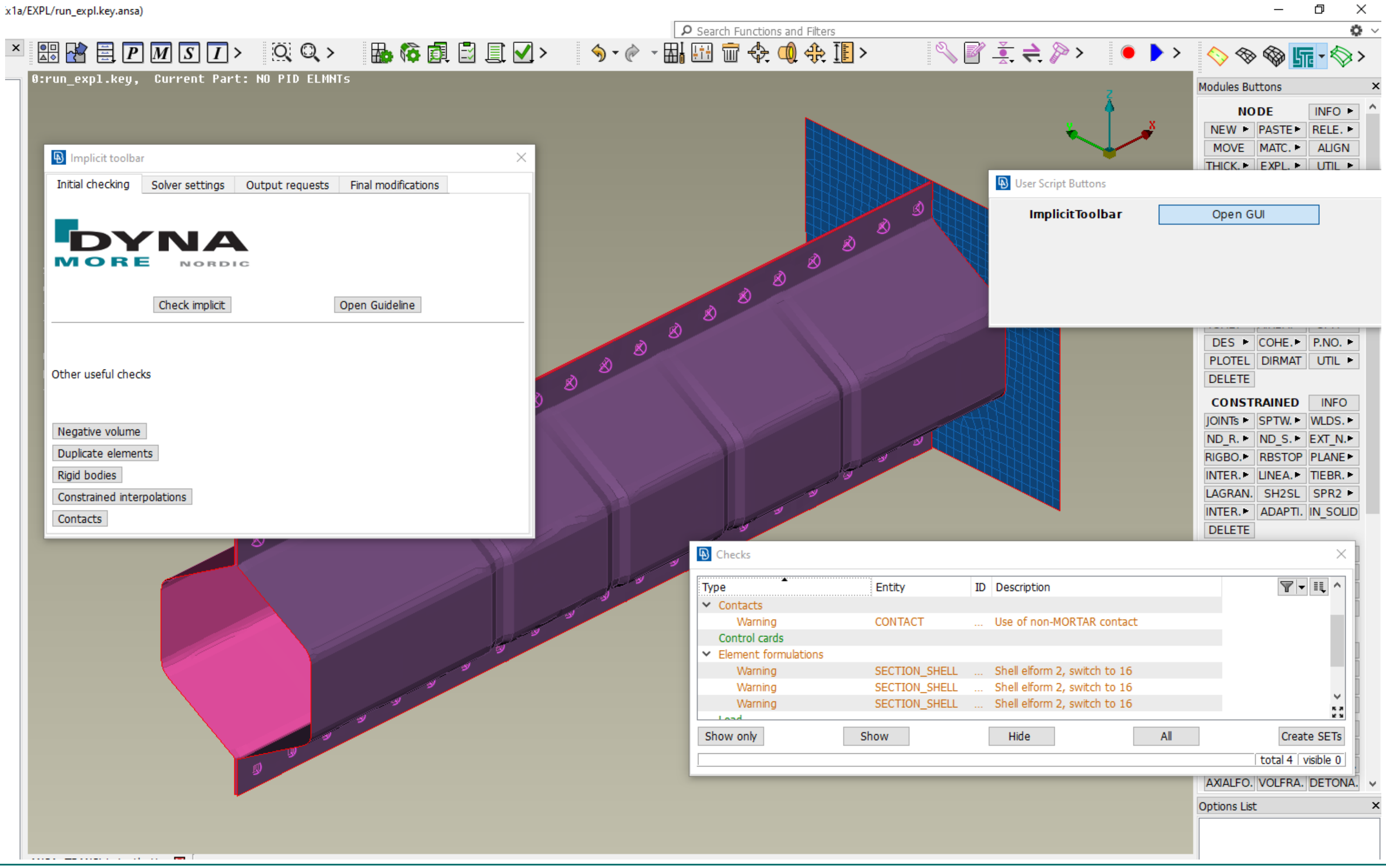
Different ways into the world of LS-DYNA implicit

- The Solution Explorer in LS-PrePost



ANSA Implicit toolbar

- Help with model check and set-up



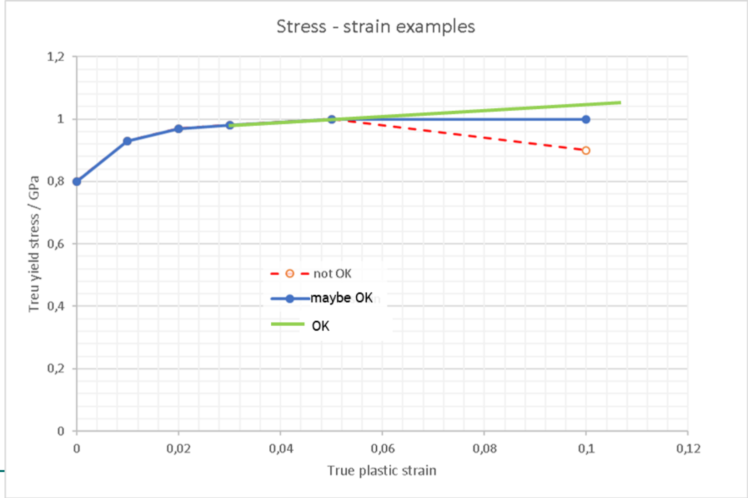
Implicit set-up in LS-DYNA

- Other sources of useful information regarding implicit analyses in LS-DYNA:
  - www.dynasupport.com/howtos/implicit
  - http://www.dynaexamples.com/implicit
  - www.dynalook.com – search conference papers
- DYNAmore / ANSYS LST also gives courses in implicit analyses:
  - Non-linear implicit analysis in LS-DYNA (Dr. T. Borrvall)
  - NVH & Frequency domain analysis in LS-DYNA
  - From explicit to implicit simulation models in LS-DYNA
  - All courses available as on-line seminars
- See also: https://www.dynamore.se/en/training/seminars and https://www.dynamore.de/en/training/seminars

- Please report bugs and errors! Send an e-mail to support@dynamore.se or call 013-236680

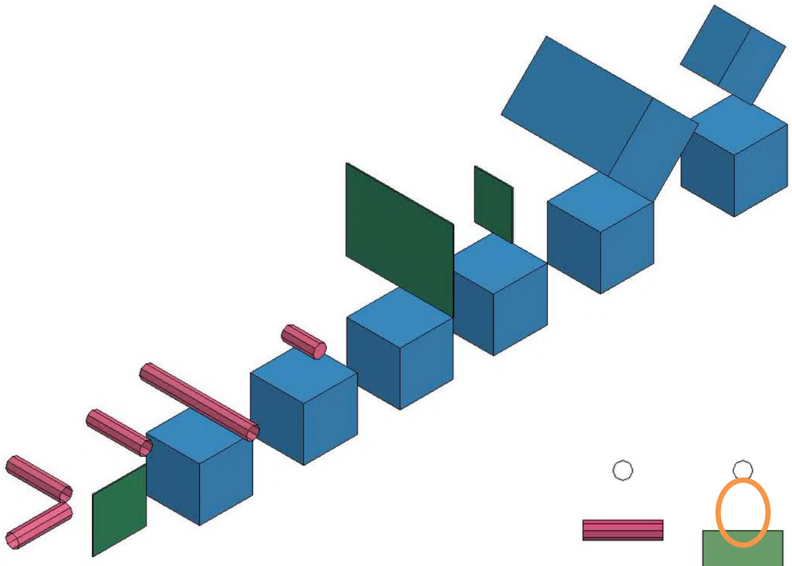
Conversion: Implicit modelling aspects

- Use the Mortar contacts
  - *CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID
  - *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID
- The same contacts modelling approach as in explicit can be applied also for implicit
  - One global single surface contact
  - One global tied contact
- Model connectivity is crucial
  - Unconnected sub-assemblies may cause non-convergence in statics
  - Loose, spinning sub-assemblies may cause slow convergence in dynamics
- Fully integrated elements
- Materials
  - Hardening curves
  - Damage / failure is available also in implicit
  - User defined material models require also appropriate tangential stiffness

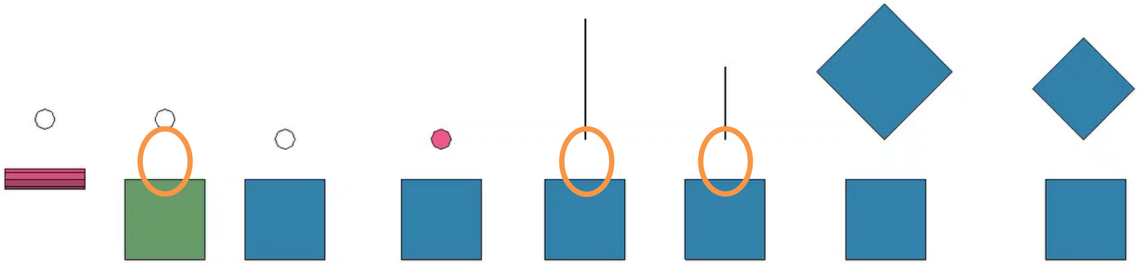


Mortar contact

- *CONTACT_AUTOMATIC_.._SURFACE_MORTAR
  - Segment-based penetration check
  - Based on consistent FE-theory
  - Focused on accuracy for implicit

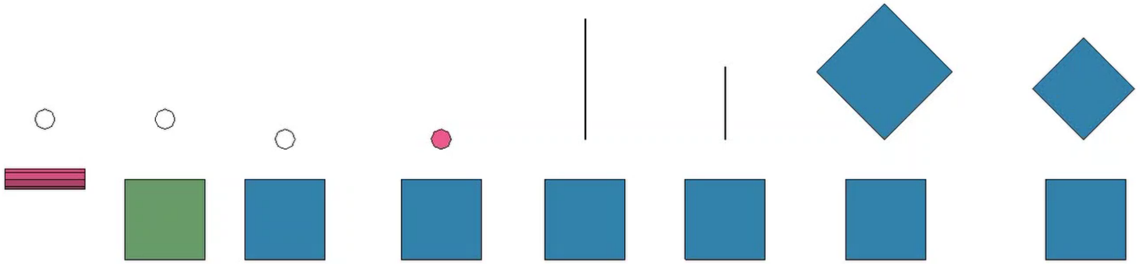


- Captured contact situations
  - Segments not allowed to penetrate segments
    - Shell edge to segment of shell and solid
    - Solid edge to segment of shell and solid
  - Beam to beam
  - Beam to shell edge (NO segment extension!)
  - Beam to segment of shell and solid
  - Element erosion
- Missed contact situations
  - None*



Mortar contact

- *CONTACT_AUTOMATIC_.._SURFACE_MORTAR
  - Segment-based penetration check
  - Based on consistent FE-theory
  - Focused on accuracy for implicit
- Captures all* contact situations
- In explicit models, *CONTACT_AUTOMATIC_GENERAL_ID is often applied for modelling beam-to-shell-edge or beam-to-beam or edge-to-edge situations
- In implicit, this should be replaced by *CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID

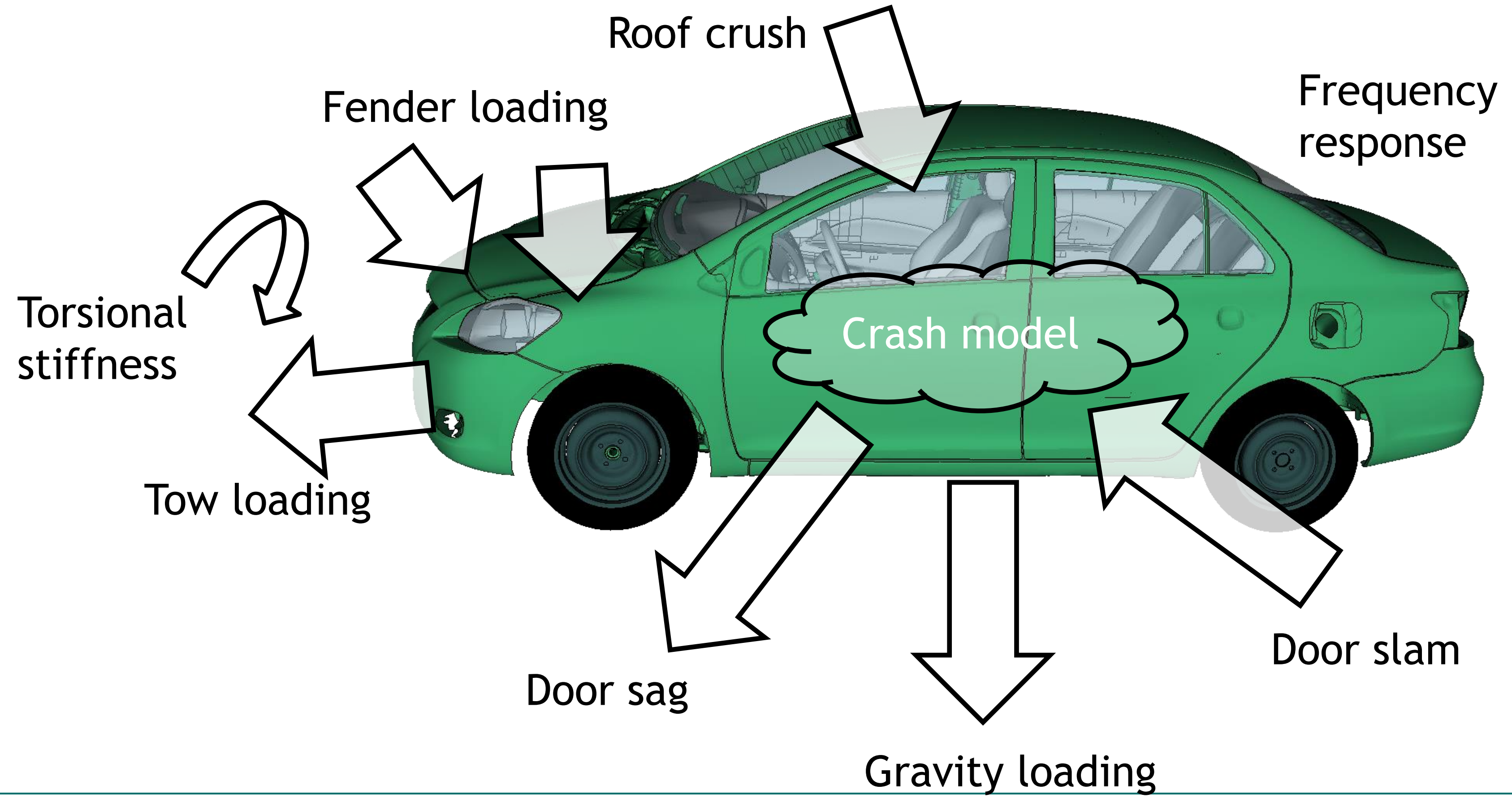


Conversion: Implicit modelling aspects

- Unconnected parts or assemblies will cause rigid body modes, which may prevent convergence in implicit statics
- Check model connectivity!
  - Perform an eigenvalue analysis. Just add `*CONTROL_IMPLICIT_EIGENVALUE`
  - Use Check > Connectivity > Detect unconnected assemblies in ANSA
  - Check tied contacts. Setting `IPBACK` = 1 on `*CONTACT_TIED_...` may be a quick fix for avoiding for example loose spot-welds
- Connectivity causing hinges or mechanisms
  - For example beam -> solid using common nodes
  - A CNRB connecting to one node of a solid will also cause a spherical joint
  - Joints
  - From R11, joint stiffness can be applied globally on `*CONTROL_RIGID`
- General model QA
  - Check mesh quality, initial penetrations, duplicate elements, negative volume etc.
  - Similar to any LS-DYNA model

Conversion: Example – The Yaris model from CCSA

- Start out with a model for explicit crash analysis
- Create a model that works in implicit for many different load cases

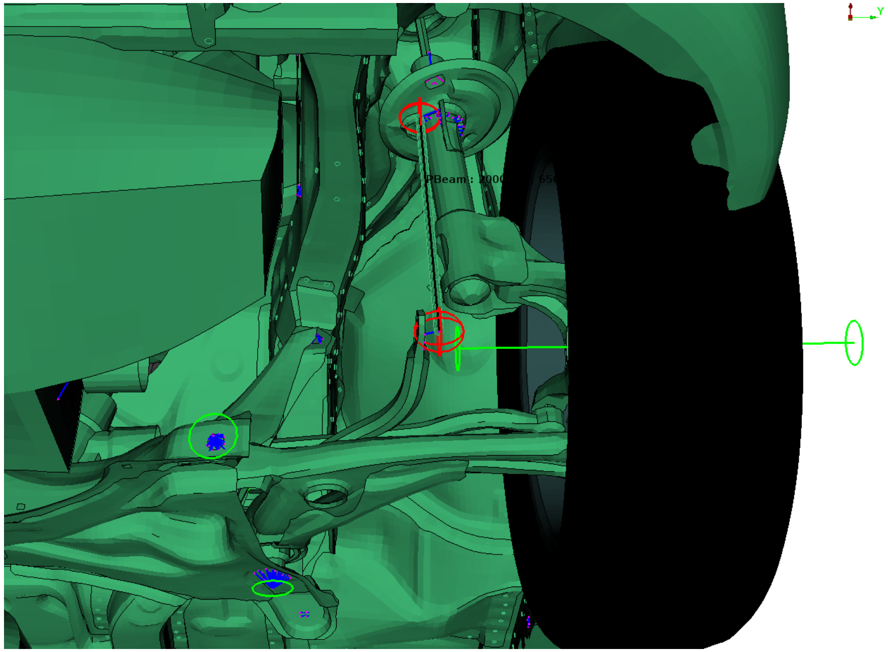


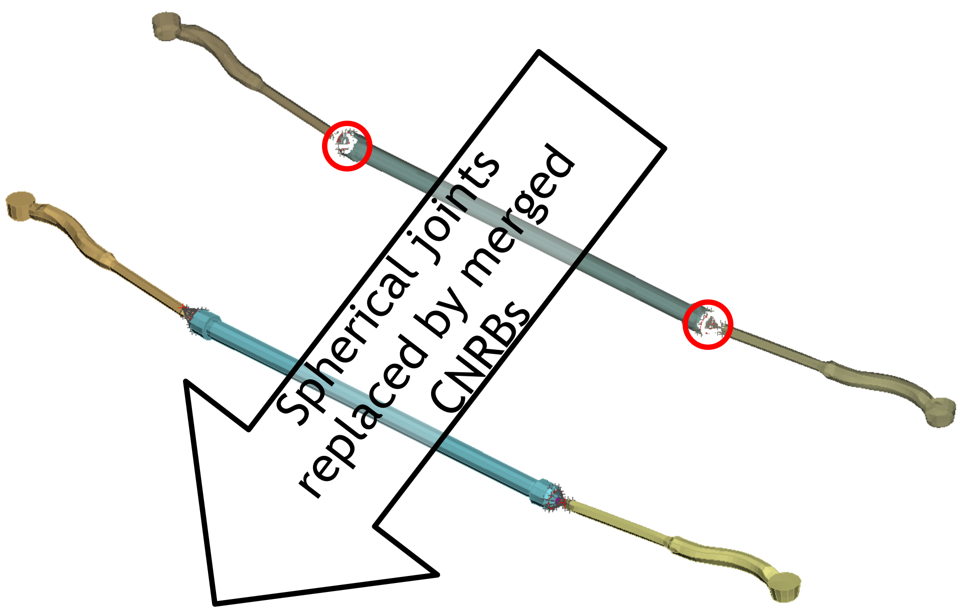
Specific modifications: Yaris

- Removed “dummies” from crash model
- The tire airbags were a separated and switched to `*AIRBAG_LOAD_CURVE`
- For the door-related load cases, the door hinges were aligned and some CNRBs between the BiW and the door were removed
- The single surface contact was switched to Mortar contact (Note! Still **one** automatic single surface contact definition for the whole model)
  - Removed null-shells from solids
- Added *IPBACK* to the tied contact for spot welds
- The suggested control card settings for non-linear implicit analyses from the Guideline were used as a basis
  - *DNORM* = 1 on `*CONTROL_IMPLICIT_SOLUTION` was used in many load cases
- The geometrical stiffness effect was disabled (*IGS* = 2 on `*CONTROL_IMPLICIT_GENERAL`)
- Rate effects were disabled (*IRATE* = 2 `*CONTROL_IMPLICIT_DYNAMICS`)
- Switched to shell elform 16 using `*CONTROL_IMPLICIT_EIGENVALUE`
  - From R11, shell elform 2 are automatically switched to elform 16 due to *IACC* = 1

LS-DYNA implicit – Modifications

- The Yaris is modeled in the gravity loaded position. Pre-loading of the suspension must be applied in some way. This was changed from the original model to `*ELEMENT_DISCRETE_LCO`.
- Spherical joints can be a potential problem, since rigid body modes may be introduced (spinning parts)
  - added some CNRBs to steering links and
  - SPCs to constrain rotation of the anti-roll bar links in the front suspension



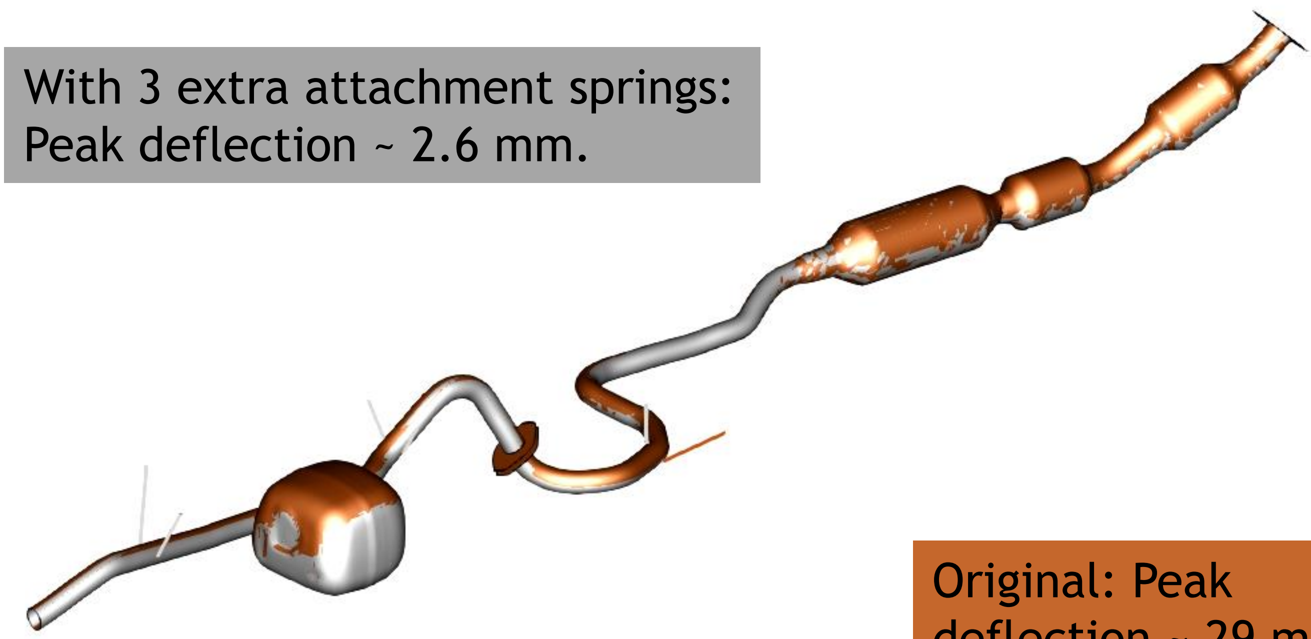


LS-DYNA implicit – Modifications

- Added three extra springs to attach the exhaust system to reduce deformation due to gravity loading

Gravity loading of exhaust system only

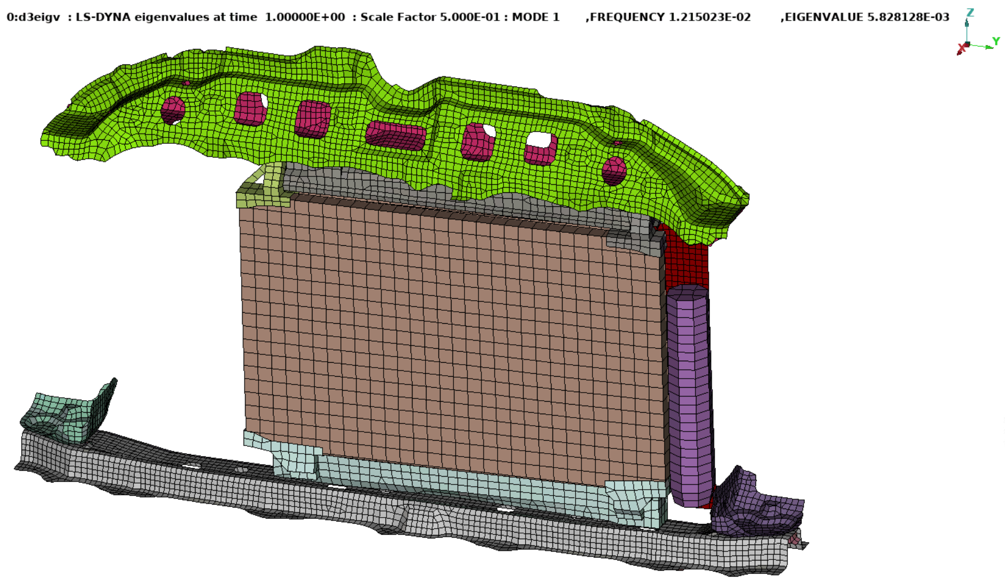
With 3 extra attachment springs:
Peak deflection ~ 2.6 mm.

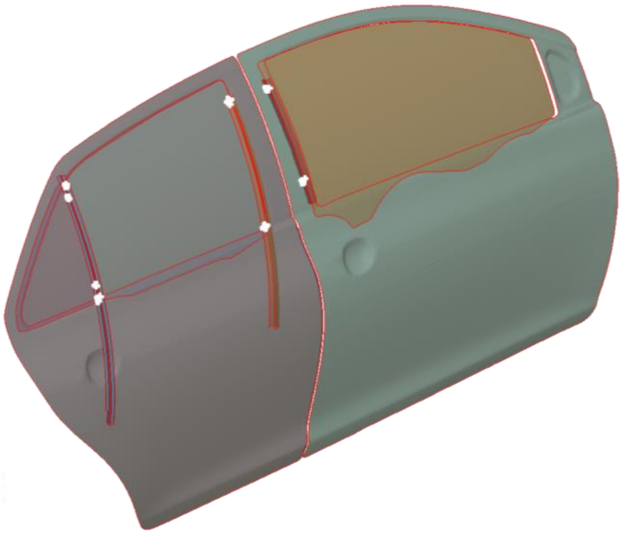


Original: Peak deflection ~ 29 mm.

LS-DYNA implicit – Modifications

- Added some CNRBs to cooler tube and windows (the rubber seals are missing)

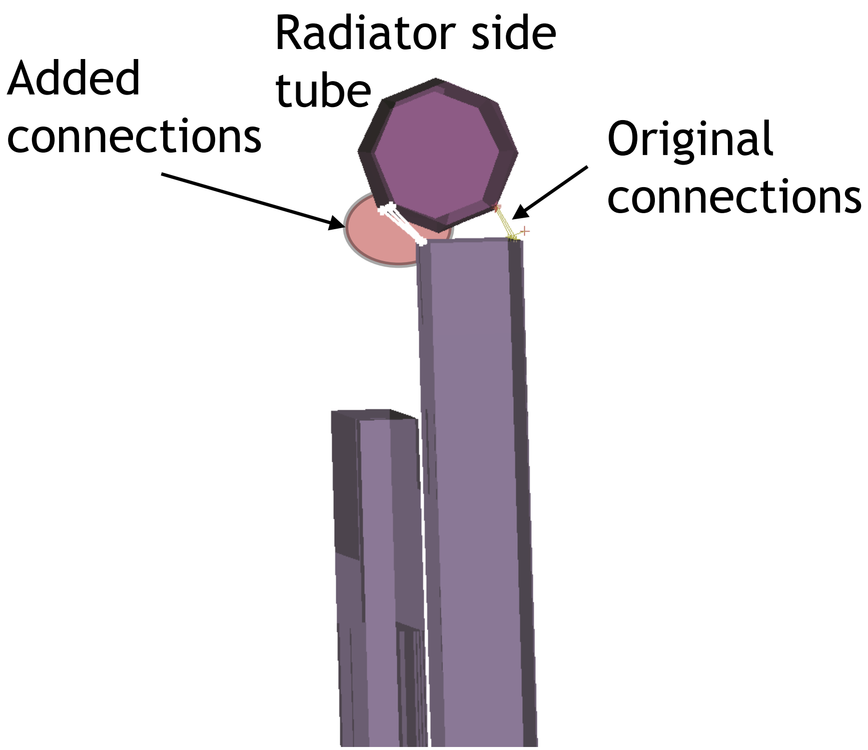


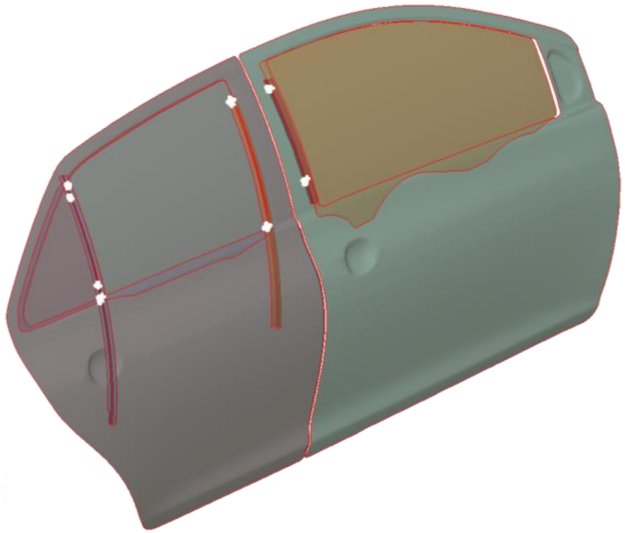


```
*** Warning 60301 (IMP+301)
    Using *CONSTRAINED_SPOTWELD with nodes without rotational dofs.
```

LS-DYNA implicit – Modifications

- Added some CNRBs to cooler tube and windows (the rubber seals are missing)

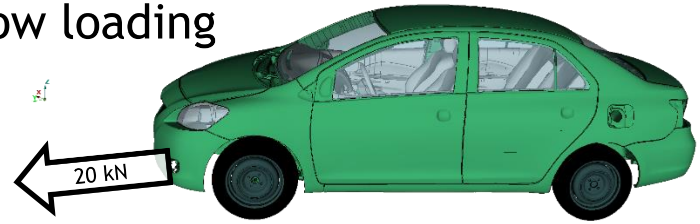




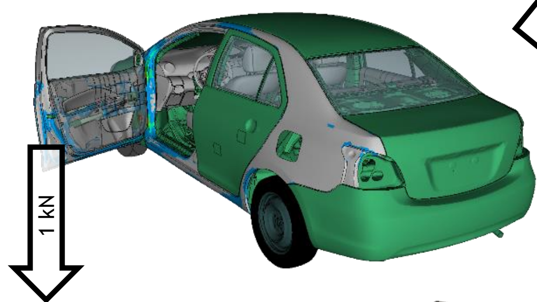
Examples of some load cases solved in implicit

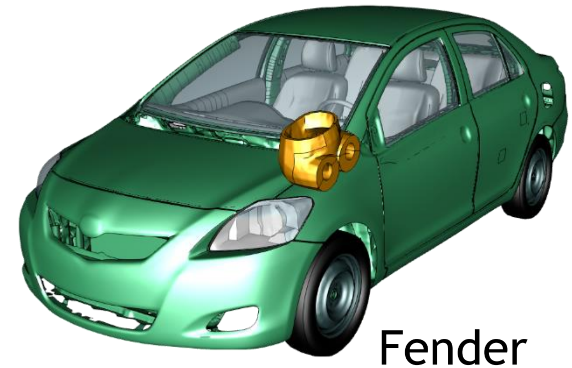
- Full car model
  - Tow loading
  - Door sag
  - Fender loading
- Partial models
  - Seating
  - IP as footrest
  - BSR analysis of IP

Tow loading



Door sag

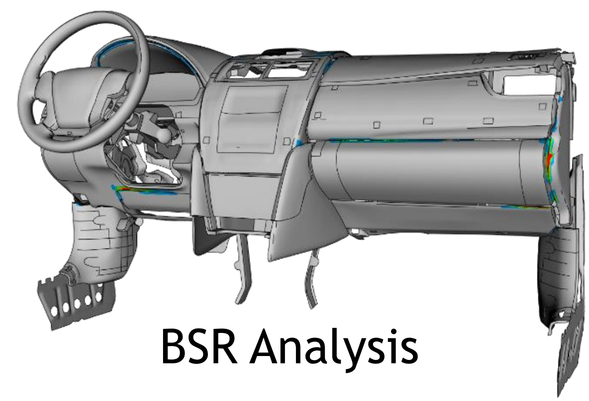




Fender loading

Seating

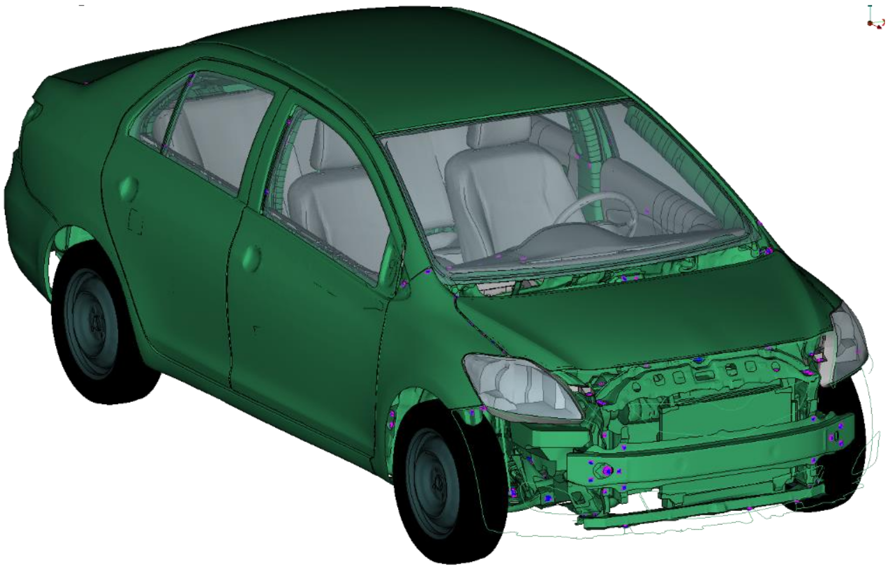
IP as footrest

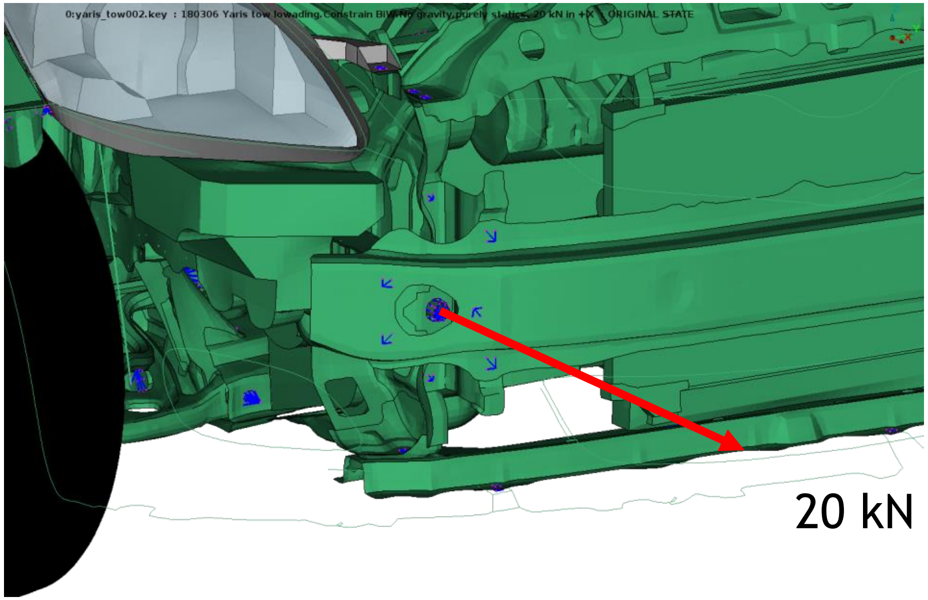


BSR Analysis

Tow loading

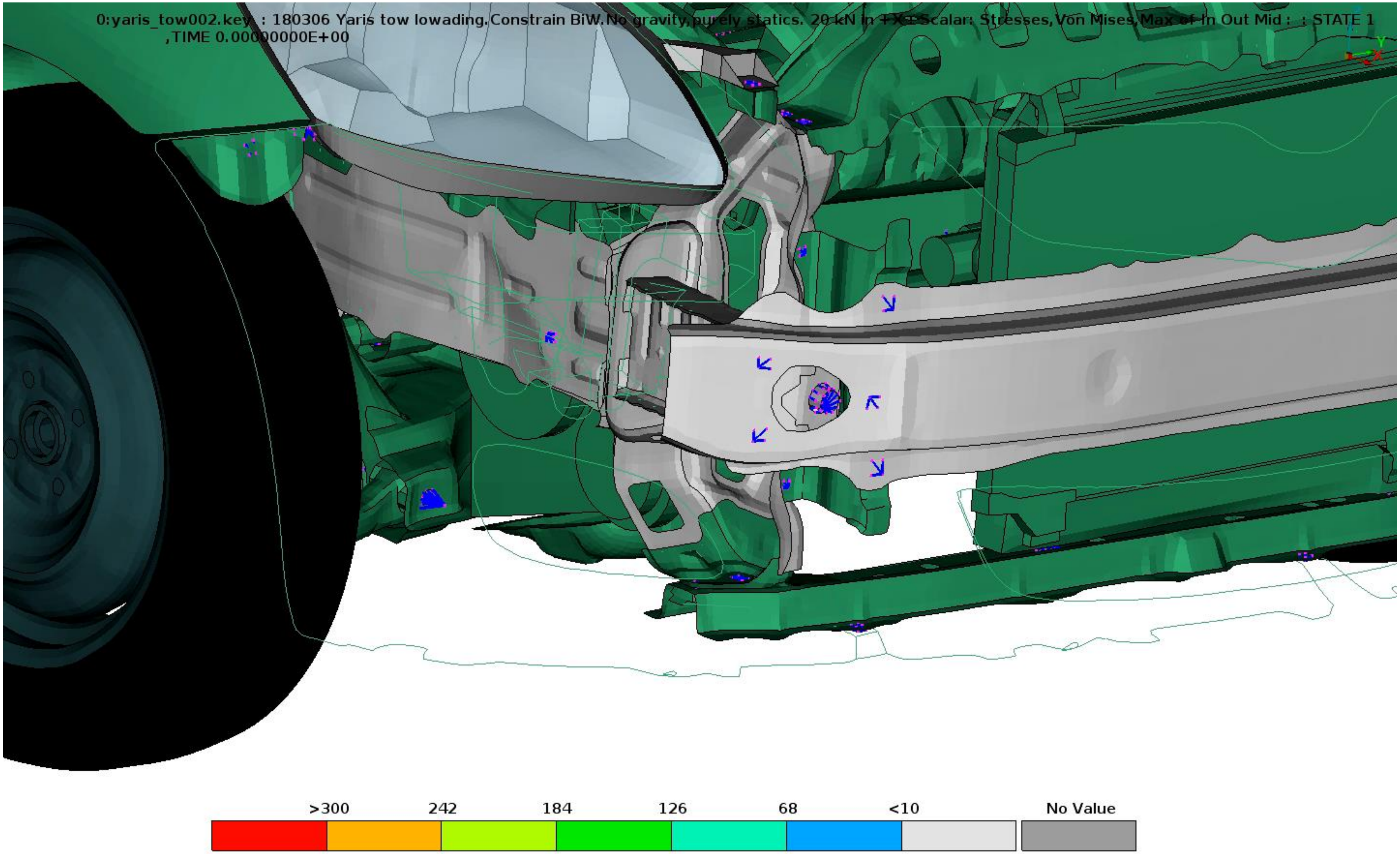
- The chassis was constrained at the wheel hubs. The BiW was constrained at the lifting positions / longitudinals
- 20 kN is applied to the towing eyelet attachment
- The Yaris model is quite simplified
  - Towing eyelet not available
  - Probably more detailed (spot) weld modelling required in the area of interest





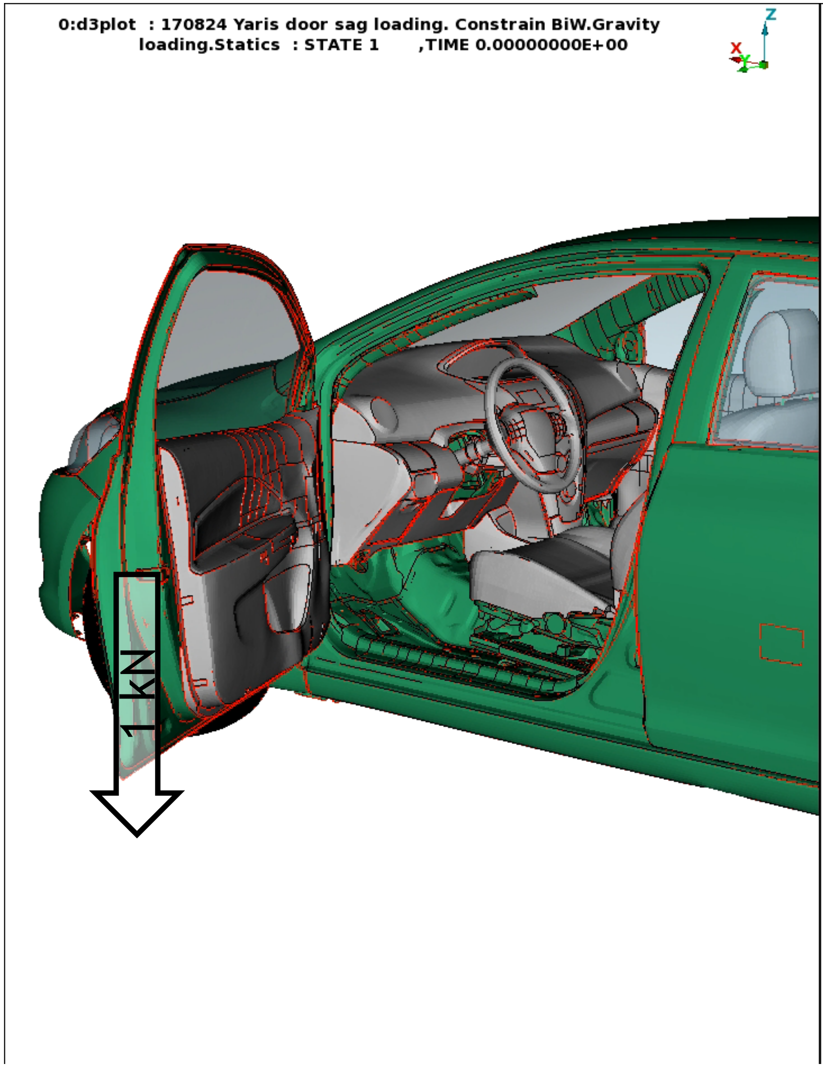
Tow loading

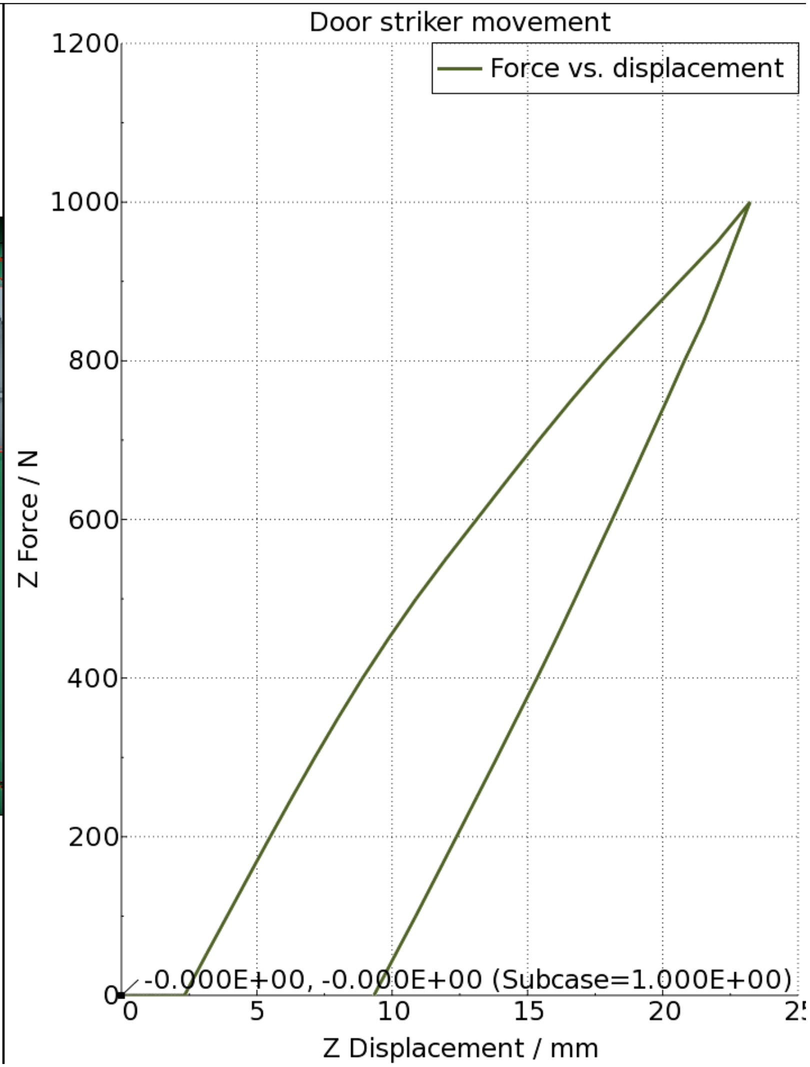
Solution time: 2h 49min on 12 cores



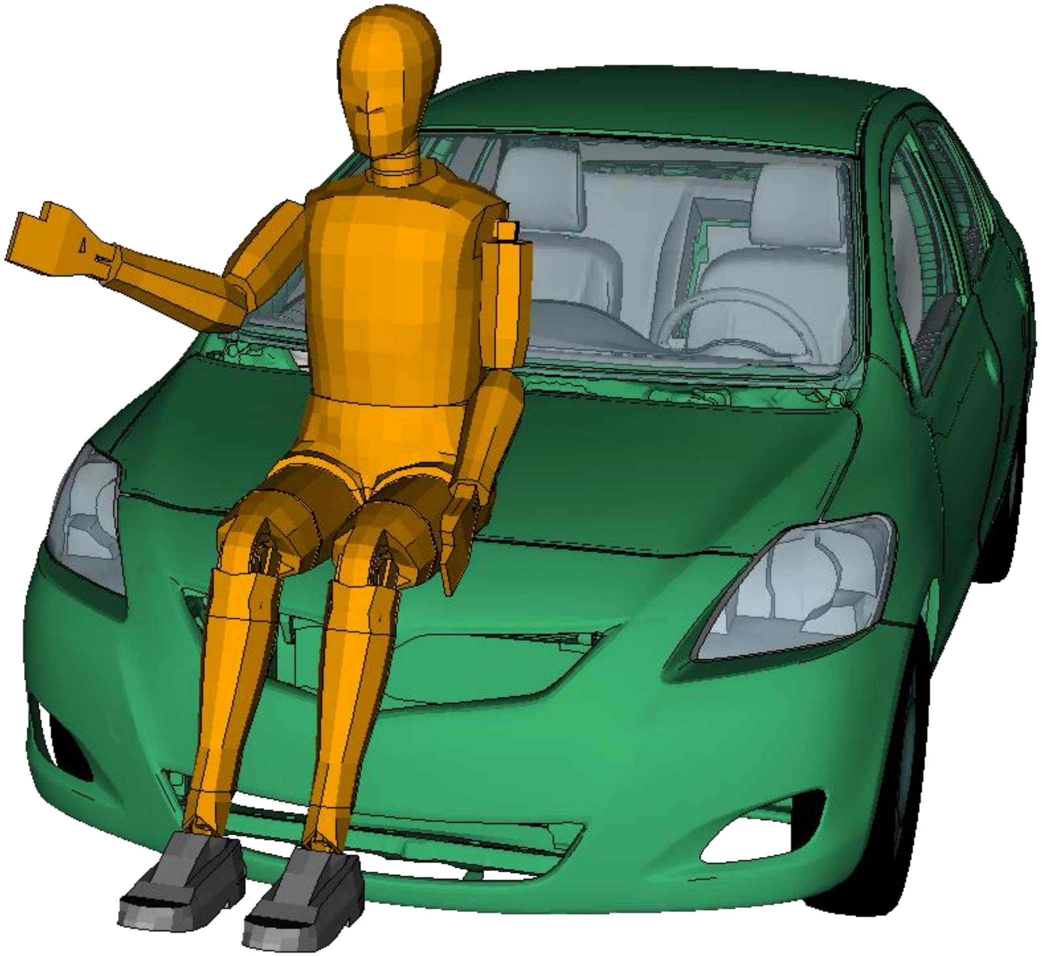
Door sag loading

Solution time: 8h 48min on 16 cores



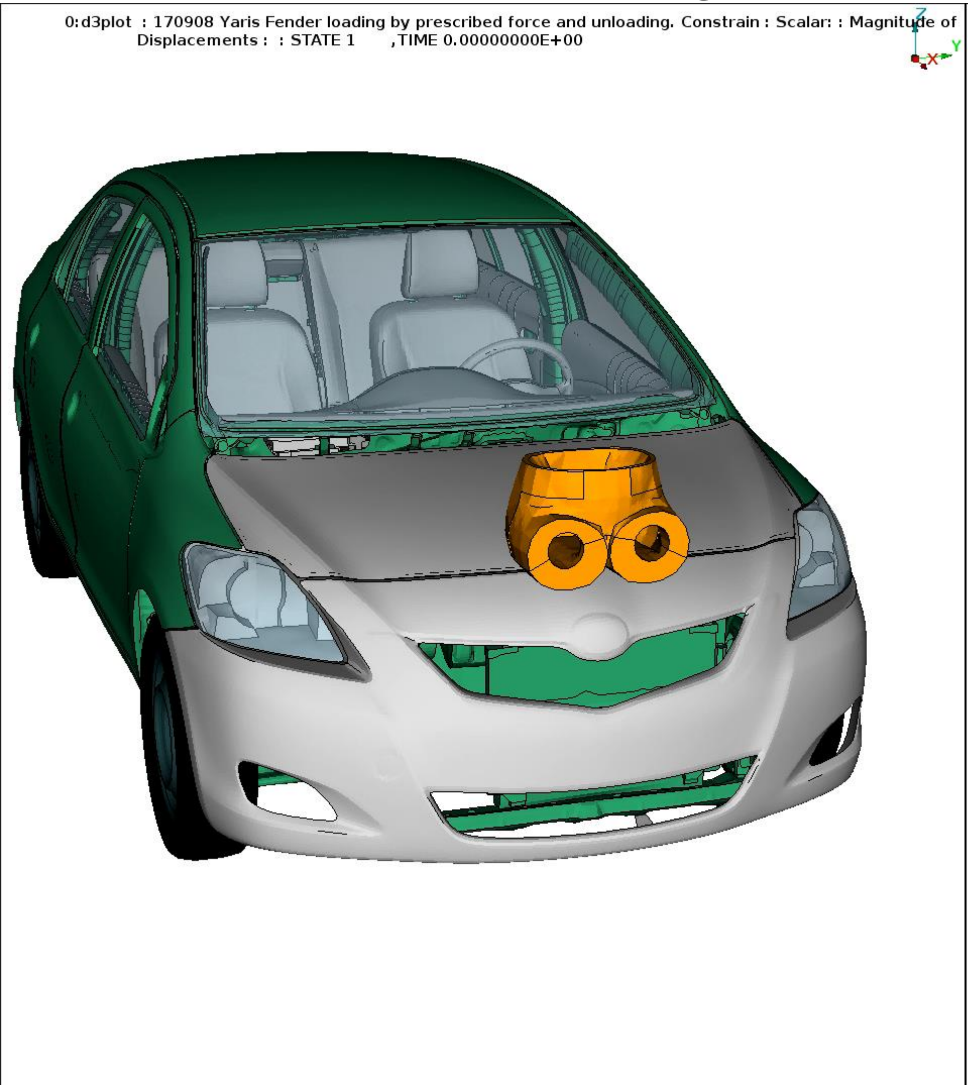


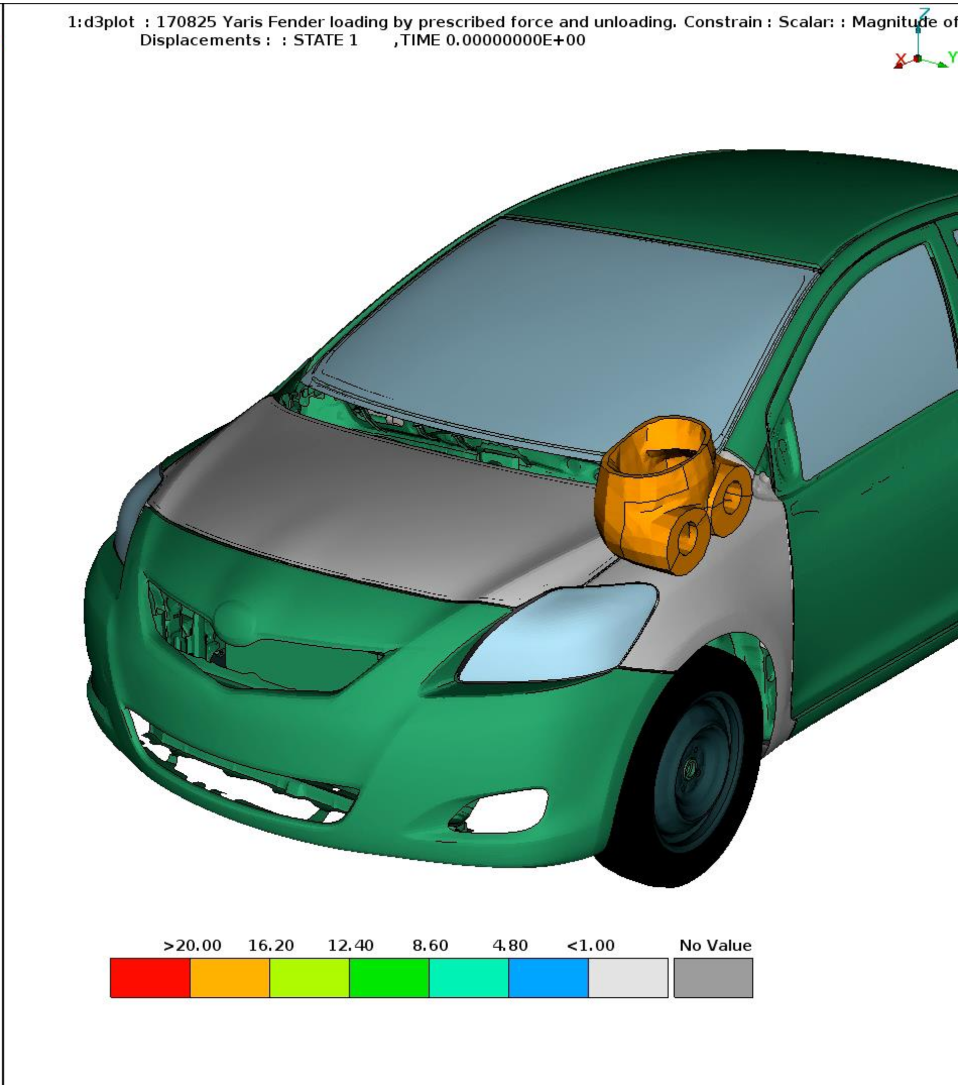
Hood / fender loading



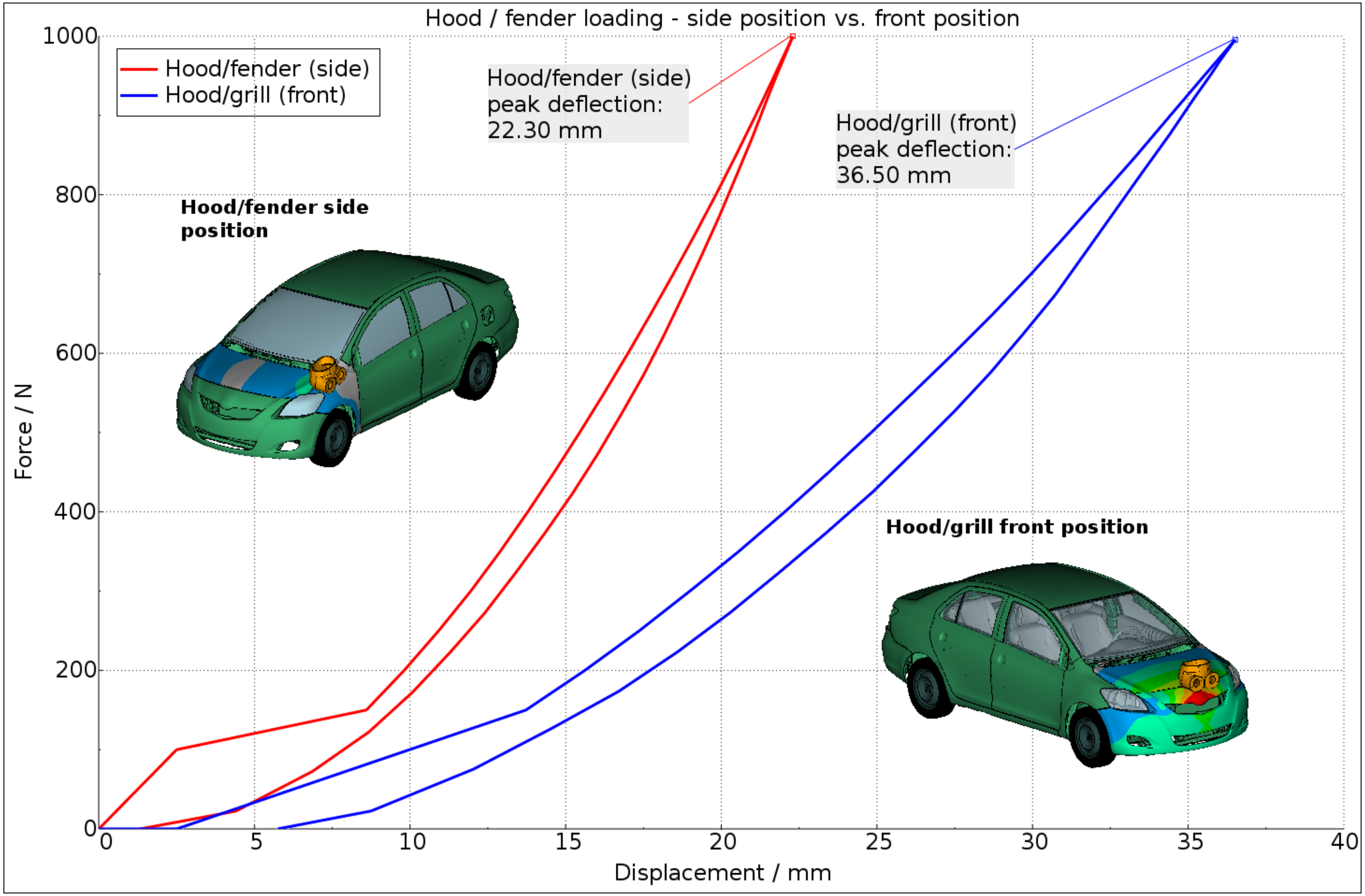
Hood / fender loading

Solution time: 7h 38 min on 24 cores



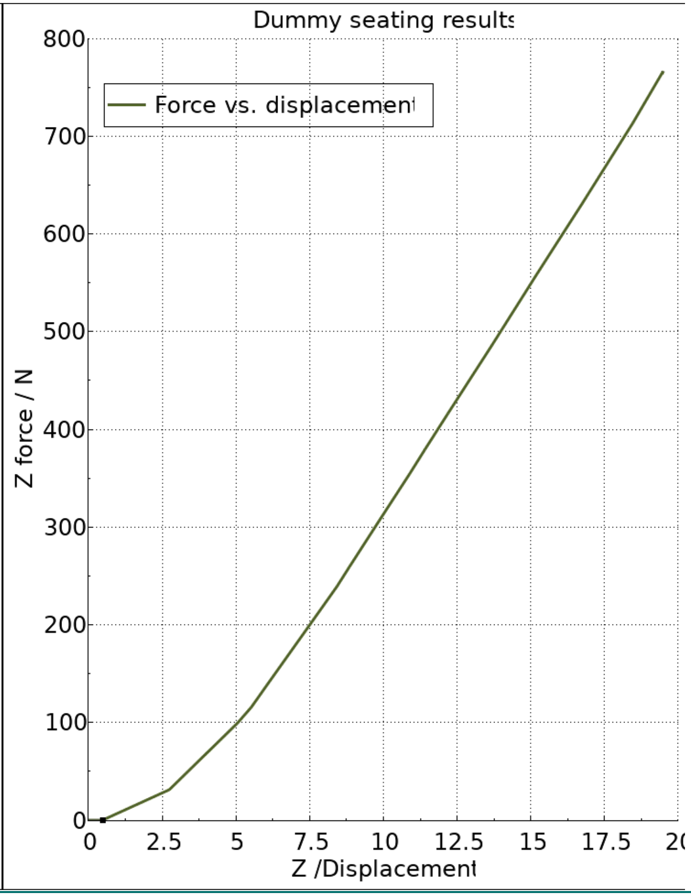


Hood / fender loading



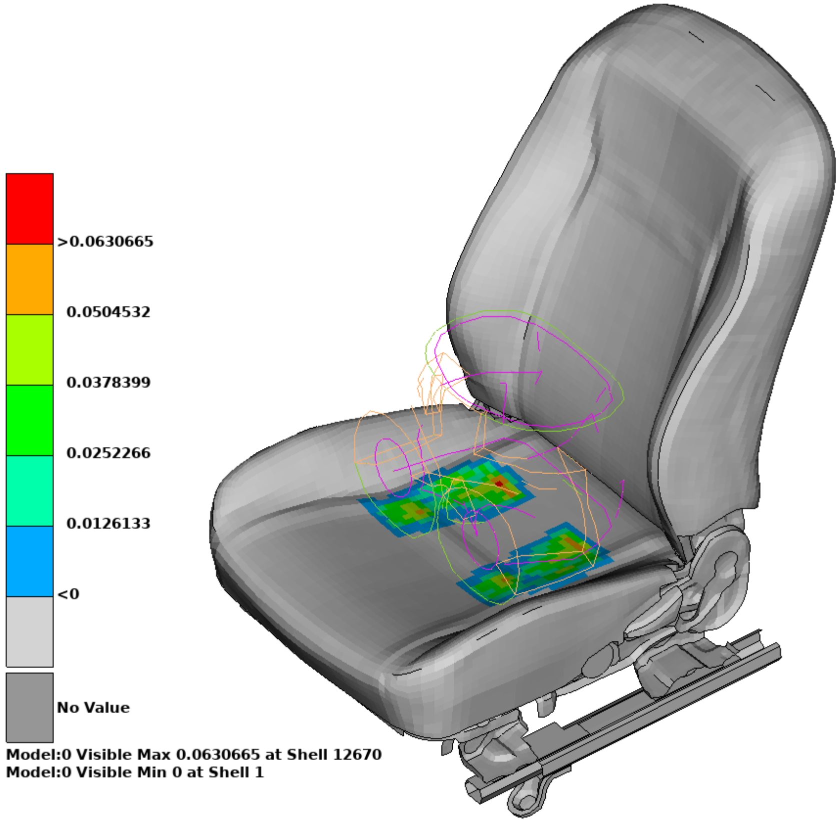
Seating

- The driver seat was isolated from the Yaris model
- The pelvis of a Hybrid III (the free Fast version from ANSYS/LST) was pushed into the seat by a force of 765 N



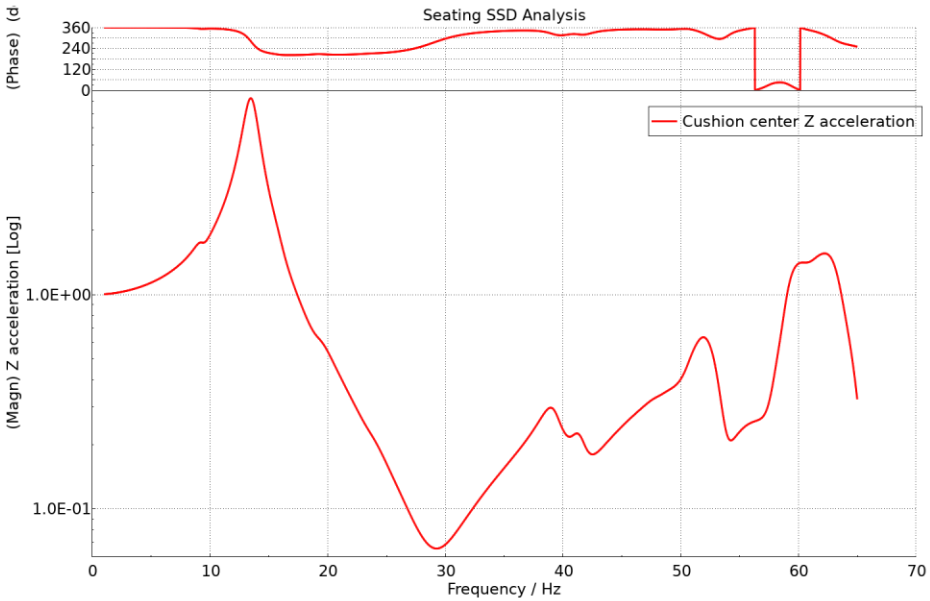
Seating

- The driver seat was isolated from the Yaris model
- The pelvis of a Hybrid III (the free Fast version from ANSYS/LST) was pushed into the seat by a force of 765 N
- The contact pressure is obtained as an indication of seating comfort



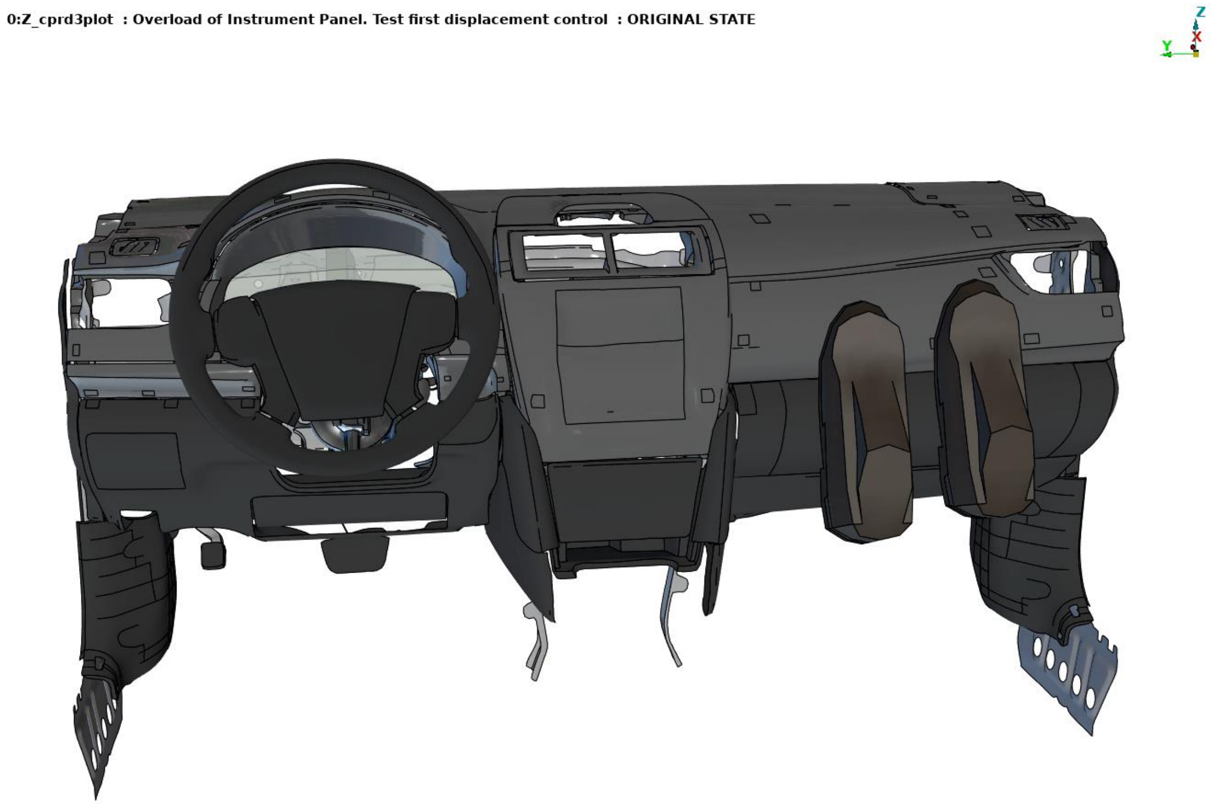
Seating

- An eigenvalue analysis of the loaded seat was performed, followed by a steady state dynamic analysis (*FREQUENCY_DOMAIN_SSD) to obtain the transfer function between the attachment points and the seat cushion



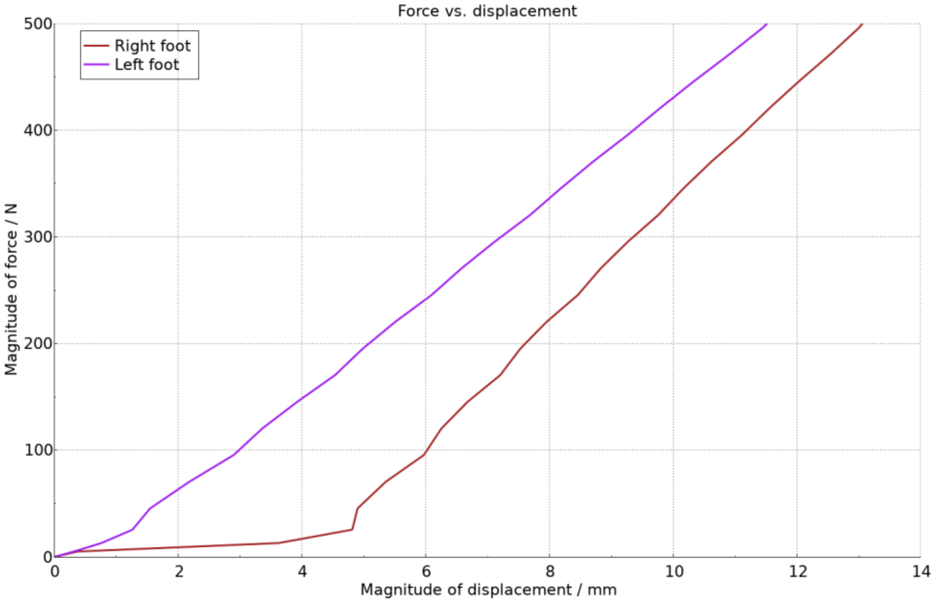
IP as footrest

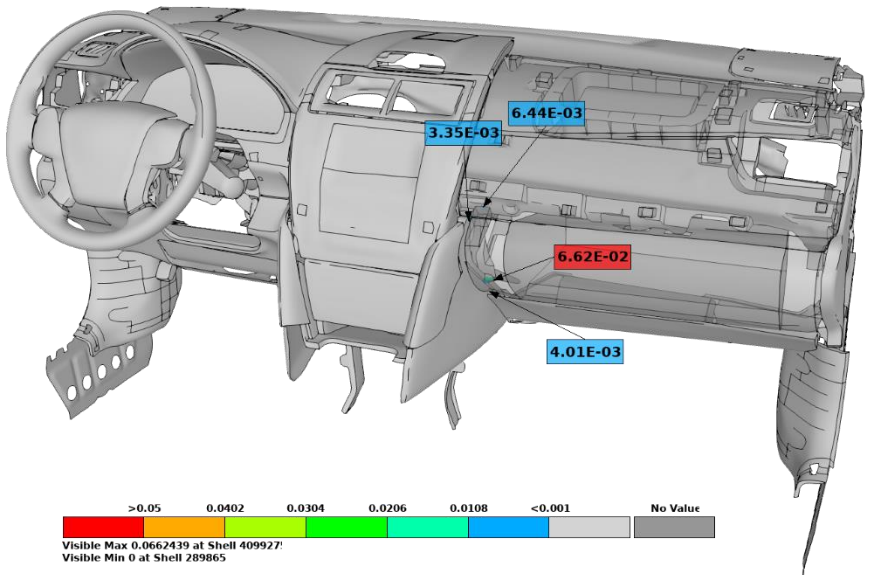
- The Instrument Panel was isolated from the Yaris model
- The feet from a Hybrid III (the free Fast version from ANSYS/LST) was pushed into the IP by a total force of 1 kN



IP as footrest

- The Instrument Panel was isolated from the Yaris model
- The feet from a Hybrid III (the free Fast version from ANSYS/LST) was pushed into the IP by a total force of 1 kN

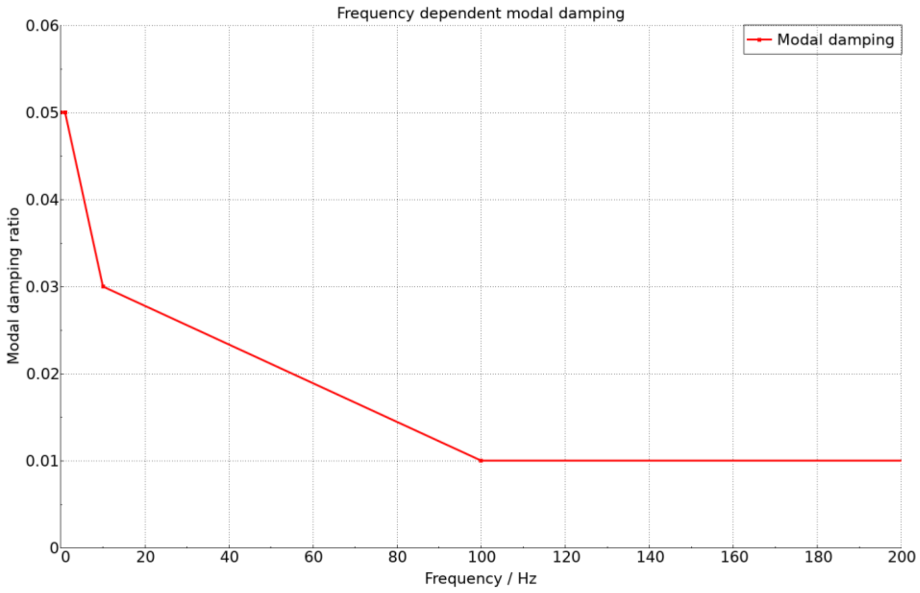




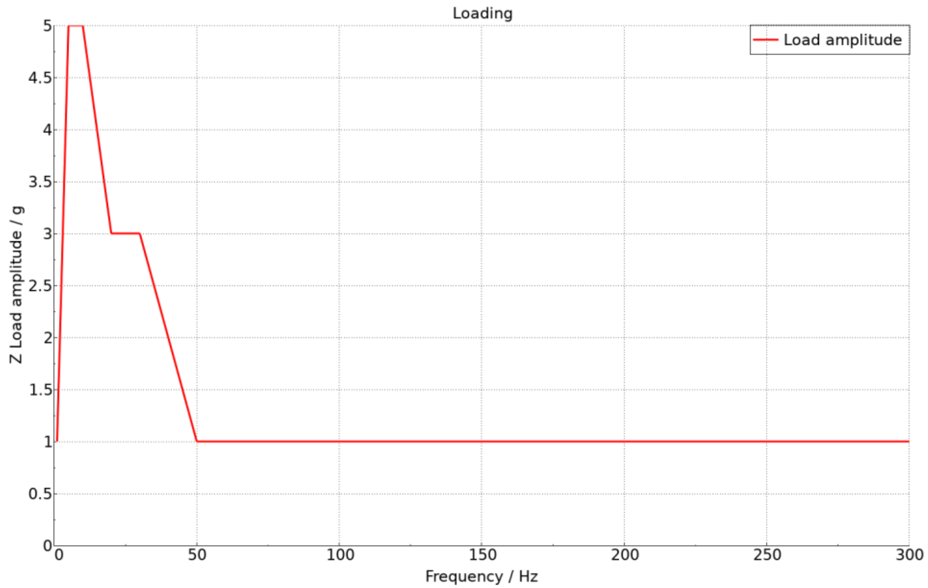
Accumulated effective plastic strain

BSR Analysis of IP

- The Instrument Panel was isolated from the Yaris model
- A Steady State Dynamics analysis was performed using frequency dependent modal damping and an assumed acceleration load



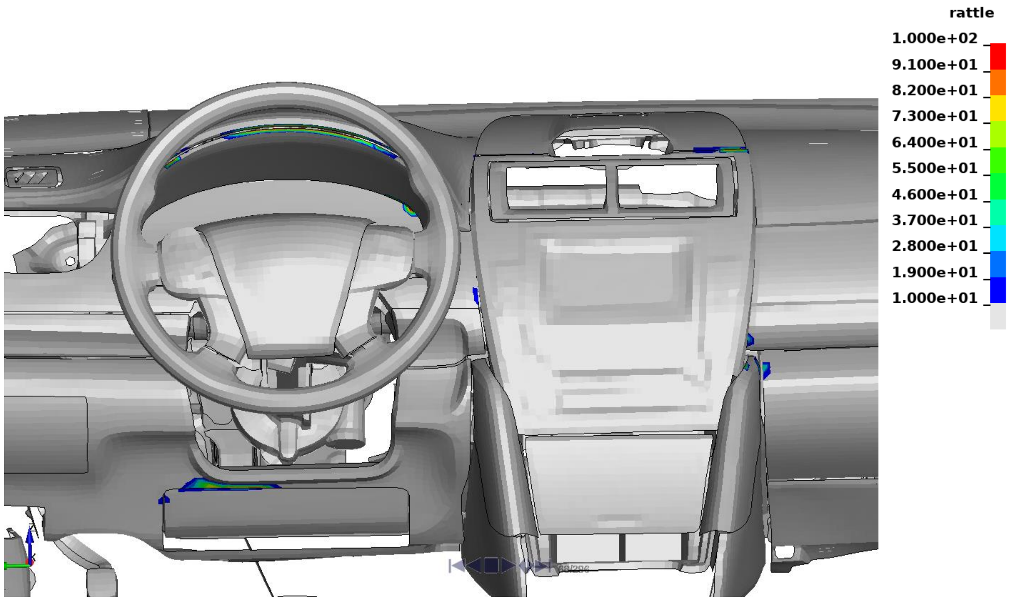
Frequency dependent modal damping

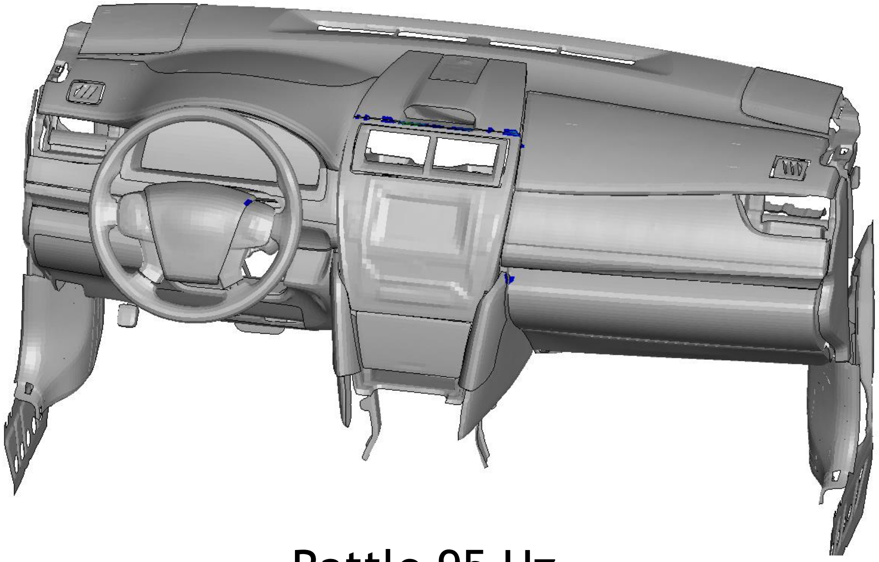


Base acceleration loading (g) vs. frequency (Hz)

BSR Analysis of IP

- Based on the SSD results (d3ssd) a Buzz, Squeak and Rattle (BSR) analysis was performed using the BSR Tool in LS-PrePost 4.7





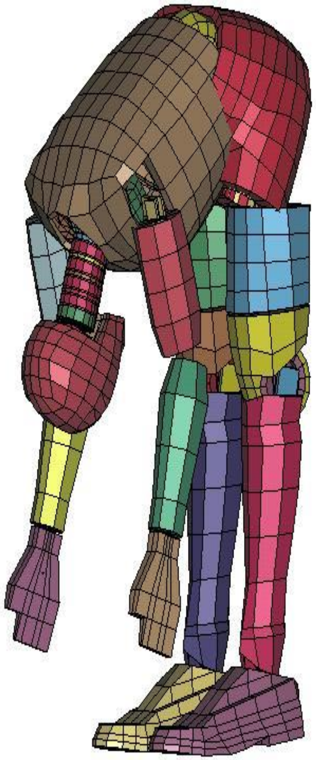
Rattle 95 Hz

Rattle 72 Hz

Summary

- FE-models for explicit analyses can in many cases be used also for implicit with minimal modifications
  - Special requirements, for example for local mesh refinement for detailed stress analysis, could also be incorporated in the model generation process
  - Extended subsystem verification for implicit could also increase model quality for explicit analyses
- The one-code strategy of LS-DYNA is well suited for multi-disciplinary optimization
- Using LS-DYNA for different disciplines makes it easier for simulation engineers from different groups to share information and experiences
- The Guideline for implicit analyses in LS-DYNA can serve as a starting point
  - Build experience for your specific needs by consistent use of settings, element types etc.
- Examples of full-car models and sub-system models were presented
- Further reading:
  - Roof-Crush Analysis of the Volvo XC40 using the Implicit Solver in LS-DYNA
  - Re-Using Crash Models for Static Load Cases with Minimal Effort

Thank you!



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