Structural Analysis of major Formula Student racecar components at TU Wien Racing: Drivetrain, Wishbone, Sandwich Structure

Altair Student Webinar Series

Speaker Profile

- Studying Mechanical Engineering, Vienna University of Technology
- 2018 – 2021: Design Engineer at Watt Drive Antriebstechnik
- 2018 – today: Member of TU Wien Racing
  - Chassis & Composite Department
  - Implicit and Explicit Simulations
  - Optistruct, Radioss and Inspire
  - Current project: Crashsimulation

Philipp Link

Member of Composites – TU Wien Racing

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ALTAIR

TU Wien Racing

EDGE12

FOUNDED
By 8 ambitious students
2006

FIRST MONOCOQUE
2012/13
From tubular steel frame to carbon monocoque

AERODYNAMICS
Keeps the EDGE stable on the ground
2012/13

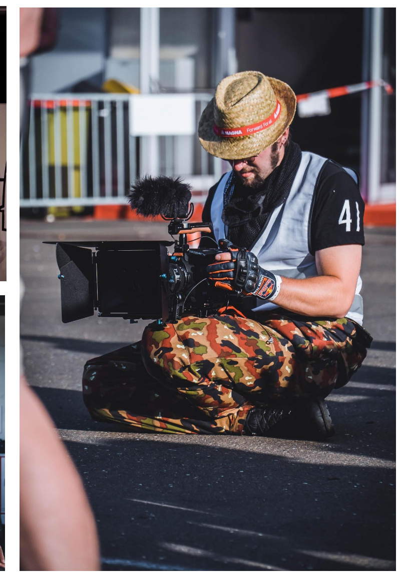
ELECTRIC POWER
2013/14
For more than seven years we have been developing electric vehicles

COMPLETE REVISION
From monocoque, to suspension, to battery pack
2018/19

THE FUTURE
today
From all-wheel drive to driverless, we never get bored. Guaranteed!

EDGE Mk I

90 Team members



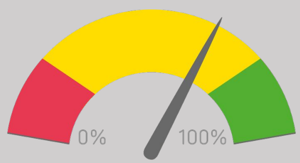
TUW racing
VIENNA FORMULA TEAM

ALTAIR

Philosophy

Lightweight Design

- analyzing loadcases
- selecting suitable materials
- optimizing subcomponents
- effective resource management
- analyzing failure modes
- improving with gathered date

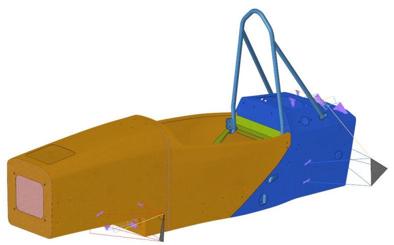


Self-developed Components

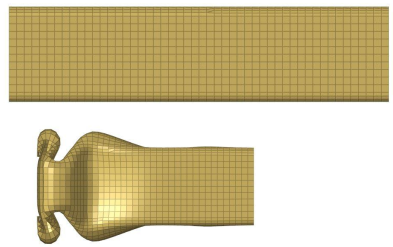
- Powertrain: Inverter, Motor & gearbox
- Wishbones, Rims & Wheel assemblies
- Battery package
- Monocoque
- Electrical systems
- Manufacturing processes

Altair Software

Optistruct

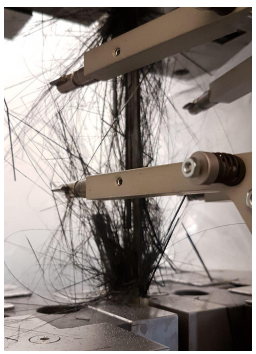


Radioss

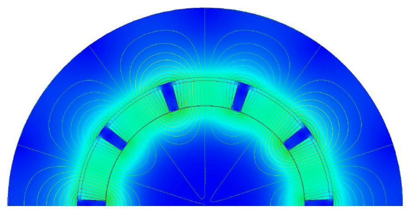


Inspire

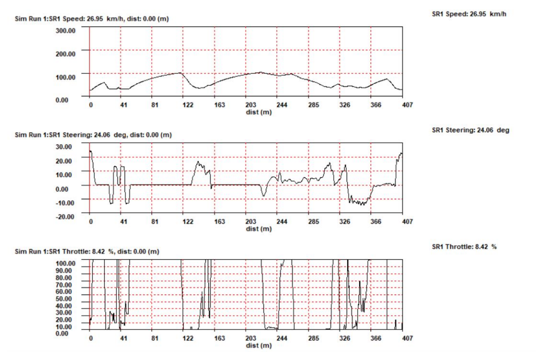
Multiscale Designer



Flux



Chassis Sim



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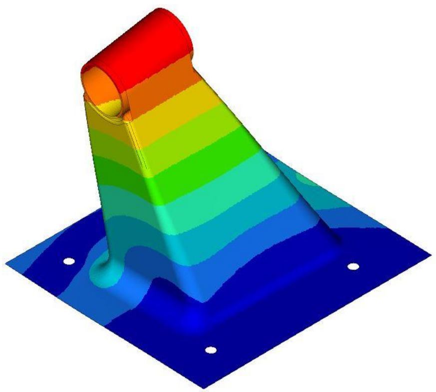
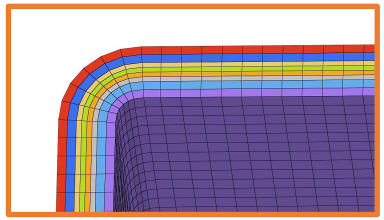
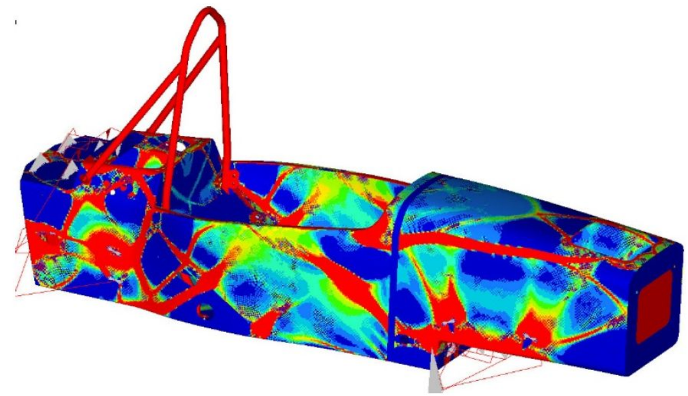
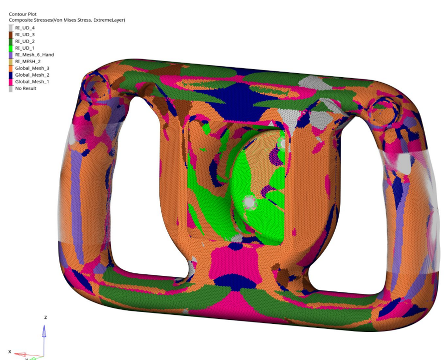
Optistruct

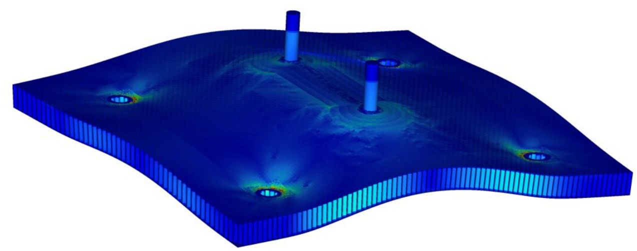






Optistruct





Drivetrain assembly analysis

- Using Altair Hyperworks meshing tools for solid mesh generation and mesh optimization
- Contact analysis setup
- Non-linear pretension analysis and using sub-load cases

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Altair Student Webinar Series

Speaker Profile

Studying mechanical engineering at Vienna University of Technology

- 2018-2019: Team member at TUW Racing
- 2019-2020: Chief Technology Officer
- 2020-today: Head of electric machines, Member of Suspension

Development of Motor, Drivetrain and Wheel assembly

Rudolph Ring

Member of Suspension – Head of electric machines
TUW Racing

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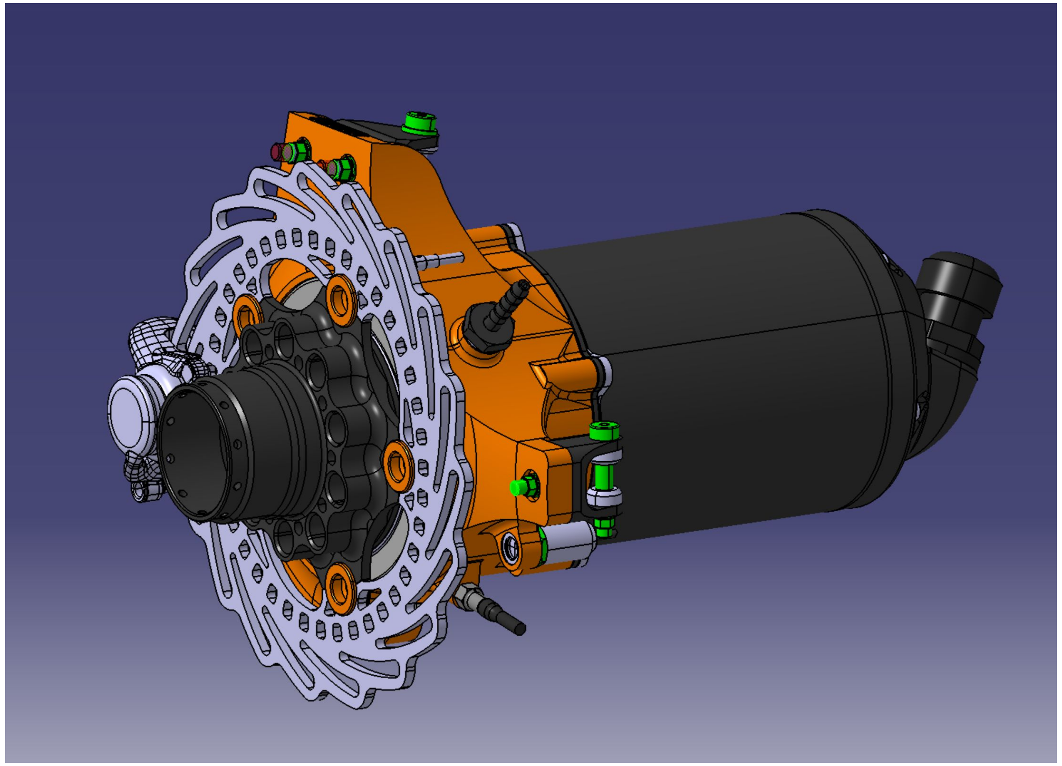
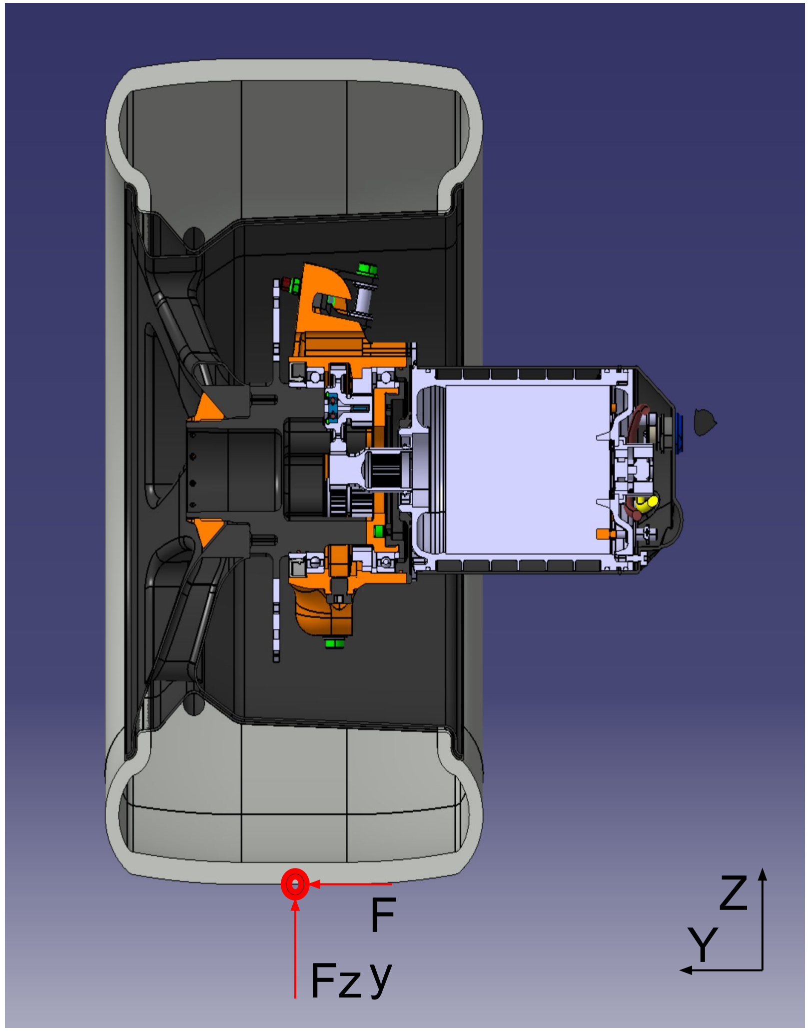
What for?

Computation of stress and displacement during different loadcases enables:

- Stiffness evaluation (Camber/Toe gain etc.)
- Opportunities for weight reduction
- Displacement of gearing components directly affects gear meshing, reducing efficiency and lifetime
- Other

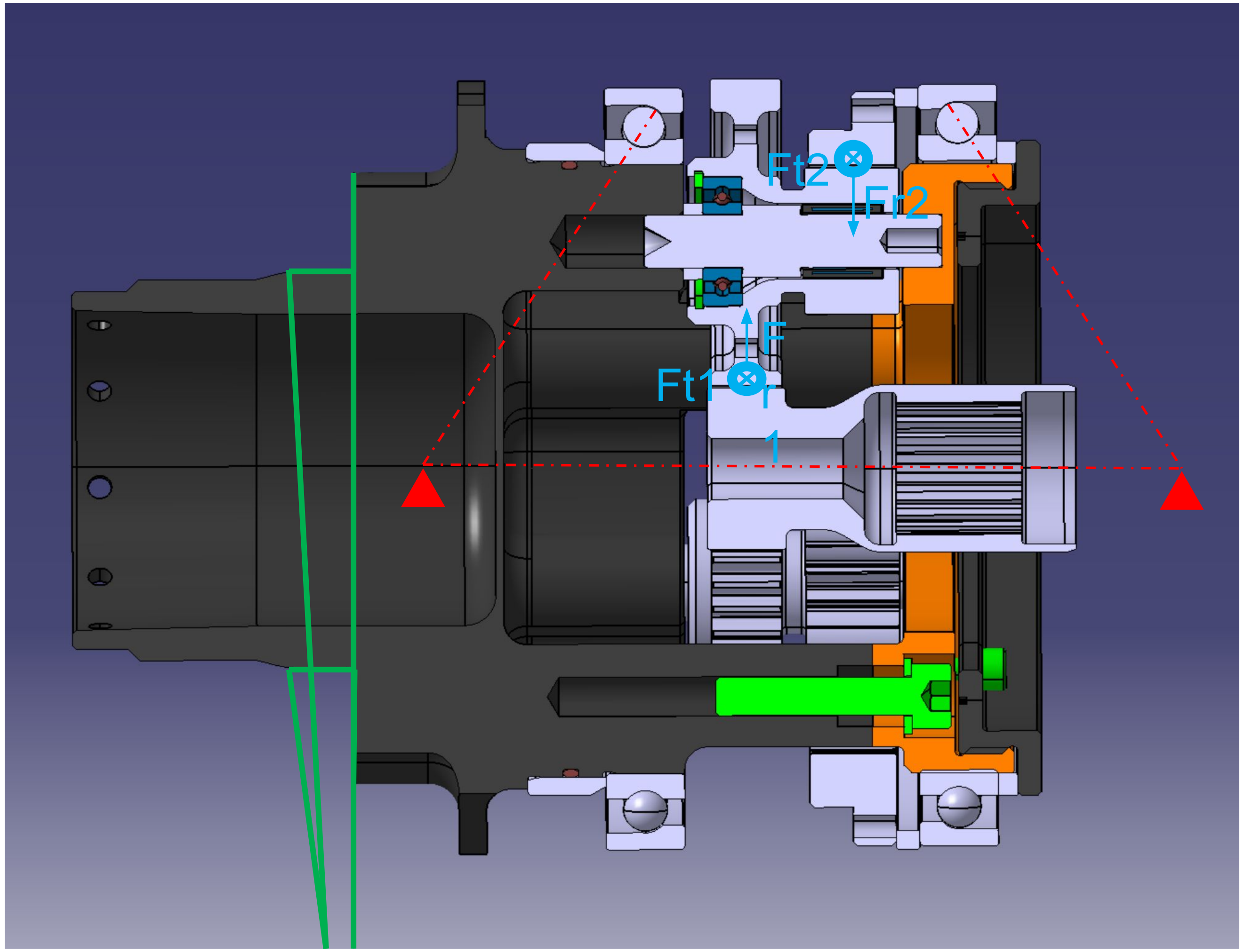
CAD Model Overview





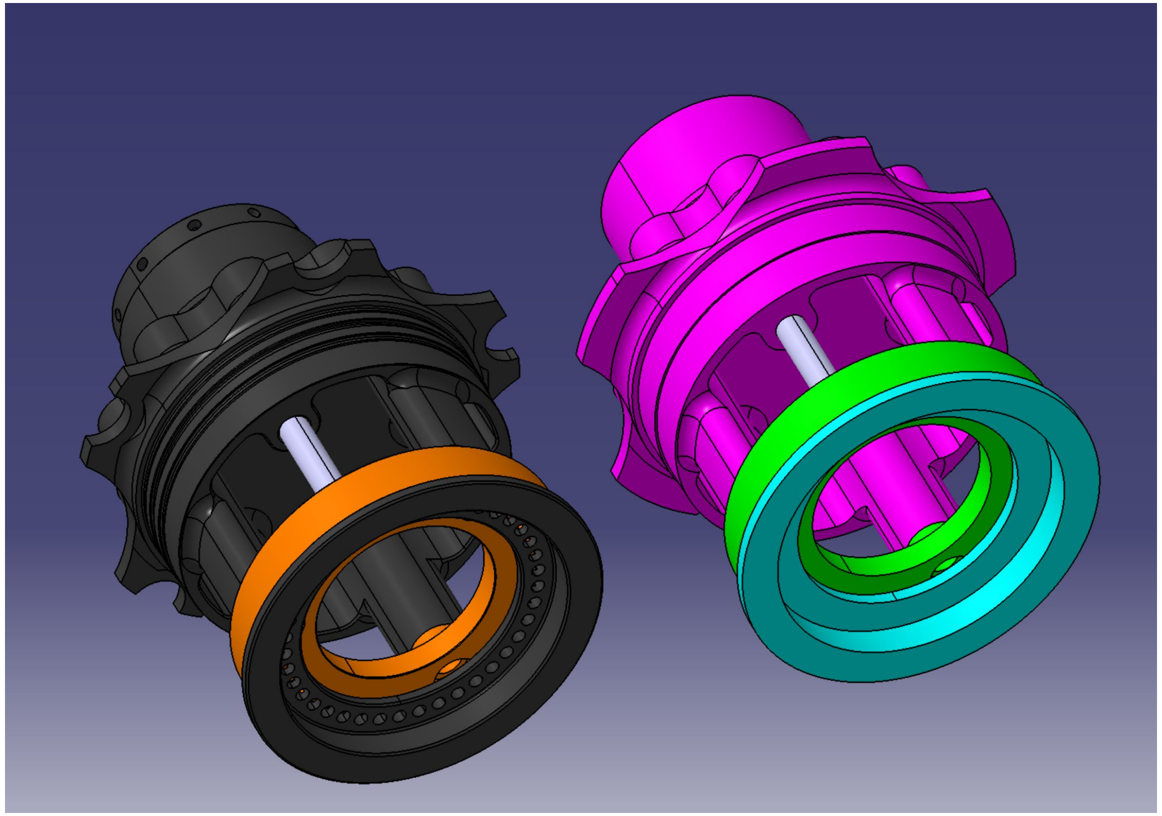
Tire forces applied at contact patch
Fy: +2000N, Fz: +1000N

CAD Model Overview



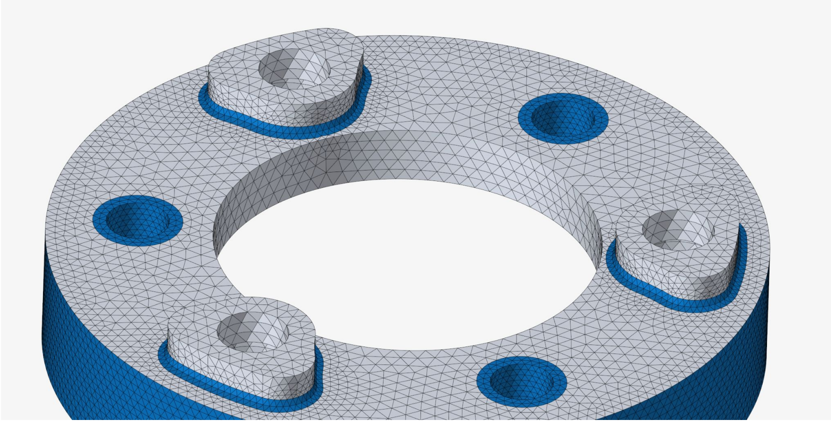
- Contact angle of the angular contact bearings will be represented in the FE-model using RBE2-elements
- Tangential and radial force components, applied to the pinshafts
- Rim and tire will not be modelled, force will be applied at contact patch center over RBE3-elements
- Constraints at the contact angle center points and contact patch center, fully constraining the model

CAD Model Simplification



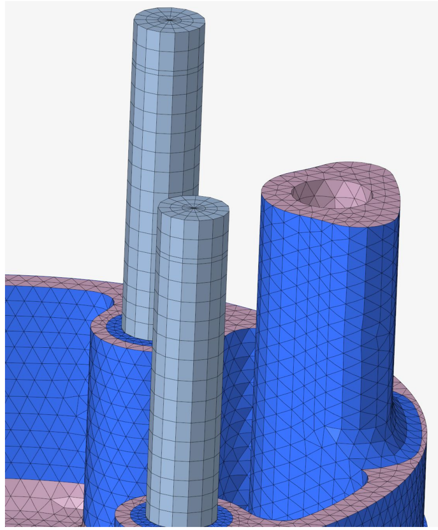
For better mesh quality and avoiding small mesh sizes, the initial model is simplified in non-critical areas, removing fillets, chamfers and other geometry

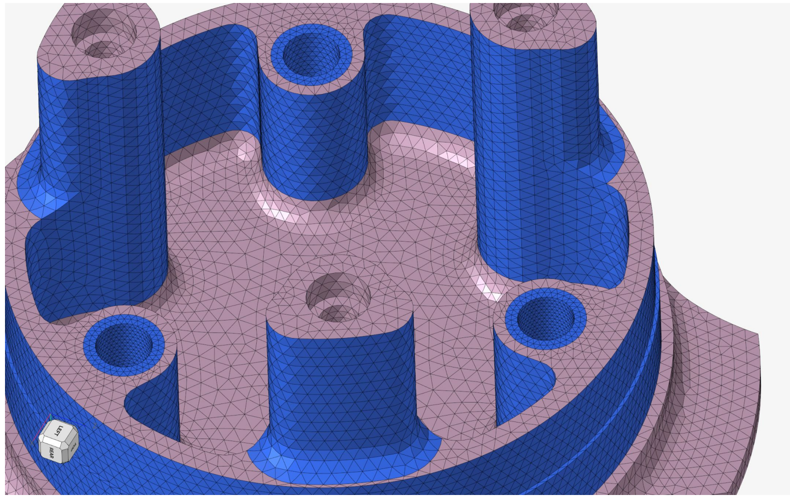
Meshing overview



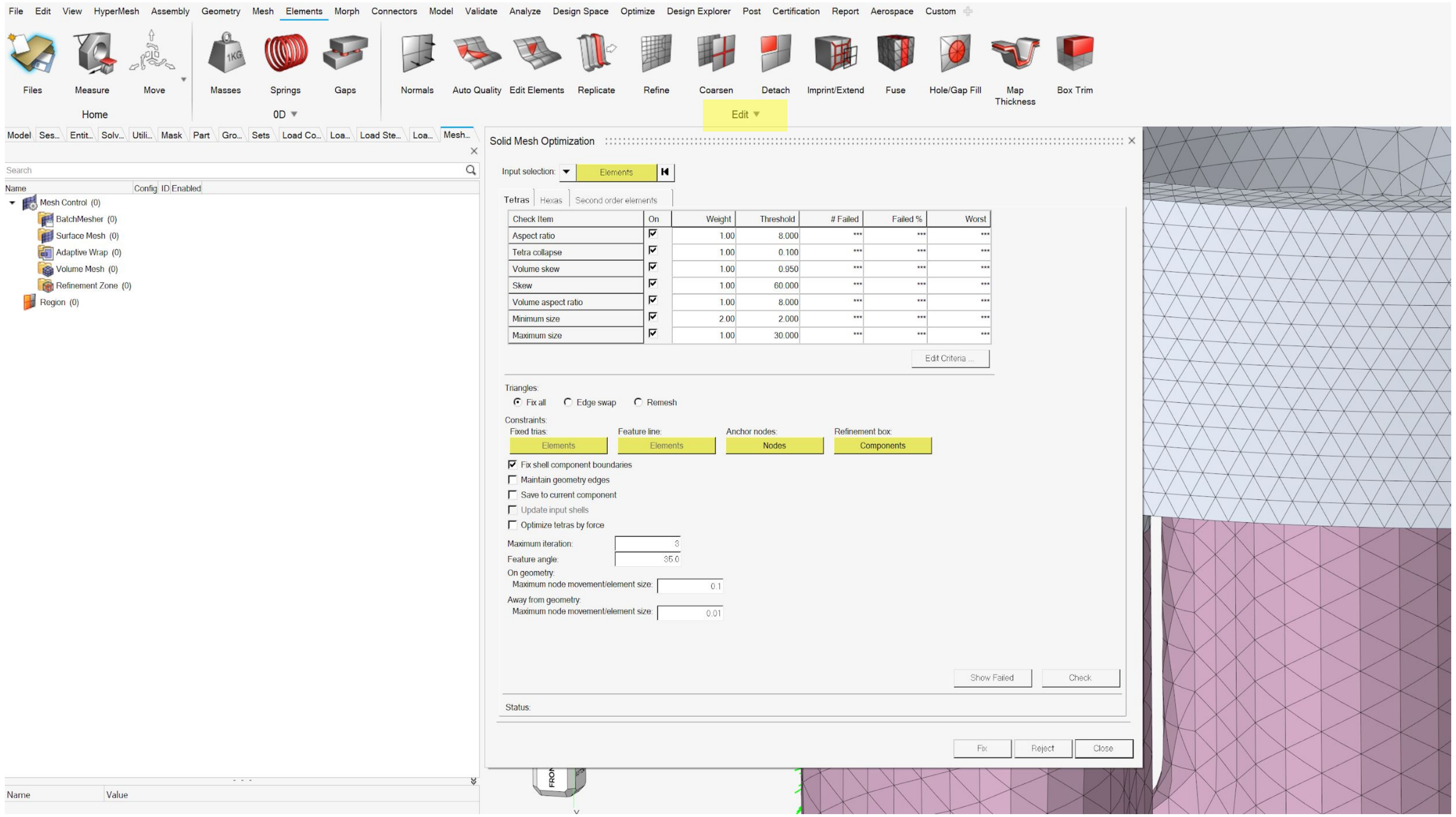
- 2D support meshes (Blue) were used for mesh refinement around critical geometry and generally better mesh control when using 3D-tetrameshes
- Using hexa-elements wherever possible for simpler geometry (solid mappable geometry, rotational symmetric etc.)

- Usual rules for discretisation apply





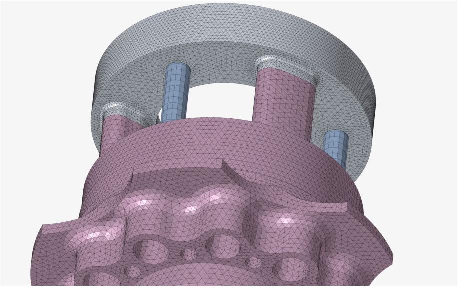
Solid Mesh optimization tool



Used quality metrics

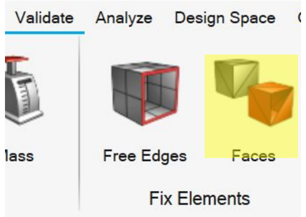
- Aspect ratio < 3
- Jacobian > 0.6
- Tetra collapse > 0.15
- Skew < 60°

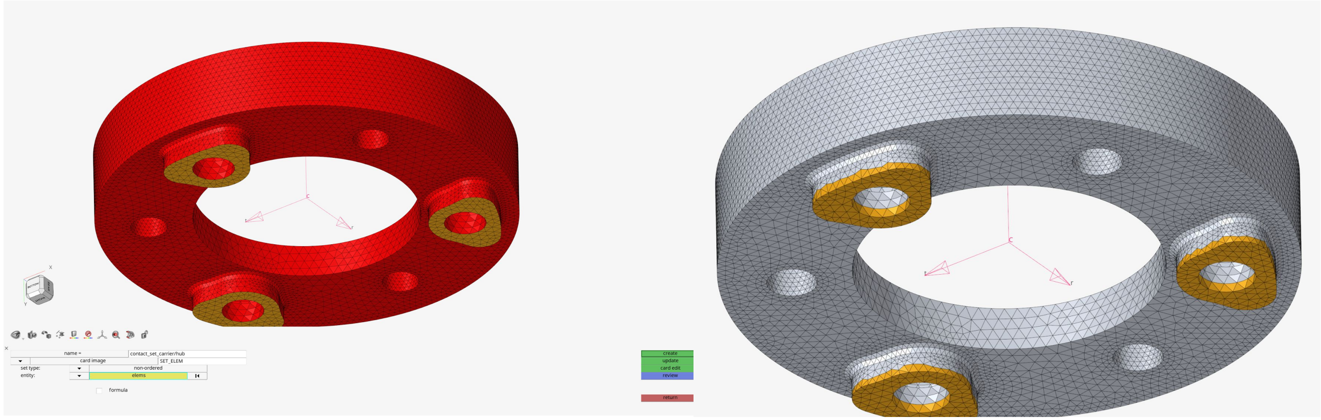
Contact definition workflow



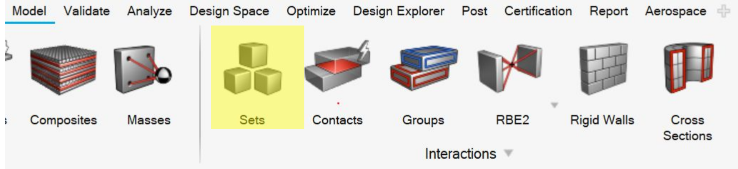
Fully meshed geometry

„Faces"-mesh generation, hide original 3D-mesh

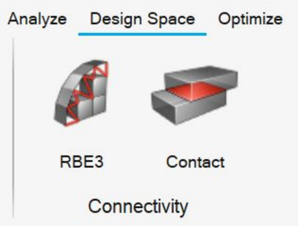




Create new element set, selecting relevant geometry using available 2D-mesh selection tools (eg. „By Face")



Show 3D-mesh, in set-selection, select option „By Adjacent", hide 2D faces mesh



Create contact group, select respective element sets, define contact behaviour

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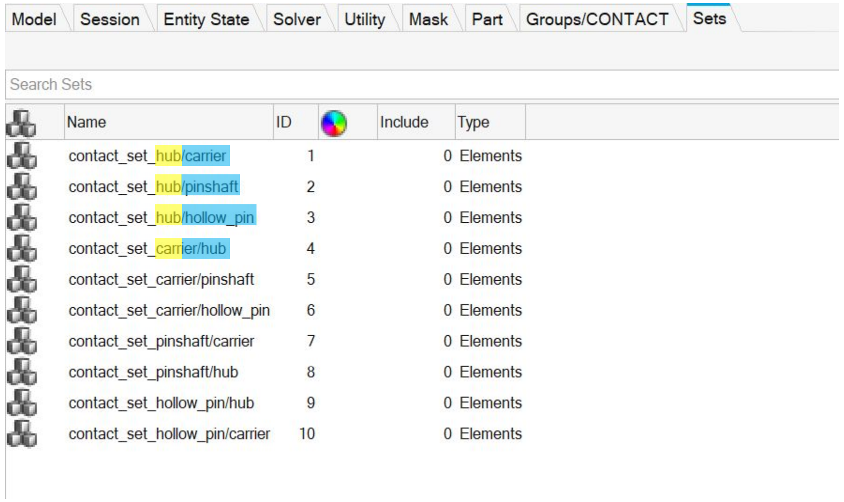
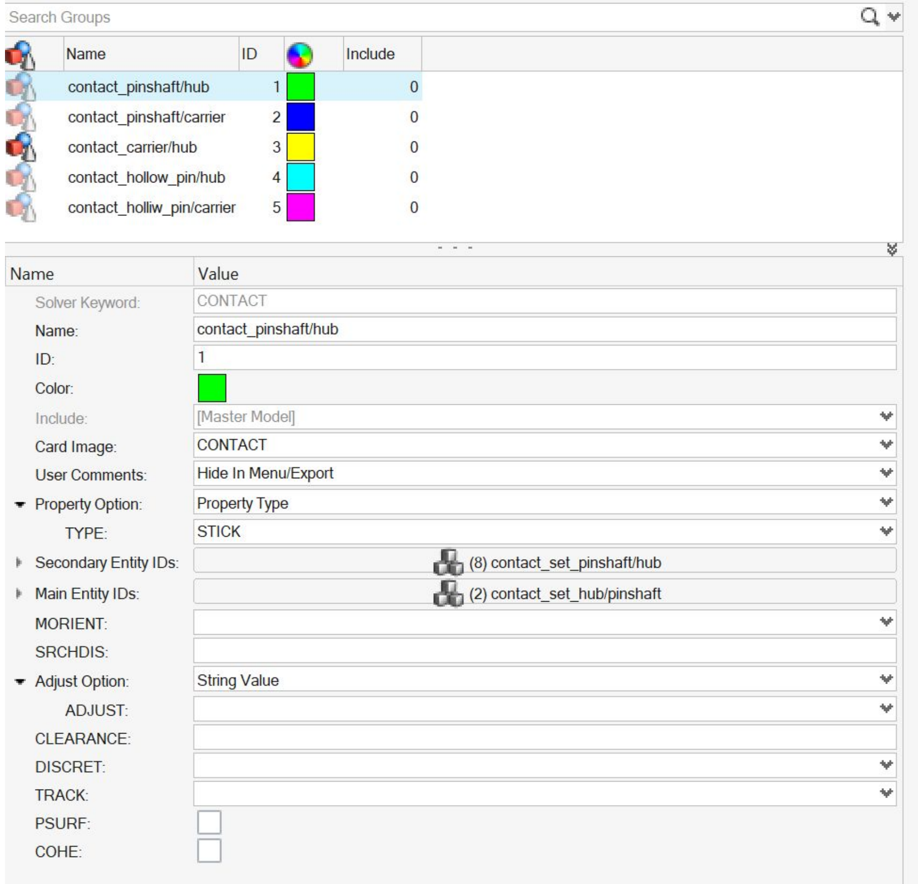
Contact definition workflow

- Human-readable element-set naming convention greatly improves overview, especially on more complex models with higher number of element sets and contacts

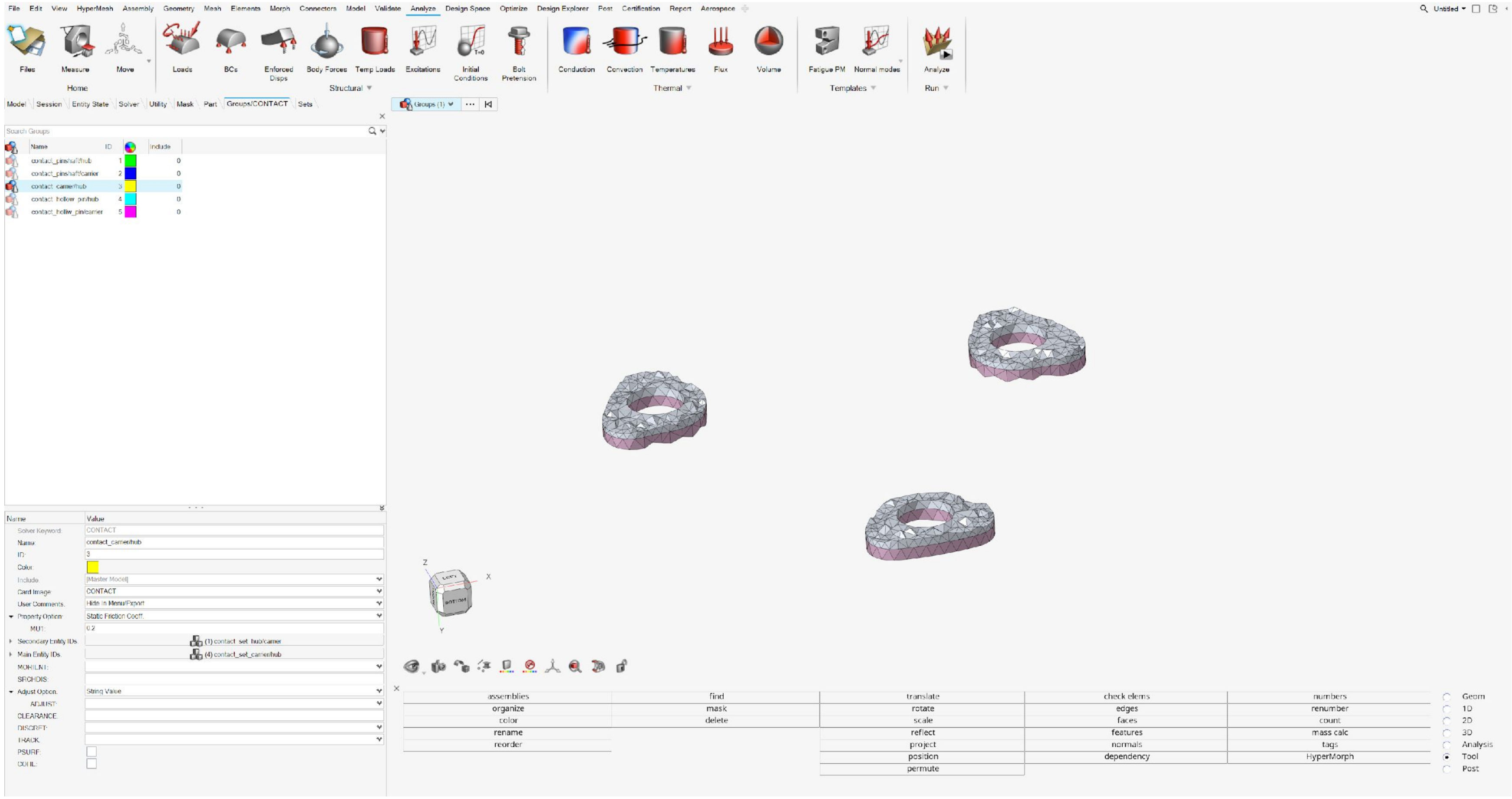


- Example for naming convention:

contact_set[first part, selected elements]/[second part]

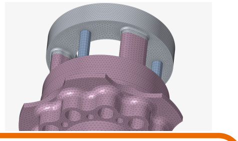


Contact definition workflow



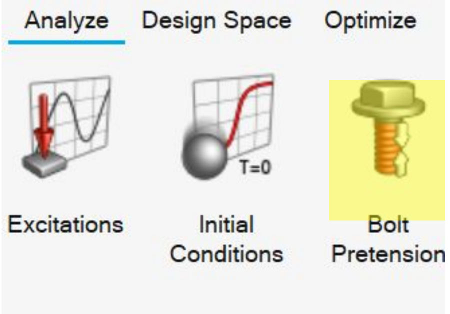
Verifying contact group using „Isolate“

Pretension definition workflow

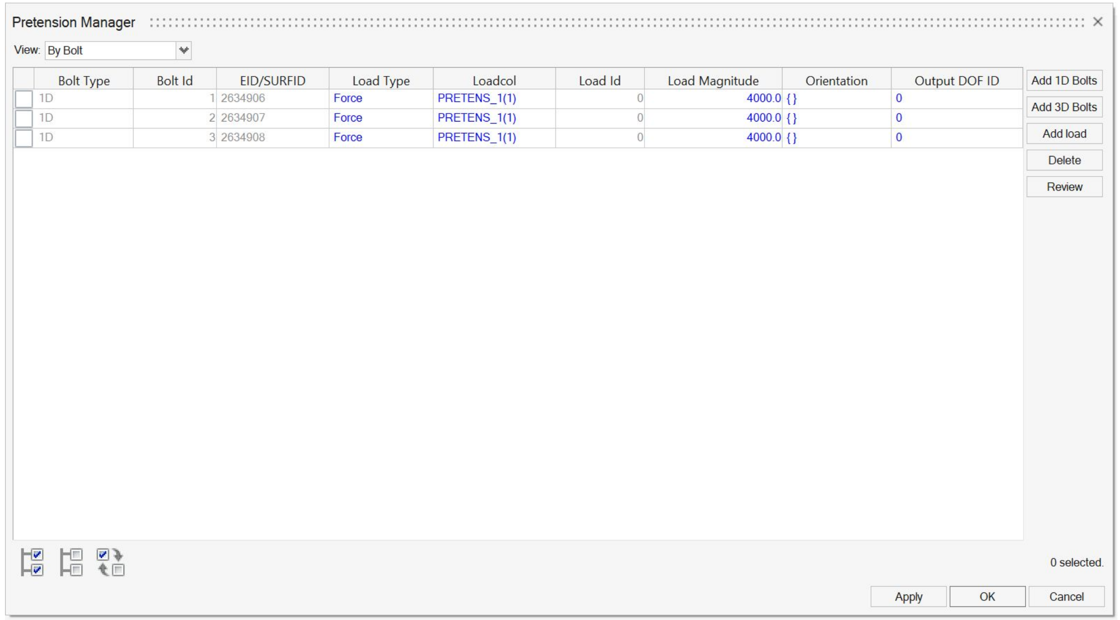


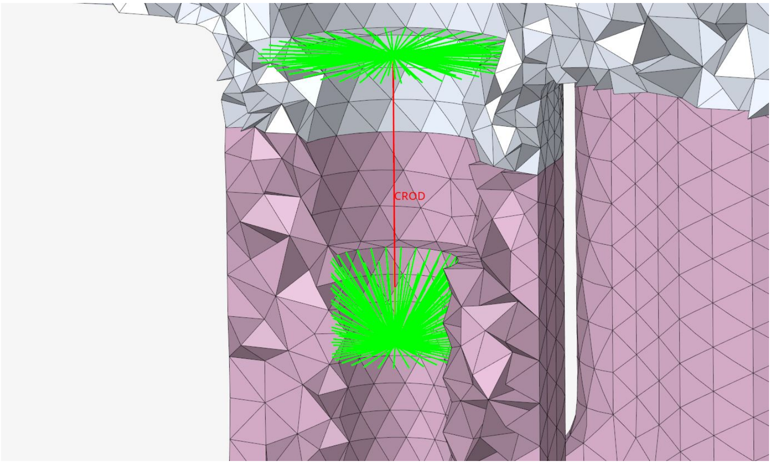
Fully meshed geometry

Generate 1D* or 3D-Bolt elements between nodes



Open „Pretension Manager“, create new loadcase, select bolt elements, define pretension or displacement





* 1D-elements like CROD, CBAR, CBEAM are selectable. Element crosssection has to be defined in the according properties

Pretension definition workflow

Create new loadstep „loadstep_pretension“, nonlinear-static in addition to the external loadstep

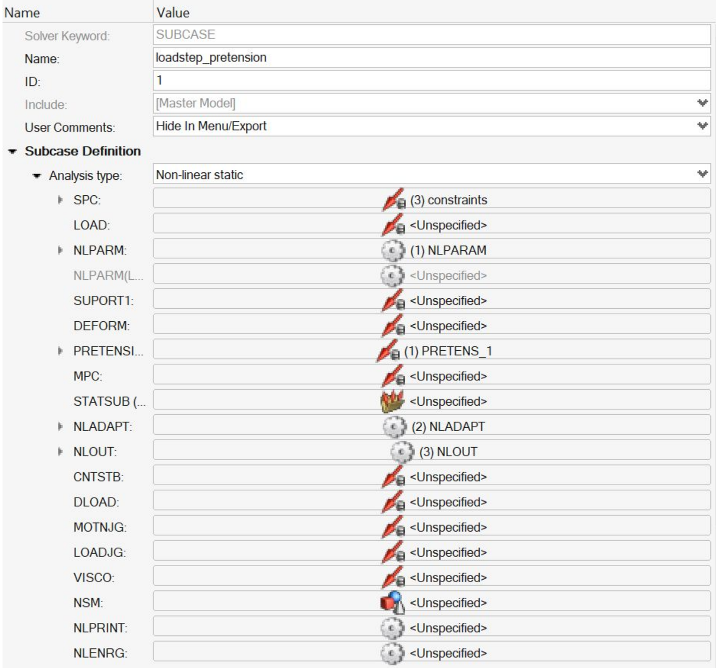
Load step inputs

Create Load step input card NLPARAM, config type „Nonlinear Parameters, default parameters

Create Load step input card NLADAPT, config type „Time step parameters“, emplty parameters

Create Load step input card NLOUT, config type „ Output parameters“, emplty parameters

Under „loadstep_pretension“ parameters, select the Load step input cards NLPARAM, NLADAPT and NLOUT, SPC and PRETENS



Pretension definition workflow

Under „loadstep_external“, select SPC, LOAD, and under STATSUB select „loadstep_pretens“

Name	Value
Solver Keyword:	SUBCASE
Name:	loadstep_external
ID:	2
Include:	[Master Model]
User Comments:	Hide In Menu/Export
Subcase Definition	
Analysis type:	Non-linear static
SPC:	(3) constraints
LOAD:	(2) load_external
NLPARM:	(1) NLPARAM
NLPARM(L...	<Unspecified>
SUPORT1:	<Unspecified>
DEFORM:	<Unspecified>
PRETENSI...	<Unspecified>
MPC:	<Unspecified>
STATSUB (...	(1) loadstep_pretension
NLADAPT:	(2) NLADAPT
NLOUT:	(3) NLOUT
CNTSTB:	<Unspecified>
DLOAD:	<Unspecified>
MOTNJG:	<Unspecified>
LOADJG:	<Unspecified>
VISCO:	<Unspecified>
NSM:	<Unspecified>
NLPRINT:	<Unspecified>
NLENRG:	<Unspecified>

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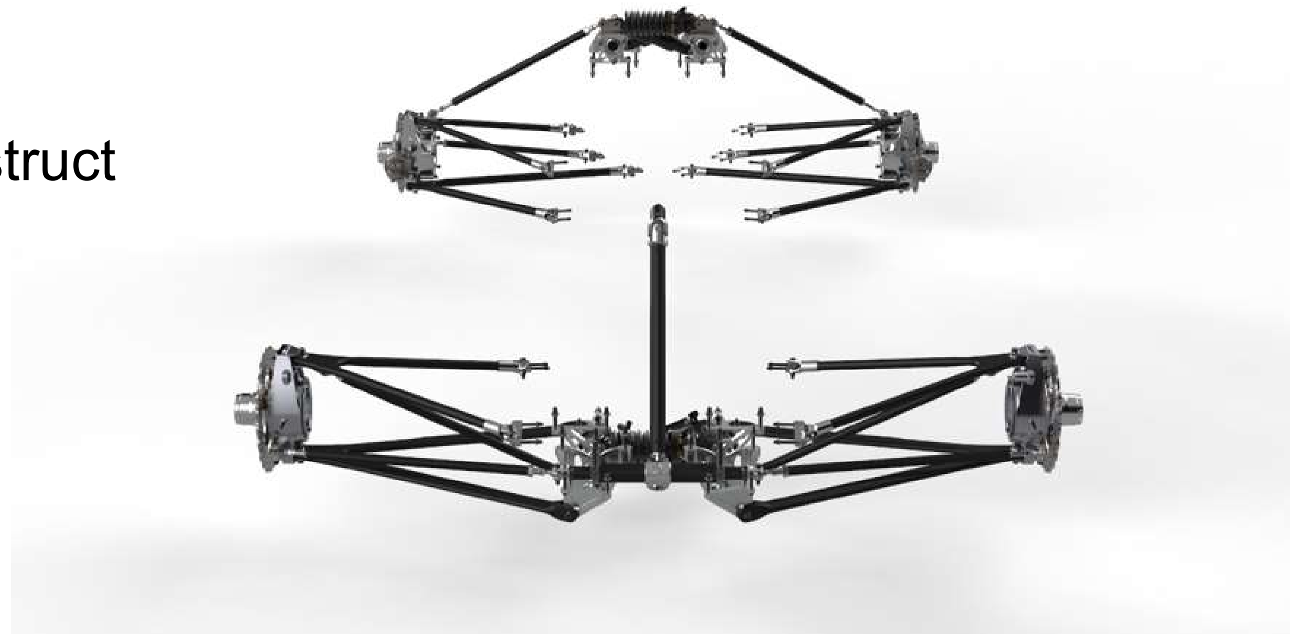
Wishbone
Linear Buckling Analysis

- Fully laminated CFRP wishbones
- Implicit analysis with optistruct



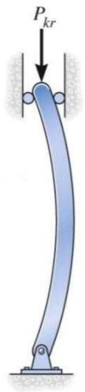
- Stability failure
- Combination of linear static and linear buckling loadsteps

Buckling Problem

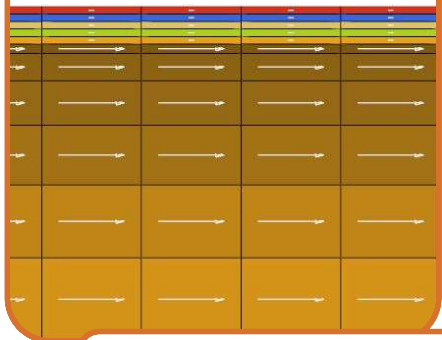
- Initial simulation and prototyp wishbones
- Critical failure mode:
  - Compression
  - Buckling (Euler Case 2)

- New Prepreg - Material
- New Ply - Layup

Development of Simulation Modell



Isotropic Tube



CFRP Tube

Wishbone

Loadsteps

- Linear Static → Displacement, Stress, Strain
- Linear Buckling → Theoretical buckling strength

Linear Buckling & EIGRL Card

Linear Buckling:

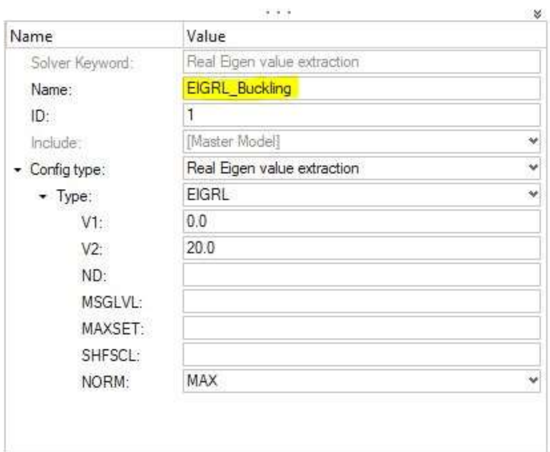
PRef → Linear Static Loadstep → Displacement **Stresses** Strains → Linear Buckling Loadstep → PCr Buckling Modes

Solving Eigenvalue – Problem:

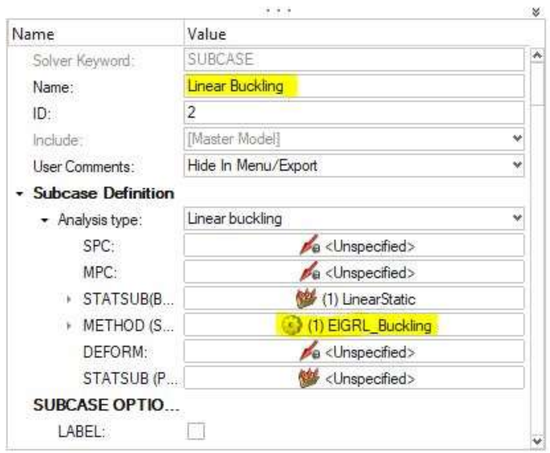
- Geometric stiffness matrix **K_G**
- $[K - \lambda K_G]\, x = 0$
- $P_{Cr} = \lambda_{Cr} P_{Ref}$

EIGRL Card:

Input data to calculate eigenvalues



Name	Value
Solver Keyword:	Real Eigen value extraction
Name:	EIGRL_Buckling
ID:	1
Include:	[Master Model]
Config type:	Real Eigen value extraction
Type:	EIGRL
V1:	0.0
V2:	20.0
ND:	
MSGLVL:	
MAXSET:	
SHFSCL:	
NORM:	MAX

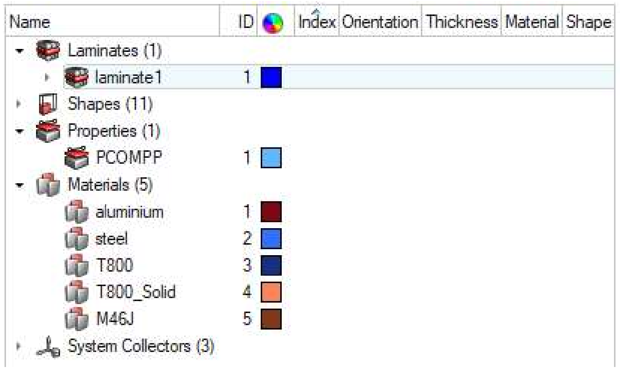


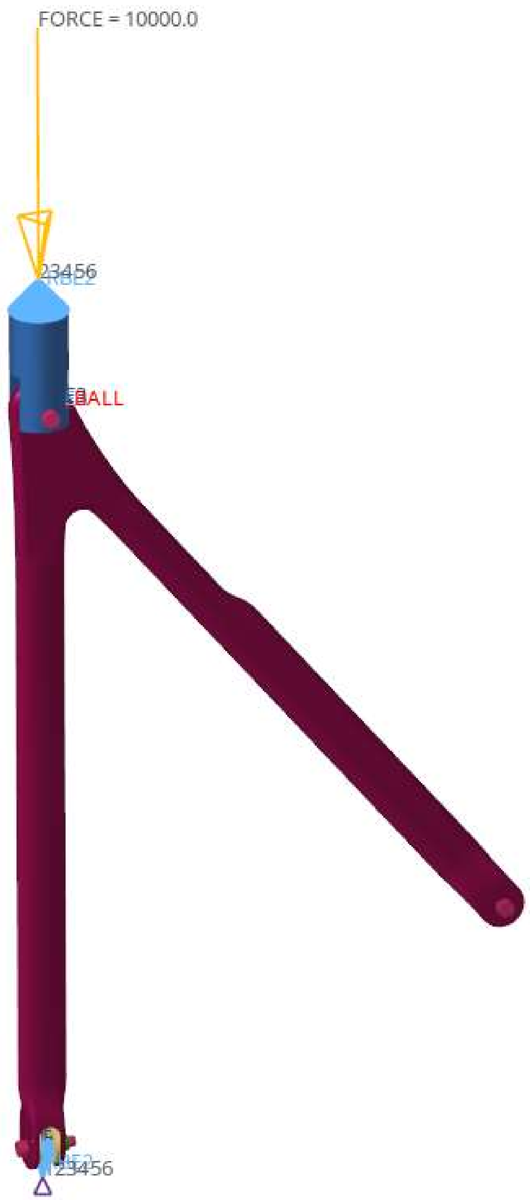
Name	Value
Solver Keyword:	SUBCASE
Name:	Linear Buckling
ID:	2
Include:	[Master Model]
User Comments:	Hide In Menu/Export
Subcase Definition	
Analysis type:	Linear buckling
SPC:	<Unspecified>
MPC:	<Unspecified>
STATSUB(B...	(1) LinearStatic
METHOD (S...	(1) EIGRL_Buckling
DEFORM:	<Unspecified>
STATSUB (P...	<Unspecified>
SUBCASE OPTIO...	
LABEL:	

Wishbone
Linear Buckling Analysis

CAD Modell:
- Wishbone
- Insert
- Balljoint

Composite Menu:





Strain Gauge:
- Maximum force of 10.000N

Physical Testing:
- Detailed modelled in simulation
- Validation for simulation
- Calibration for strain gauges

Modelling

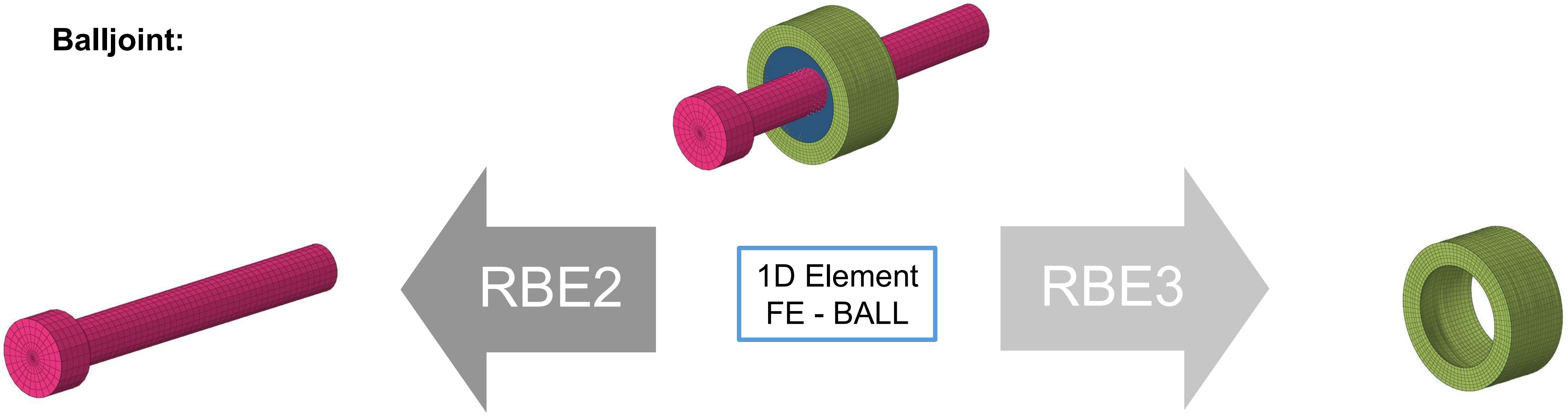
Overall:
- 2D shell elements
- 3D elements
  (Inserts & Stacked CFRP)
- Quads / Trias
- Second Order

CFRP Laminate:
- Mat 8
- PCOMPP
- Tsai-Wu

Inserts, Stacked, Testdevices:
- Mat 1 / Mat 9 Ort
- PSolid

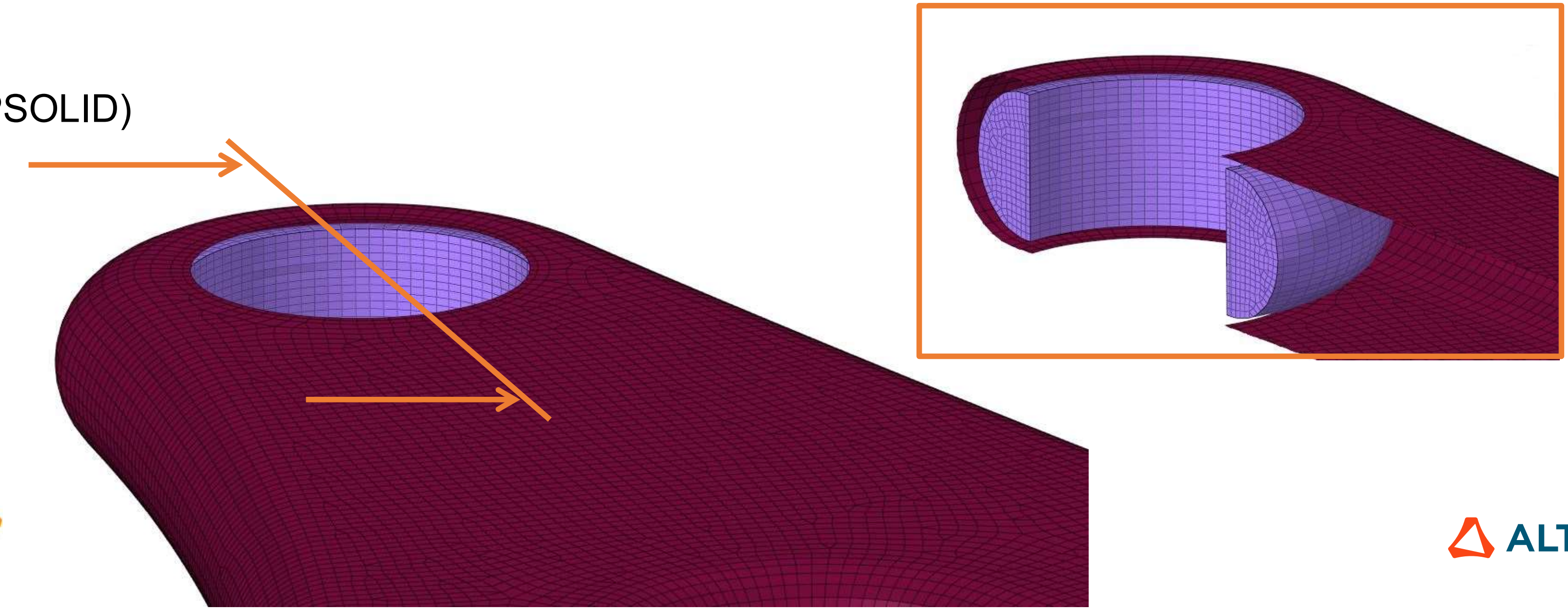
Modelling

Balljoint:



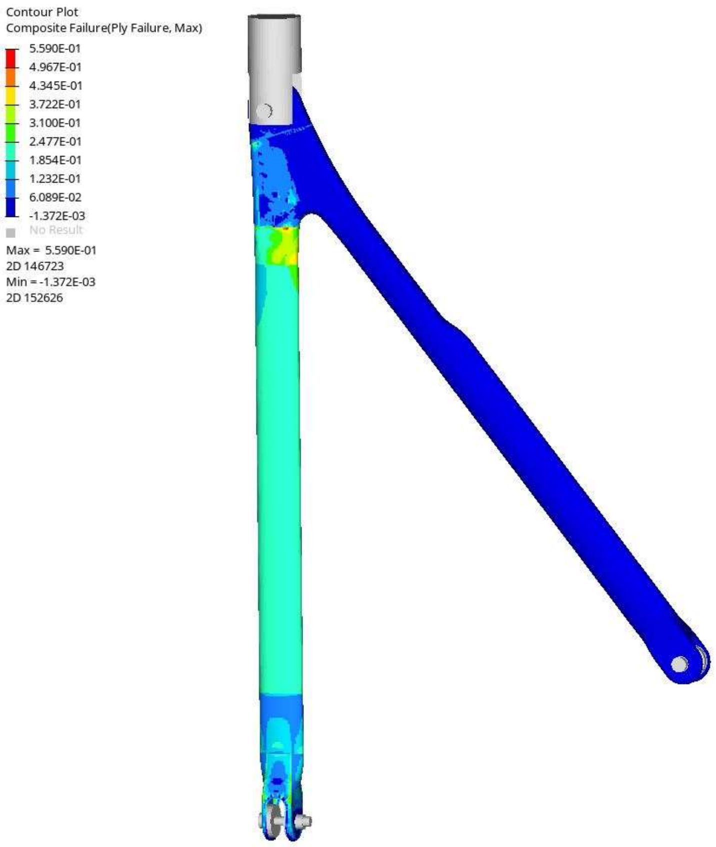
Stacked CFRP:

(PCOMPP + PSOLID)



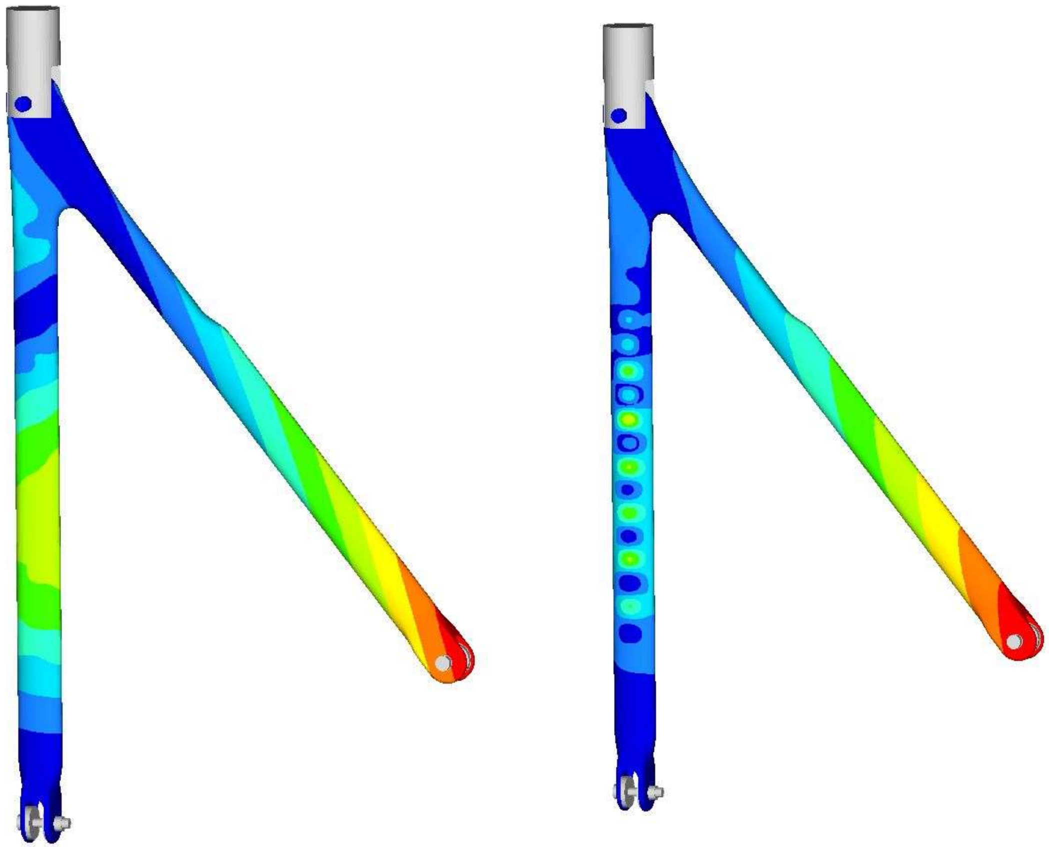
Simulation Results

Linear Static:



Composite Failure Index < 1

Linear Buckling:

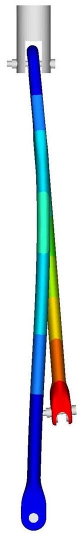


Investigation of buckling modes and P_{cr}

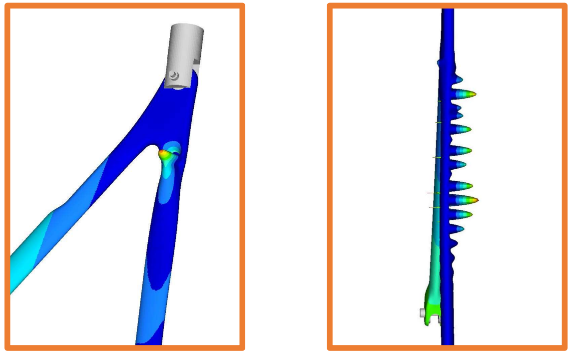
Mode 5 (left), Mode 7 (right)

Validation

#	Simulation	Physical Testing
Displacement (Load 10.000N) [mm]	0,739	0,801
Stiffness [N/mm]	13.532	12.484
Difference [%]	8,39	



Global Buckling
Mode 1

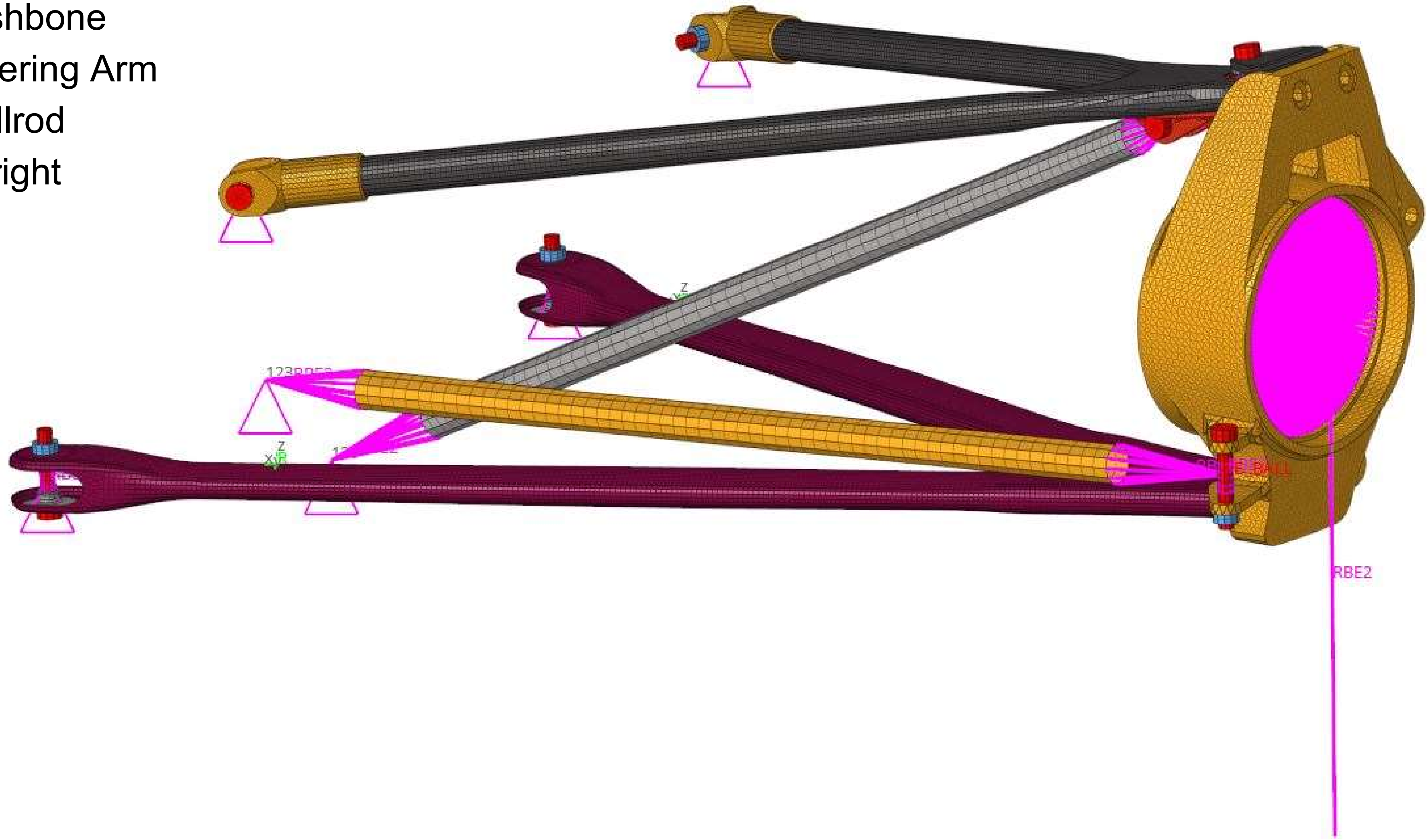


Mode 2 (left), Mode 12 (right)

Local loss of stability
- Local buckling modes

ASM Front Left Suspension

- Structural Analysis of ASM Front Suspension
  - Wishbone
  - Steering Arm
  - Pulllrod
  - Upright



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- Studying Mechanical Engineering, Vienna University of Technology
- 2018 – today: Member of TU Wien Racing
  - 2018 Member of Composites
  - 2018/19 Head of Chassis
  - Since 2019 Member of Chassis/Composites development
  - Current project: optimization of suspension pick up points

Martin MOLNÁR
Member of Composites – TU Wien Racing

E-Mail: martin.molnar@racing.tuwien.ac.at
LinkedIn: www.linkedin.com/in/MartinMolnar3/

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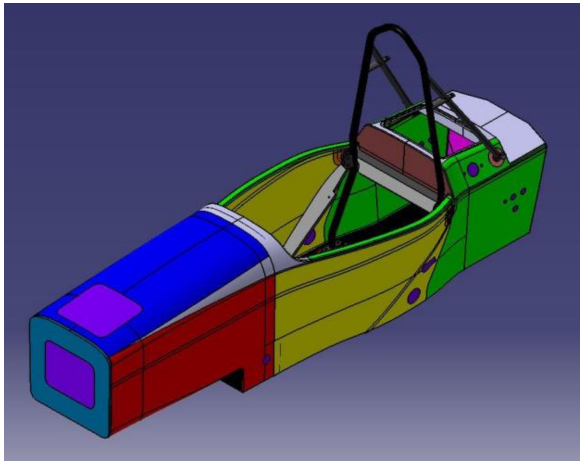
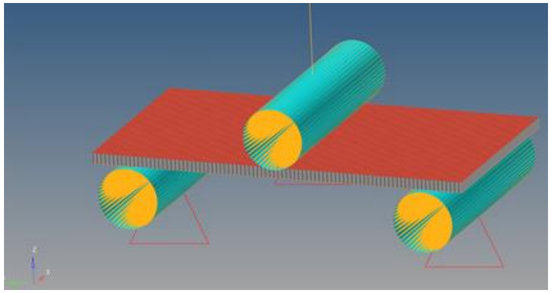
Sandwich Structure – 3 Point Bending

calculation – analyses – physical testing

- Formula Student rules, SES (Structural Equivalency Spreadsheet):
  - Structural integrity
  - Equivalency
  - Safety





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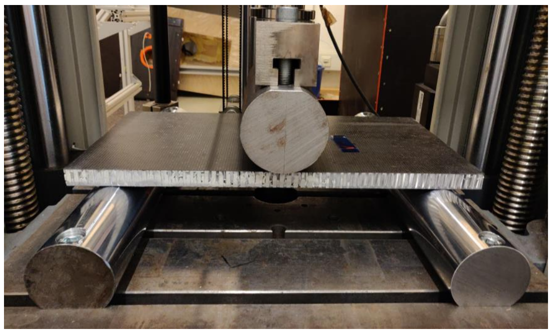

HyperWorks - Optistruct

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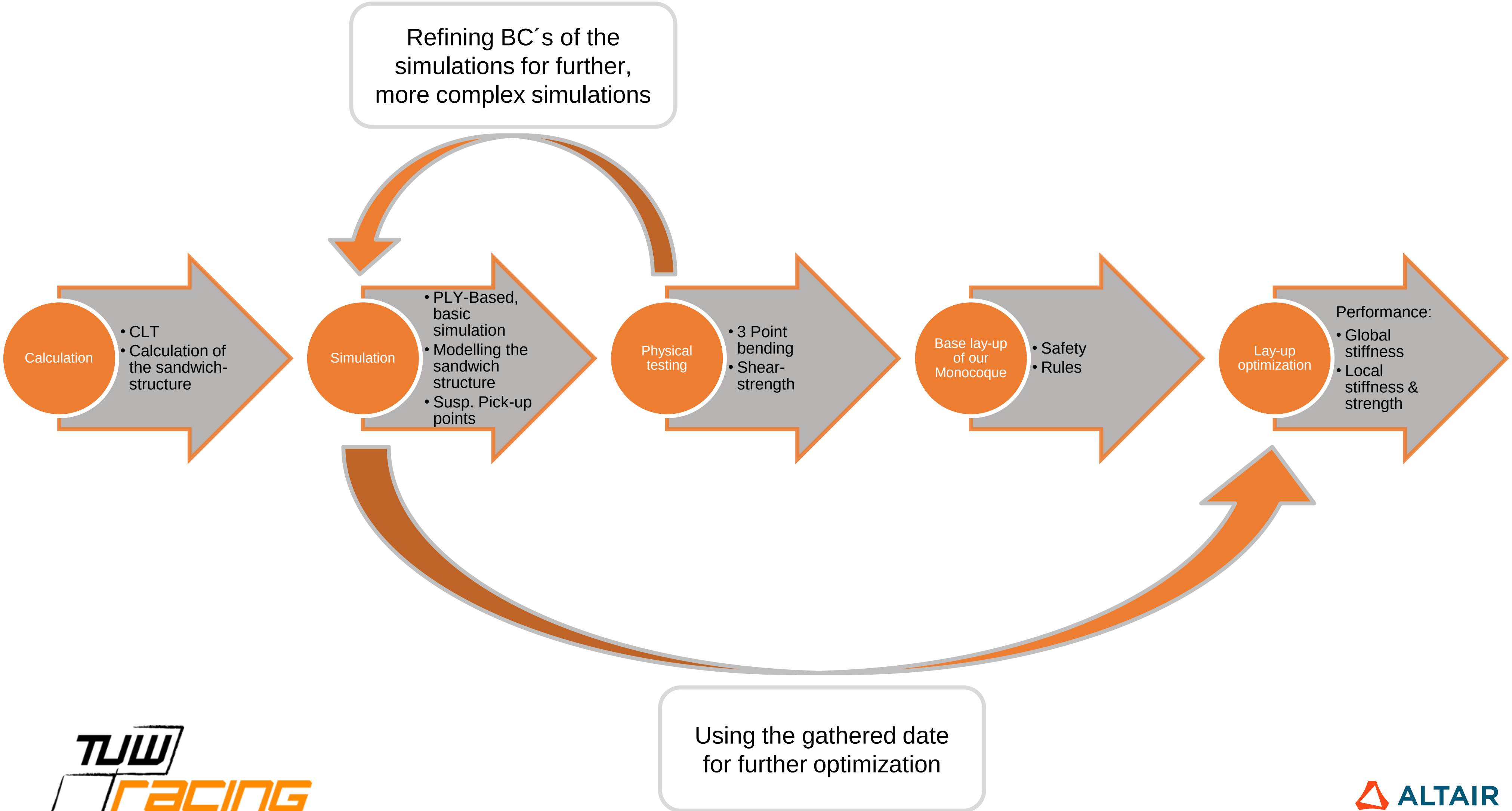
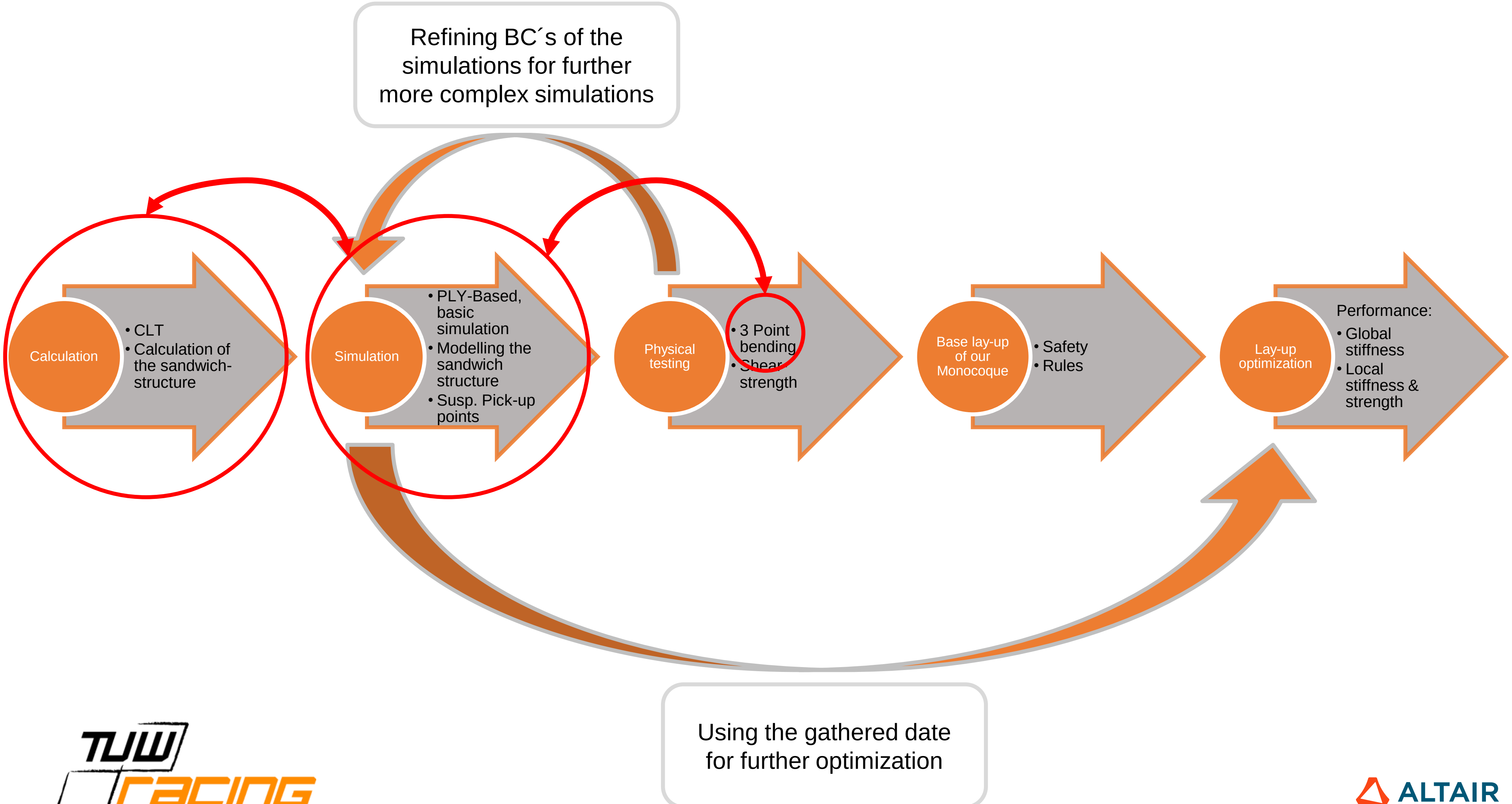
Sandwich Structure – 3 Point Bending
calculation – analyses – physical testing



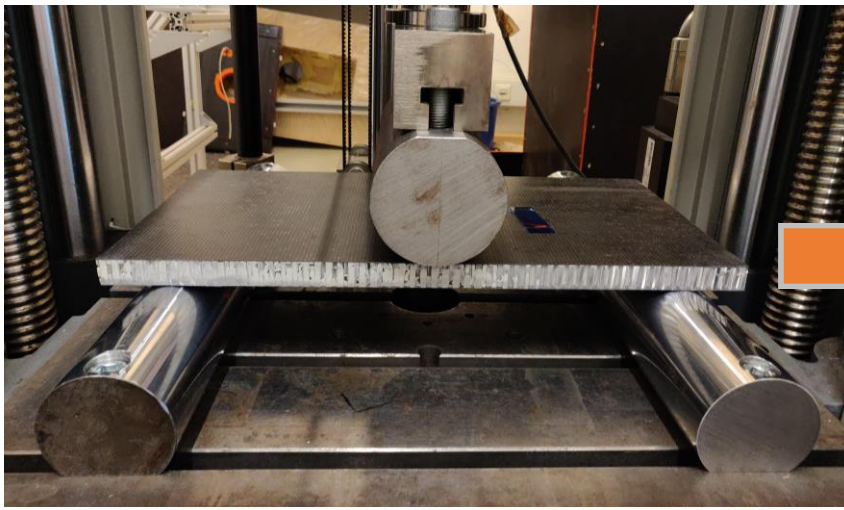
Sandwich Structure – 3 Point Bending
calculation – analyses – physical testing

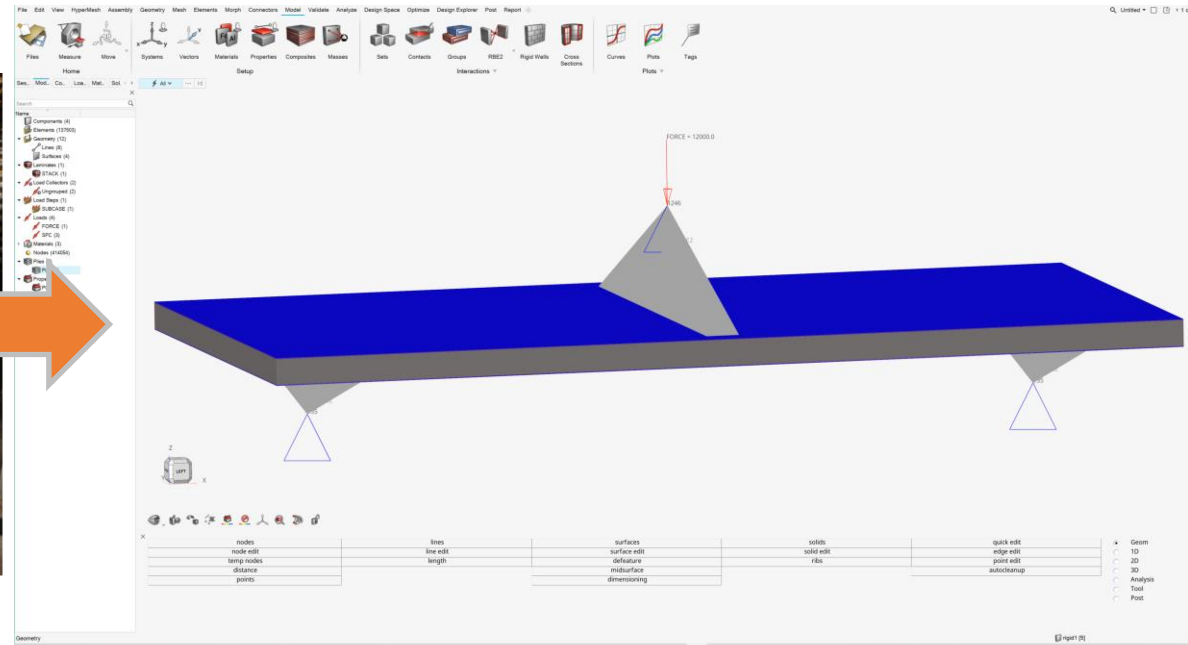


Sandwich Structure – 3 Point Bending
calculation – analyses – physical testing

- Simplifying for the initial simulation

→ Sandwich structure modelled as PLY



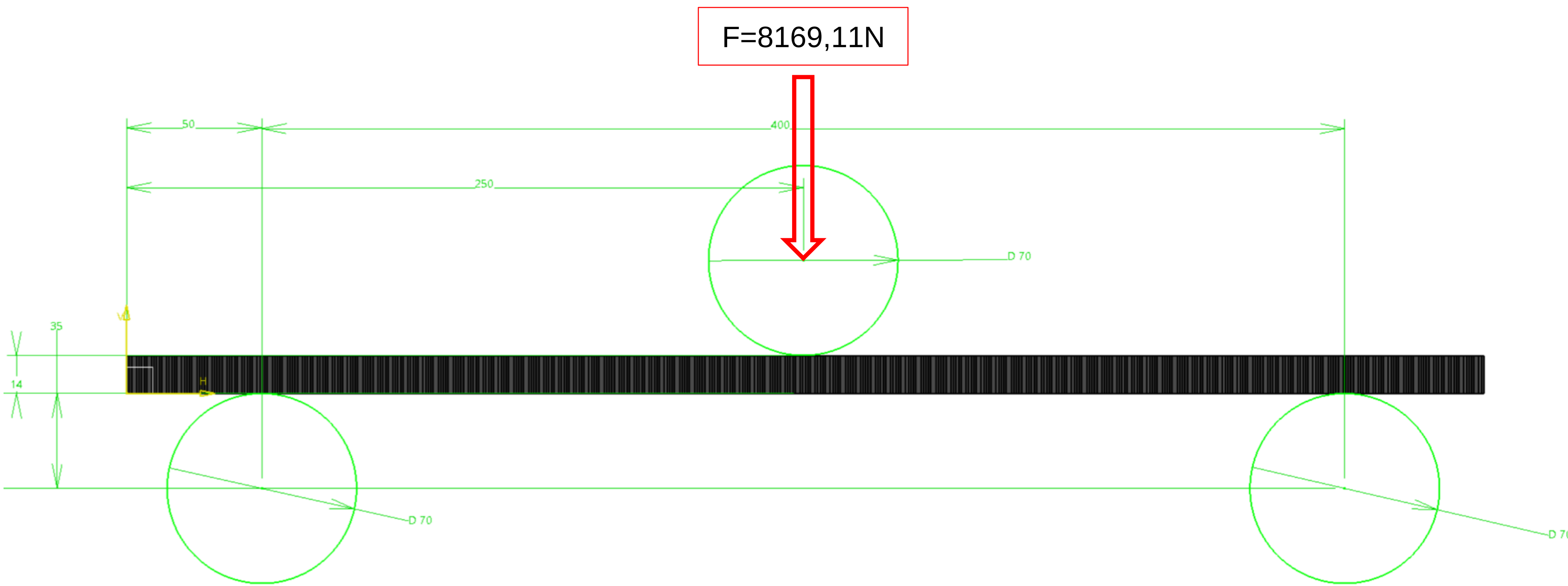


Sandwich Structure – 3 Point Bending
calculation – analyses – physical testing

- Data for the simulation:

  Test setup:

  - 275mmx500mm



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Sandwich Structure – 3 Point Bending
calculation – analyses – physical testing

- Data for the simulation:
  - Material data AGP 193 RC38:

    MAT8:

    Ply Thickness: 0,19mm

E1 [Mpa]	E2 [Mpa]	G12 [Mpa]	Nu12 [1]	RHO [kg/t]	Xt [Mpa]	Xc [Mpa]	Yt [Mpa]	Yc [Mpa]	S [Mpa]	GE [Mpa]	F12 [Mpa]
66000	66000	4960	0,046	1,57e-07	769	844	1172	753	781	56	-8,09e-07

  - Material data M21 E/34% UD134:

    MAT8:

    Ply Thickness: 0,13mm

E1 [Mpa]	E2 [Mpa]	G12 [Mpa]	Nu12 [1]	RHO [kg/t]	Xt [Mpa]	Xc [Mpa]	Yt [Mpa]	Yc [Mpa]	S [Mpa]	GE [Mpa]	F12 [Mpa]
178000	11800	5200	0,28	1,58e-07	3050	1500	56	200	95	56	-2,1984e-02

  - Material data Al Honeycomb, 5056-3,6/0,025/14:

    MAT8:

    Core Thickness: 14mm

E1 [Mpa]	E2 [Mpa]	G1Z [Mpa]	G2Z [Mpa]	G12 [Mpa]	Nu12 [1]	RHO [kg/t]	Xt [Mpa]	Xc [Mpa]	Yt [Mpa]	Yc [Mpa]	S [Mpa]
1	1	10	137	310,264	0,35	5,126e-11	1	1	1	1	1,2

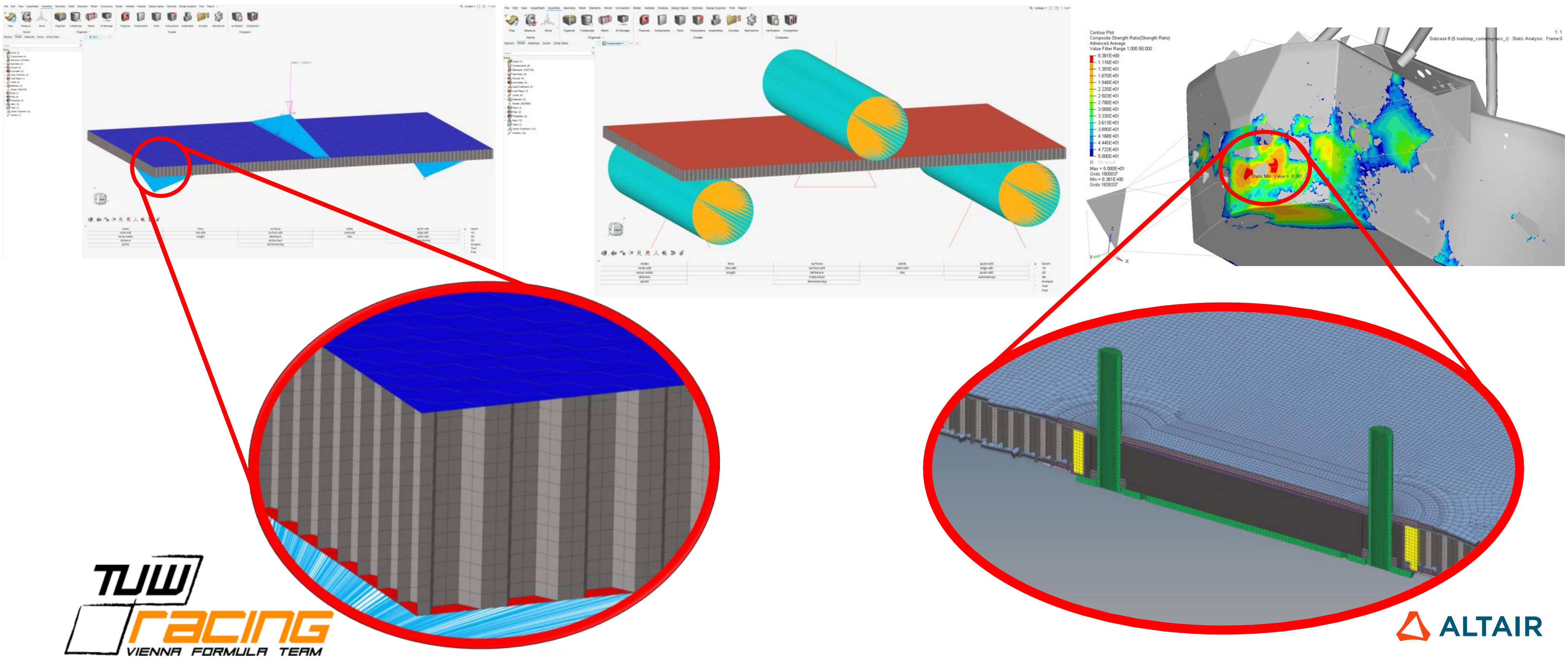
Sandwich Structure – 3 Point Bending
calculation – analyses – physical testing

- Simulation/Tutorial:

Sandwich Structure – 3 Point Bending
calculation – analyses – physical testing

Modelling the core specifically

1st step basic model control the BC´s → 2nd step modelling the 3P-bending specifically → 3rd step modelling the suspension pick-up points



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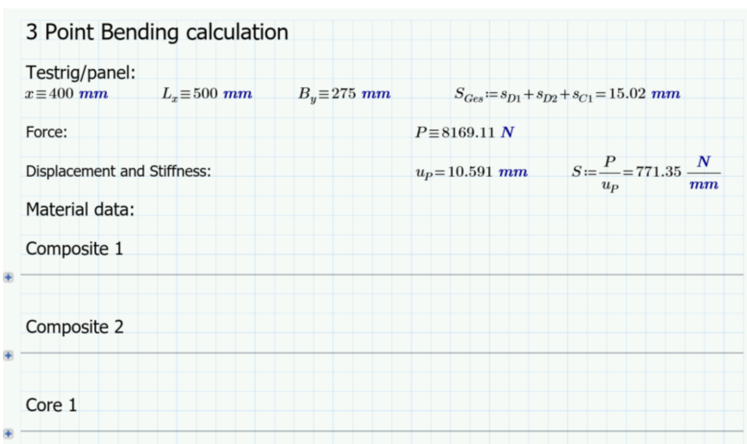
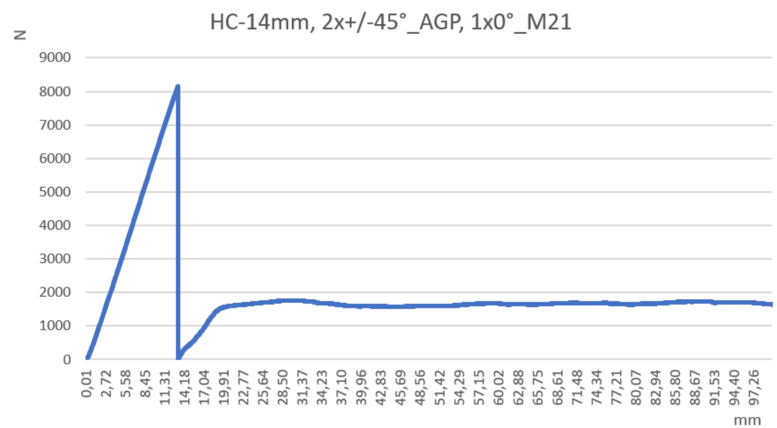
Sandwich Structure – 3 Point Bending
calculation – analyses – physical testing

Comparison of the different methods, physical testing and calculation:

#	Calculation	PLY Based	Modelled Core	Physical testing
Displacement [mm]	10,591	11,655	11,741	11,718
Stiffness [N/mm]	771,35	700,91	695,78	697,14
Difference to physical testing [%]	-10,641%	-0,541%	0,196%	=





Thank you ALTAIR !

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Q & A

- **Drivetrain**
  - Contact Prop´s
  - Pretension definition
- **Wishbone**
  - EIGRL Card
  - Buckling Modes
- **Sandwich Structure**
  - Calculation
  - PLY-Based Simulation
  - Results

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