Extended Abstract

Advanced dynamic modeling, analysis and testing for an aeronautic system

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Summary:
The dynamic behavior of a complex system is studied in this work by following a multi-step approach: models of increasing complexity are analyzed, correlated with experimental data, and then gradually assembled until the achievement of a predictive finite element model of the full system. Specifically, the linear and nonlinear dynamic characterization is addressed by explaining the solutions to representative problems often occurring when dealing with assembled structures working in vibrating environments.

Keywords: Structural dynamics, numerical-experimental correlation, nonlinear vibration, model updating, aeronautic assembly.

1 General context

Assessing the dynamics of complex structures is a critical juncture in the design process, and it involves several challenging tasks from the model definition to its validation through vibration testing and numerical simulations. For complex systems, these steps should be repeated at each stage of the assembly process from the single components up to the final resulting structure in order to insure its performance, as in the pyramidal approach sketched in Figure 1.

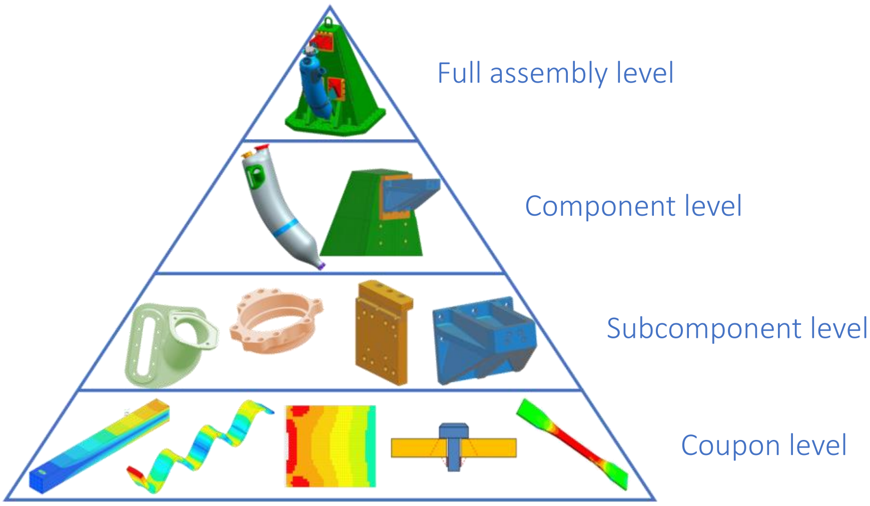

Figure 1

In the present study, the linear and nonlinear dynamic characterization of a complex part of an aeronautic engine is addressed. The assembly is represented in Figure 2.

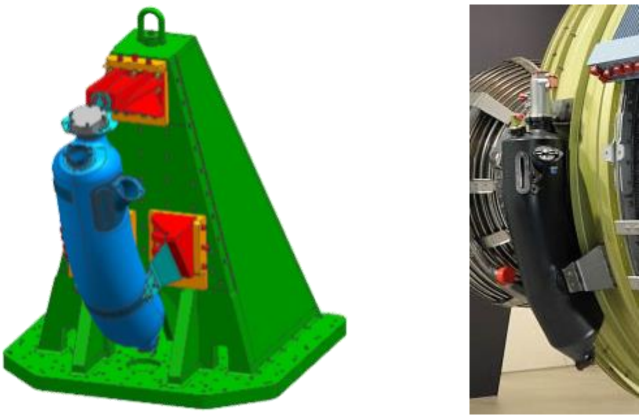

Figure 2

2 Development of FEM models

For the achievement of a good correlation between the numerical model and the vibration tests in terms of modal parameters (i.e. natural frequencies, mode shapes, damping ratios, participation factors) and frequency responses at the top of the pyramid of Figure 1, accurate finite element models must be developed at the lower stages. In this work, several meshing strategies are investigated for the single parts, and different approaches are analyzed for the connection of the parts inside the assemblies. An example is given in Figure 3, in which the dependency of the first natural frequency of a component on the mesh size is represented for different type of elements, together with the corresponding models for which convergence is achieved.

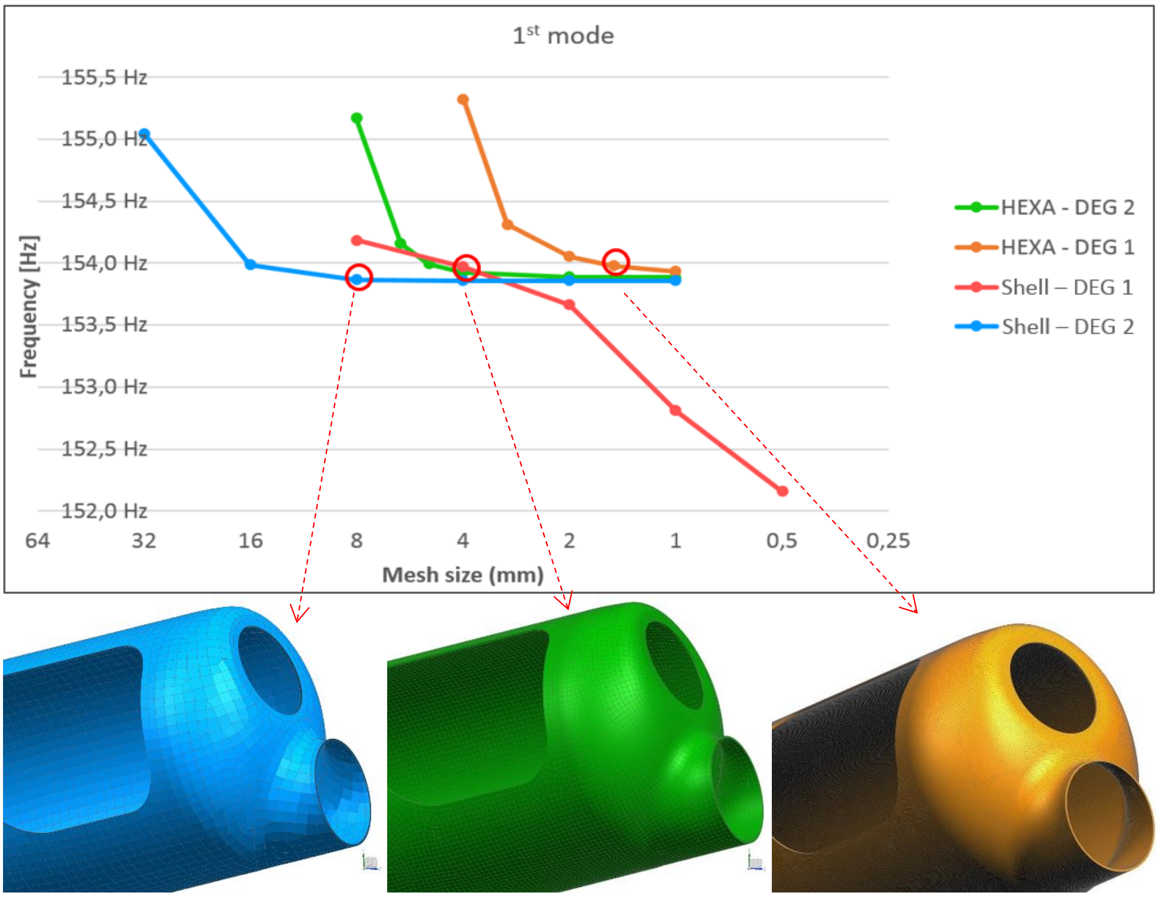

Figure 3

Moreover, an optimization process for the fine tuning of the modal parameters is proposed with regard to a subcomponent, which design is confidential. Figure 4 shows that it is possible to retrieve the experimental natural frequencies (depicted in blue) when the optimal structural parameters are used into the FEM (which frequencies are in orange).

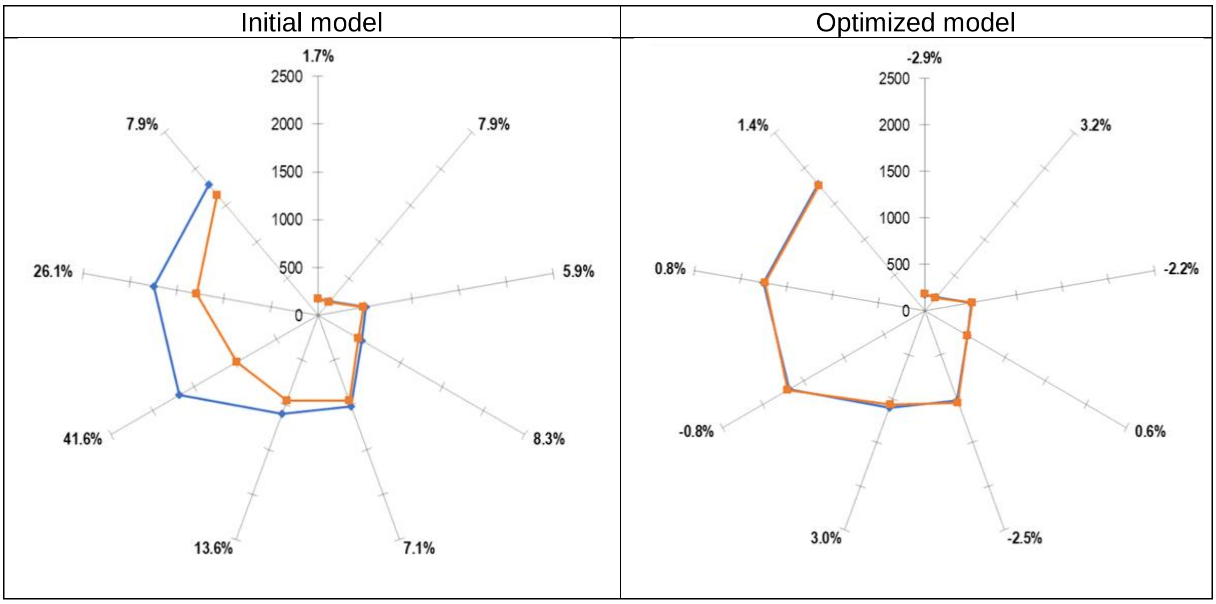

Figure 4

3 Extension to non-linearity

Additional analyses of the system responses, as measured during the environmental tests in Figure 5, are carried out to characterize the dynamical behavior of the assembly in nonlinear regimes of motion.

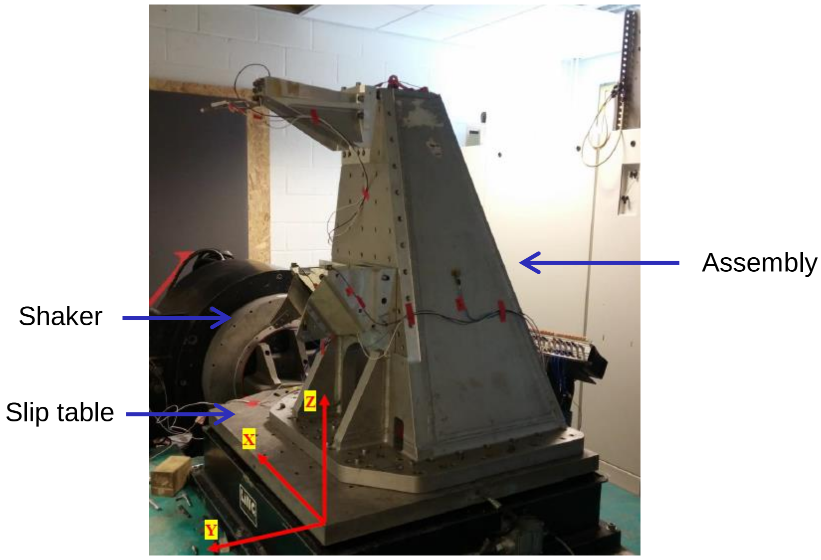

Figure 5

Figure 6 compares the time responses to two different base-excitation levels (0.1 g in green and 1.0 g in red): the non-proportional variation of the acceleration amplitudes and the shift of the resonant frequencies are remarkable in these two sine-sweep responses of the same sensor.

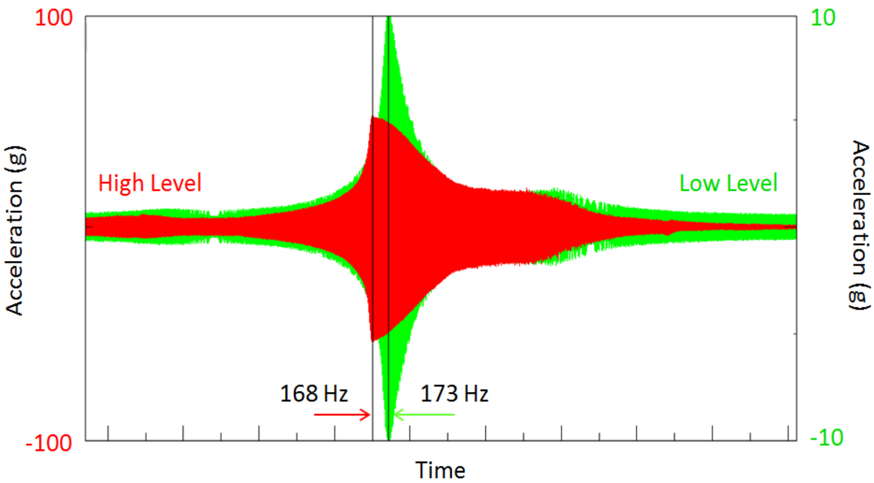

Figure 6

From an experimental identification based on these recordings, it is possible to enrich the finite element model with nonlinear elements at the junctions between components. It is proved that these extra elements are responsible for the peculiar phenomena observed during the tests, such as the dependency of the modal parameters on the excitation amplitude (shown in Figure 6), but also the effect of the initial conditions on the steady-state dynamic response and the modal interactions.

4 Acknowledgement

The support of the Clean Sky program JTI-CS-2009-2-SAGE-02-003 is gratefully acknowledged.

5 References

[1] CleanSky research programme: http://www.cleansky.eu/

[2] Siemens suite: Samcef, BossQuattro, SimCenter

Presentation

NAFEMS 18 France Conference
Simulation numérique : moteur de performance
état de l'art - pratiques - tendances - impact industriel
November 14-15, Paris

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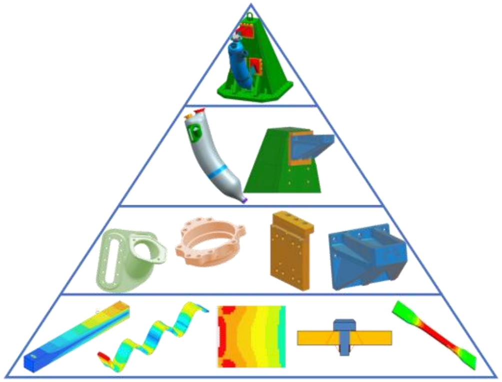
Quick presentation of the company

The system studied here

"Divide et Impera" approach



Studies with increasing level of complexity:

- Experimental testing
- Finite Element modeling
- Nonlinear dynamic behavior

GDTech group & overview

+190 employees

- Sami Engineering (Belgium)
- GDTech Belgium (HQ) (Belgium)
  - GDTech France (France)
- OPEN ENGINEERING (Belgium)

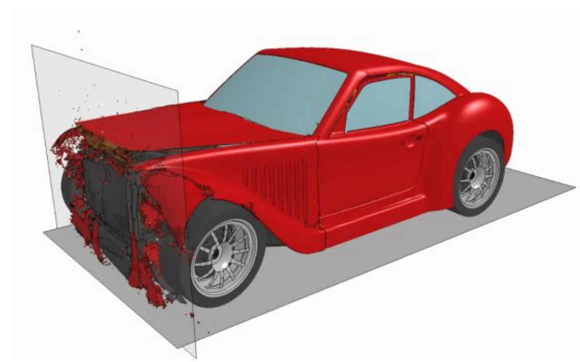
- Integrated services (CAD/CAE, product development process)
- Specialized in systems, equipments, energetics, thermal and CFD studies
- Strong coupling multiphysics engineering software development (**OOFELIE**)
- Industrial services and technical assistance

- GDTech is level#1 supplier of SAFRAN, working with SAFRAN for about 20 years

Overview of the activities in simulation

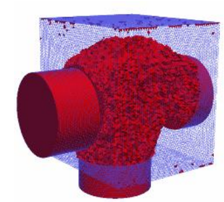
Mechanical/structural FEA

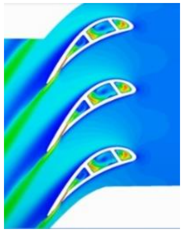
- Assessments of assembled parts (bolted, riveted, welded)
- Optimization
- Nonlinear analysis, including crash
- Fracture mechanics
- Composites
- Smooth Particle Hydrodynamics impact
- Fan Blade Out
- Flexible Mechanisms
- Rotor dynamic assessments
- Dynamic response, random vibrations
- Thermo-mechanical analyses
- Additive Manufacturing
- Fluid-Structure interaction

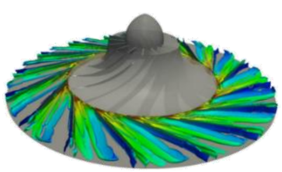


CFD

- CFD assessments (+ link to structure)
- Combustion assessments
- Thermal analysis







Assessing the dynamics of complex structures

it is not a piece of cake

courtesy of SAFRAN

Green and Innovative Lubrication Devices: GILD

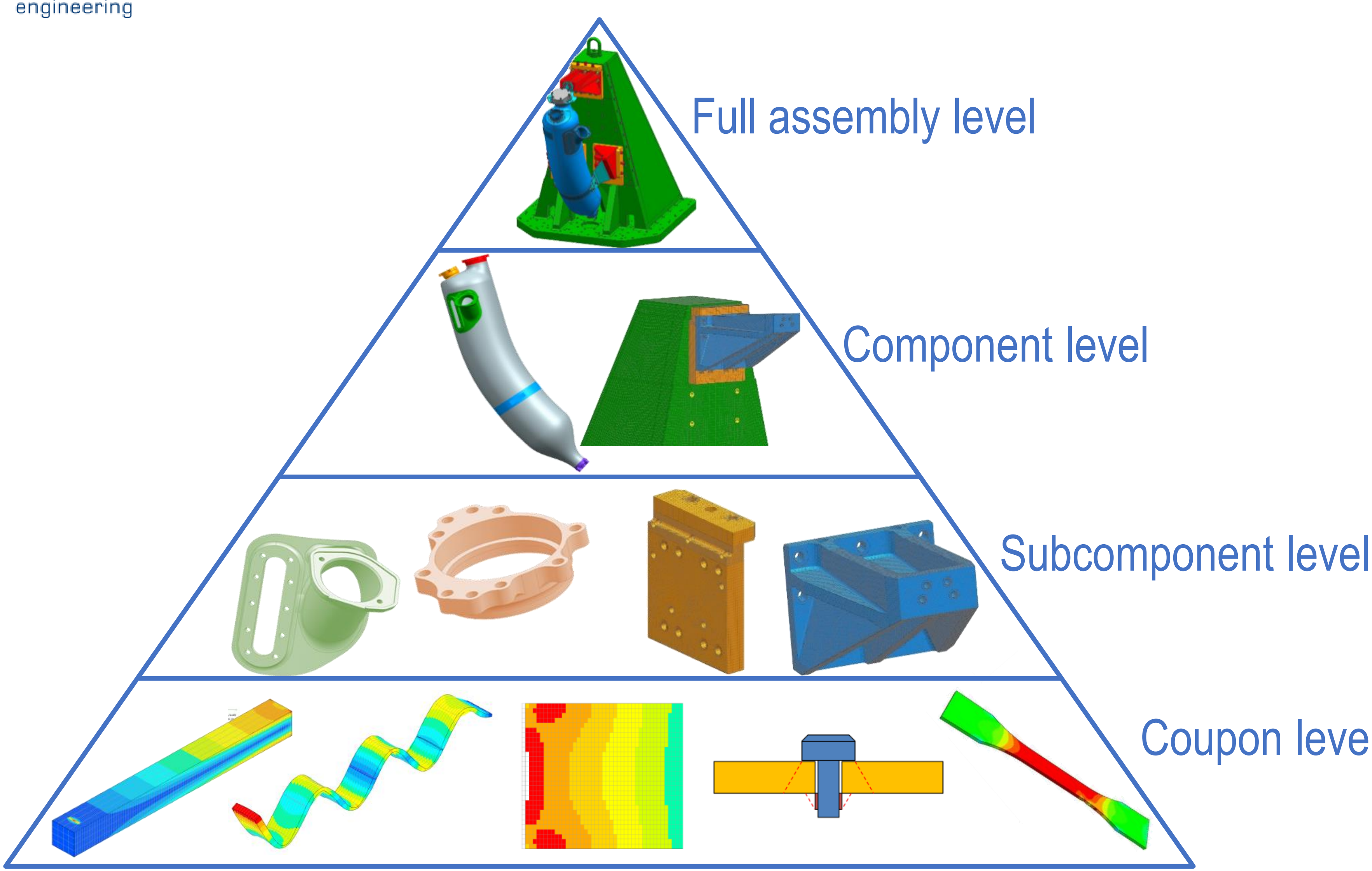
it is not a piece of cake

- Experimental testing
- Finite element method for modeling

⇒ Development of a finite element model correlated with test results

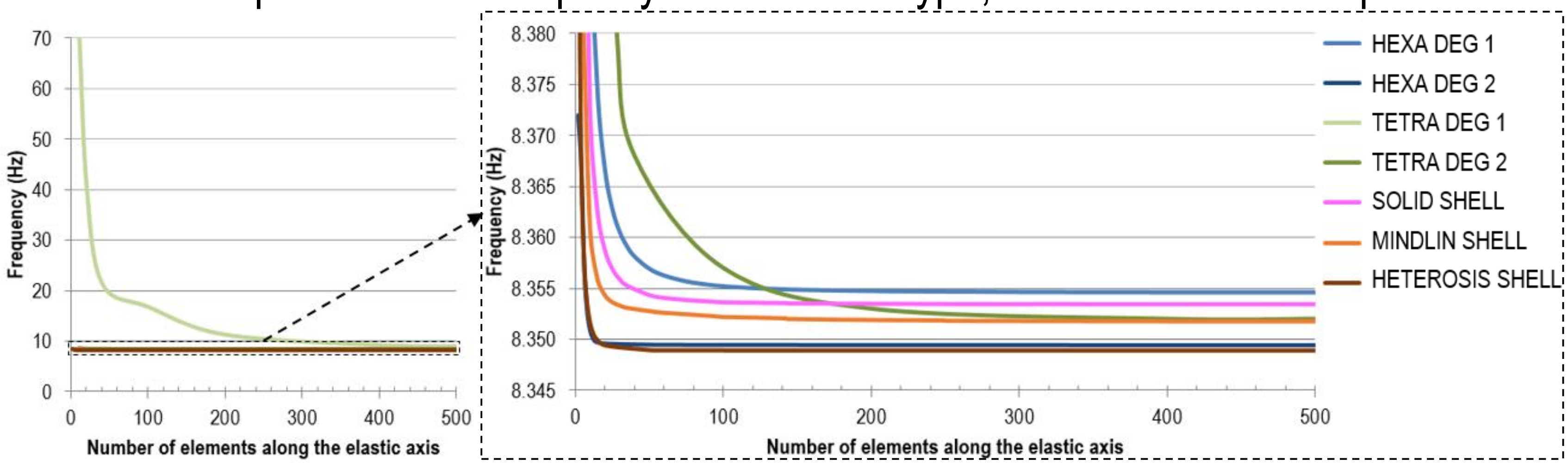
Green and Innovative Lubrication Devices: GILD

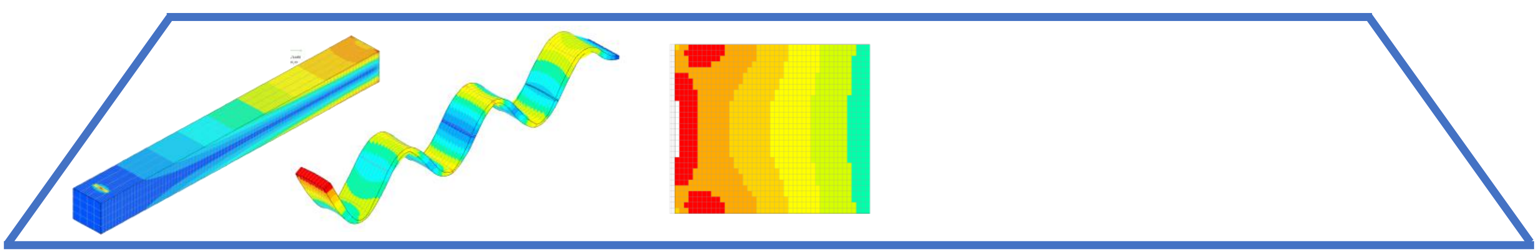
Simplify the problem: “divide et impera”



Preliminary analyses are fundamentals for a good modeling

- The identification of the local effects induced by the B.C. is important
- Solution depends on mesh quality and element type; different minimal requirements:*





*FE software: SAMCEF (SAMTECH | Siemens Company)

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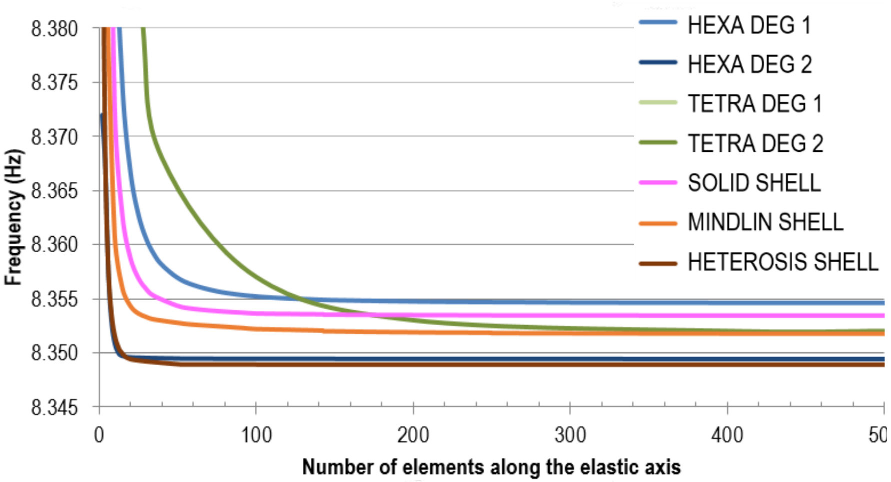
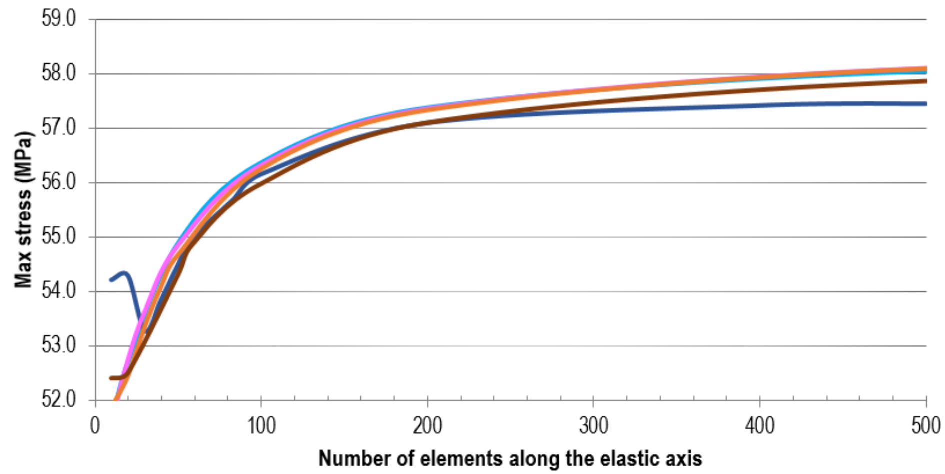
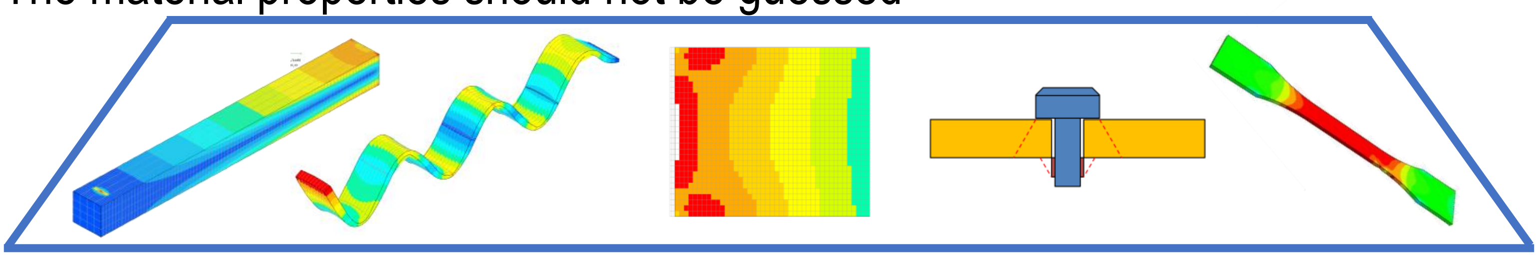


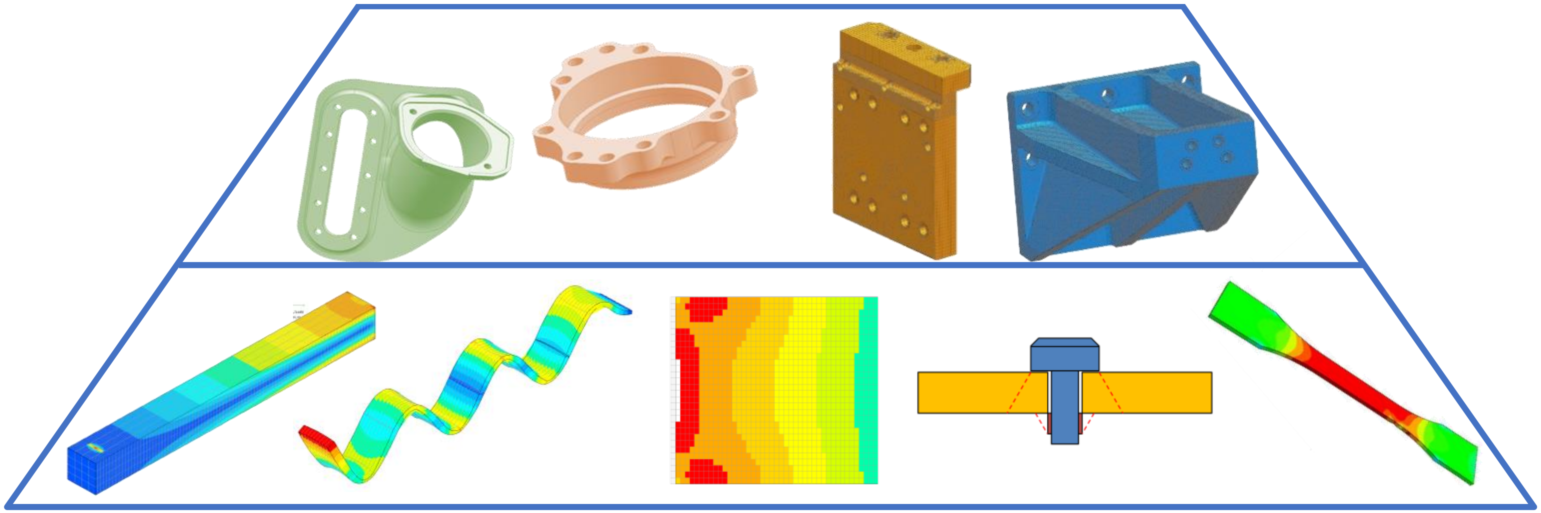


- Bolt connections will strongly affect the final results, so it is recommended to investigate their effects already at an early step of the design process
- The material properties should not be guessed



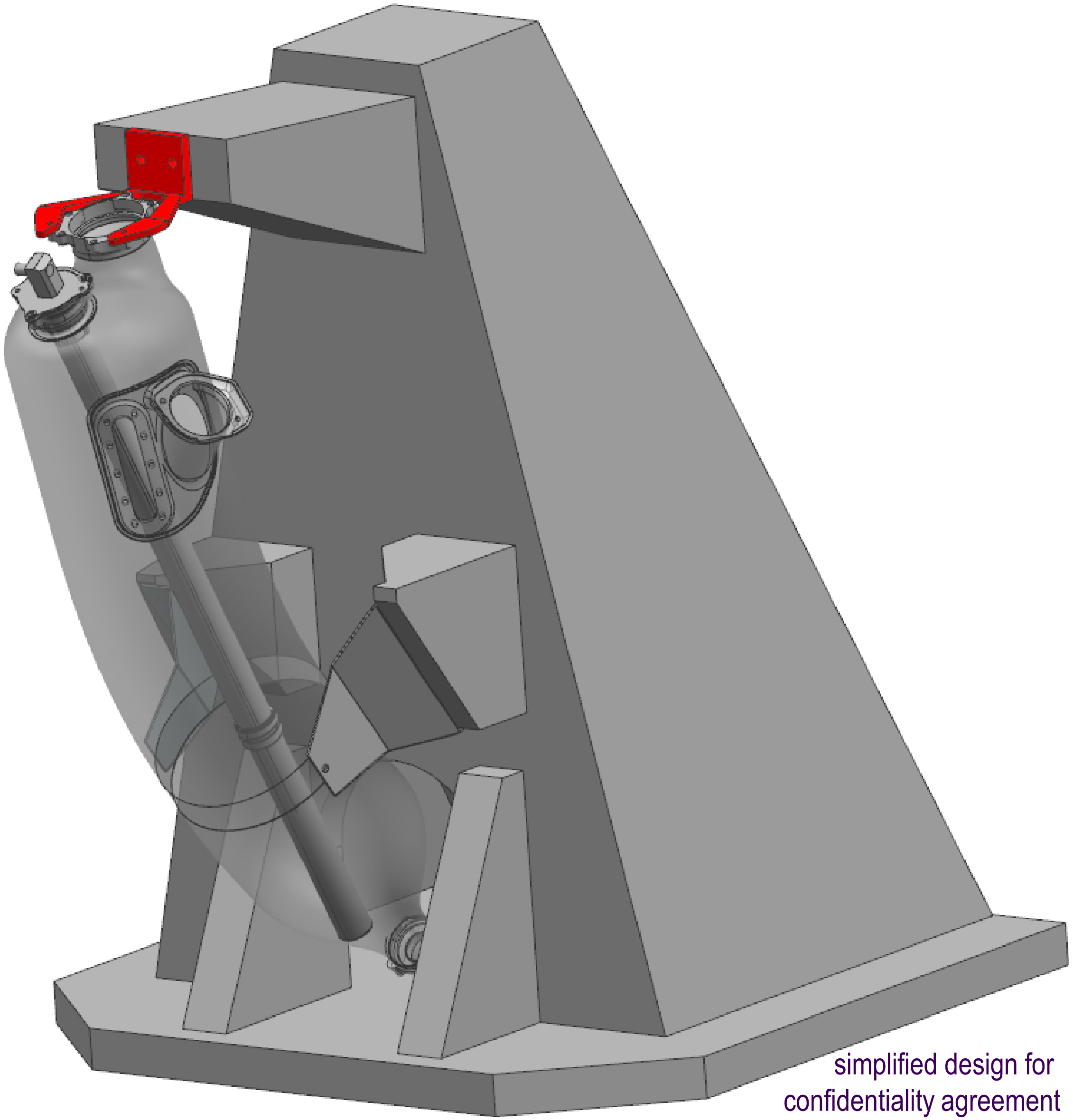
*FE software: SAMCEF (SAMTECH | Siemens Company)

from the preliminary analyses to the basic subcomponents



Upper bracket

- Experimental testing
- Discussion on FE modeling and influence on the correlation



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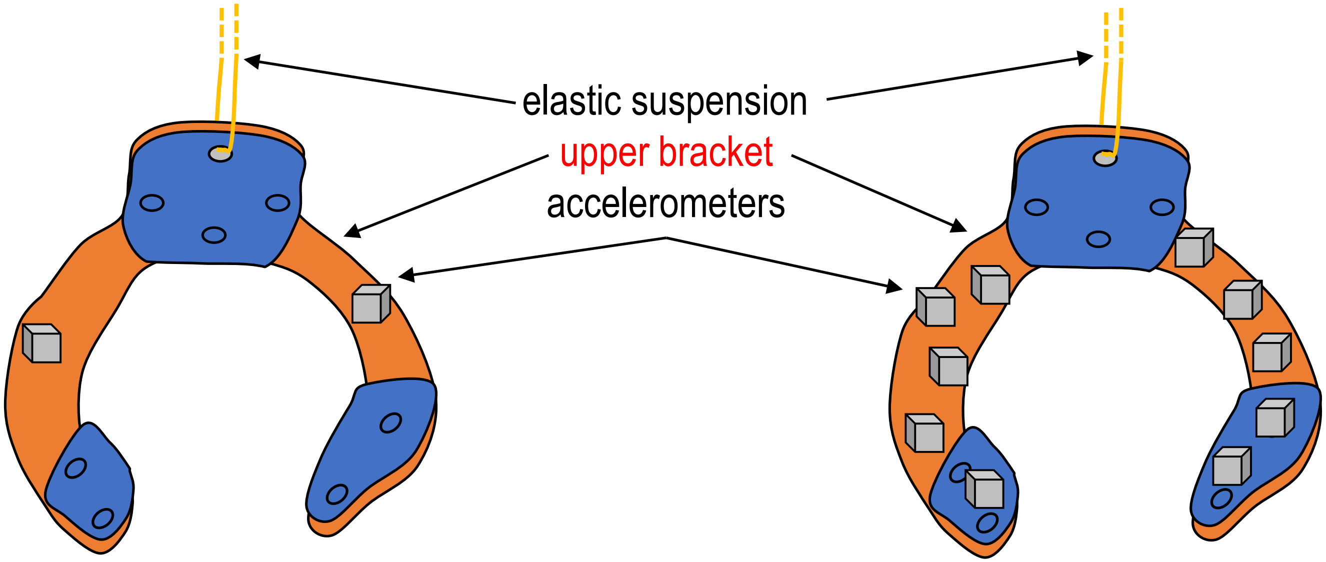
Importance of the experimental testing on small components



<u>Test 1:</u>

- 23 tri-axial measurement points
- Roving accelerometer test (12 test repetitions with 2 tri-axial accelerometers)

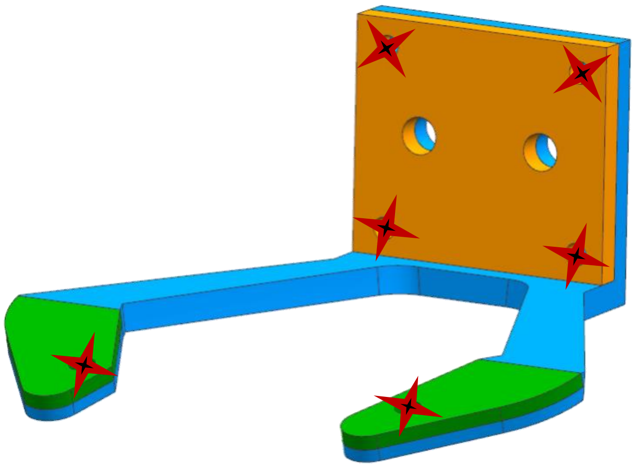
<u>Test 2:</u>

- 10 single-axis accelerometers
- Single Input Multi Output (SIMO) test

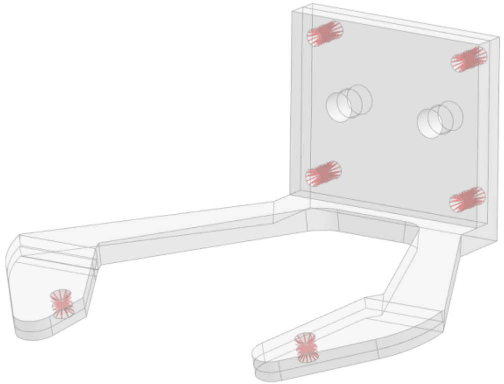
The mass of the accelerometers induces a not-negligible shift of the natural frequencies corresponding to each test of the roving: up to 6% of frequency shift

Possible models of the rivets

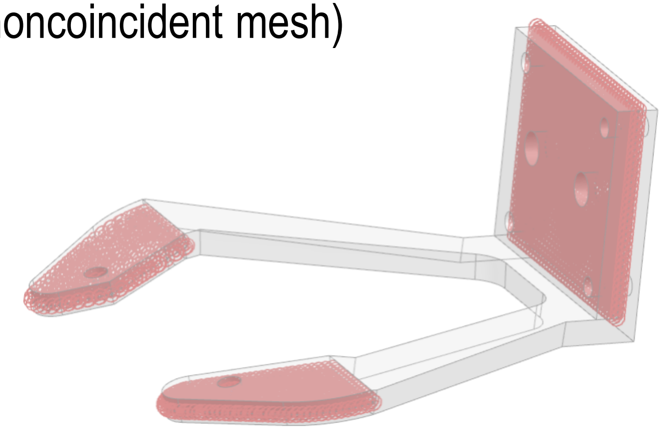
Upper bracket



A. Rigid body elements (RBE) between the nodes belonging to the hole surfaces and a central node corresponding to the rivet COG



B. Gluing of the sheets using nodes belonging to corresponding surfaces (noncoincident mesh)



<u>FEM description:</u>

minimal mesh according to previous step (~50000 nodes)

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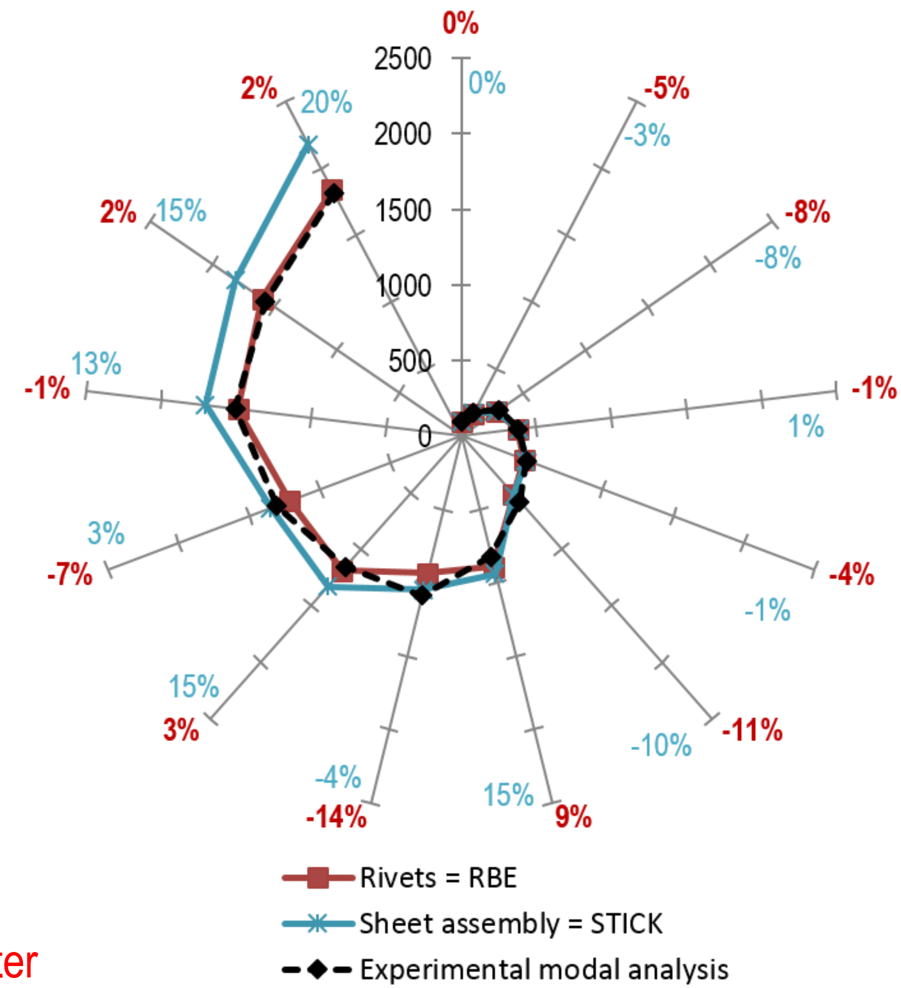
The modeling influences the Num/Exp correlation

mode shapes: MAC matrix

1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	1.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
0.00	0.00	0.00	0.01	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.01	0.00	0.00	0.00	0.98	0.01	0.01	0.00	0.00	0.00	0.01
0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.98	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.97	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.97	0.01	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.73	0.22	0.03
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.19	0.73	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.90

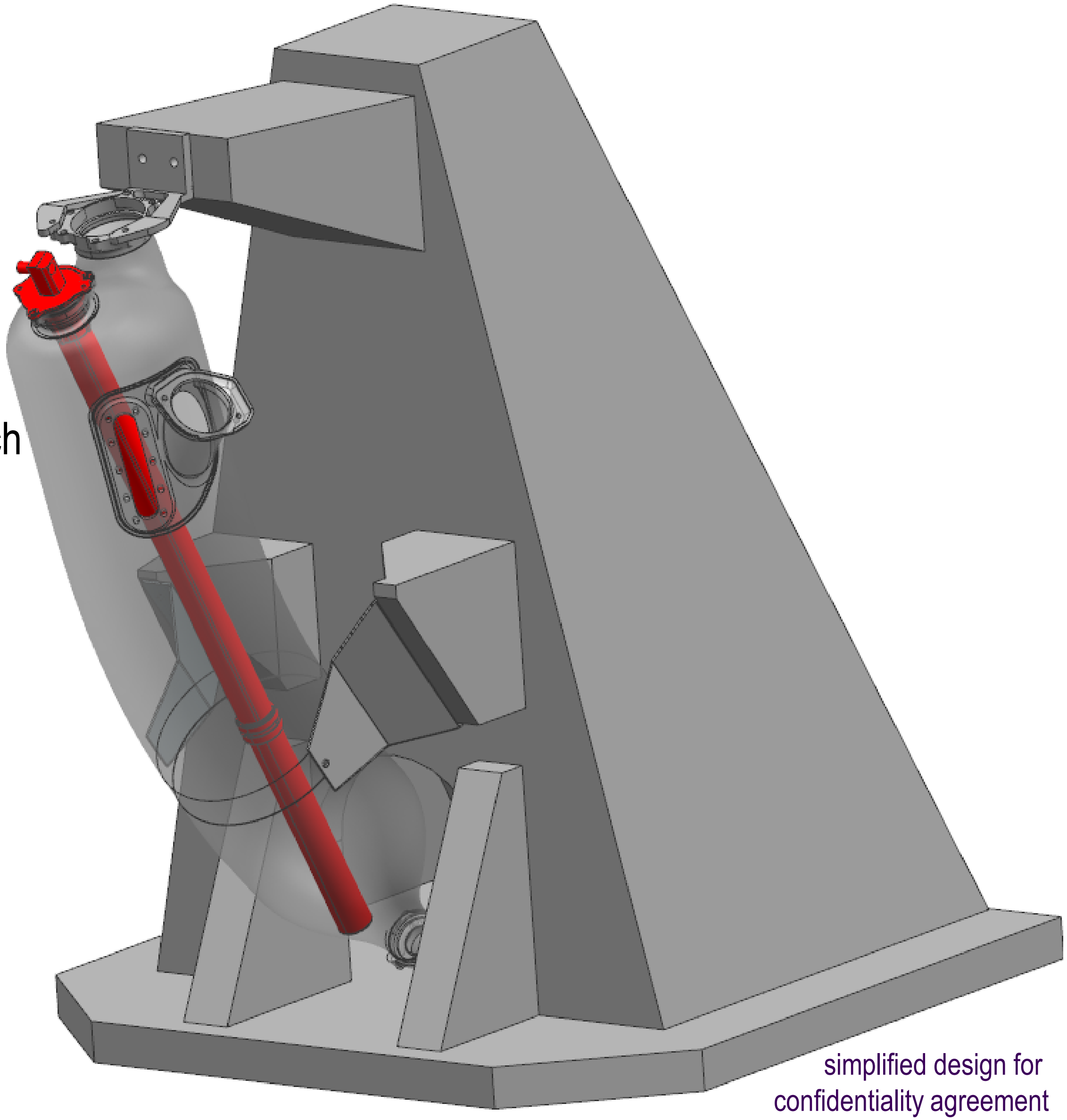
natural frequencies: relative error



⇒ in our application,
Modeling A of the rivets is better

Oil Level Sensor

- No access to the geometry
- Experimental testing
- FEM modeling and model updating with numerical optimization to match the test results



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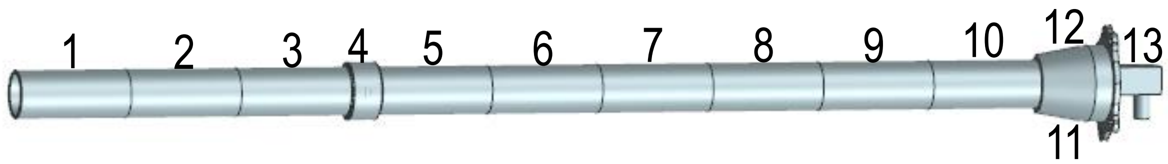
How to model an unknown component of the assembly

- Model updating based on optimization, with BOSS/Quattro*
  - Goal = modify the value of some parameters to have a model with the same frequency content as the physical component
  - Objective function $F = \sum \frac{1}{2}\left(\frac{f_{i,num} - f_{i,exp}}{f_{i,exp}}\right)^2$
  - Updating parameters

$$0.01MPa \leq E_i \leq 0.3MPa$$

$$1kg/dm^3 \leq \rho_i \leq 10kg/dm^3$$



  - constraint $\sum \rho_i V_i =$ total mass
  - termination criterion on the objective function equal to 1%

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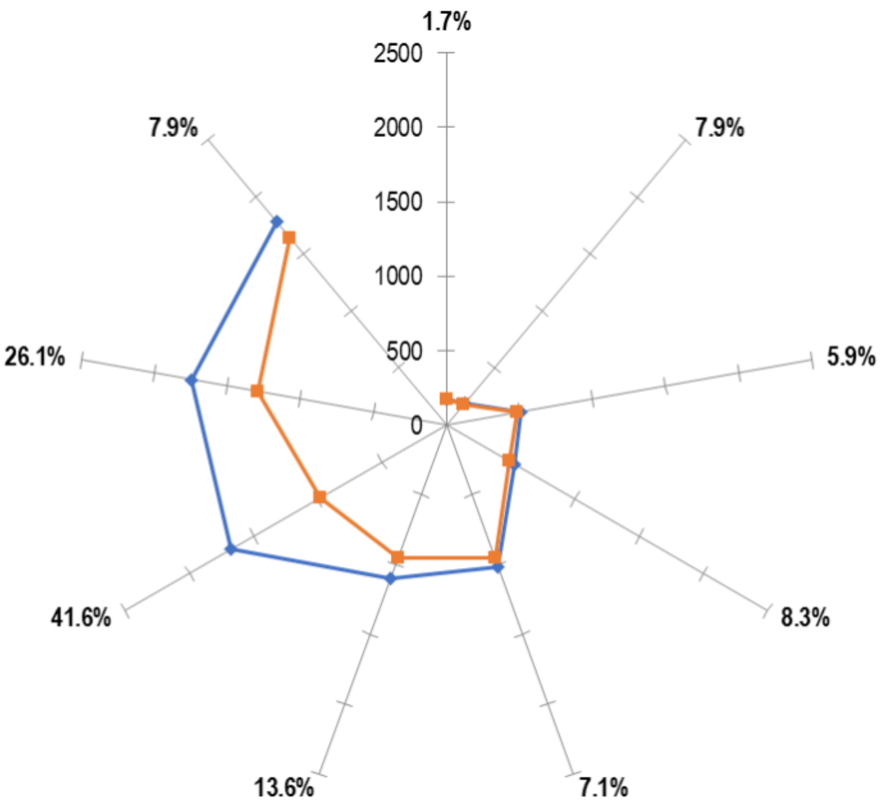
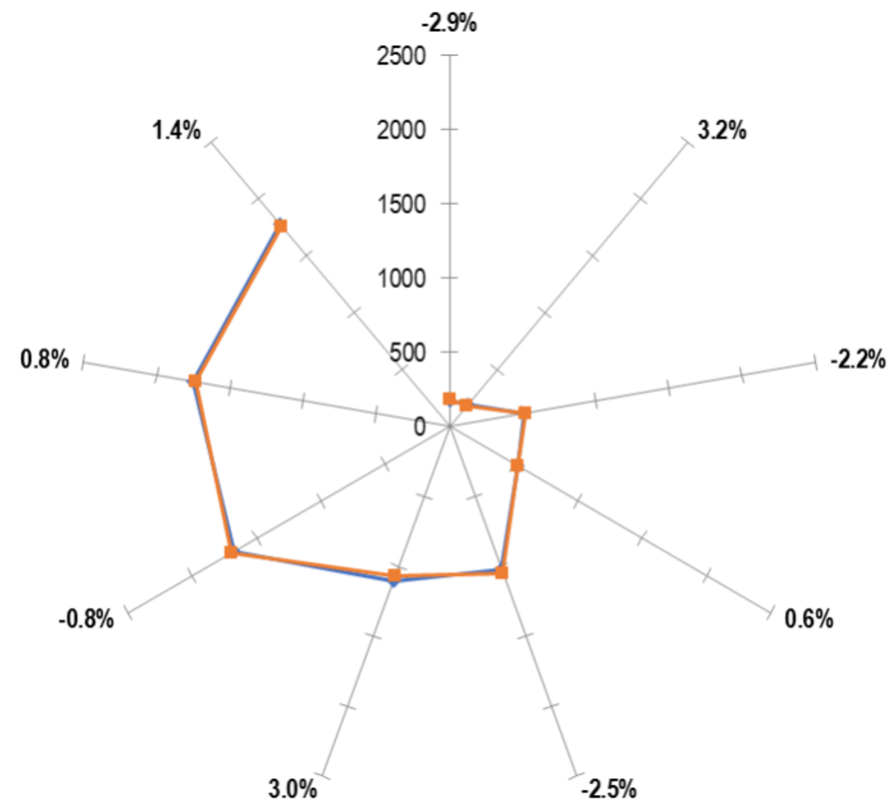
* (SAMTECH | Siemens Company)

The optimization process converges to an optimal model

- initial model



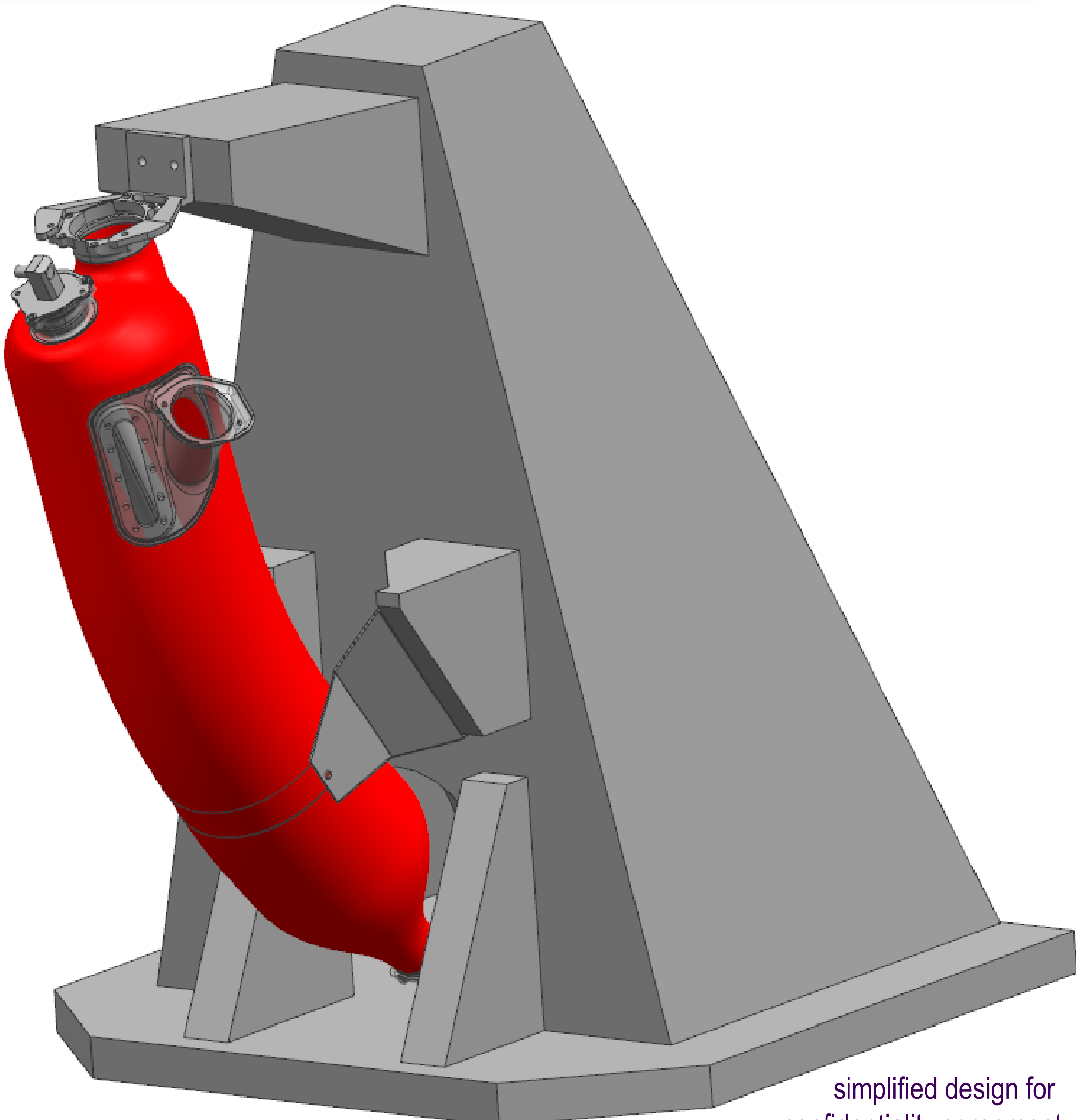
- updated model (after 11 iterations)



FEM
EXP

Oil Tank

- No experimental testing
- FEM modeling to reach a converged numerical solution



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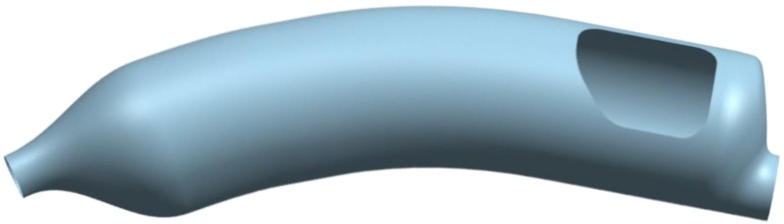
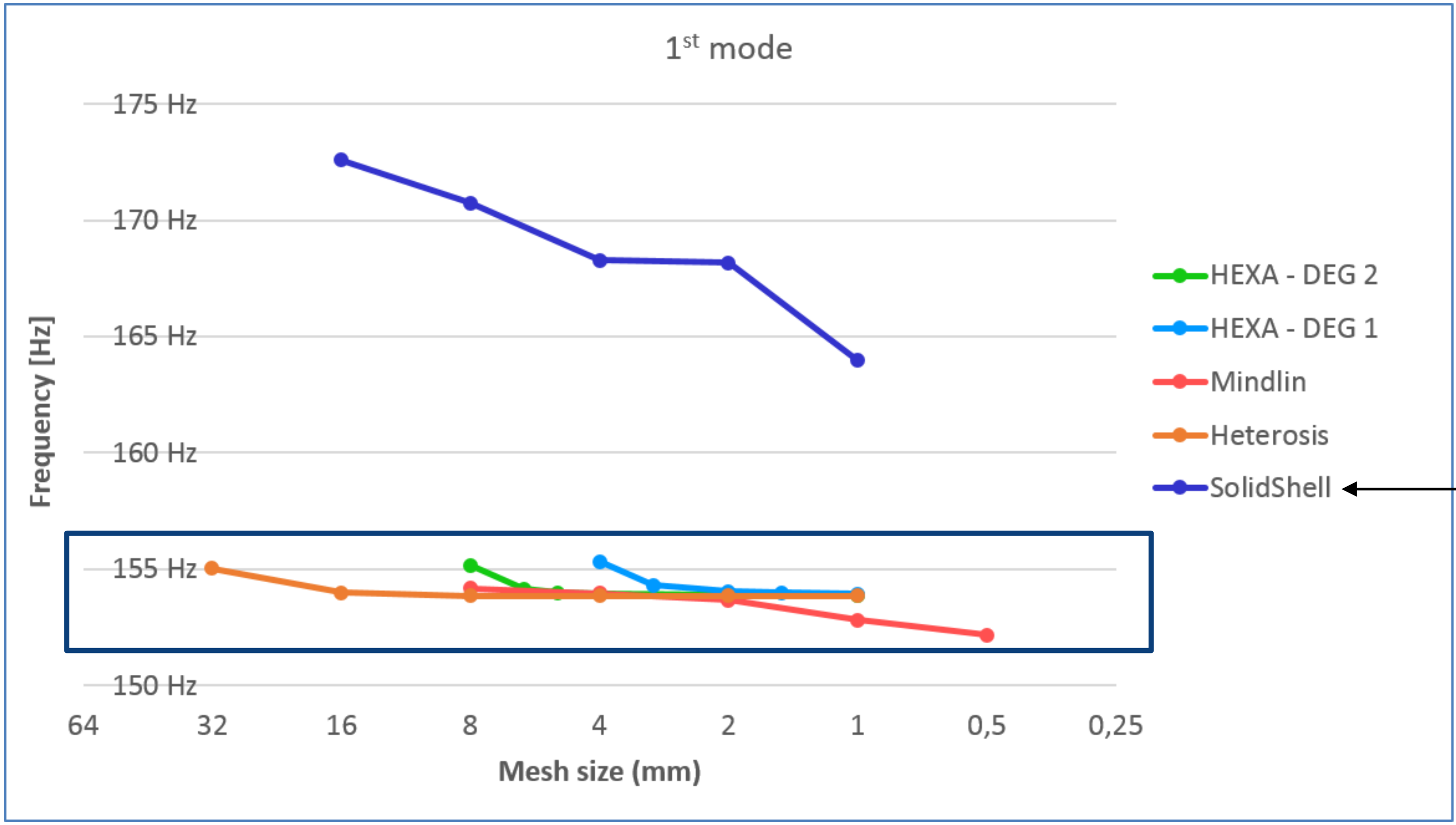
Convergence study of the tank mesh





to be avoided

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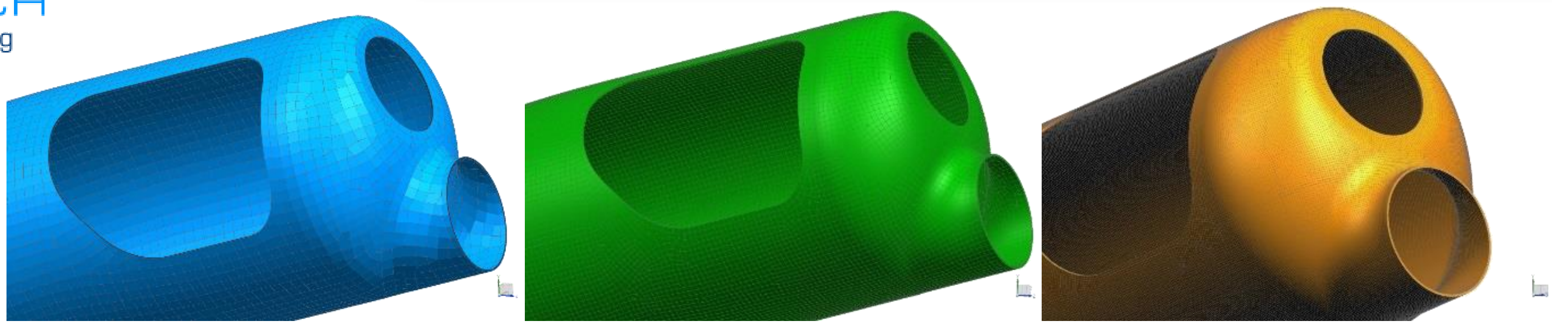
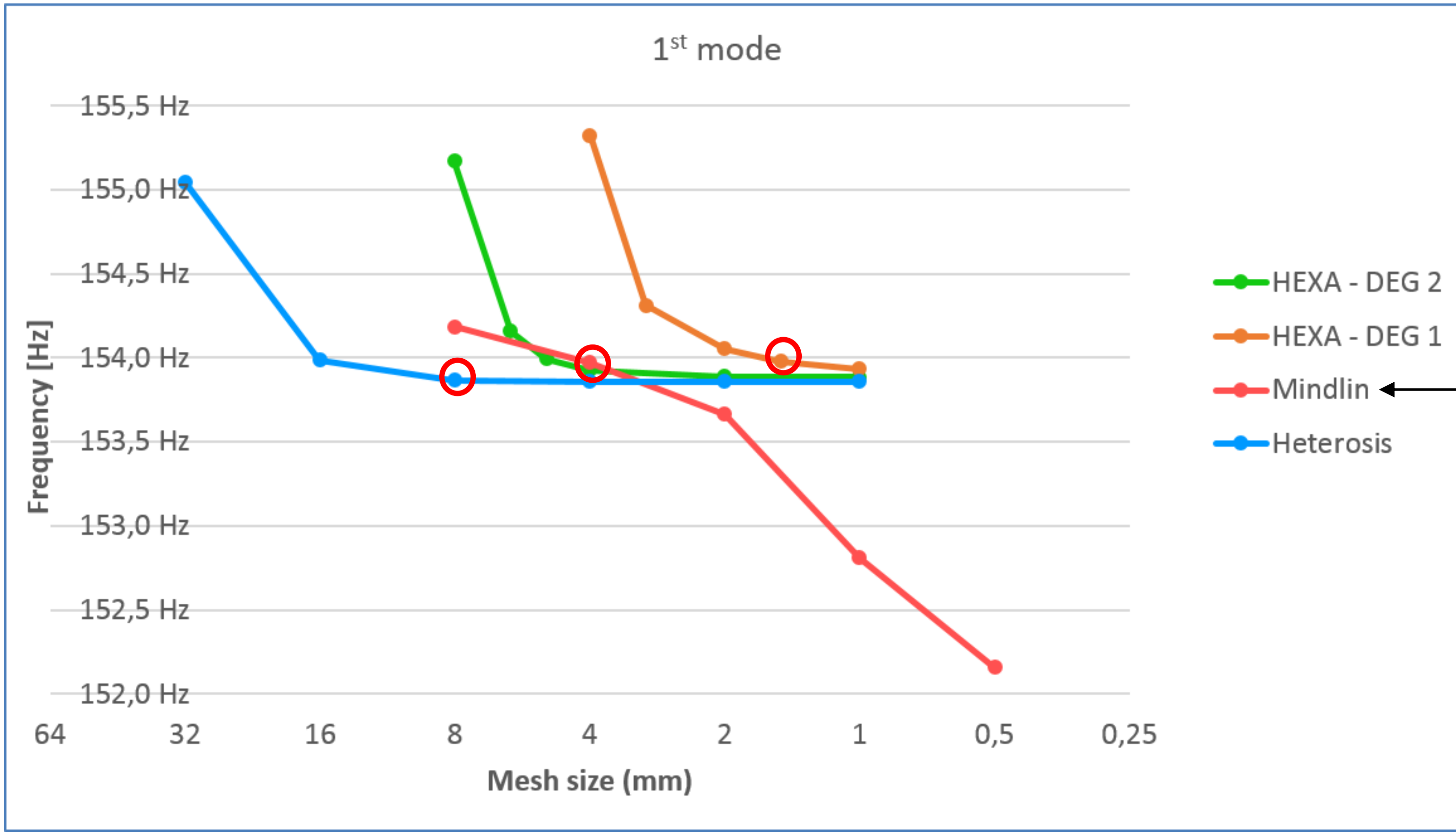
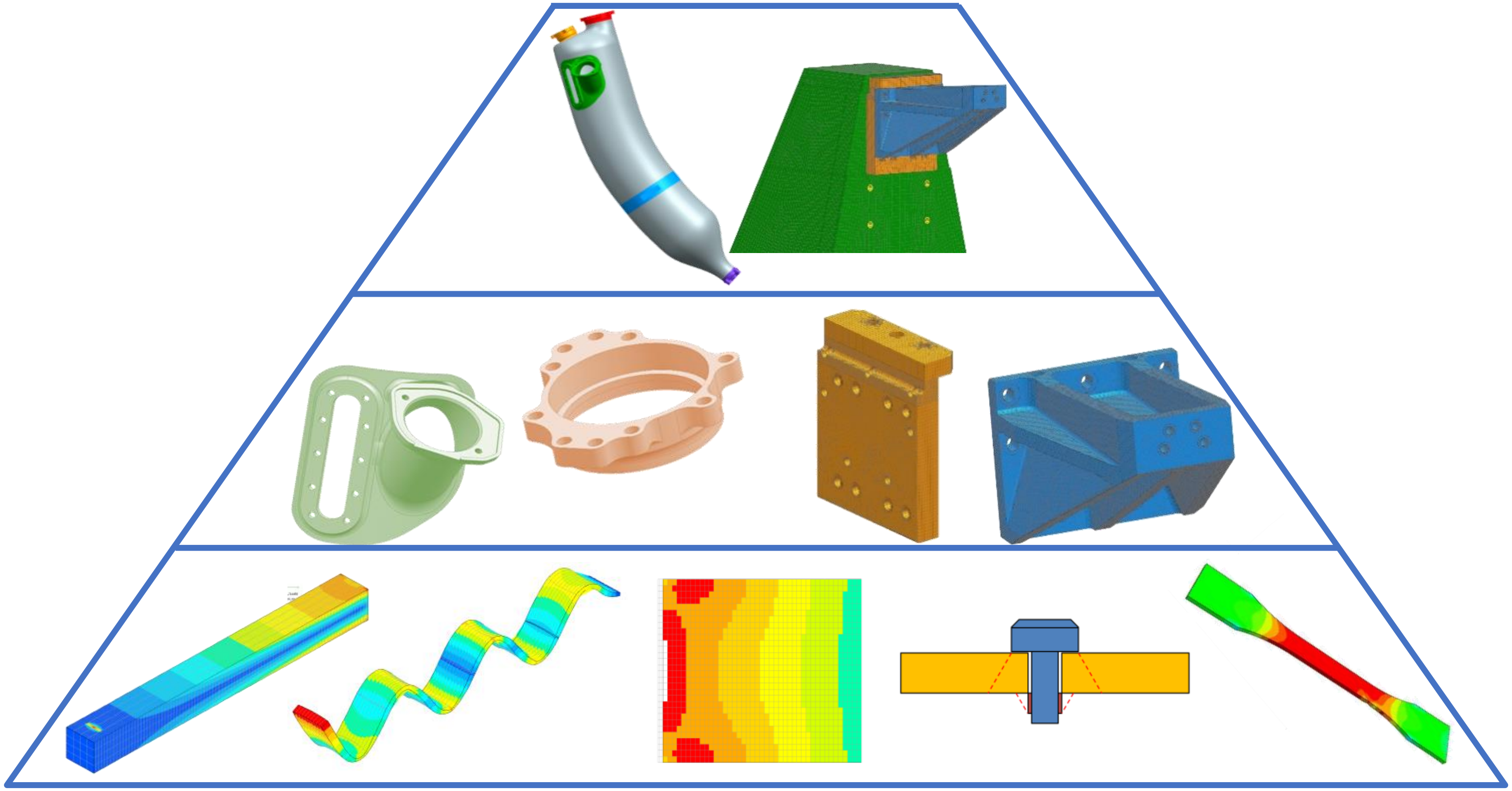
Convergence study of the tank mesh



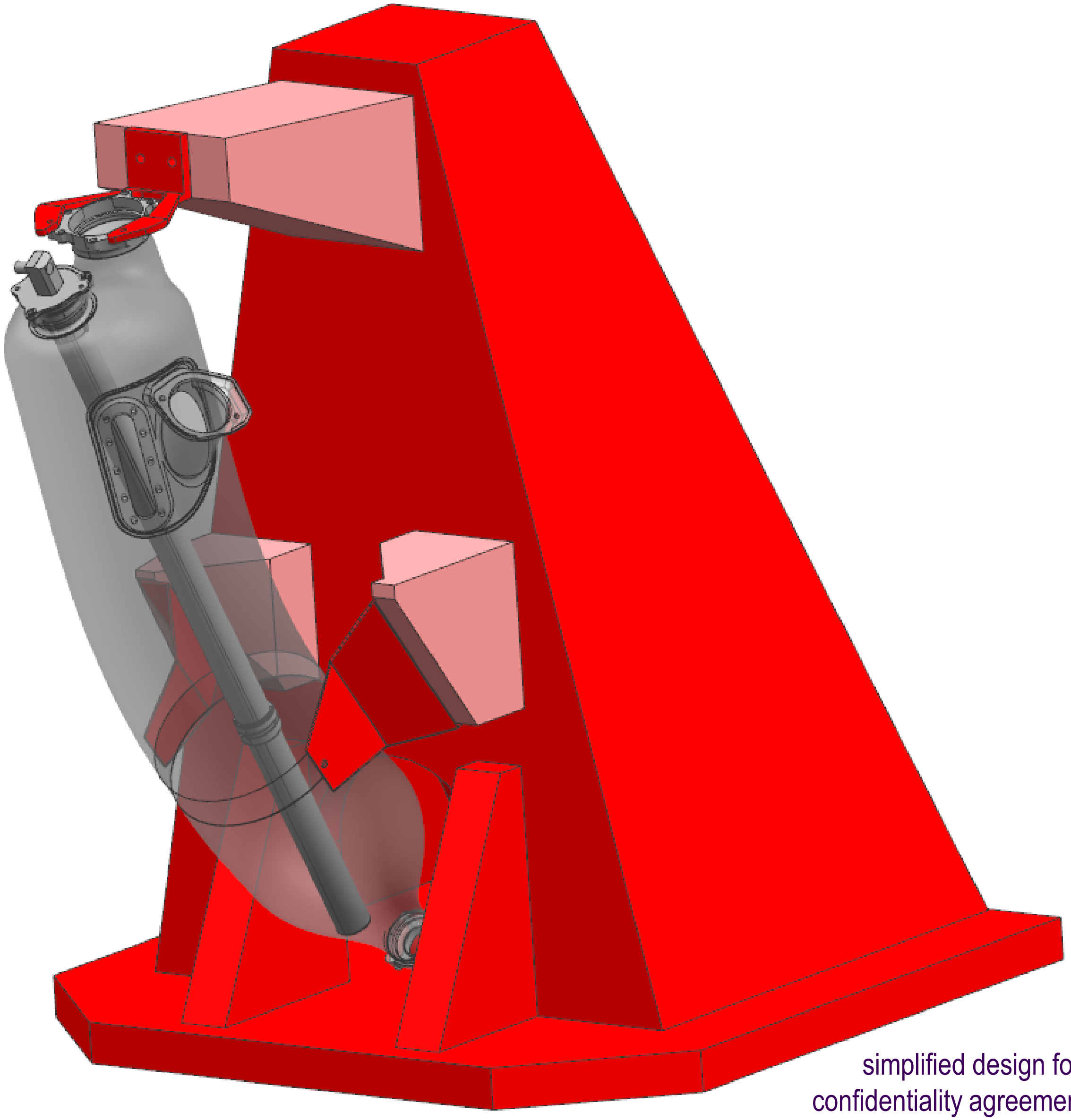


to be avoided



Tooling
Upper bracket
Left bracket
Right bracket
(connection parts)

- Experimental testing
- Modeling of fasteners
- Nonlinear dynamic behavior



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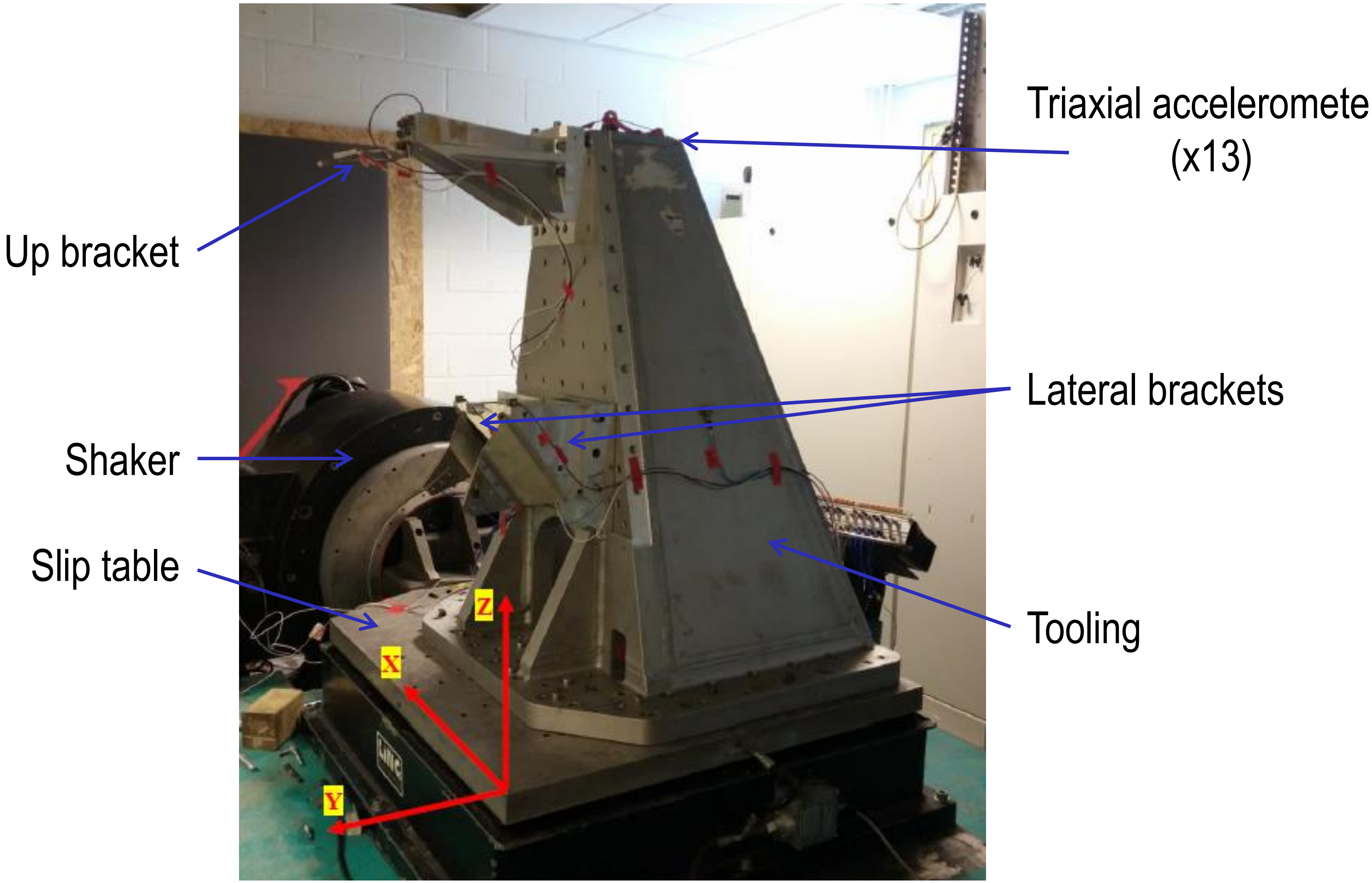
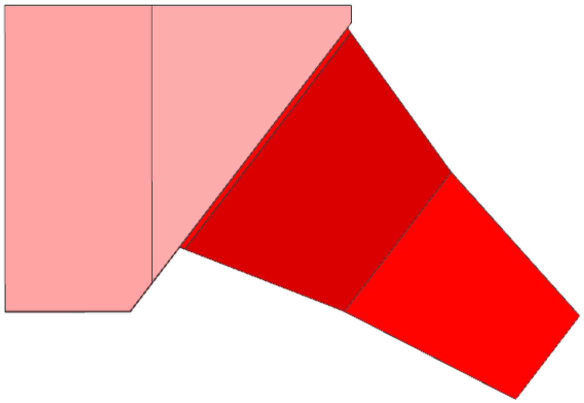
Environmental tests are required at this level

Tooling + brackets undergo sine-sweep base-excitation along the 3 directions

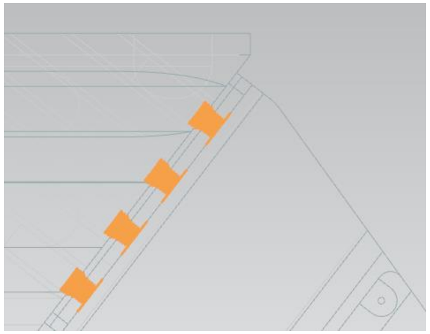
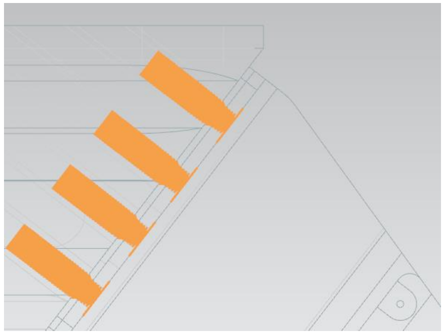
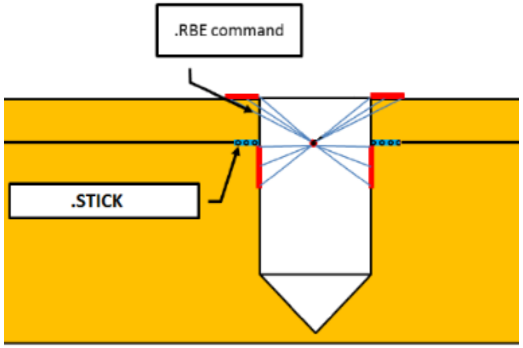


Assembling the brackets on the tooling

- Different connection models are compared



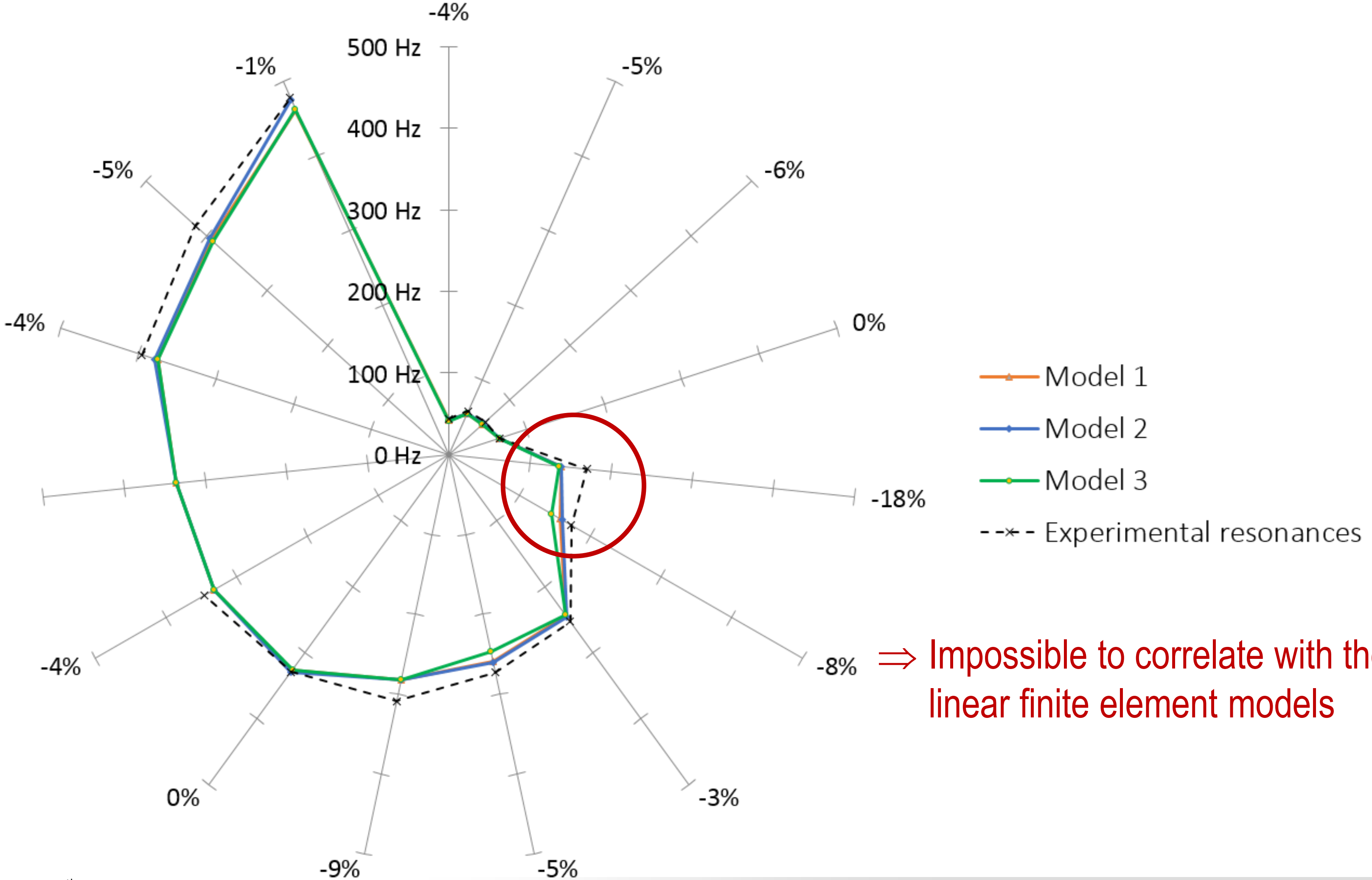
Rigid body elements between the nodes under the screw head and the nodes on the surface corresponding to the 3 first threads

Model 1	Model 2	Model 3
		

considering longer threads than model 1

model 1 + gluing at the interface

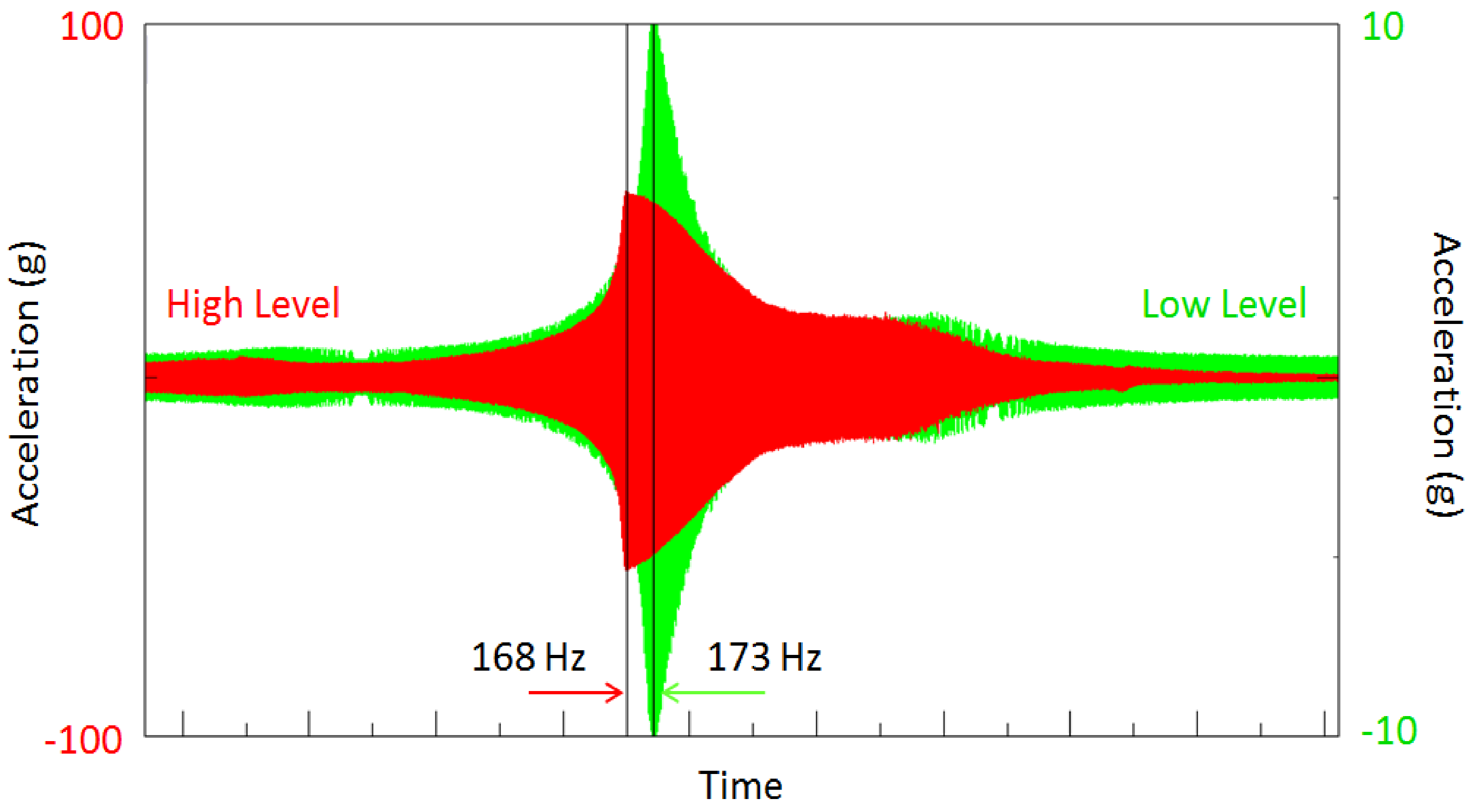
- The relative error on the natural frequencies is comparable for the first 2 models



⇒ Impossible to correlate with the linear finite element models

A closer look at the time responses to assess the results

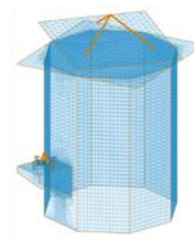
- Non-proportional variation of the response to different excitation levels



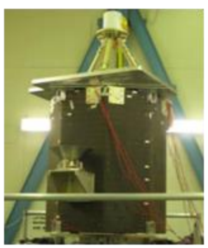
The NONLINEAR vibration analysis can enhance the model

Nonlinear Identification to Design
Software

LINEAR FINITE
ELEMENT MODEL



VIBRATION
MEASUREMENTS



MEASURE → IDENTIFY → SIMULATE → UNDERSTAND → DESIGN

Identify nonlinear connections

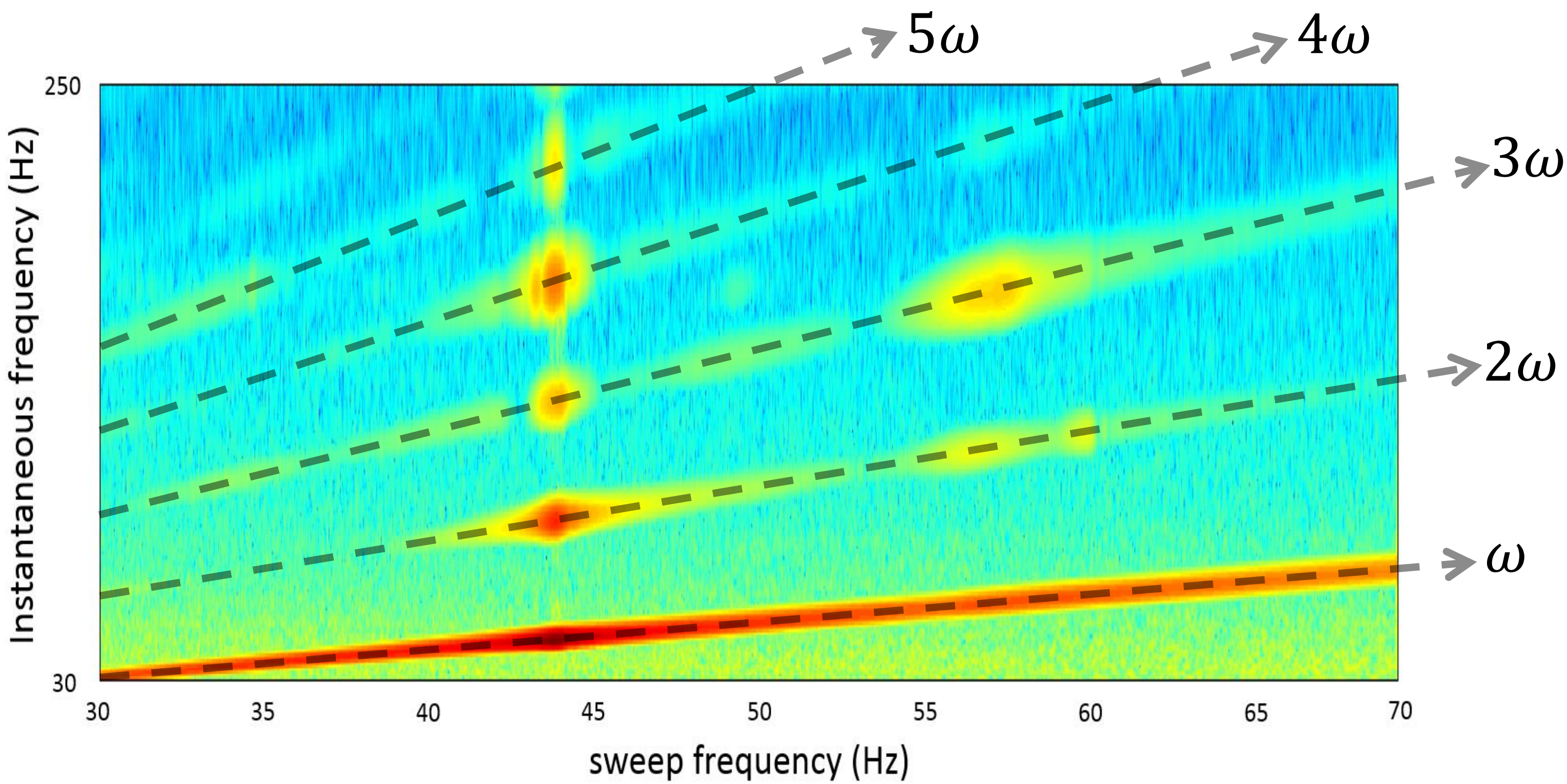
Compute nonlinear features
and responses

(Nolisys | University of Liege)

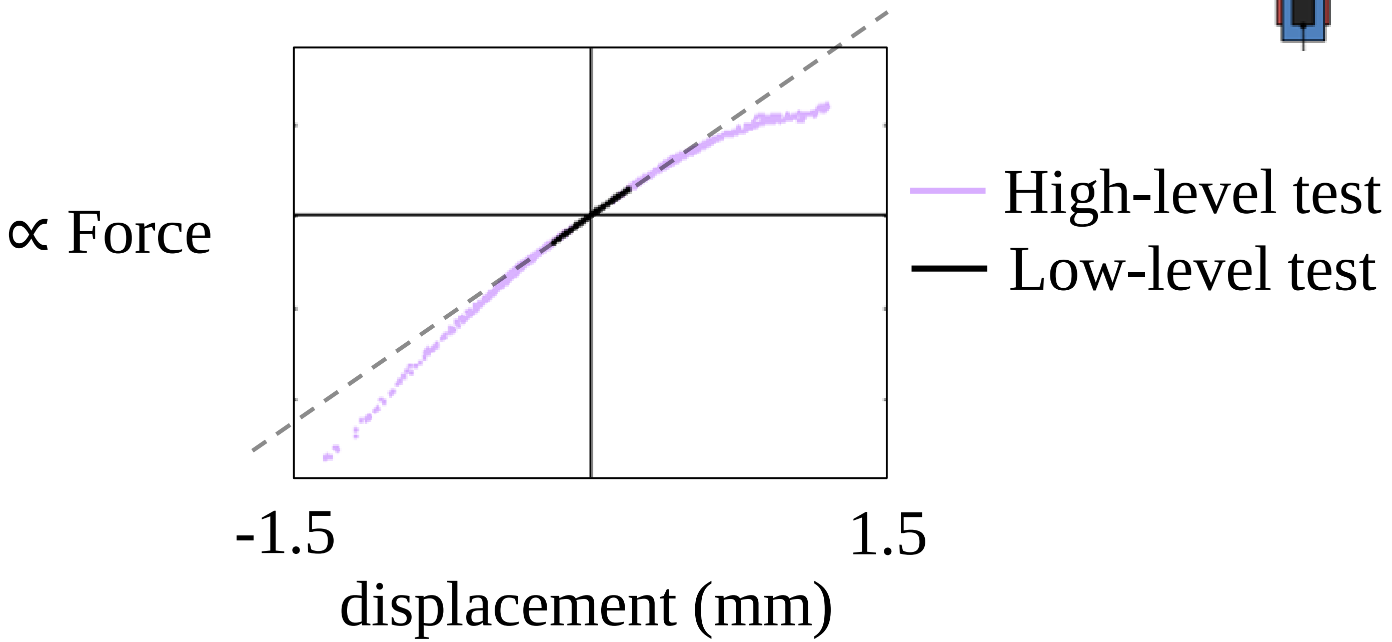
GDTECH engineering

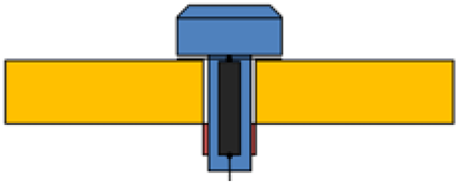
Applying the procedure at the system “tooling + brackets”

- Higher harmonics identified from the WAVELET of the measured responses



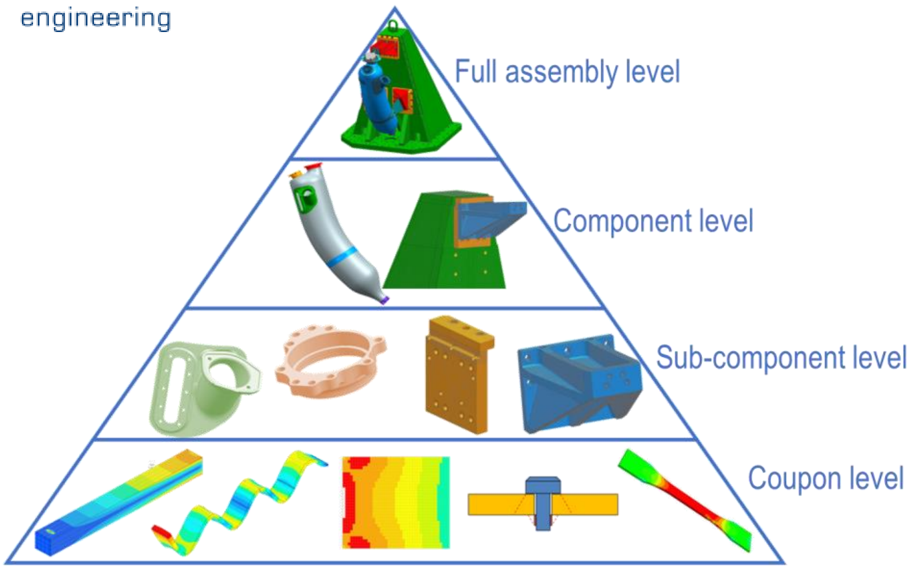
- The nonlinear stiffness can be identified from the experimental data* for each bolted connection and each component (displacement along X,Y and Z)

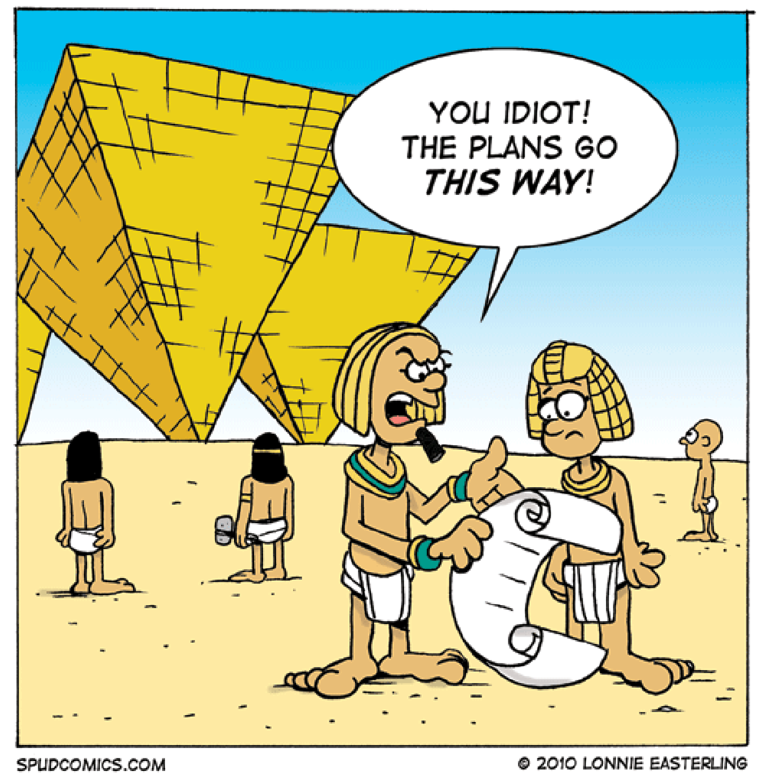




*Acceleration Surface Method: Ni2D (Nolisys | University of Liege)

The bottom-up approach is the winner



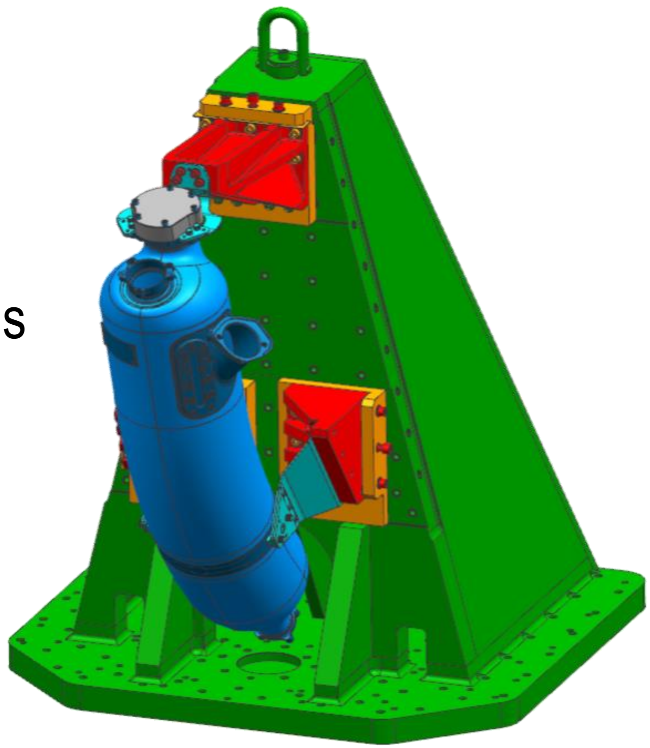


Full assembly

- Experimental testing
- Finite Element Modeling
- Nonlinear dynamic response analysis

Fluid-structure interaction

- Experimental testing
- Finite Element Modeling
- Modeling of the coupling



Thank you for your attention

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- The support of the Clean Sky program JTI-CS-2009-2-SAGE-02-003 is gratefully acknowledged

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