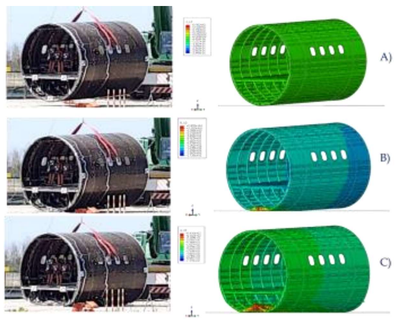
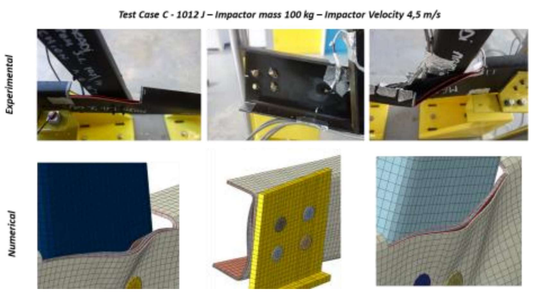
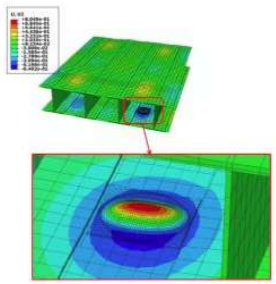
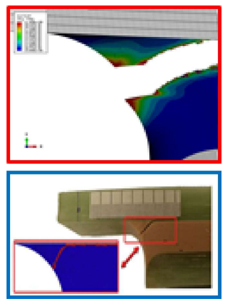
Design Optimization and analysis methods development

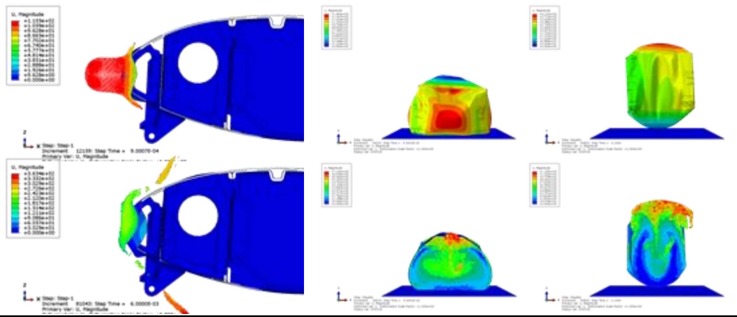
Francesco Di Caprio, Ph.D
f.dicaprio@cira.it
Airframe Design and Dynamic Lab.
Structural & Material Division





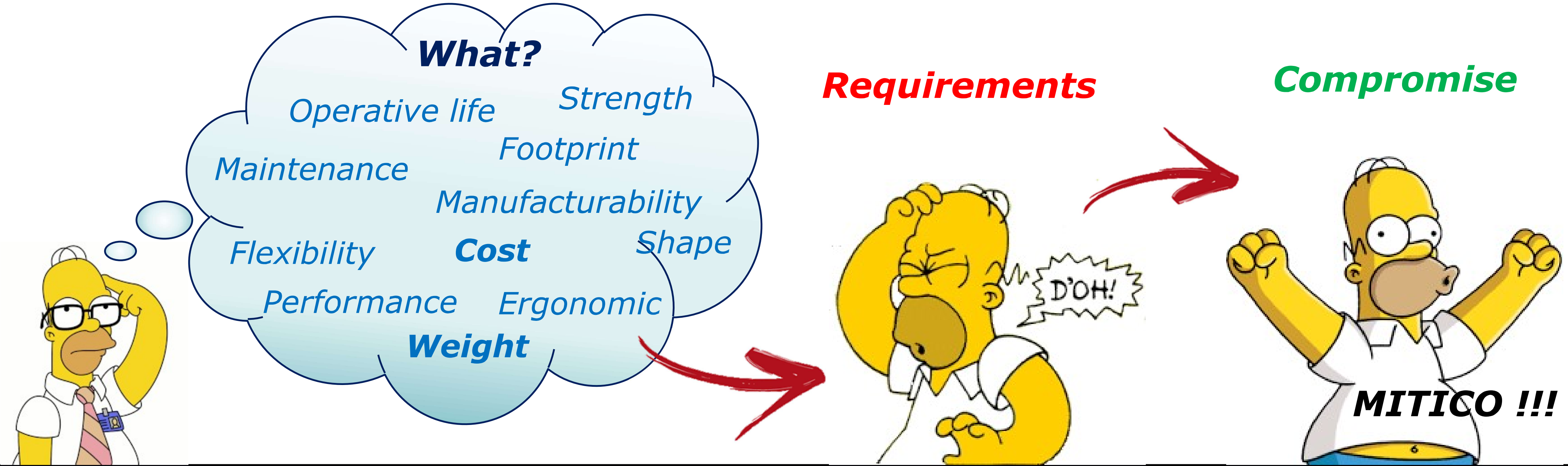






Why optimize?

- Generally not for all products a rigorous optimization analysis is performed, this depends on the benefit-cost ratio
- It is quite unlikely that it will be done for small parts… but if their number is high, non-execution could result in a non negligible error!
- If the designer wants his component to be the best, he must spend time optimizing
- For any structural component (part) there are a lot of reasons to optimize…



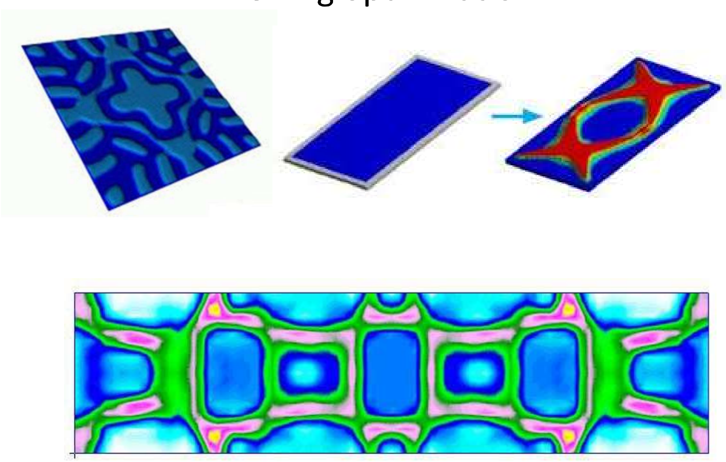
What kind of optimization approach are available?

- There are many optimization tool based on different theories area available: deterministic, stochastic, evolution methods
- A lot of them are available in dedicate general-purpose commercial codes and/or in a CAE environmental

Classes of Design Optimization (CAE/FEM)

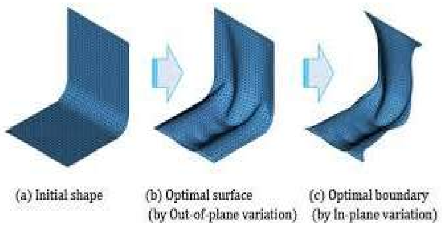
SIZING OPTIMIZATION
Element, Material and Connectivity properties can be used as design variables

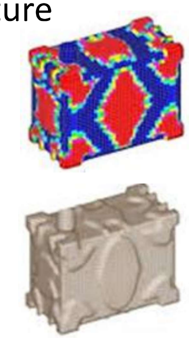
TOPOMETRY OPTIMIZATION
Special automated procedure for sizing optimization

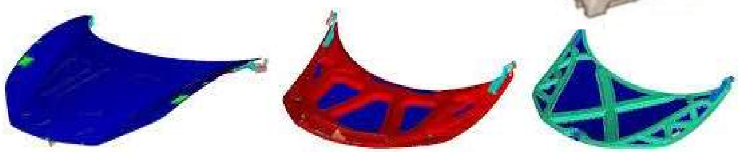


SHAPE OPTIMIZATION
The shape of the structure can be varies to satisfy specific requirements

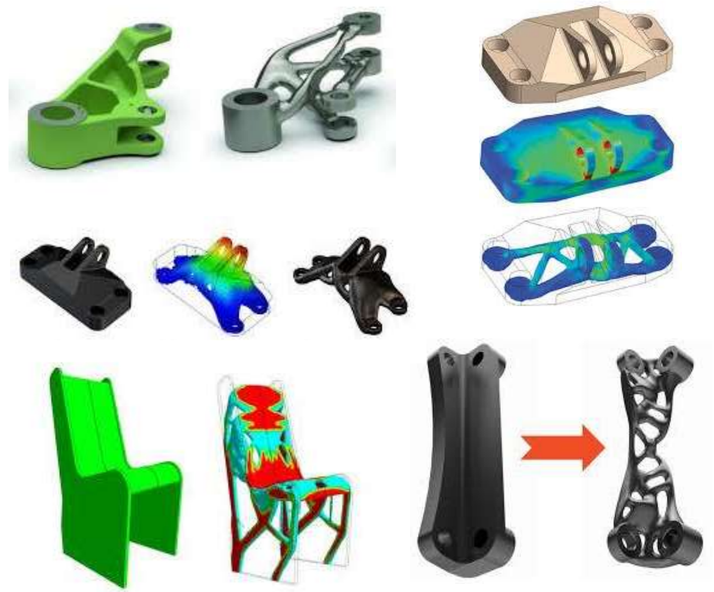
TOPOGRAPHY OPTIMIZATION
Special shape optimization procedure in which bead Theory is used to modify the shape of the structure



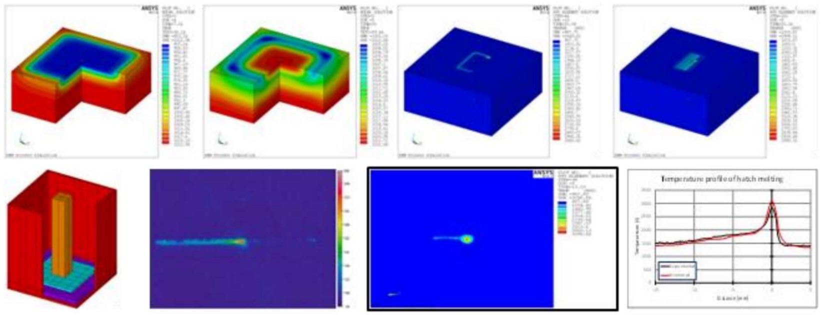




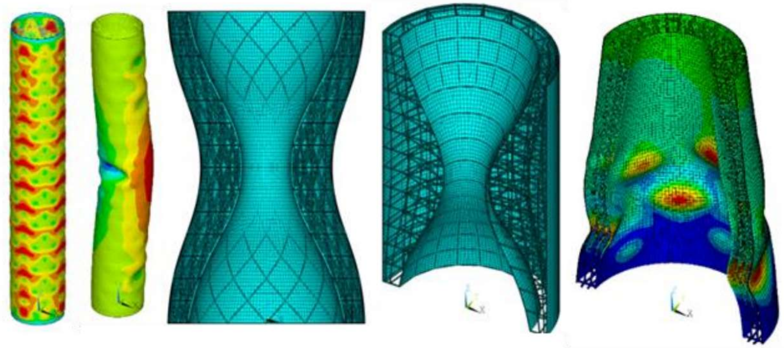
TOPOLOGY OPTIMIZATION
It finds an optimal distribution of material given the package space, loads and boundary conditions



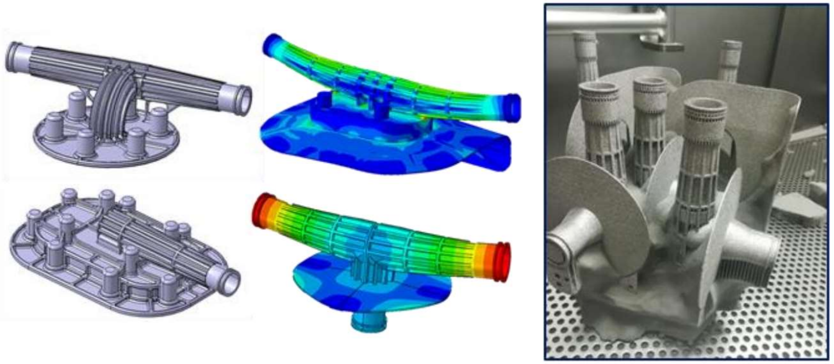
Simulation for additive…. Think additive!



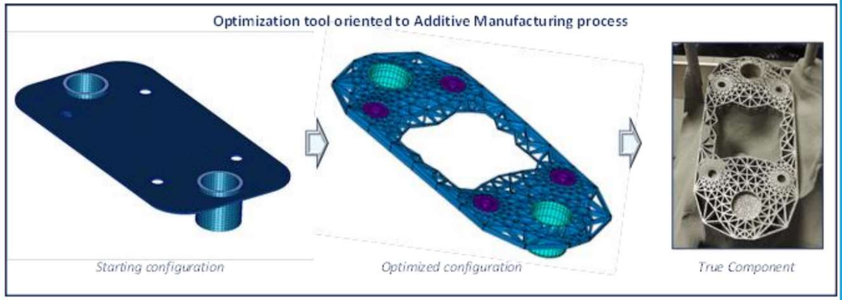
Simulation of the sintering process
Spatial and temporal distribution of temperatures
Application: Optimization of process parameters



Lattice / solid structures (titanium-composite)
Application: Shock absorbers, nozzles
Optimization tool with CAD model (ready to print)



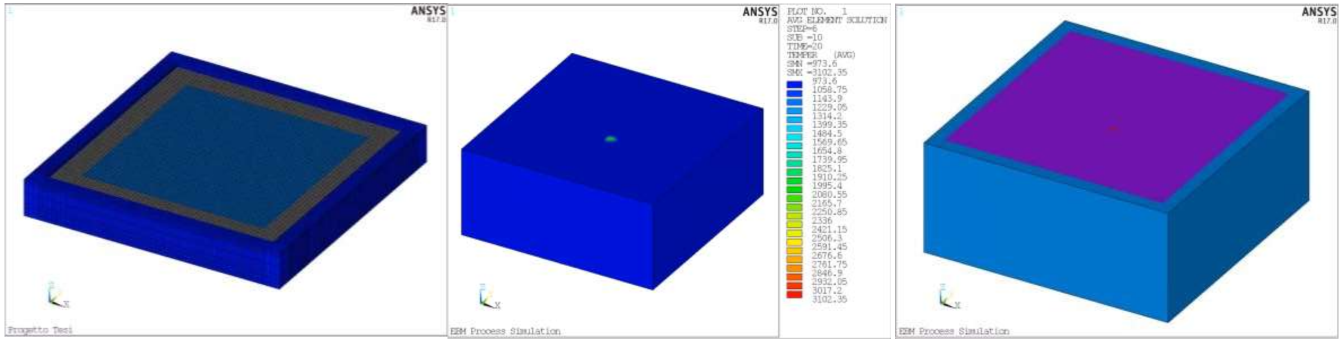
Optimization tool for complex metal components
Input: boundary condition, working volume
Automatic generation of ready-to-print CAD model

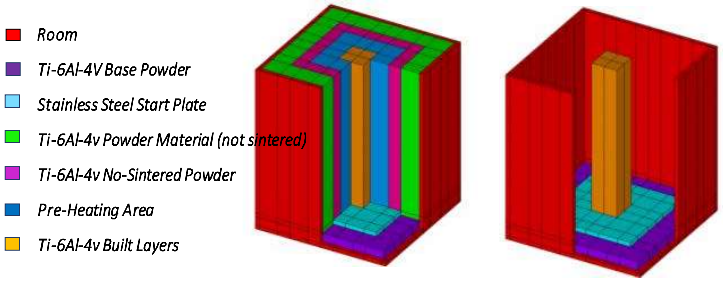


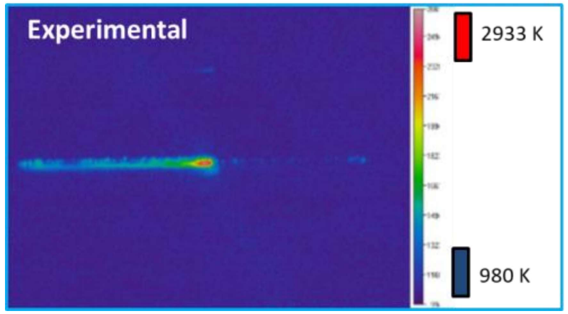
Optimization tool based on genetic algorithms
For lattice structure type
Automatic generation of ready-to-print CAD model

Simulation for Additive Manufacturing Process

- Development of a numerical methodology for the simulation of the entire manufacturing process of a metal component using EBM-type powder bed fusion additive processes
- All the phases of the real manufacturing process have been incorporated into the numerical simulation:
  - *Working chamber preheating*
  - *Spreading powders*
  - *Preheating of powders*
  - *Contour melting*
  - *Hatch melting*
  - *Final cooling*







Spot Melting Temperature:
Numeric: 3096 K (2823 ° C)
Experimental: 2933 K (2660 °C)

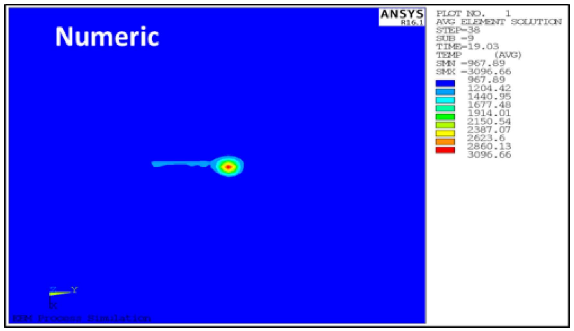
ΔT ≈ 160 K
Errore ≈ 6 %

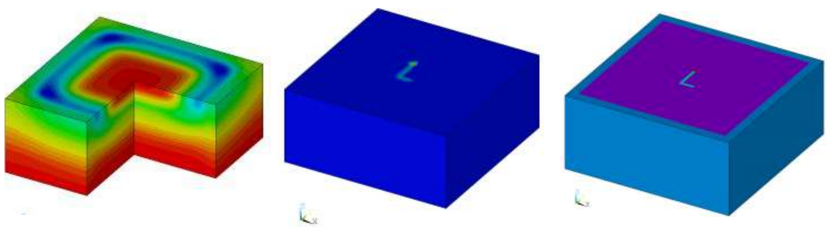
Temperature close to spot:
Numeric: 967 K (694 ° C)
Experimental: 980 K (707 °C)

ΔT ≈ 13 K
Errore ≈ 2 %

Solidification length:
Numeric: 4.25 mm
Experimental: 4.59 mm

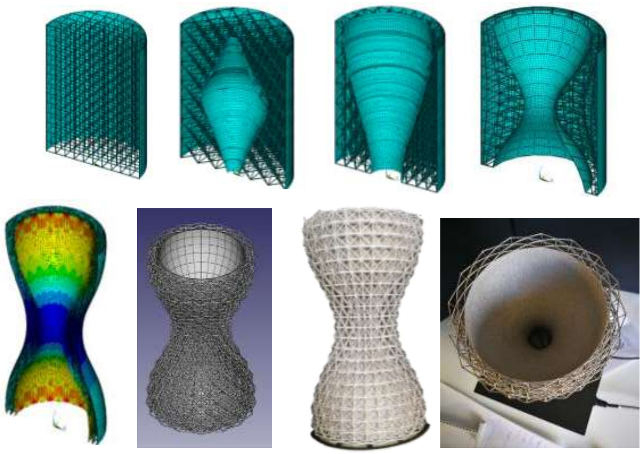
ΔS ≈ 0.34 mm
Errore ≈ 7 %





Structural optimization thinking additive

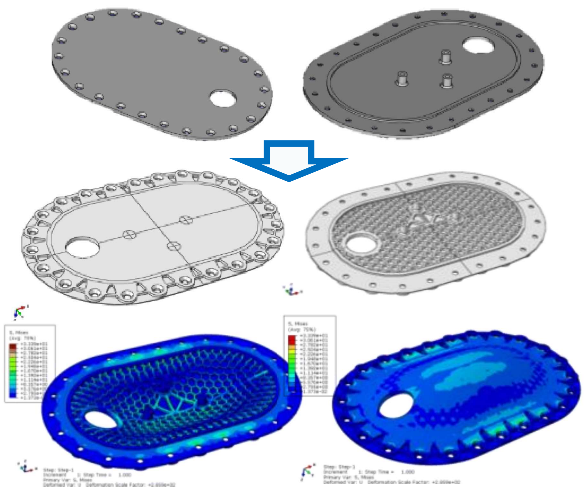
Hybrid Nozzle (composite/Titanium)



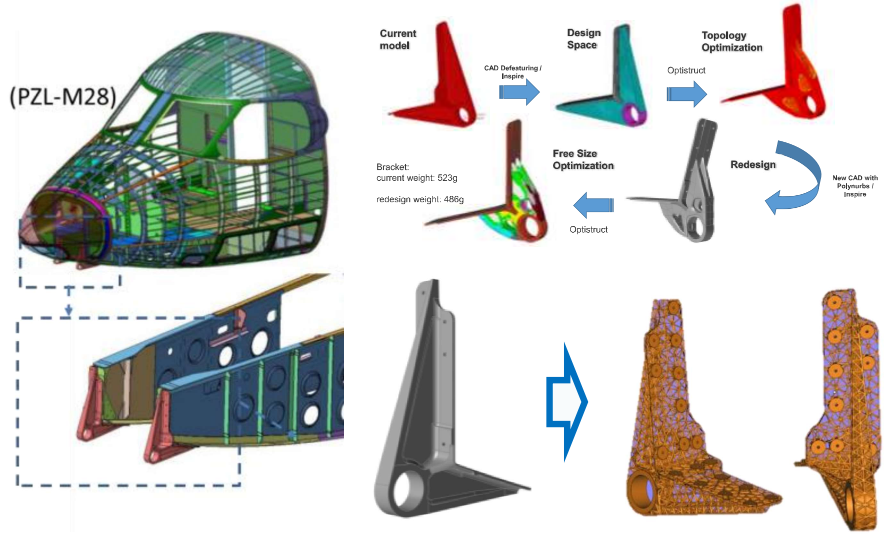
Nozzle – FEM/CAD

Manufactured

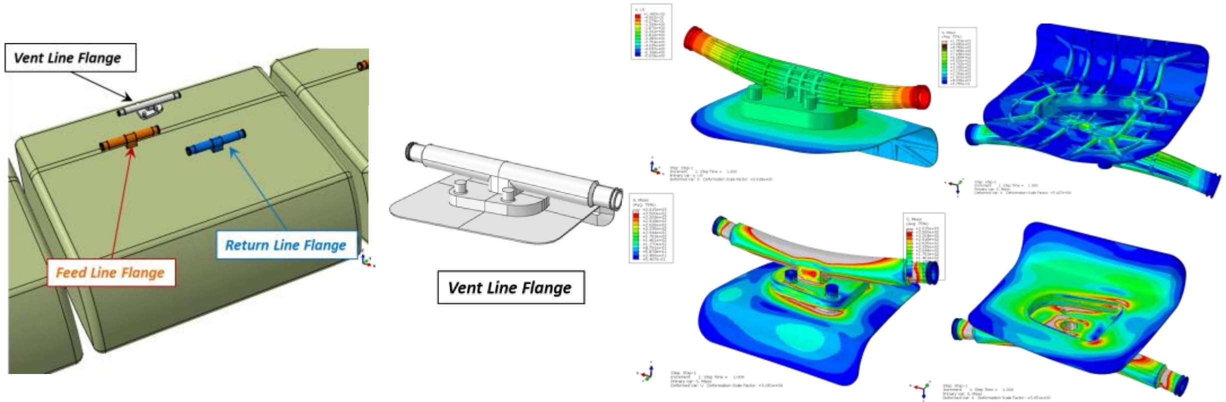
Closure Plate for Bladder tank (original: 0.5 kg, opt: 0.30 kg)



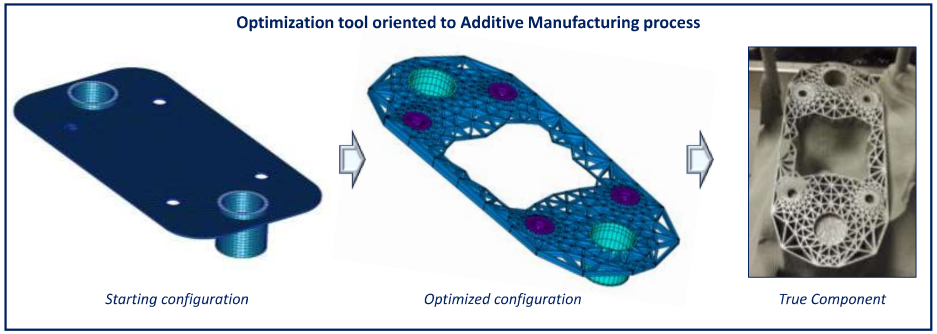
Nose landing gear fitting (PZL-M28) – Al: 524g; Ti: 473g



Fuel Tank Flanges (original - Aluminum: 300 g, opt Titanium: 318 g

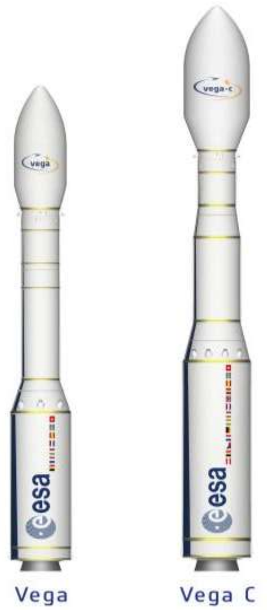


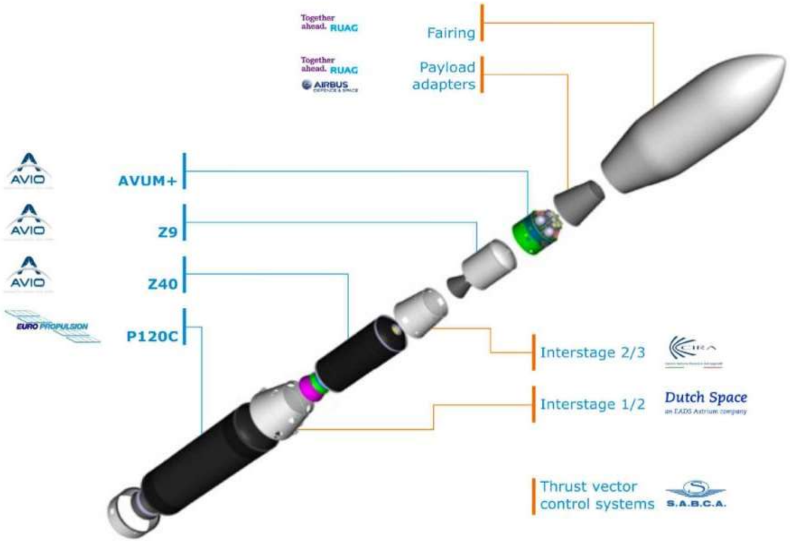
Equipment support – Interstage 2/3 (CNC: 225g; ALM: 150g)

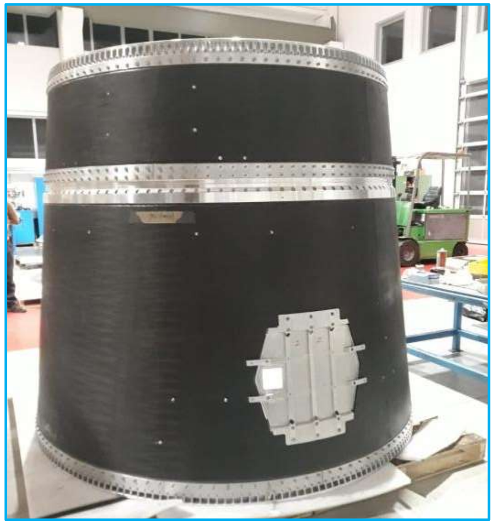


Structural optimization for CNC in Space field

- ***The project of Vega C launcher is focused on capability improvement of the current Vega launcher.***
- ***The Vega C launcher is characterized by an increase of pay-load capacity from the 1500 kg (present Vega launcher) up to 2200 kg (new Vega C) in LEO orbit. All that will enable an improvement of performance and costs.***
- ***The Interstage structure is realized in a composite ANISO-GRID architecture. The grid structure, respect to metallic structure, allows to provide similar longitudinal stiffness, higher longitudinal compressive strength and a low mass density (almost 0.5 respect to similar metallic structures).***

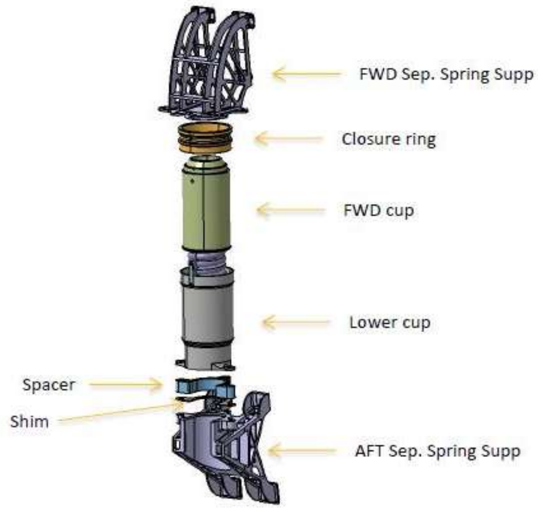


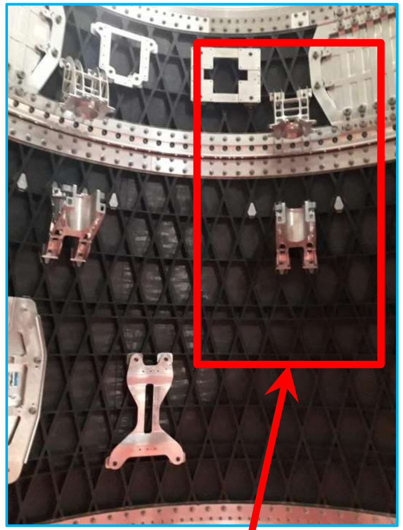


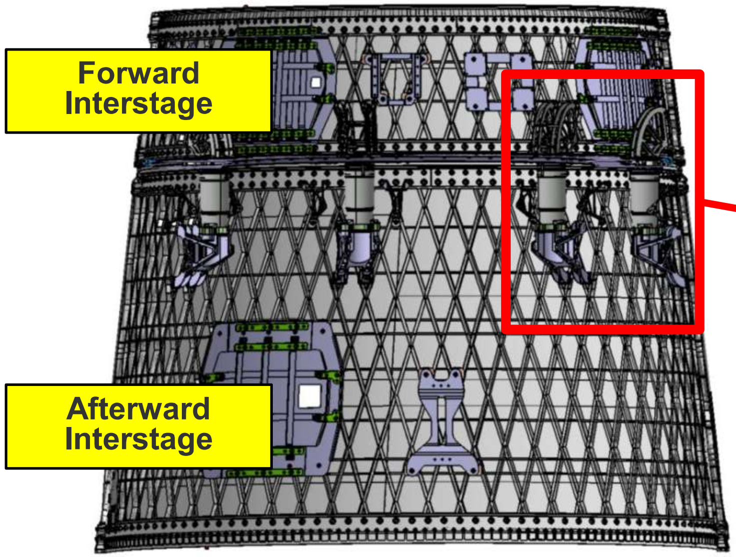


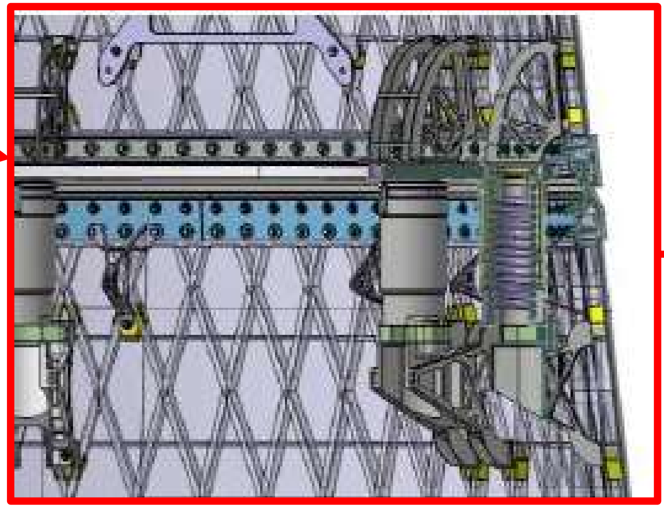
Structural optimization for CNC in Space field

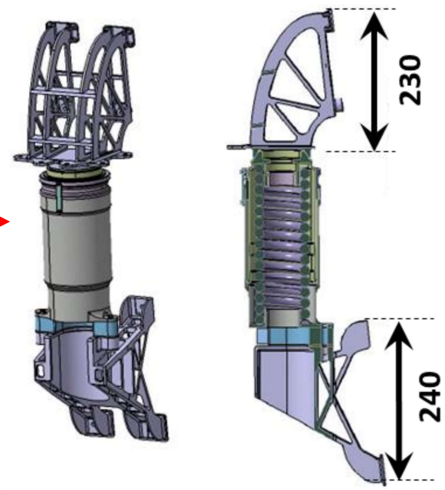
- ***The Interstage 2/3 project cover the design and manufacturing of all internal metallic secondary structure (separation spring assemblies, equipment supports and the basecover)***
- ***All component has been designed by CIRA and manufactured by an AVIO third-party.***
- ***All component have been installed and tested in the DMO model (global test)***











Structural optimization for CNC in Space field

Some Load cases (total: 8 + 6-FSA)
With specific requirements

Many highly requirements challenging
Moreover... the total mass has to be as small as possible!

CASE 1 – Forward spring support Verification

Items:
- Forward Spring Support

Load Condition:
- Axial Force: 12168 N

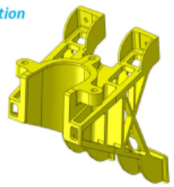
Requirements :
- Max Axial displacement: < 0.5 mm
- Max rotation angle (spring axis) < 0.1°
- MoS > 0

CASE 2 – Afterward spring support Verification

Items:
- Afterward Spring Support

Load Condition:
- Axial Force: 12168 N

Requirements :
- Max Axial displacement: < 0.5 mm
- Max rotation angle (spring axis) < 0.1°
- MoS > 0

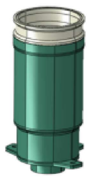


CASE 4 – Lower Cup Verification

Items:
- Lower Cup
- Closure ring

Load Condition:
- Max Spring Axial Force: 12168 N

Requirements :
- MoS > 0
- Max radial displacement at the end: < 0.02 mm
- No interference with upper cup

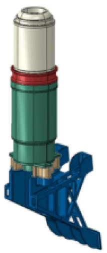


CASE 6 – Verification of Spring Assembly deflection

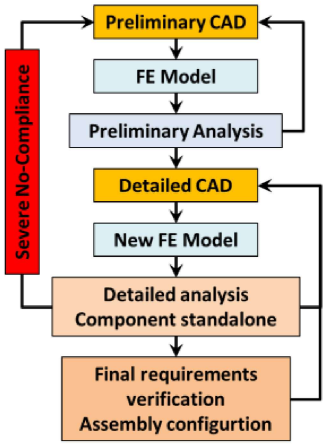
Items:
- Afterward Spring Support
- Lower Cup
- Upper Cup
- Closure Ring
- Separation Spring Spacer
- Shim

Load Condition:
- Lateral Force (Radial / Tangential): 1000 N

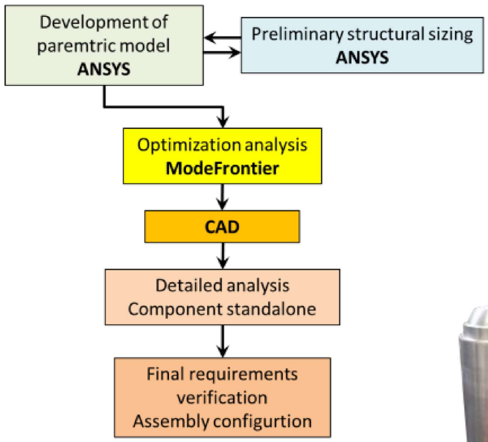
Requirements :
- Max lateral displacement: < 1.5 mm
- MoS > 0



Standard Design Approach

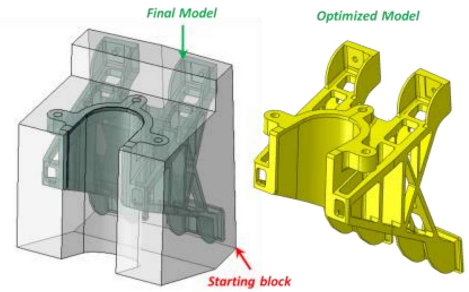


Developed Design Approach

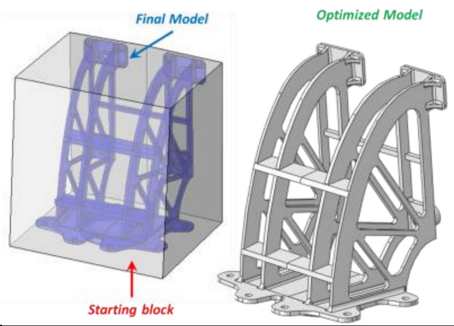


Spring Assembly - Estimated Mass		
Upper Cup	0.535	*[kg]*
Lower Cup	0.555	*[kg]*
Forward Spring Support	0.658	*[kg]*
Afterward Spring Support	1.447	*[kg]*
Spacer	0.145	*[kg]*
Closure Ring	0.177	*[kg]*
Total Mass	3.517	*[kg]*

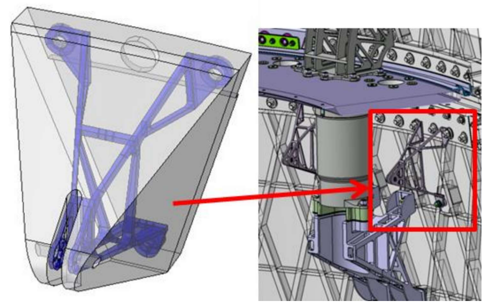
AFT Support (1447 g)



FRW Support (658 g)

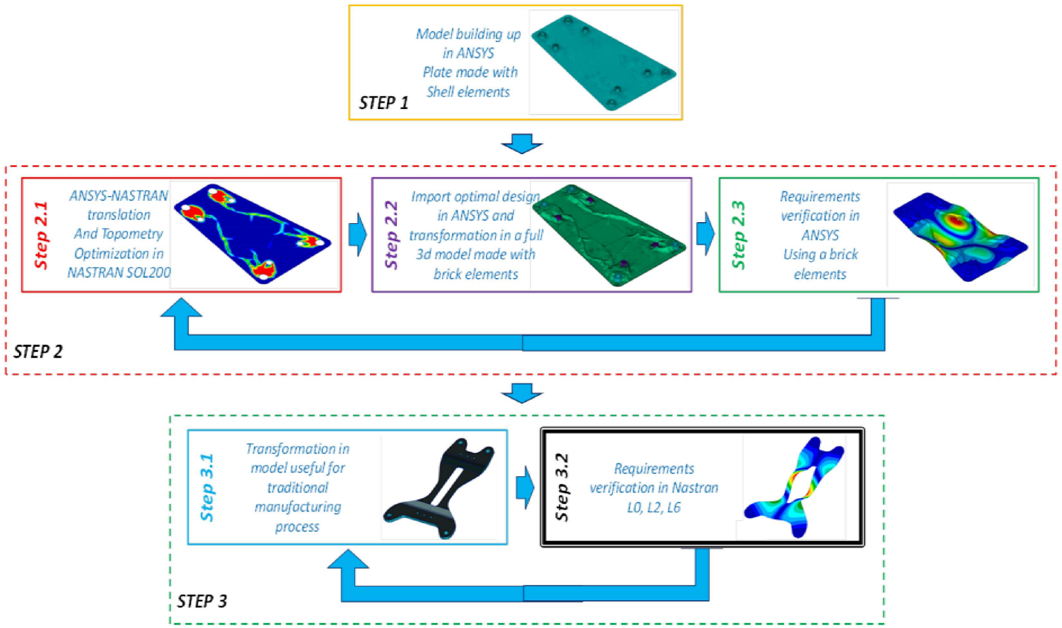


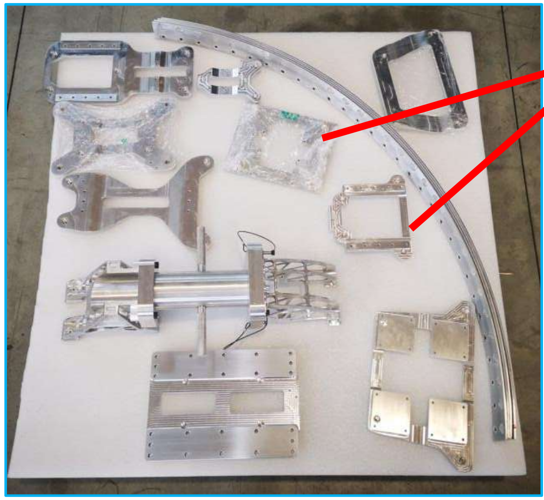
Retainer – Interstage 2/3 (76 g)

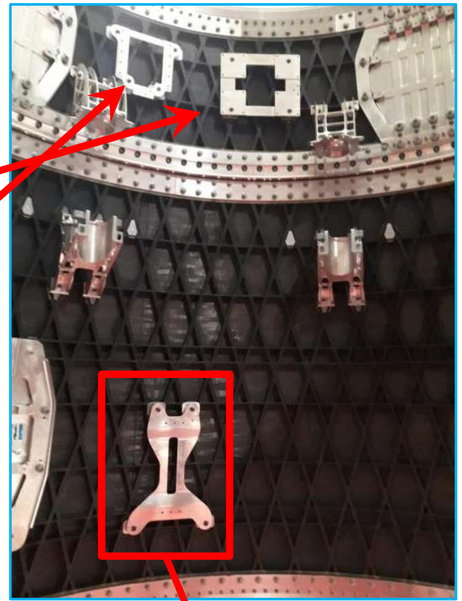


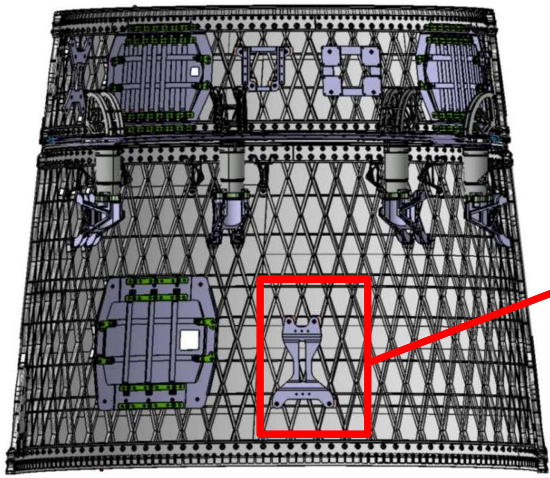
Structural optimization for CNC in Space field

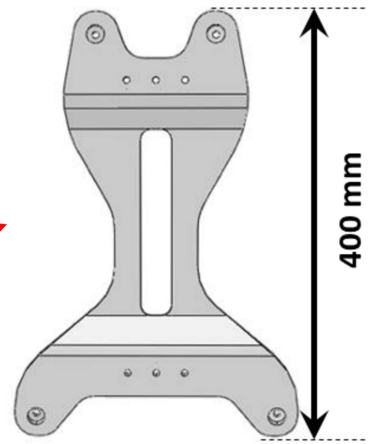
In order to satisfy the requirements and to guarantee the smaller weight, a numerical optimization procedure was set up. The procedure uses the commercial code ANSYS and NASTRAN connected each other by means of a dedicate routine (written in APDL). The procedure starts with a model discretized by shell element and finish with a numerical model discretized by 3D elements.









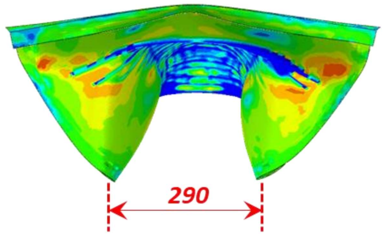


Structural optimization for performance improvement

- **_Leading edge under bird impact_**
- **_Bird initial velocity: 129 m/s_**
- **_Bird mass: 3.68 kg_**
- **_Impact Energy: 30 kJ_**

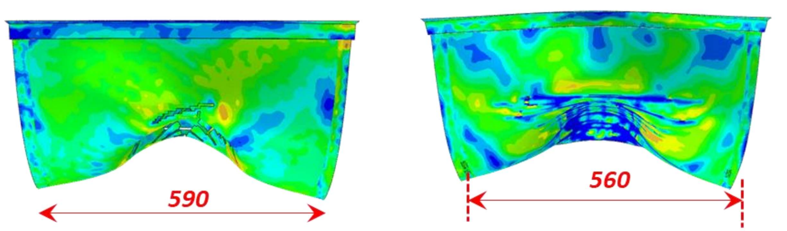
Experimental Results

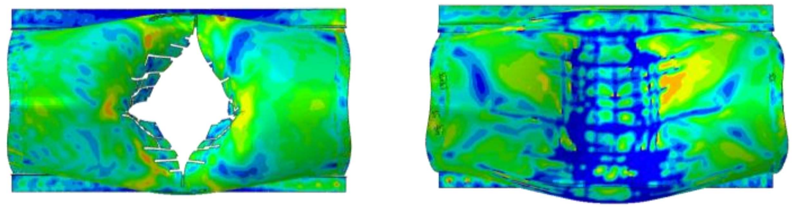
Starting Configuration

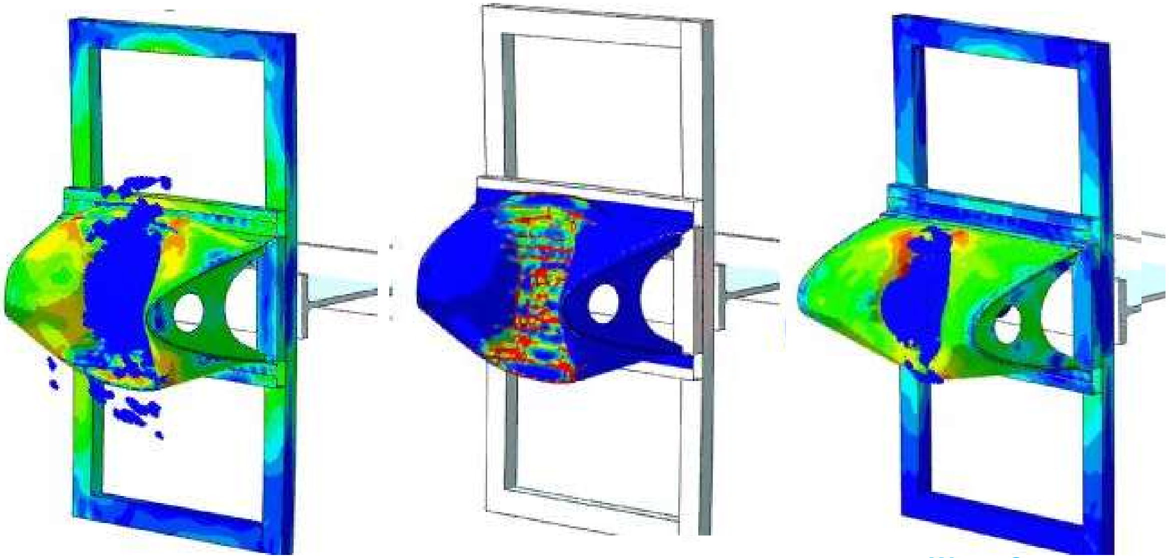


	Startin	Worst	Best
TH INNER [mm]	0.4	0.4	0.4
TH OUTER [mm]	1.4	0.5	1.4
TH CORE [mm]	6.35	6.35	12.7
MASS [kg]	2.53	1.4	2.65

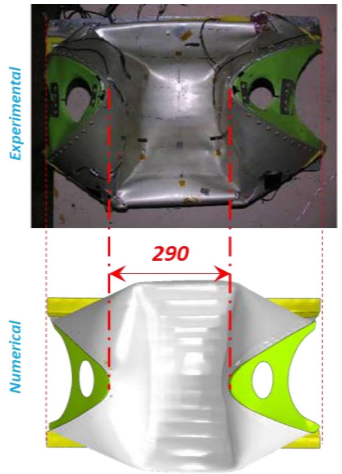
Worst Configuration *Best Configuration*



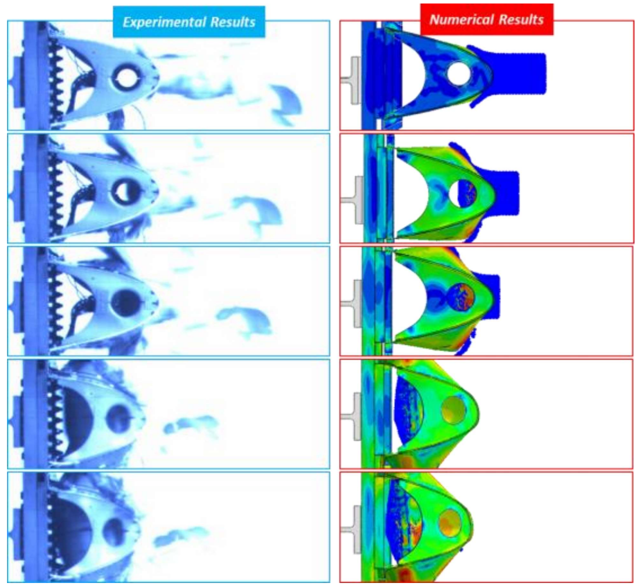




Numerical Results - Staring Configuration *Worst Case*



Post impact permanent deformations



What are next steps?

- ***Improvement of the tool for the manufacturing process simulation***
  - ***Reduce the computational cost***
  - ***Further validation test cases***
  - ***Increase the flexibility***

- ***Improvement of the numerical methods for design optimization of lattice structure***
  - ***Increase the capabilities***

- ***Development of black-box design tools for all users***
  - ***App development***

- ***Study other optimization tools (commercial code) in order to highlight advantages and disadvantages of our procedures***

- ***Development of novel approaches to reduce the computational cost for structural optimization in crashworthiness field***