THE TOPOLOGY OPTIMIZATION APPROACH, A PROMISING TECHNOLOGY TO ADOPT AS A DESIGN FOR DEMISE SOLUTION

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R.Tech Research & Technology

1. Context

2. Need for Design-For-Demise

3. An innovative solution ?

4. Simulation on a real case

5. Conclusion and perspectives

The French Space Operation Act (FSOA) enforces the assessment of prospective risks

- National regime of authorization and supervision for space activities
- LEO satellites need to be removed by re-entering the Earth's atmosphere

Technical Regulations (TR): maximum allowable probability to have at least one victim

- 10^{-4} for controlled reentries and uncontrolled reentries

French Space Agency in charge of ensuring compliance with the TR associated to FSOA

DEBRISK v3 / Electra: French certification tools

- Asses the debris survivability
- Asses the risk on ground
- Provided to the French Operators

***PAMPERO**: Spacecraft-oriented reentry code*

- Validate / Improve assumptions for DEBRISK
- Realized special studies for complex equipment
- Design-For-Demise (D4D) analysis

The CNES Tech4SpaceCare project (T4SC)

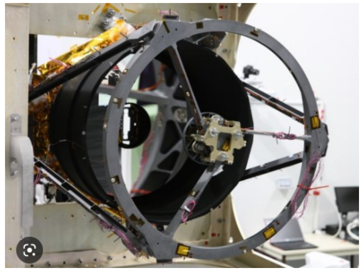
- Aims to develop technological solutions allowing platforms to comply with the TR

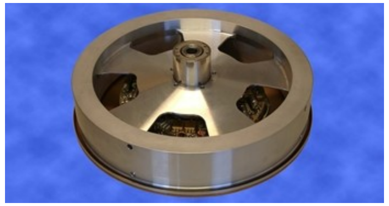
WHY DO WE NEED DESIGN-FOR-DEMISE (D4D) ?

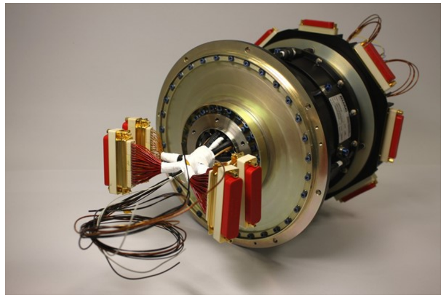
Some elements are identified as critics:

- Propellant tanks
- Reaction wheels
- Magnetorquers
- Mechanisms (SADM, …)
- Pressure tanks
- Payload-specific elements (Optical payloads, …)
- …

Find a safety solution







Different solutions

- Design-for-Demise (D4D)
- Design-for-Containment (D4C)
- Design-for-Breakup (D4B)
- …

- Some inovative solutions exist, but have **low** maturity and are not well described
- **Topological Optimization as a promising solution ?**

Topological Optimization
+
Additive Manufacturing

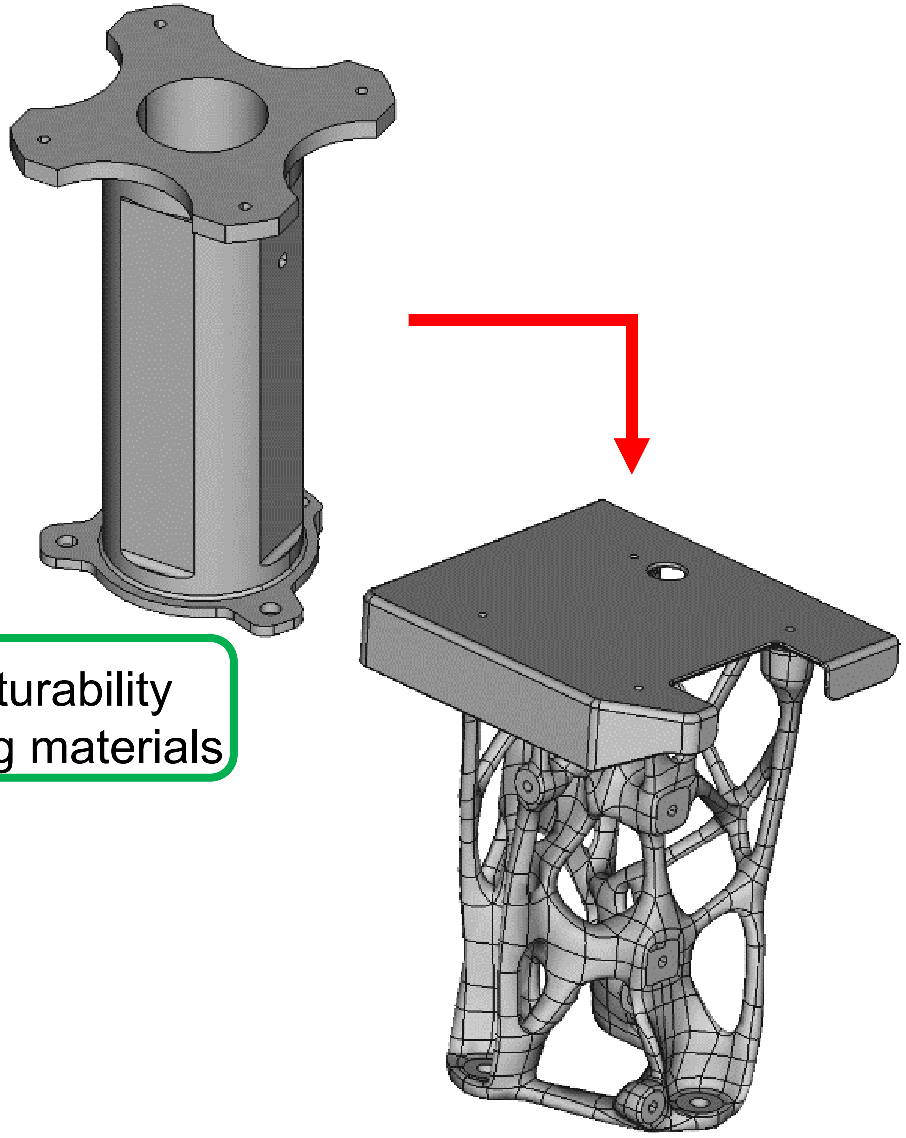
- Constrained optimization + 3D printing
- Technology widely used today.
  - ✓ Automotive, aeronautics, space
  - ✓ Mass and volume reduction
  - ✓ Equivalent/better mechanical or thermal performances

- Freeform

- Manufacturability
- Changing materials

?

- Maximize heat flux
- Demisable material

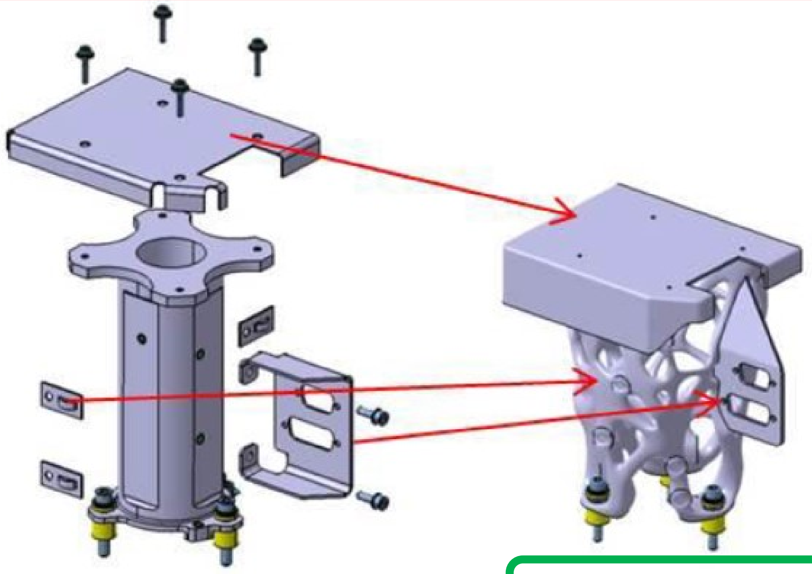


Is TO+AM a promising solution ?

Proposed study case

TARANIS sun assembly sensor (SAS) support

- Classical optimization ➔ mass and cost reduction
- Define/Validate a new AM process for space applications
- Without D4D constrains



Code used

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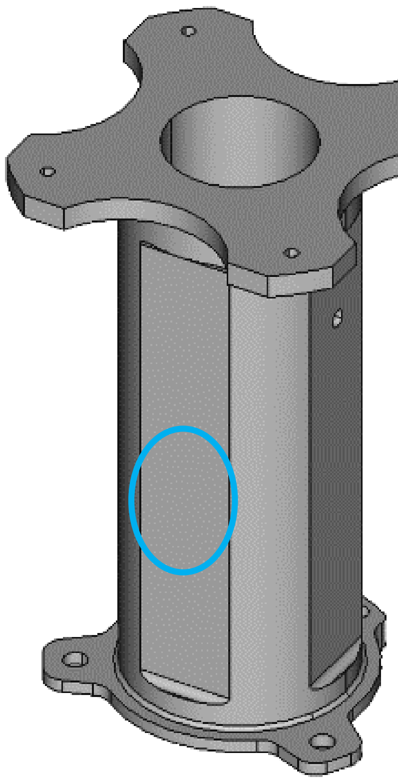
PAMPERO (CNES) - Spacecraft-oriented tool

- 3D unstructured volume mesh
- Non-coincident mesh
- 6 DOF trajectory model
- Aero and aerothermodynamics models
- 3D thermal heat transfer
- Anisotropic conductivity
- Oxidation models
- Pyrolysis/Carbonisation models
- Fragmentation and Ablation process

Analyze the potential of TO+AM to design demisable vehicles



Classical shape

m = 0,505 kg

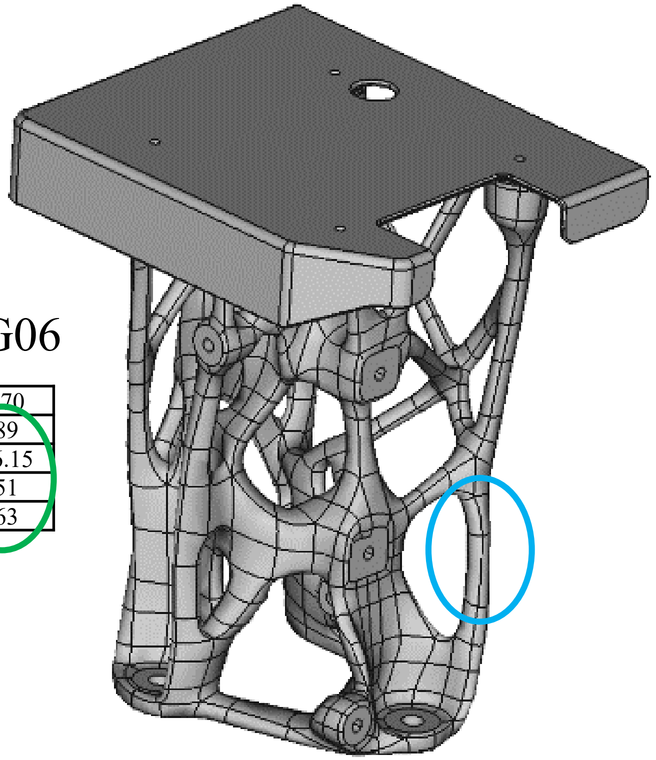
Aluminum AA2618 T851

Density [kg/m³]	3000
Spec. Heat of Melting [kJ/kg]	390
Melting Temperature [K]	943.15
Thermal Conductivity [W/m.K]	150
Spec. Heat Capacity [J/kg.K]	880

m = 0,310 kg

Aluminum A357 AS7G06

Density [kg/m³]	2670
Spec. Heat of Melting [kJ/kg]	389
Melting Temperature [K]	886.15
Thermal Conductivity [W/m.K]	151
Spec. Heat Capacity [J/kg.K]	963



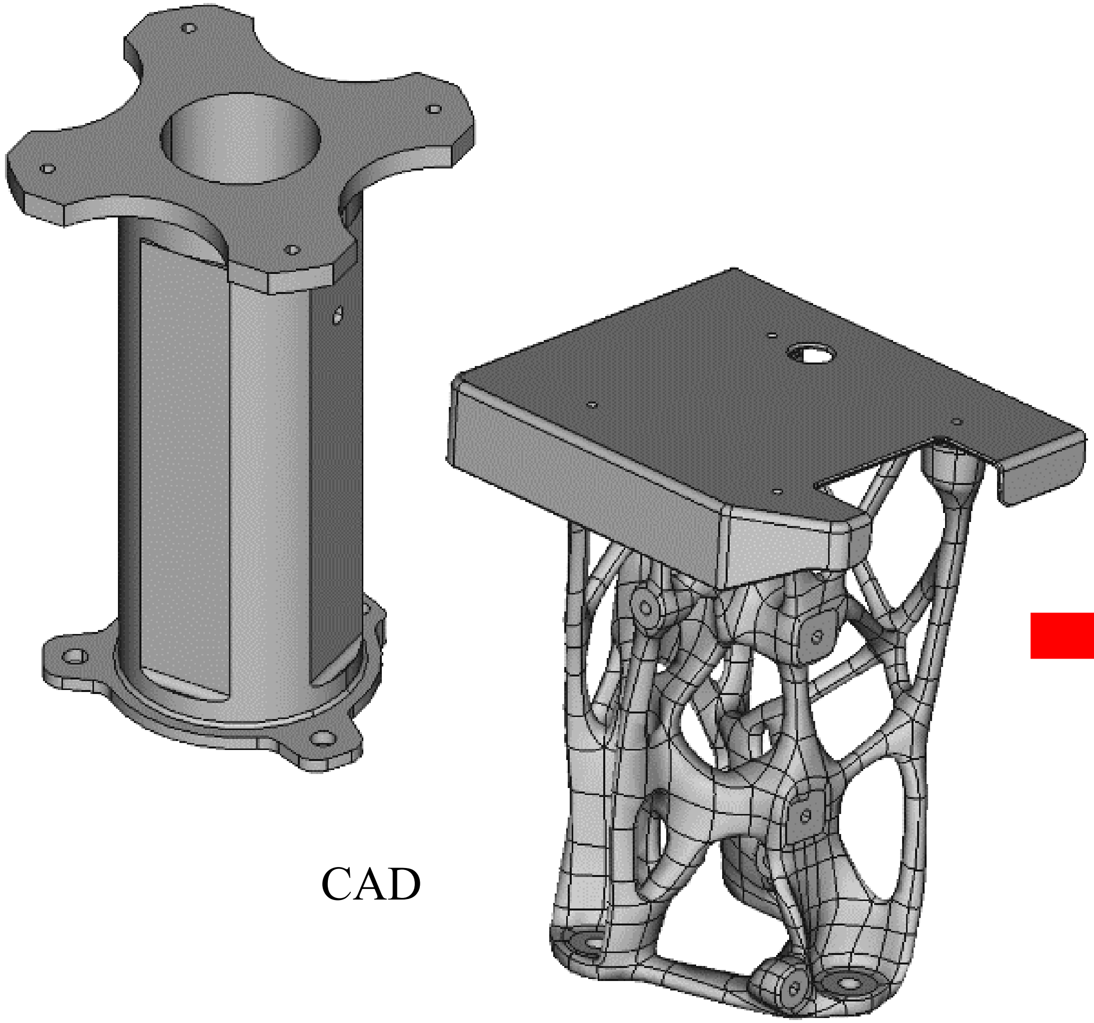
Optimized shape

Mass reduction
Demisable material
Smaller curvature radius

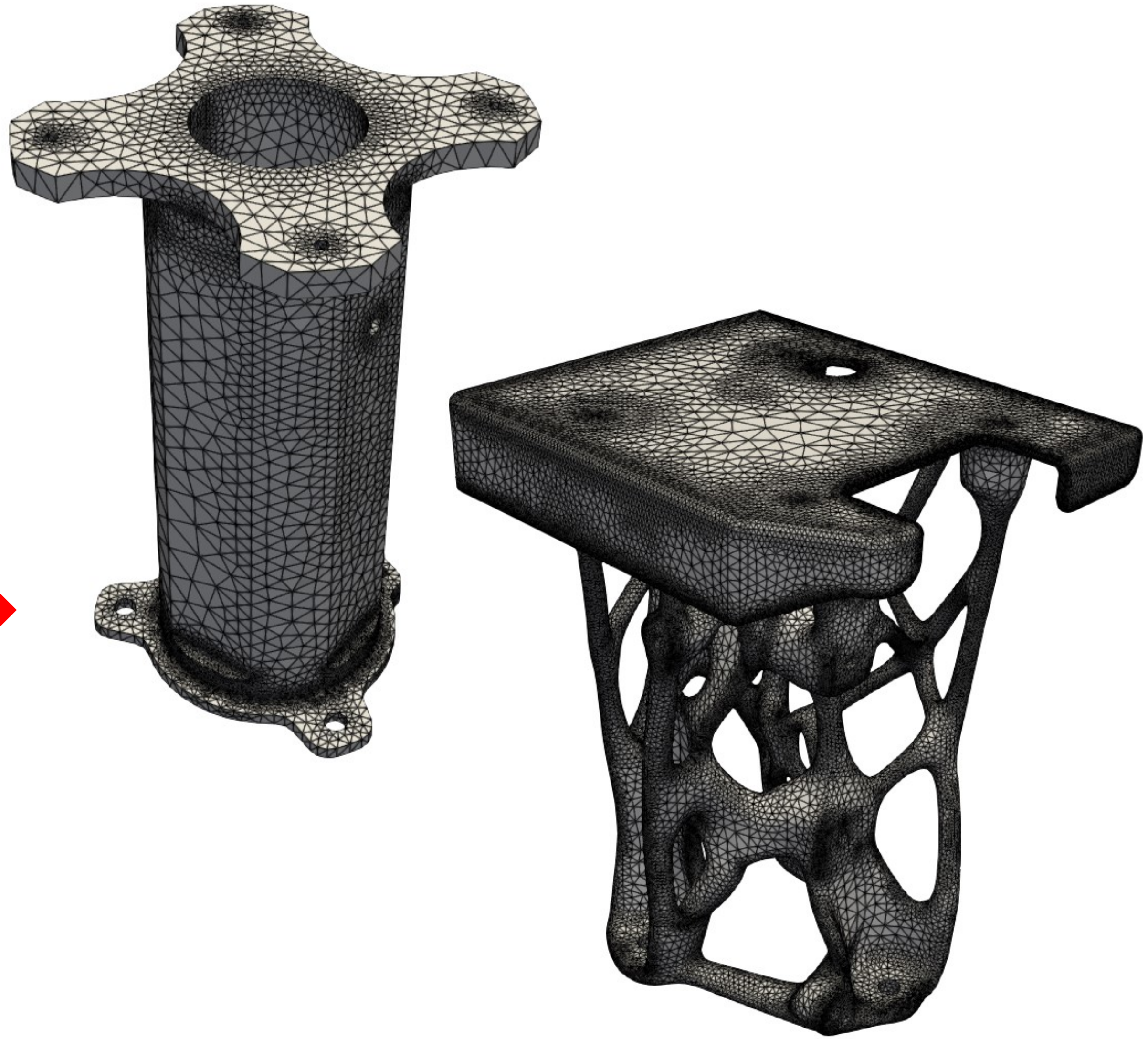
PAMPERO analysis → **D4D features ?**

- To analyze re-entry trajectories, aerodynamic, aerothermal and thermal computations
- To validate the free-form design resulting from TO+AM as a D4D solution

MESHES FOR COMPUTATIONS



CAD



Unstructured tetrahedral Meshes

Equipment break-up ~ between 100 km and 60 km → **Variation of release altitude**

Initial conditions of TARANIS for DEBRISK v3 computations

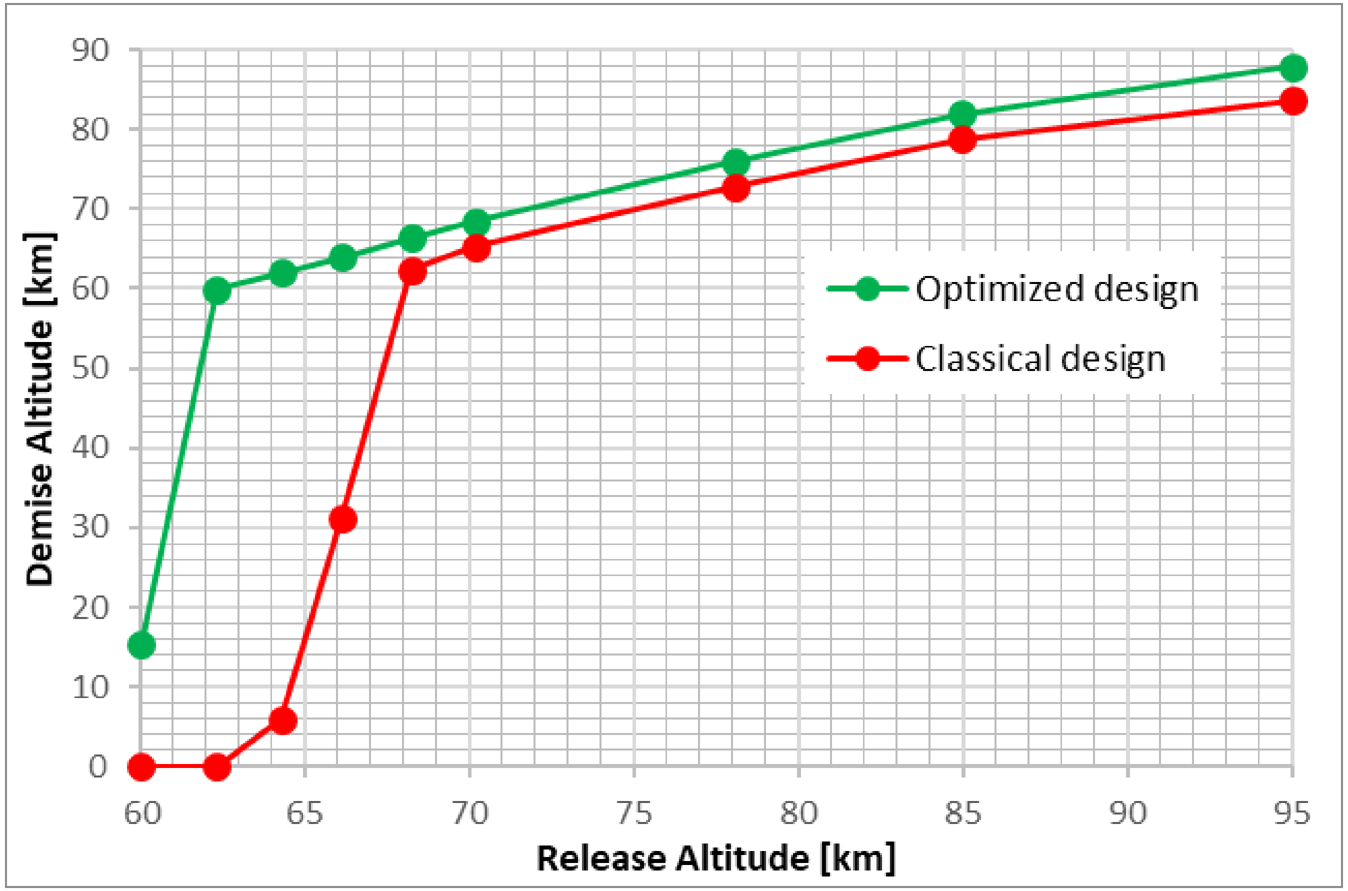
Epoch	01/01/2050
Time (hms) (GMT)	00:00:00
Semi Major Axis [km]	6518.13646
Eccentricity	0
Inclination [°]	98
RAAN [°]	0
Argument of perigee [°]	0
True anomaly [°]	0
Apogee [km]	140
Perigee [km]	140
Altitude [km]	140

Initial conditions of release altitude for PAMPERO computations

Alt. [km]	Lat. [deg]	Long. [deg]	Vel. [km/s]	FPA [deg]	Azi. [deg]
95	18,6501	50,9604	7,86	-0,3820	191,6341
85	8,2830	48,7997	7,73	-0,6441	191,4159
78	3,8673	47,9106	7,52	-0,9590	191,3729
70	0,5466	47,2471	7,07	-1,5061	191,3550
68	-0,0667	47,1247	6,91	-1,6796	191,3526
66	-0,6643	47,0056	6,71	-1,8902	191,3502
64	-1,1284	46,9130	6,51	-2,0928	191,3483
62	-1,5773	46,8235	6,27	-2,3337	191,3463
60	-2,0446	46,7303	5,96	-2,6508	191,3438

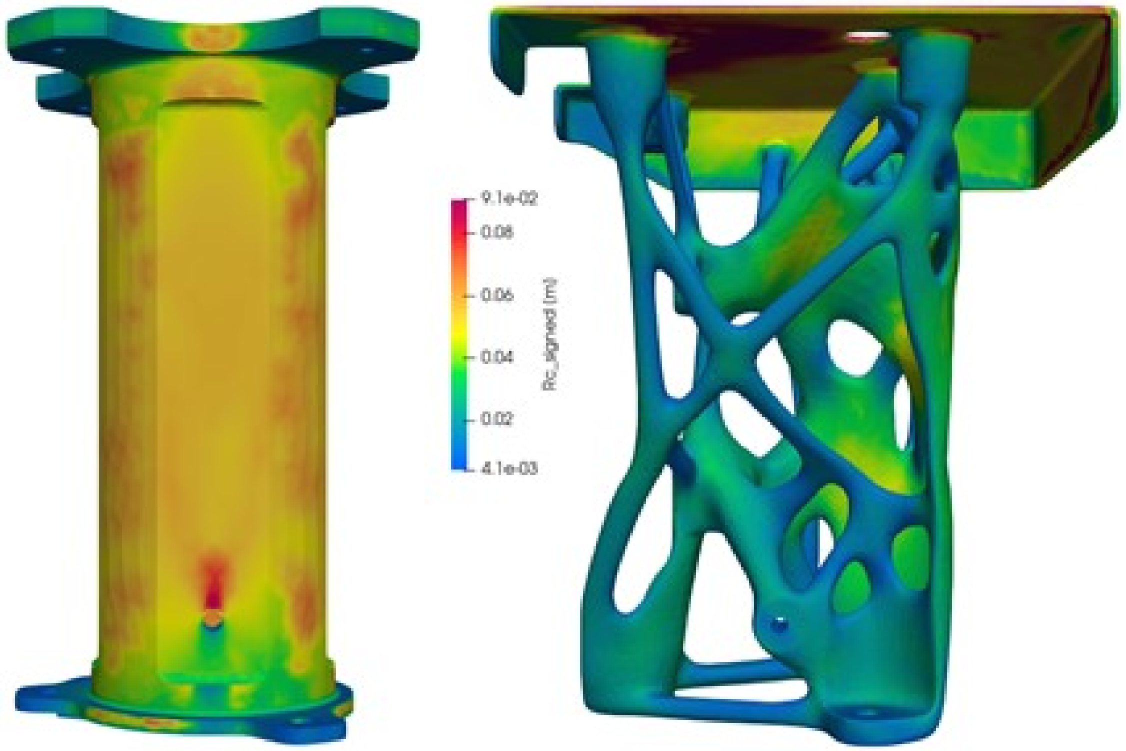
The computations can stop due to several conditions:

- Complete ablation.
- Impact on ground.
- Kinetic energy reaching the limit of 14J, which is considered as a non-lethal energy limit.

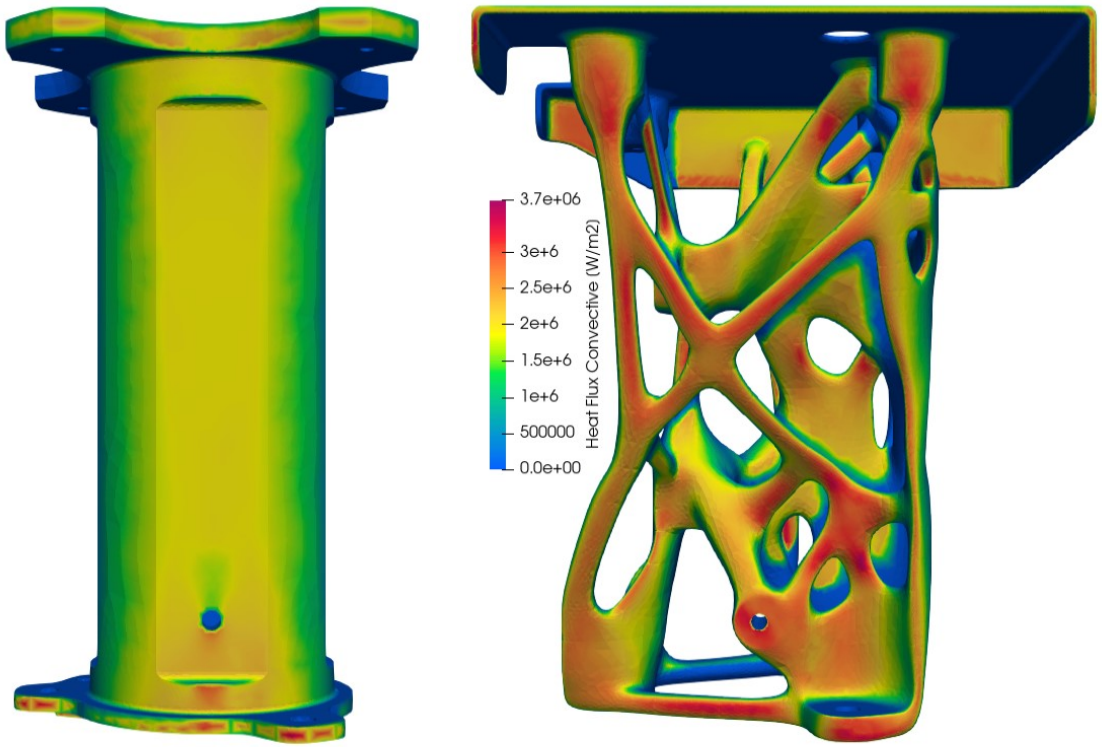


Release Altitude [km]	Fragment trajectory [km]	
	Classical	**Optimized**
95	Ablated	Ablated
85	Ablated	Ablated
78	Ablated	Ablated
70	Ablated	Ablated
68	Ablated	Ablated
66	Impact Energy < 14 J	Ablated
64	Impact Energy < 14 J	Ablated
62	Ground reached	Ablated
60	Ground reached	Impact Energy < 14 J

- **Demise altitude : Optimized shape > classical one**
- Over 68 km : improvement ~ 4 km
- Under 68 km : improvement increase
- Altitude range of fully ablated shape is largest for optimize one



Curvature Radius mapping



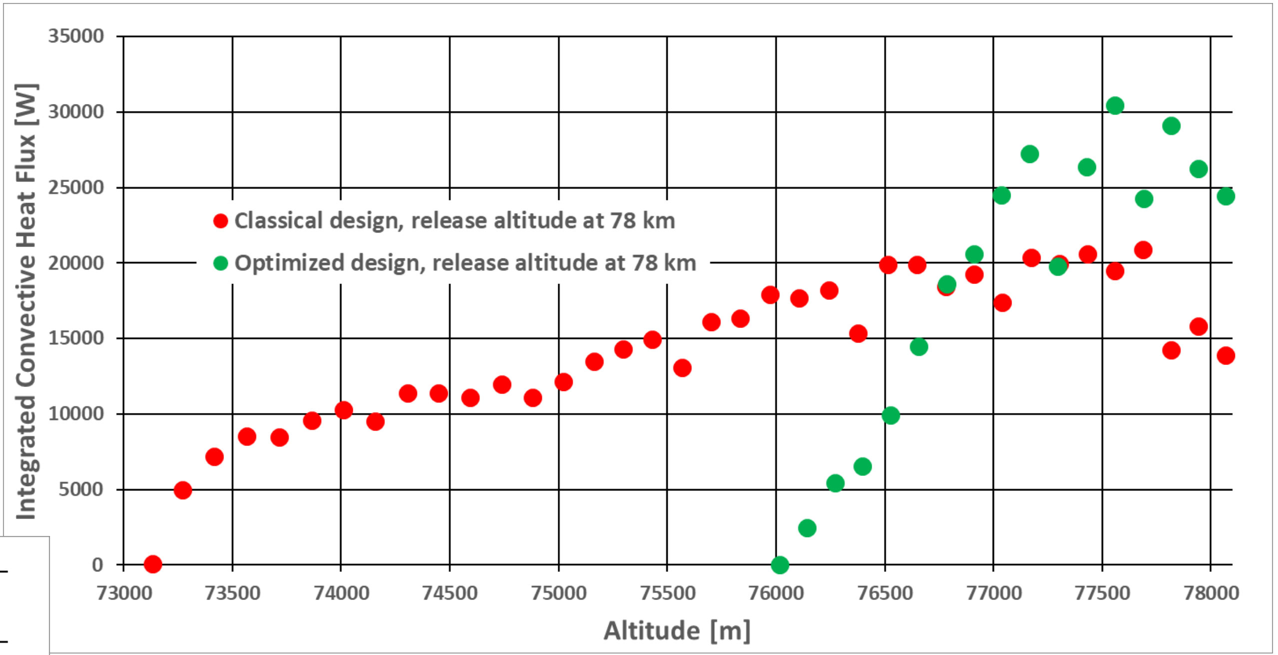
Convective Heat Flux mapping at 78 km

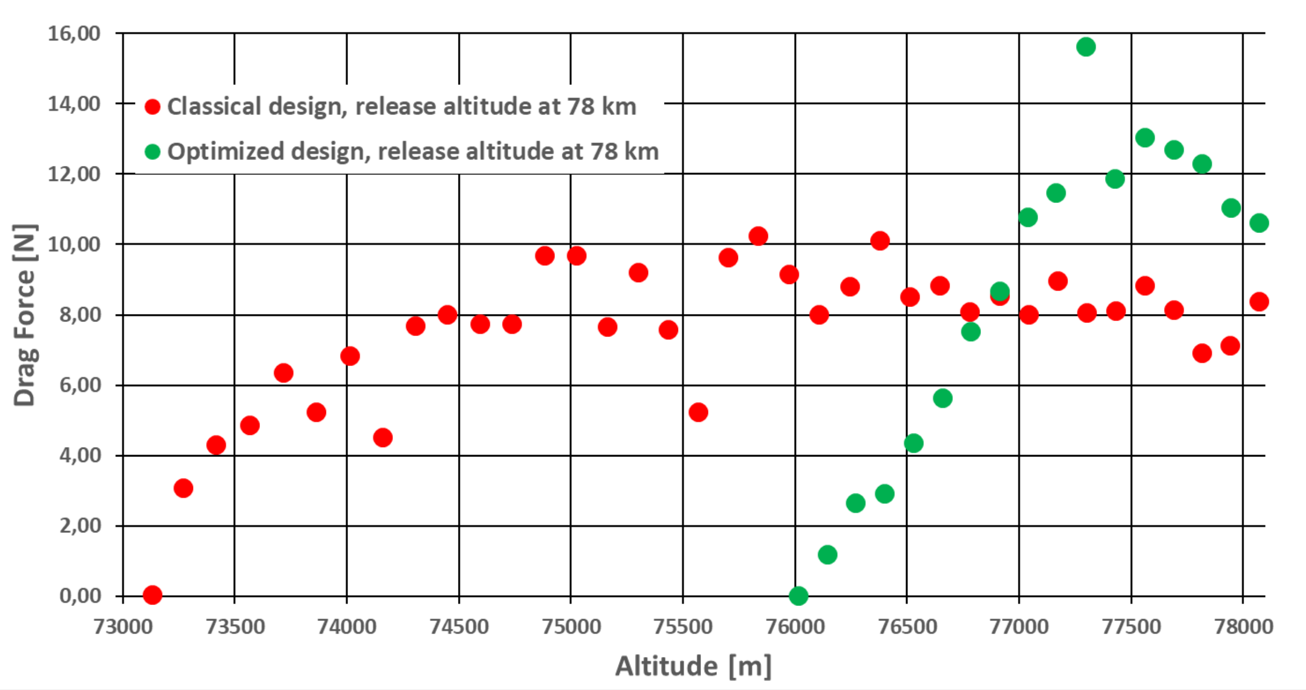
Smaller curvature radius → Higher Convective Heat Flux

INTEGRATED FORCES ALONG TRAJECTORY

Smaller curvature radius

Higher Integrated Convective Heat Flux at the beginning of the trajectory





- More surface area to the flow
- Lower mass

Higher Drag force at the beginning of the trajectory

- Lower melting temperature
- Previous aero-thermal analysis

Higher Integrated Net Heat Flux
at the beginning of the trajectory

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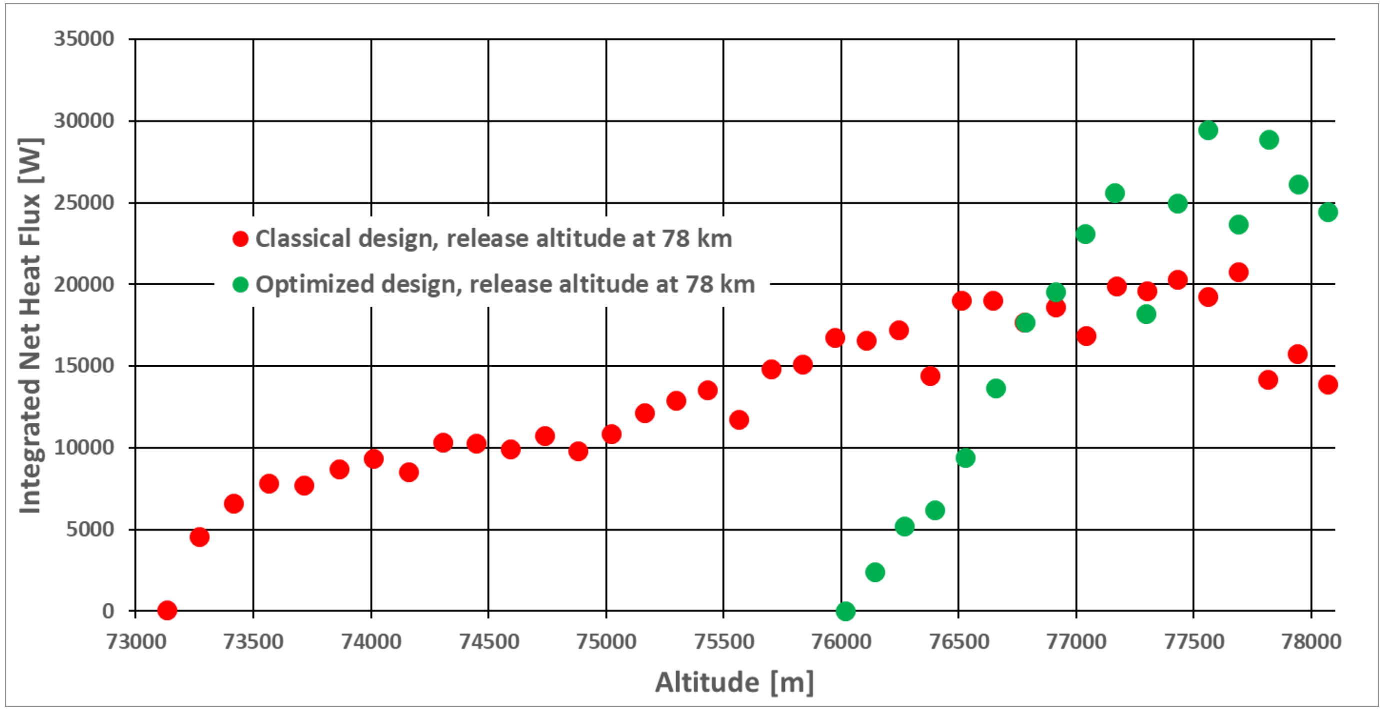


- Lower material density
- Free-shape from TO

2

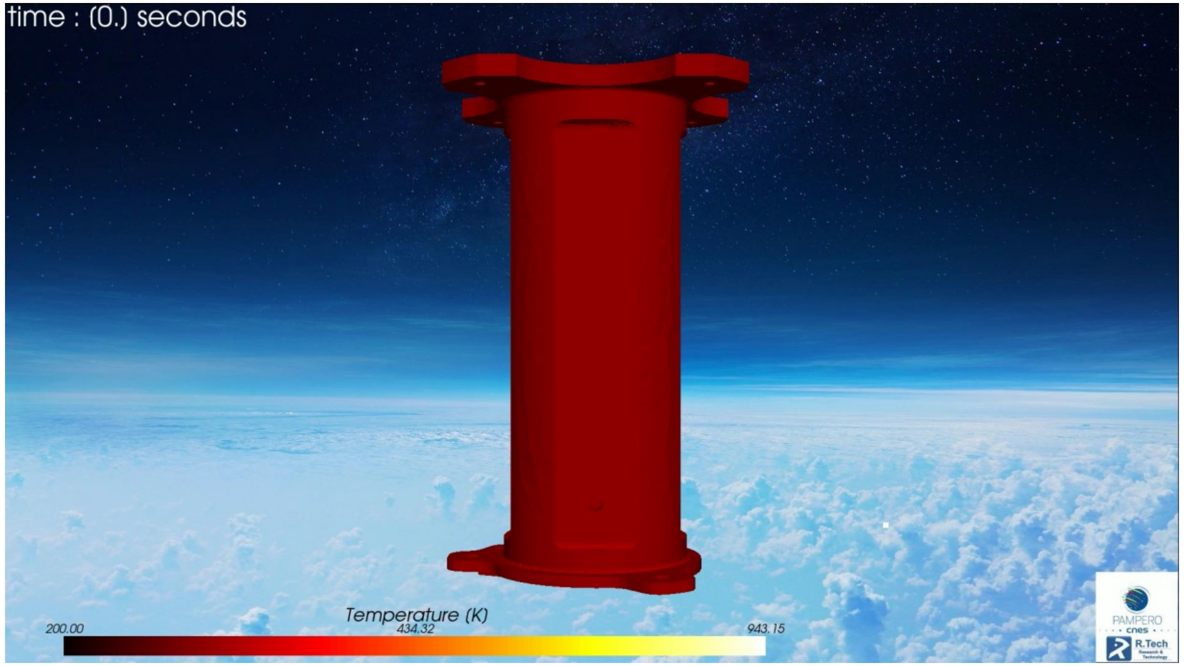
Less material to ablate

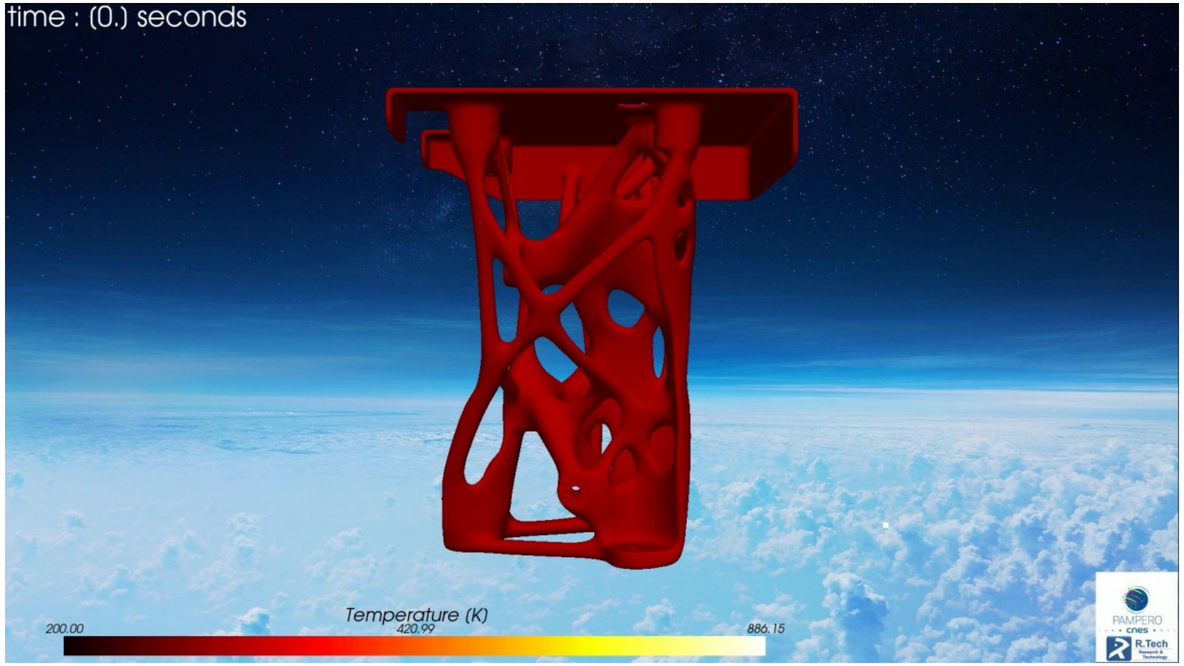
$$H_{demise} = m_{init} \times \left[C_P \times \left(T_{fusion} - T_{init} \right) + \Delta H \right]$$

	Heat of demise [kJ]
Classical	483
Optimized	296

3

Heat of Demise 40% lower





Ablation begins from the flat parts, and continues slowly on the trunk

Ablation begins from the flat top, and continues quickly on the branches

Regarding the results:

- The topological optimization allows smaller curvature radii than classical manufacturing, which leads to higher convective flux densities.
- Additive manufacturing allows changing the material in order to obtain a lower heat of demise
- Coupled, the additive manufacturing and the topological optimization allow a different redistribution of material and/or the use of material with a lower material density. Both, lead to less material to ablate.

D4D features seem to be guaranteed by TO+AM

Regarding the methodology:

- Although the classical design of the SAS support of TARANIS is not a critical equipment in term of ground risk, PAMPERO has highlighted the demisability process of its optimized version in comparison with the classical manufactured one.

- Although the optimized design of the SAS support of TARANIS has been realized without specific constraints dedicated to a demise goal, this study has shown to what extent this optimization is already interesting, and allow reducing the risk on the ground.

This work is a very first step in the PAMPERO's "Design for Demise" road map, to assess the potential of additive manufacturing to design demisable vehicles during their atmospheric re-entry.

Regarding the code:

- PAMPERO has shown its ability to take into account the free-form resulting from topological optimization.

- The next step in the optimization process, as a Design-for-Demise technique, is to take into account additional constraints, those concerning the demisability during the atmospheric re-entry of the spacecraft, and its components. This step will require the coupling of classical optimization codes, as those for example used to optimize the SAS support of TARANIS, with PAMPERO.

MAIN GOAL

Use PAMPERO to develop new solutions for the design of vehicles and its components, allowing to reduce to the maximum the potential risks of ground impacts by ensuring their total ablation during re-entry.

Thank you for your attention!

