“High Altitude Break-up Concepts with Additively Manufactured CF-PEEK ”

Joel Patzwald, 22.09.2021

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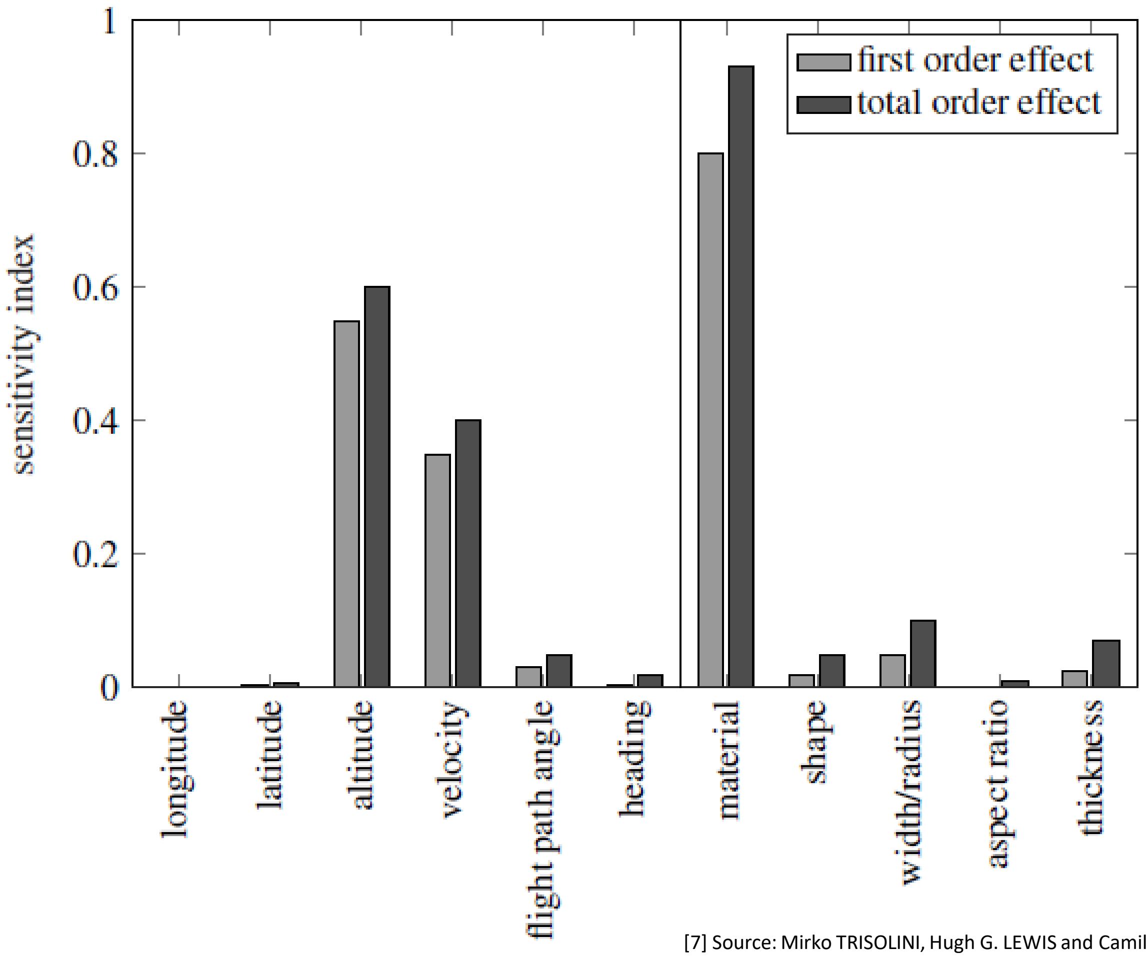
Design-for-Demise (D4D)

- Designing a spacecraft so that it ablates/ demises when entering the atmosphere uncontrolled
- Why? Reduce risk for humans on Earth


[3]

D4D techniques

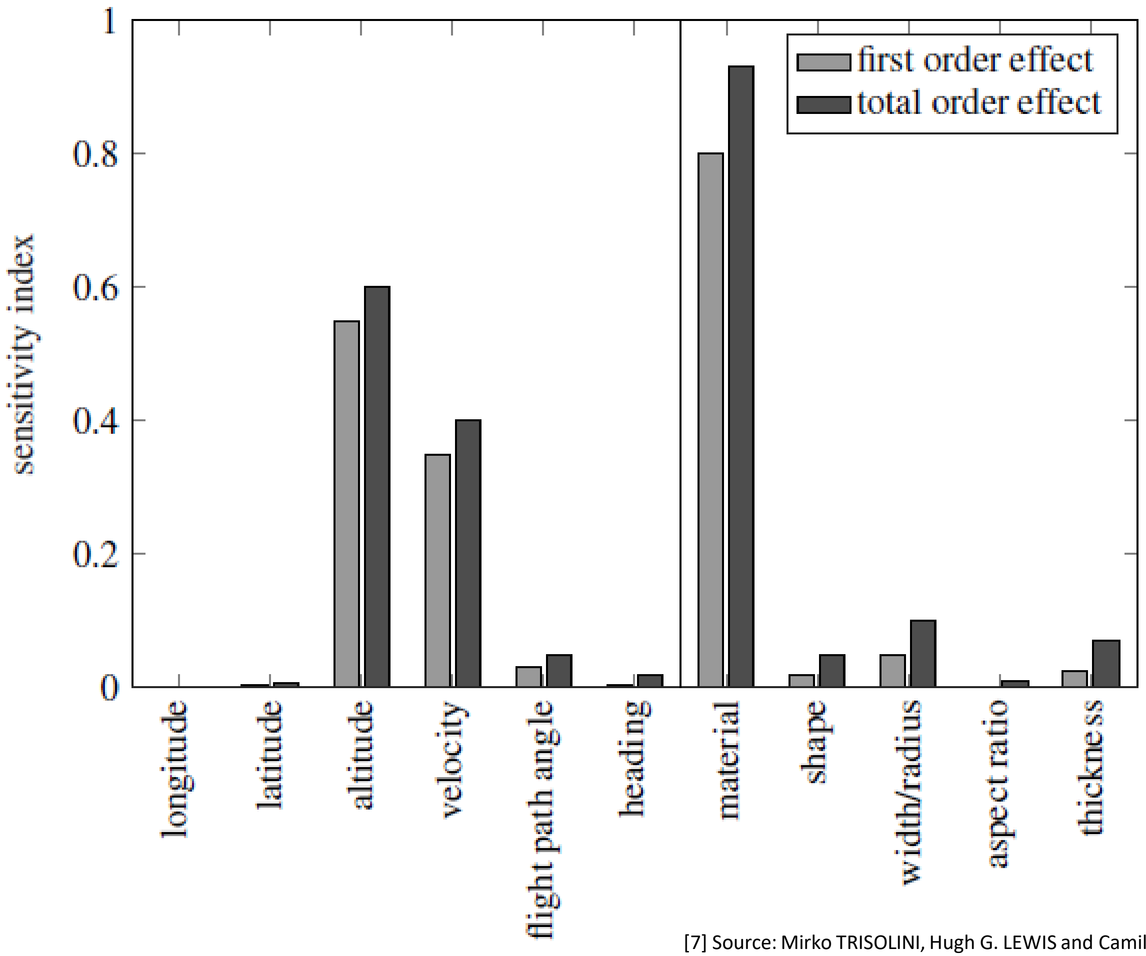


➔ Most effective D4D techniques:

- **Maximize the break-up altitude**
- Maximize the re-entry velocity
- Use **more demisable material** where possible and later **improve the components area to mass ratio**

[7] Source: Mirko TRISOLINI, Hugh G. LEWIS and Camilla COLOMBO. Demisability and survivability sensitivity to design-for-demise techniques. In: Acta Astronautica 145 (2018), pp. 357–384. ISSN: 00945765. DOI: 10.1016/j.actaastro.2018.01.050

D4D techniques



➔ Most effective D4D techniques:

- **Maximize the break-up altitude** ⟶ **Goal of this work**
- Maximize the re-entry velocity
- Use **more demisable material** where possible and later **improve the components area to mass ratio**

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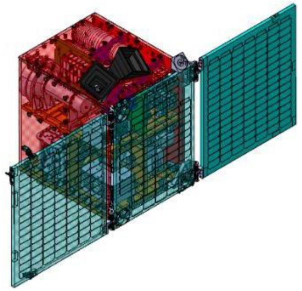
Course of the presentation (work flow)

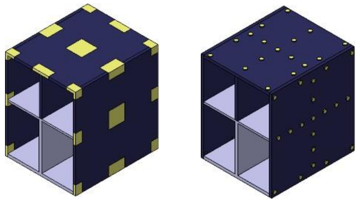
Goal: Maximize the satellite break-up altitude using additive manufacturing

End-to-end design development procedure

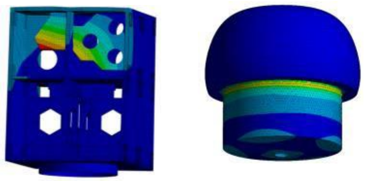
1. Ref. satellite case



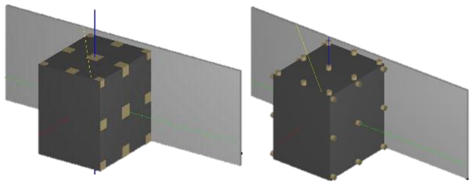
2. Design concepts & material char.



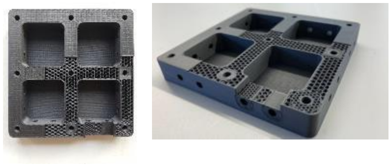
3. Structural analyses



4. Re-entry analyses



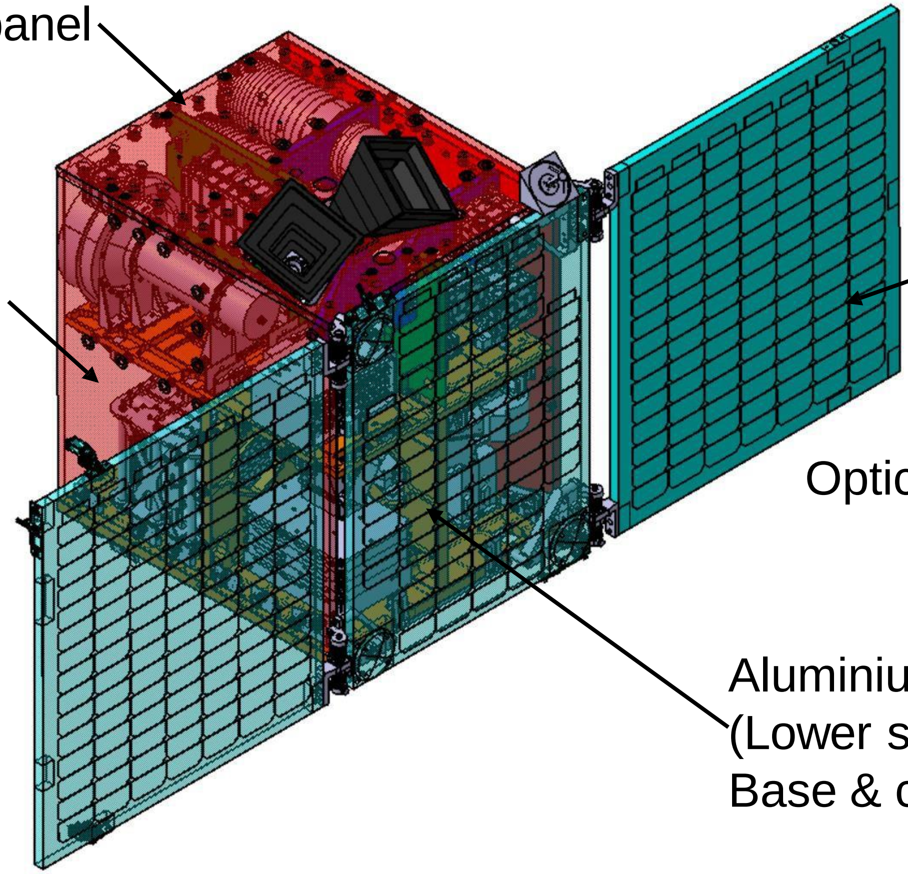
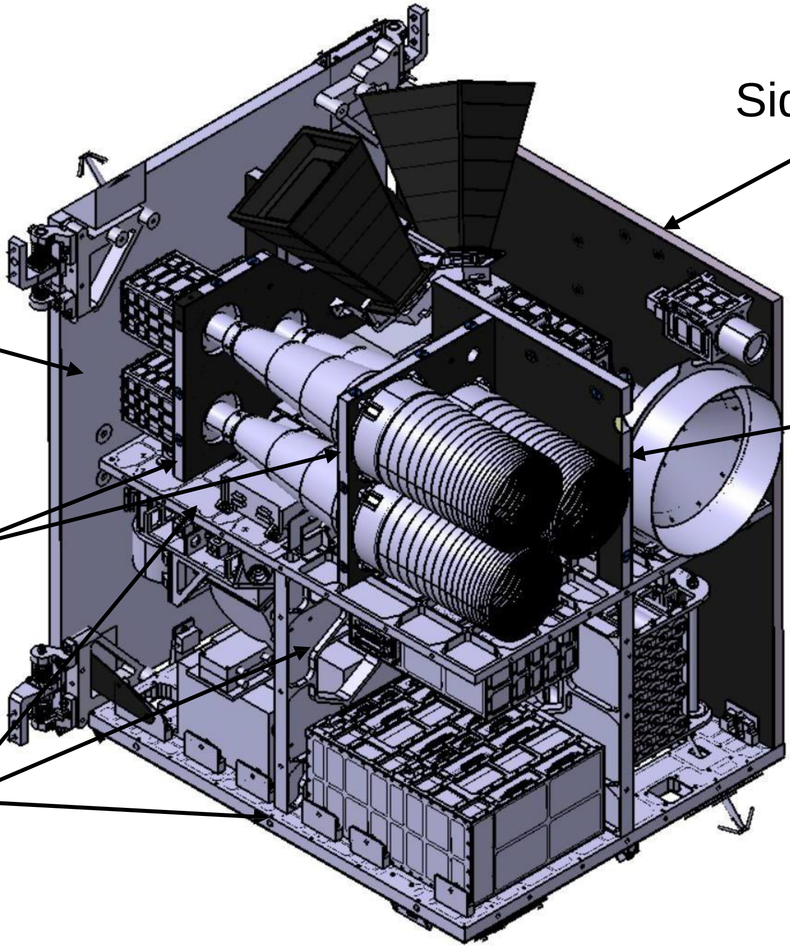
5. Demonstrator



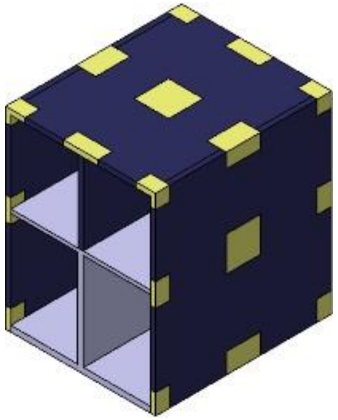
1. Satellite case

Satellite case: Flying Laptop (FL)

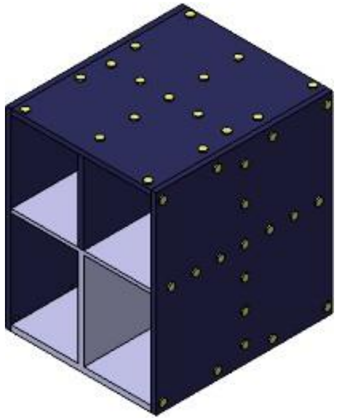
Earth observation, 60x70x85 cm, 109 kg (small satellite is not optimal case for D4D but was available)

2. Primary structure design concepts

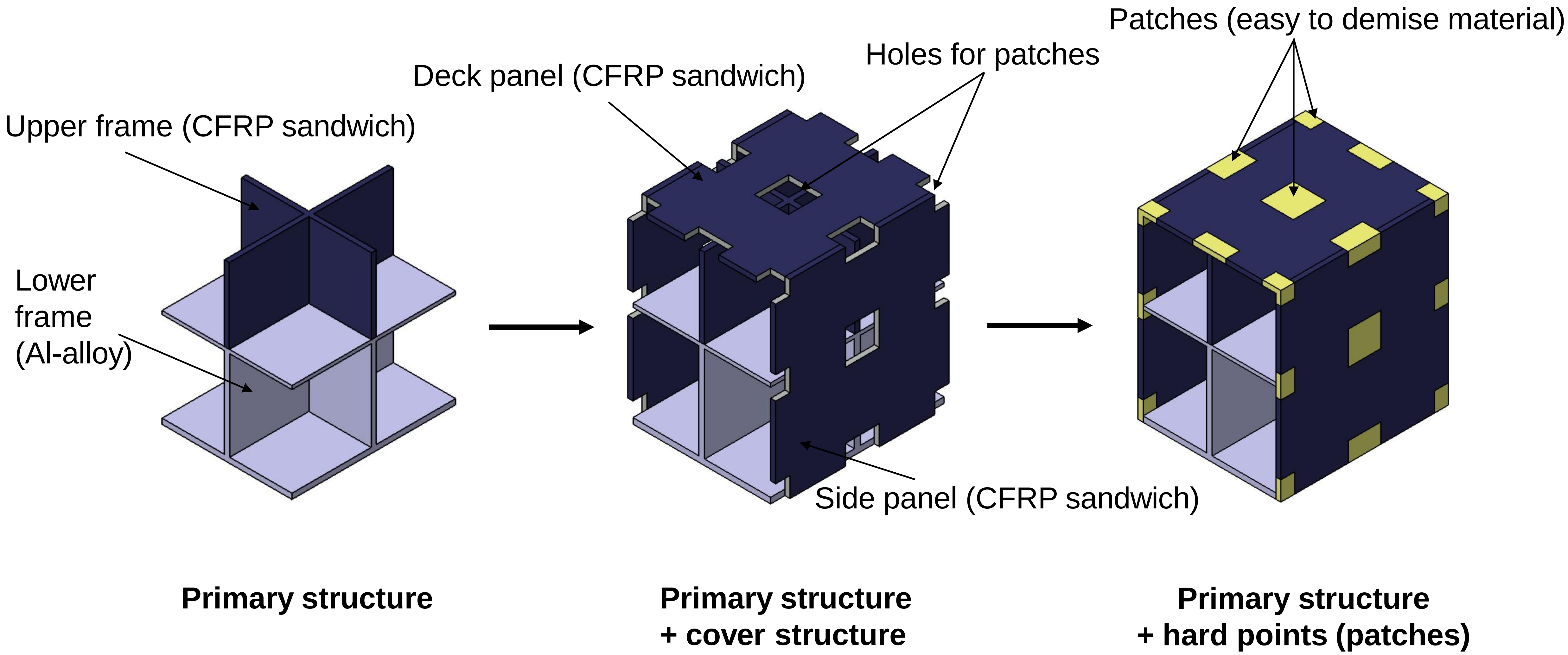


Patch concept

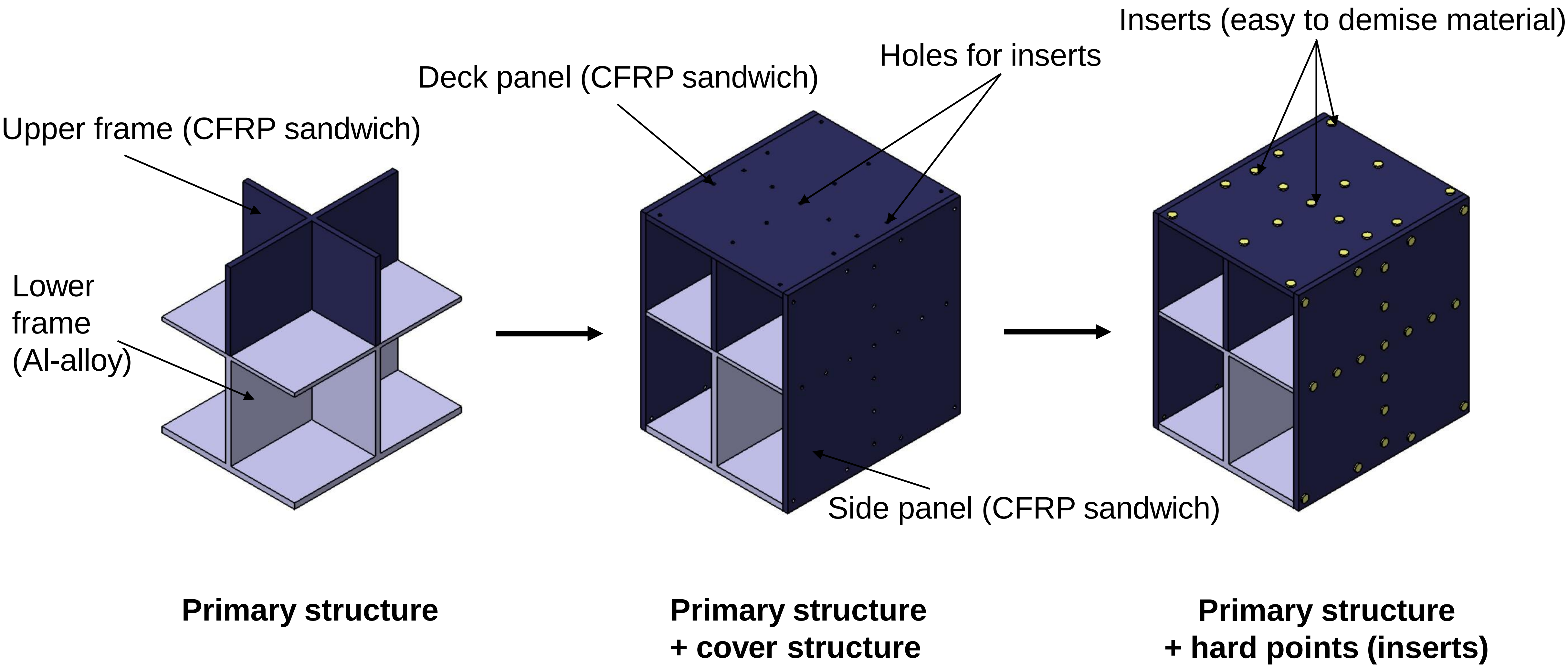


Insert concept

Proposed design: Patch concept



Proposed design: Insert concept



Enhancing demisability of connectors (patches, inserts)

$$Q > m \times h_a / A_s$$

⇨ Reduce mass and heat of ablation and increase surface area

Material selection

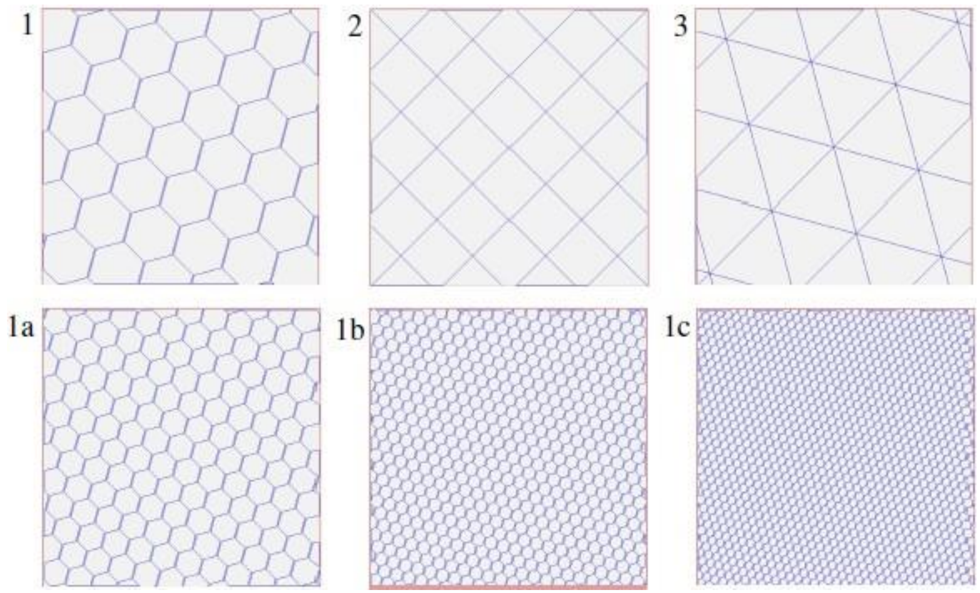
$$Q > \boxed{m \times h_a} / A_s$$

- DLR BT prints ceramics, metals, thermoplastics
- Ceramics: High thermal properties ➔ not suitable for high altitude demise
- **Metals**: Wide range of mechanical/ thermal properties ➔ can be suitable
- **Thermoplastics**: Good thermal properties but mechanically “weak” ➔ can be suitable

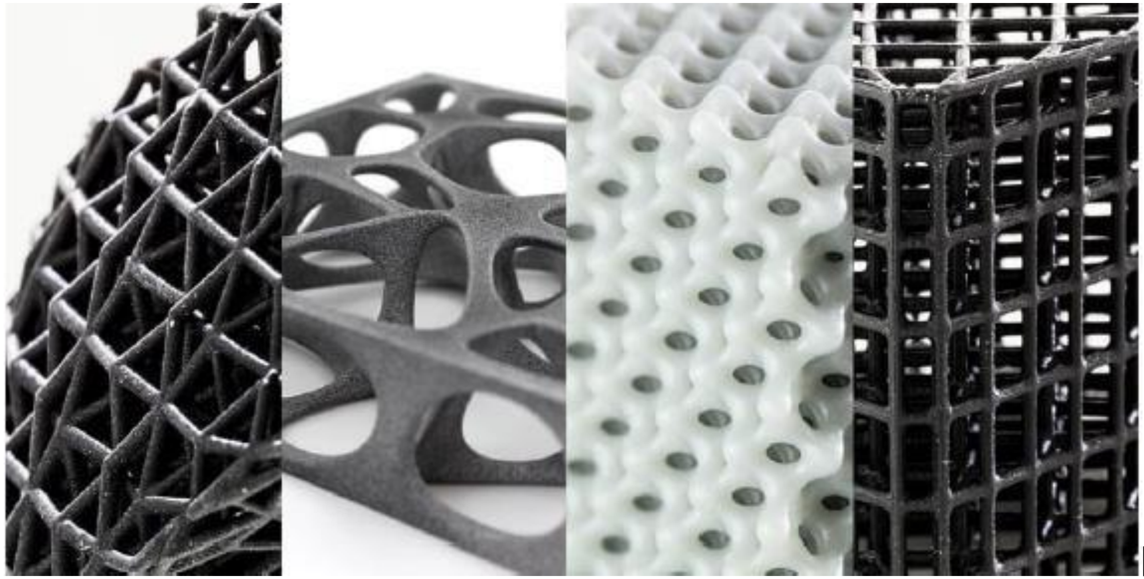
➔ CF30-PEEK selected

Geometry adaption by additive manufacturing

$$Q > m \times h_a / A_s$$



Infill

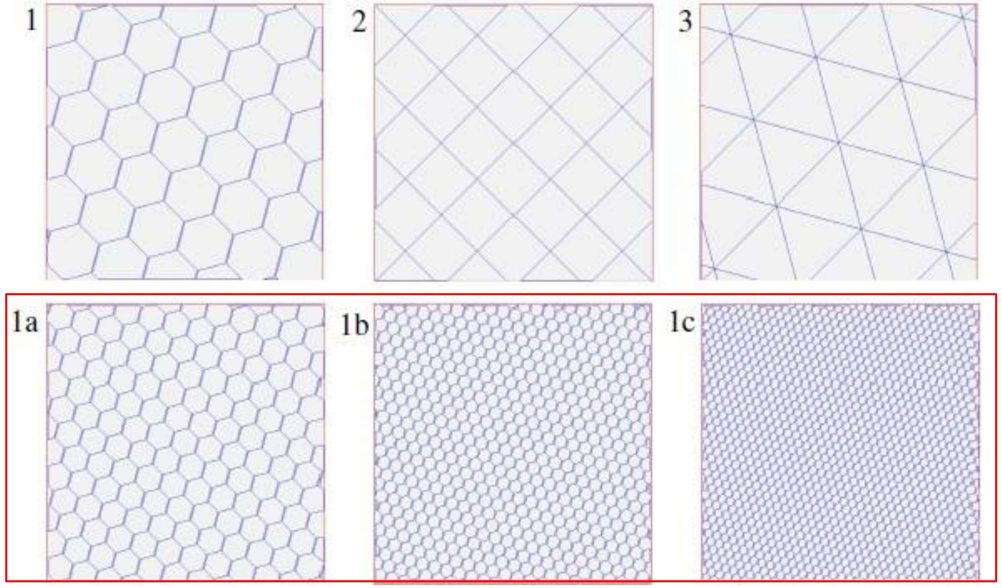


[8]

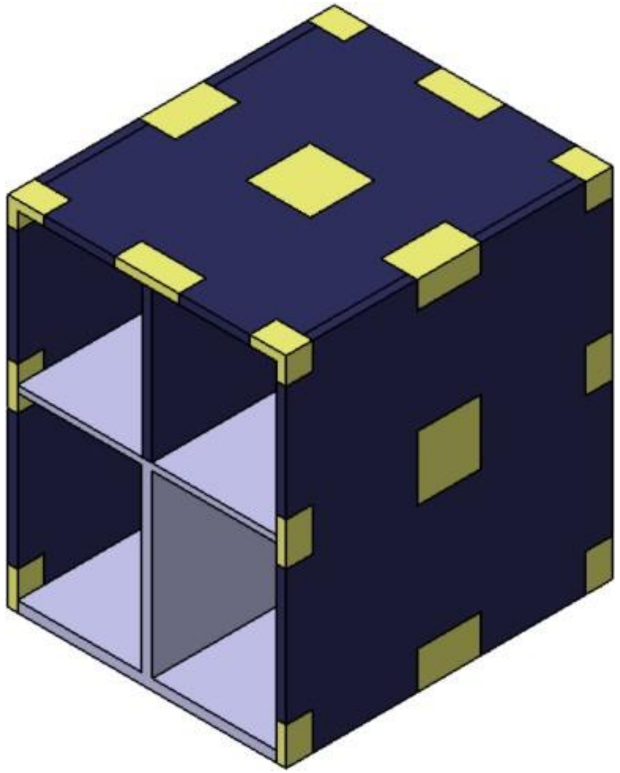
Lattice

Geometry adaption: Patch concept

$$Q > m \times h_a / A_s$$



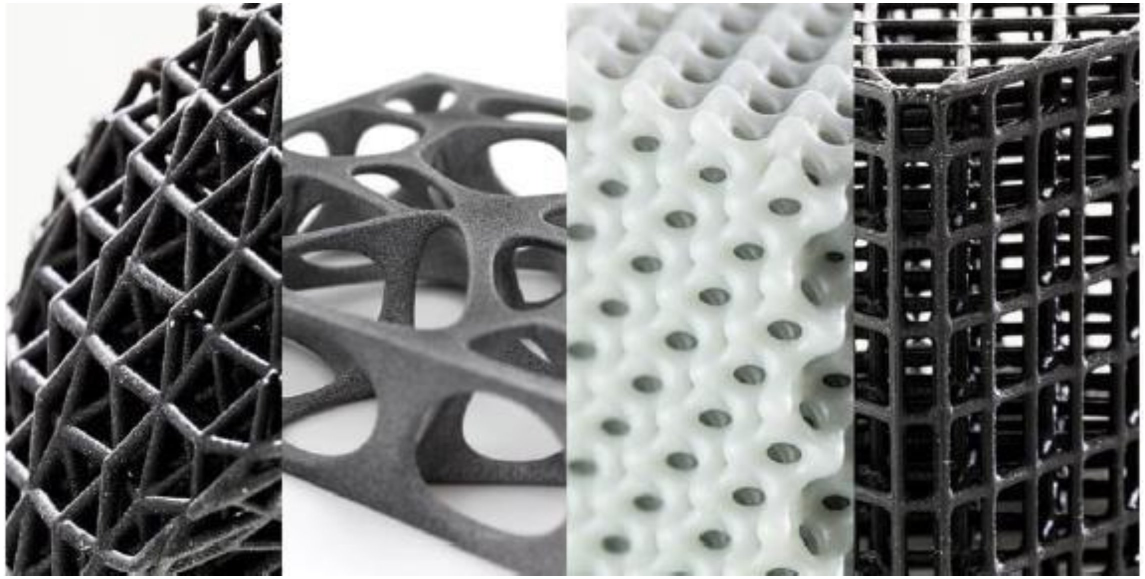
Hexagonal honeycomb infill



Patches: Sandwich parts

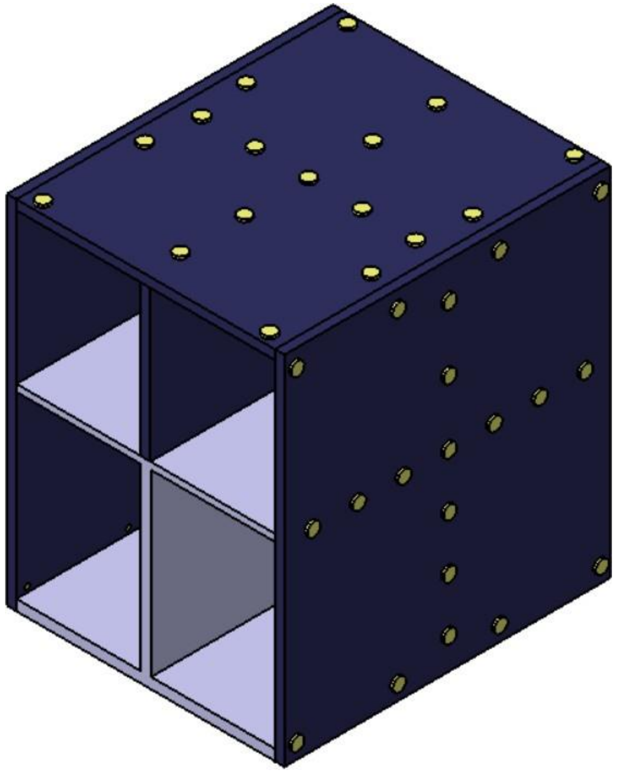
Geometry adaption: Insert concept

$$Q > m \times h_a / A_s$$



[8]

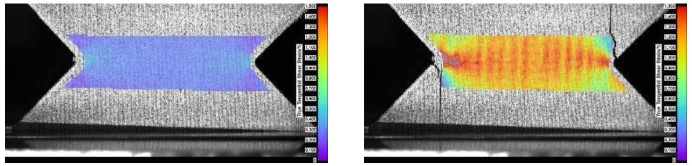
Lattice cell structure



Inserts: Topology optimised

Material characterisation CF30-PEEK

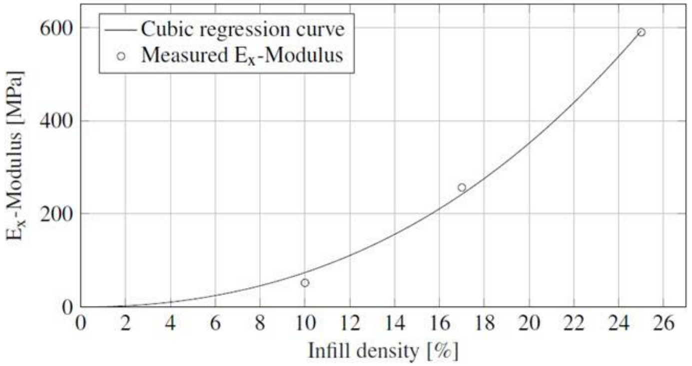
Thermal and mechanical material testing CF30-PEEK



Mechanical:

- G_{xy}, G_{xz} solid material: Shear testing
- $E_{x;y}$, E_z hex. honeycomb infill (ρ [%] = 10, 17, 25): Compression testing
- G_{xz} hex. honeycomb infill (ρ [%] = 10, 17, 25): Shear testing

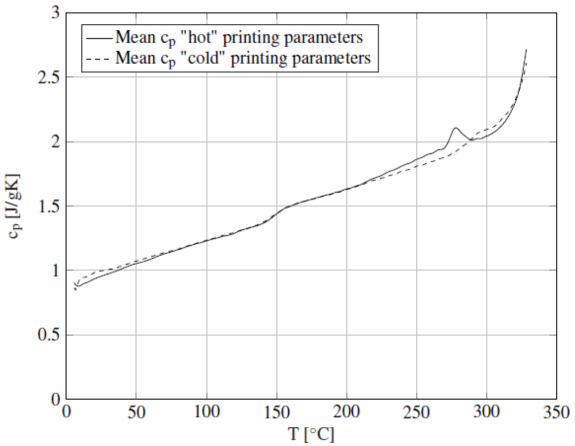
➔ For structural analyses

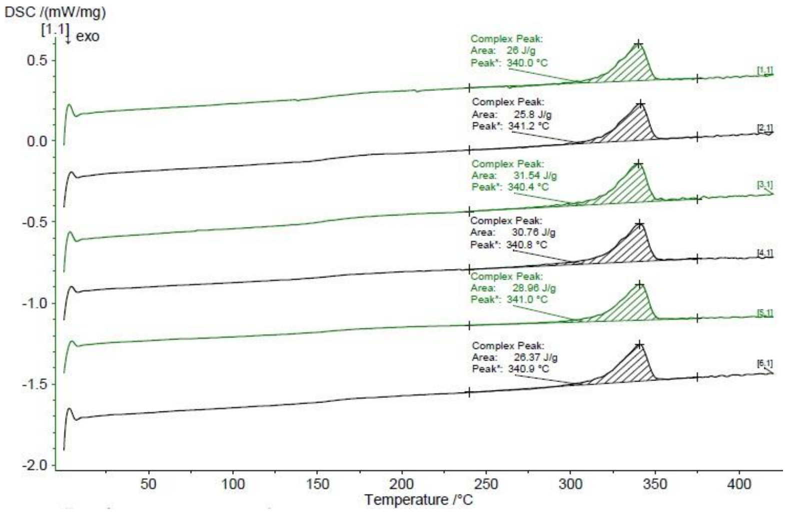


Thermal:

- T_m, h_f: Differential scanning calorimetry
- c_p: Differential scanning calorimetry
- λ: Laser flash analysis

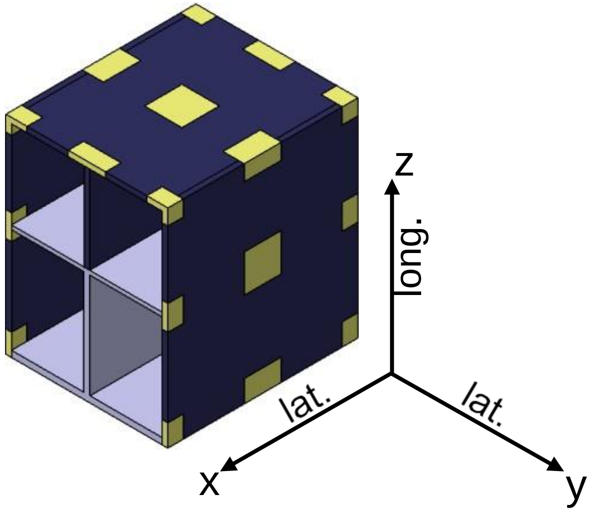
➔ For re-entry analyses





3. Structural analyses

Structural analyses requirements and performed analyses

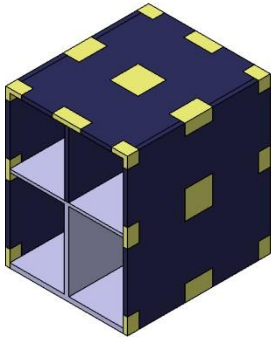


Launcher: PSLV →

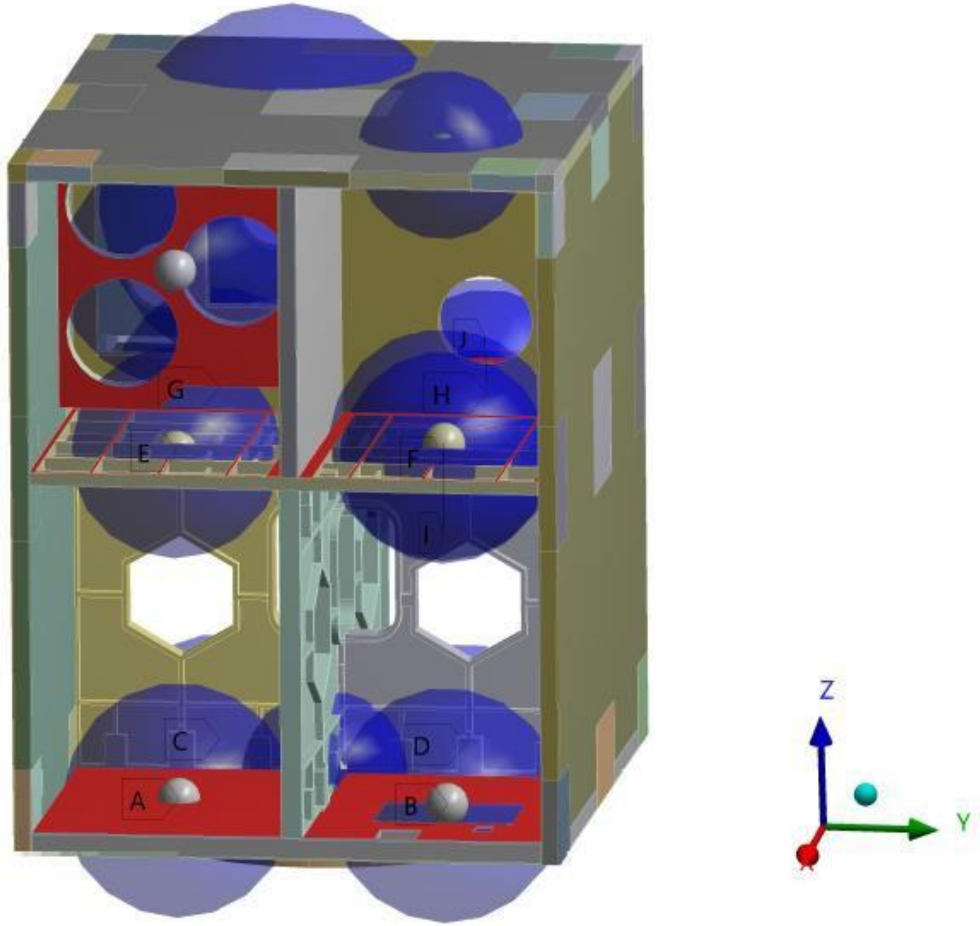
	Longitudinal	Lateral
QSL	$+7g/-2.5g$	$\pm 6g$
Eigenfrequency	$>90Hz$	$>45Hz$

Type of FEA performed		Goal
Static structural analysis	→	no failure
Modal analysis	→	rigid behaviour

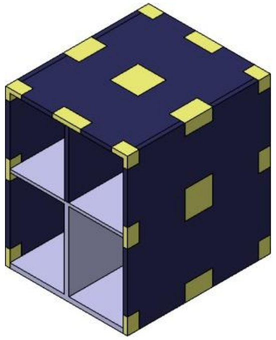
Structural analyses: Patches



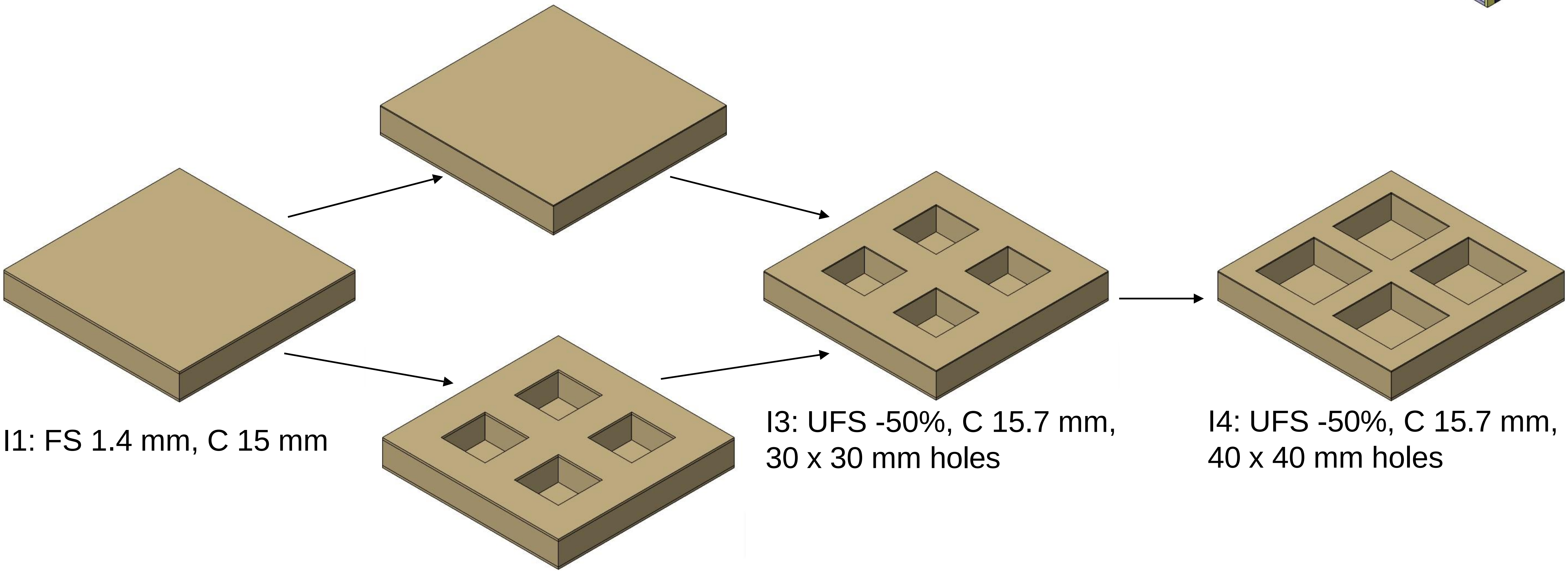
Patch concept: FE-model (ANSYS)



- Satellite simplified
- Patches and deck/ side panels: Sandwich parts (25 % hex. core infill)
- Material values: FL project data, literature and experimental characterisation of CF30-PEEK
- Subsystems added as point masses



Patch concept: Design development steps



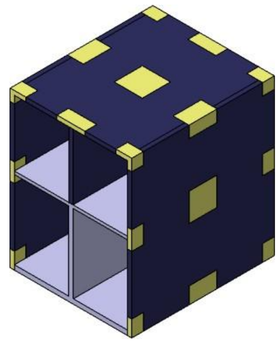
I2a: UFS -50%, C 15.7 mm

I1: FS 1.4 mm, C 15 mm

I2b: FS 1.4 mm, C 15 mm, 30 x 30 mm holes

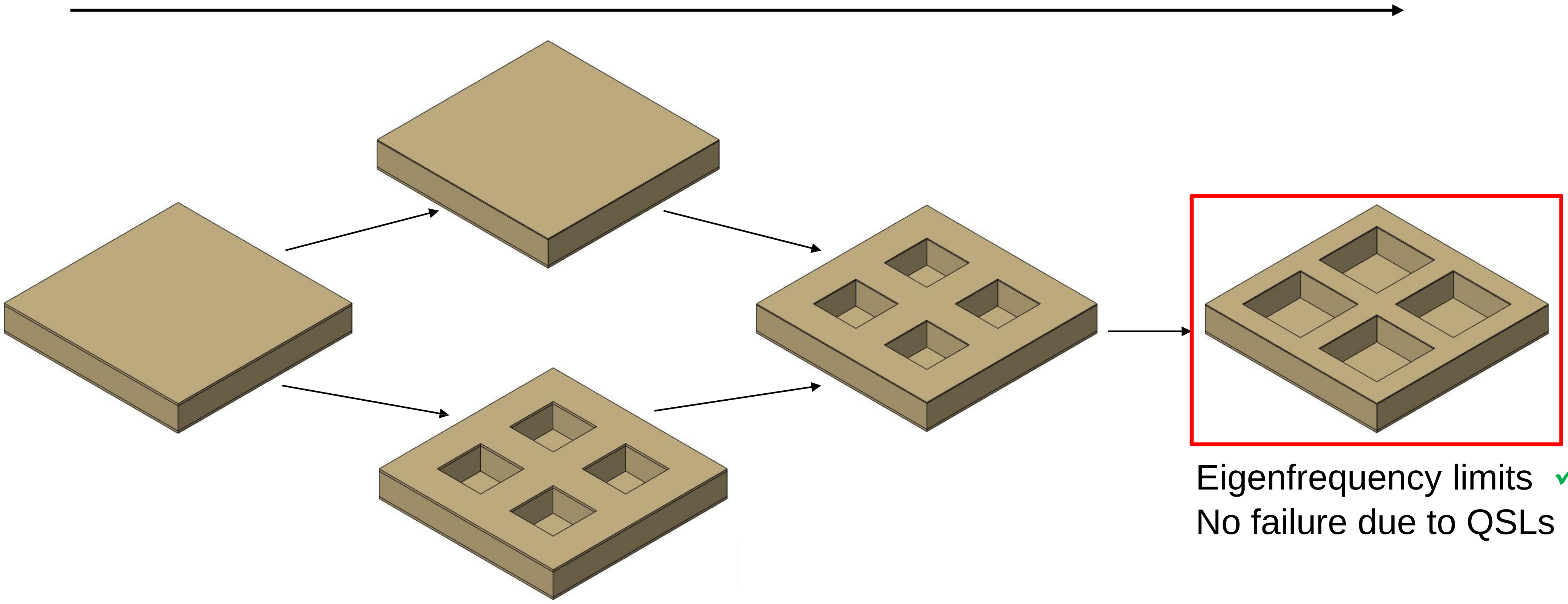
I3: UFS -50%, C 15.7 mm, 30 x 30 mm holes

I4: UFS -50%, C 15.7 mm, 40 x 40 mm holes



Patch concept: Design development steps

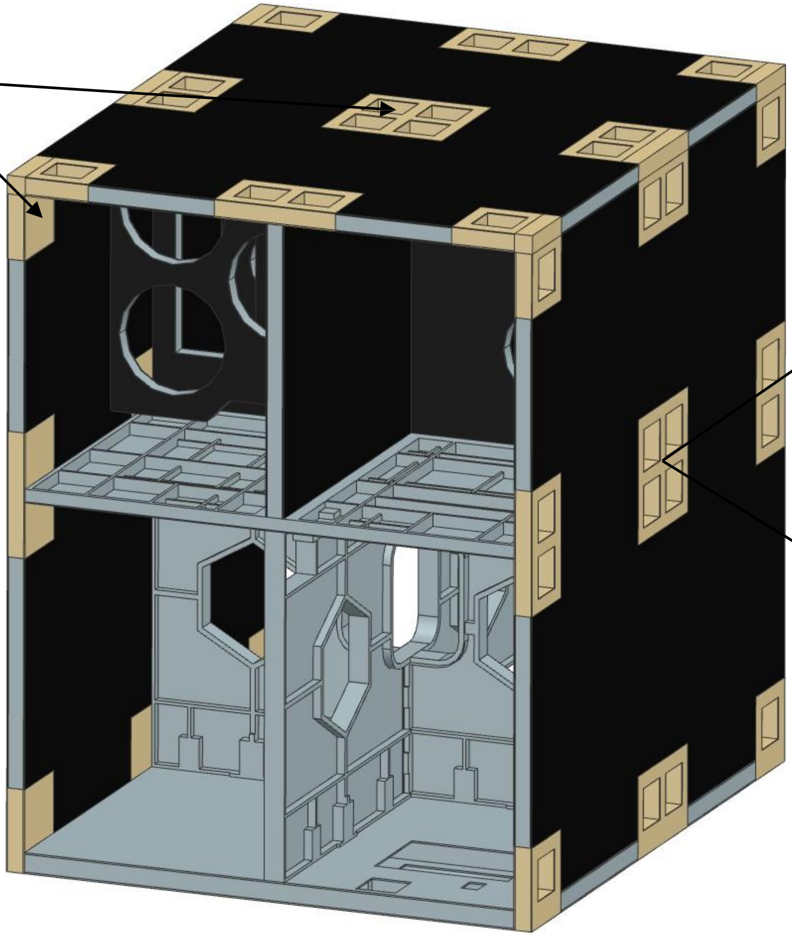
Reduced stability, increased demisability



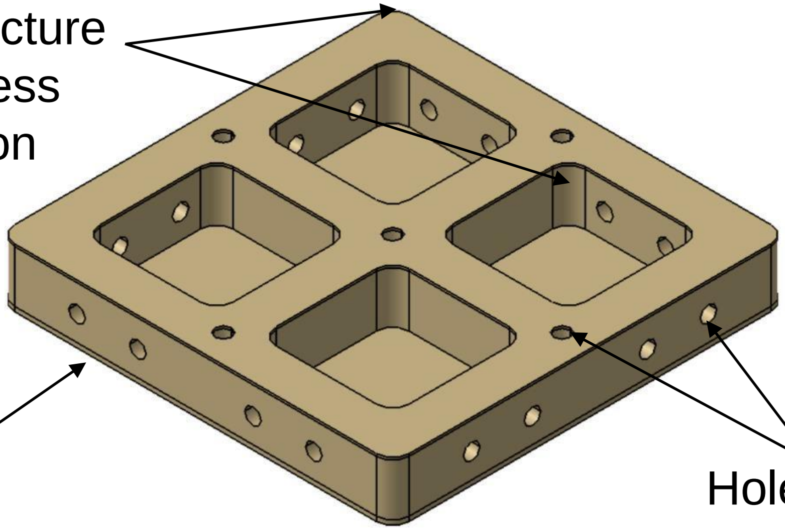
Eigenfrequency limits ✓
No failure due to QSLs ✓

Patch concept: Final design

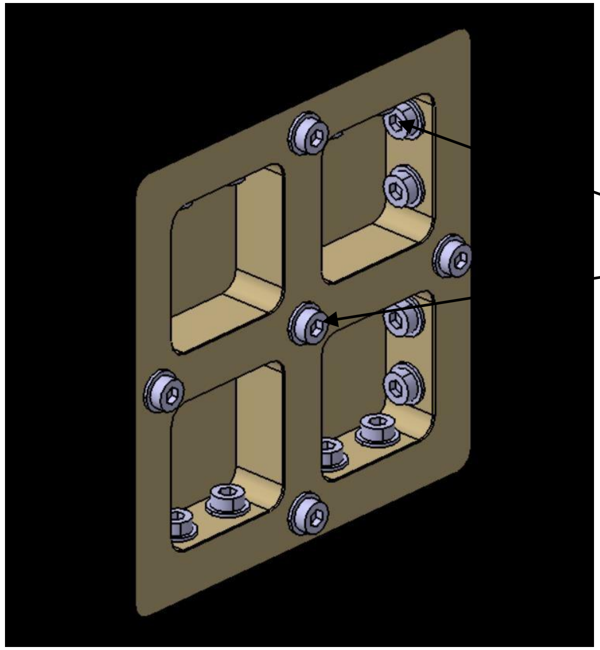
Sandwich components: Solid FS, 25% hex. honeycomb core (CF30-PEEK)



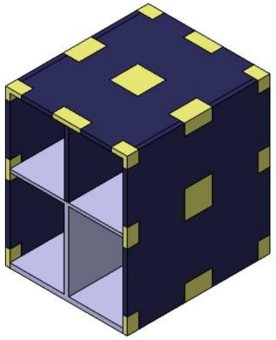
Roundings for manufacture and stress reduction



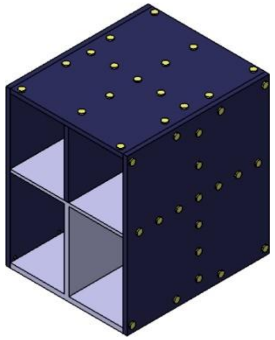
Holes for assembly



Screws, washers, inserts for assembly



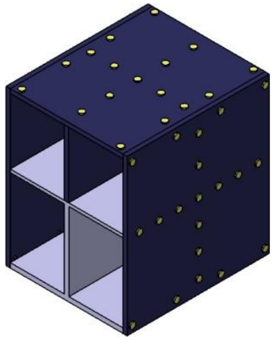
Structural analyses: Inserts



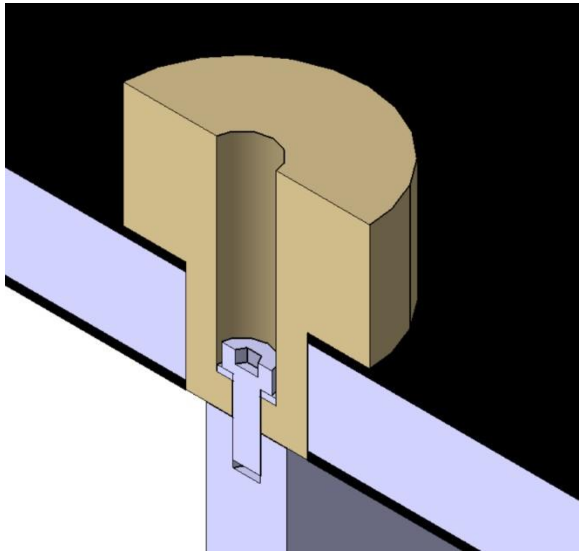
Optimisation of the insert design

- Insert geometry is optimised using resulting force on part and load limits
- Insert printed such that fibres align along main load axis

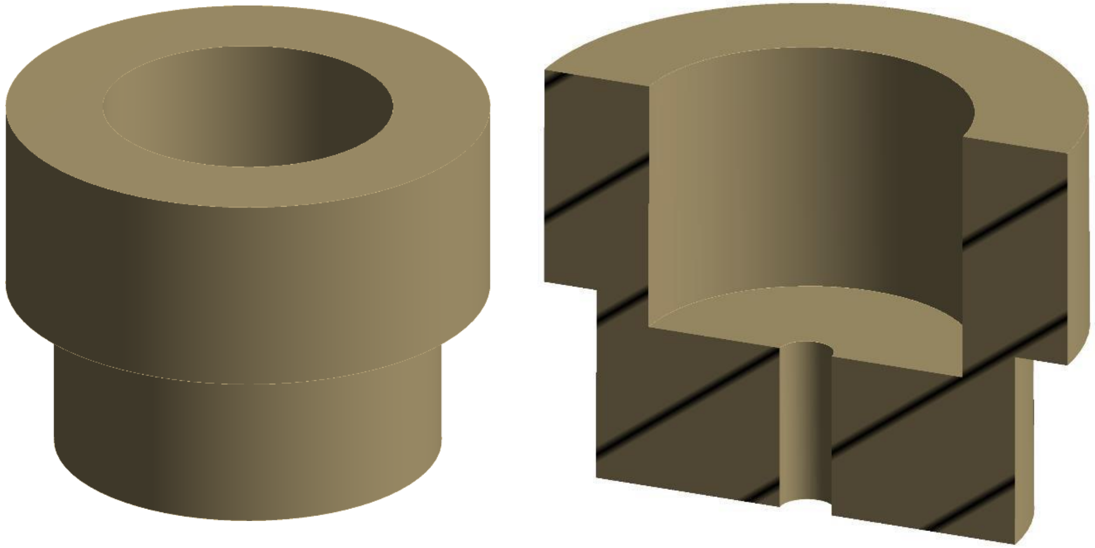
Bolt pretension	Tensile force	Resulting axial force
2965 N	1580 N	4545 N



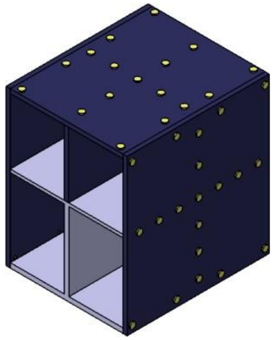
Insert optimisation process



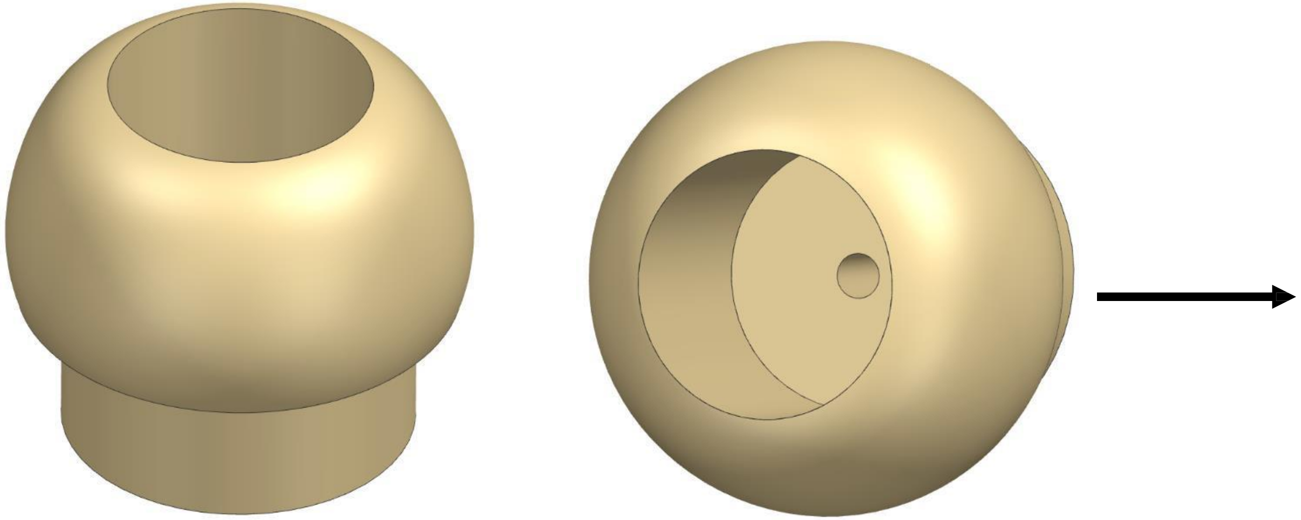
Starting point

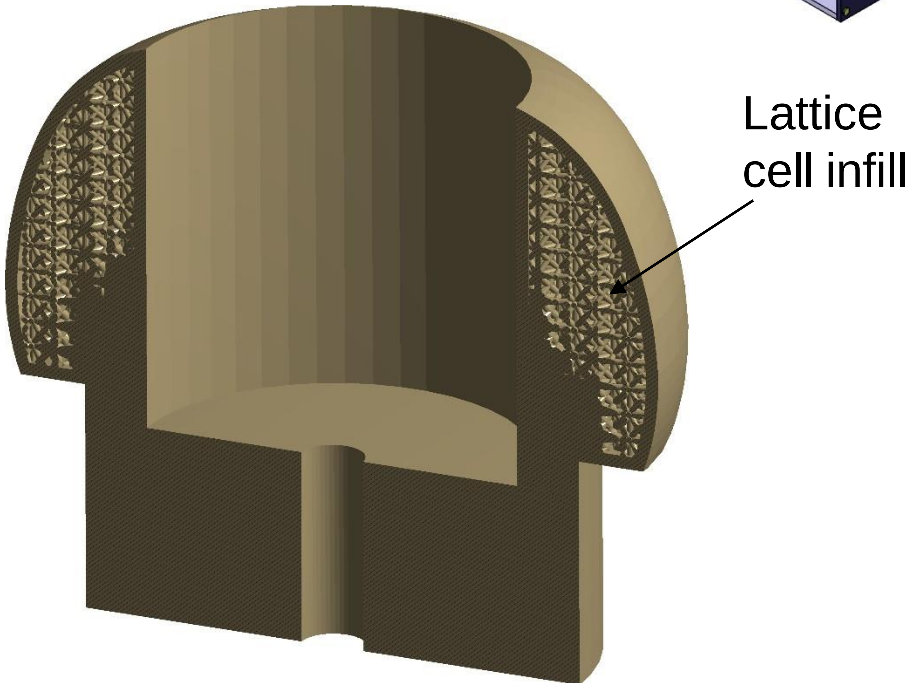


Parameter optimised geometry



Insert optimisation process

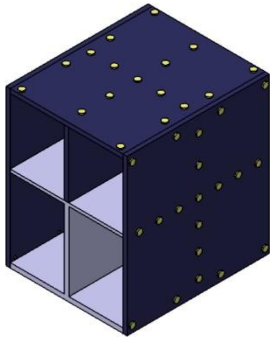




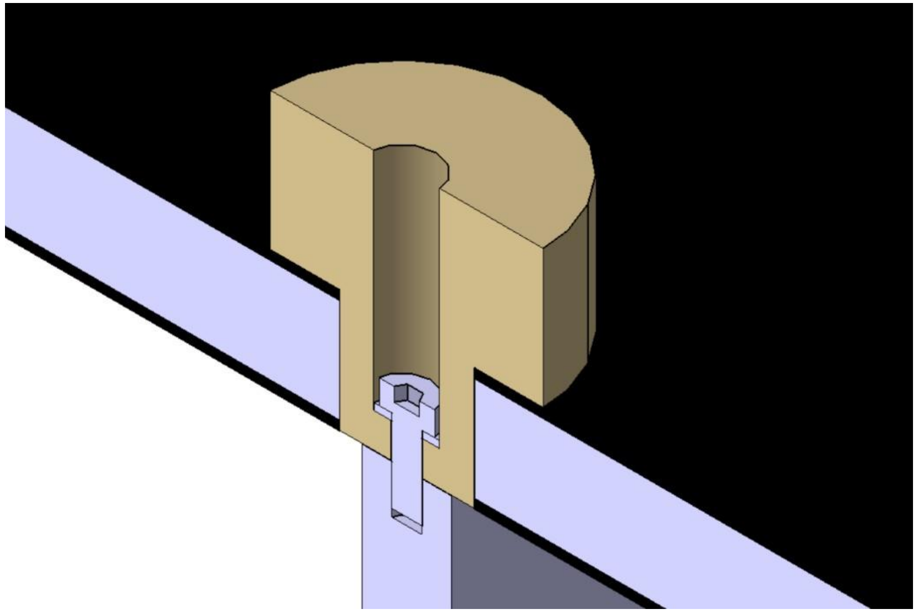
Lattice cell infill increases “dome“ surface area by factor 7 ➔ much better demisability

Topology optimised geometry

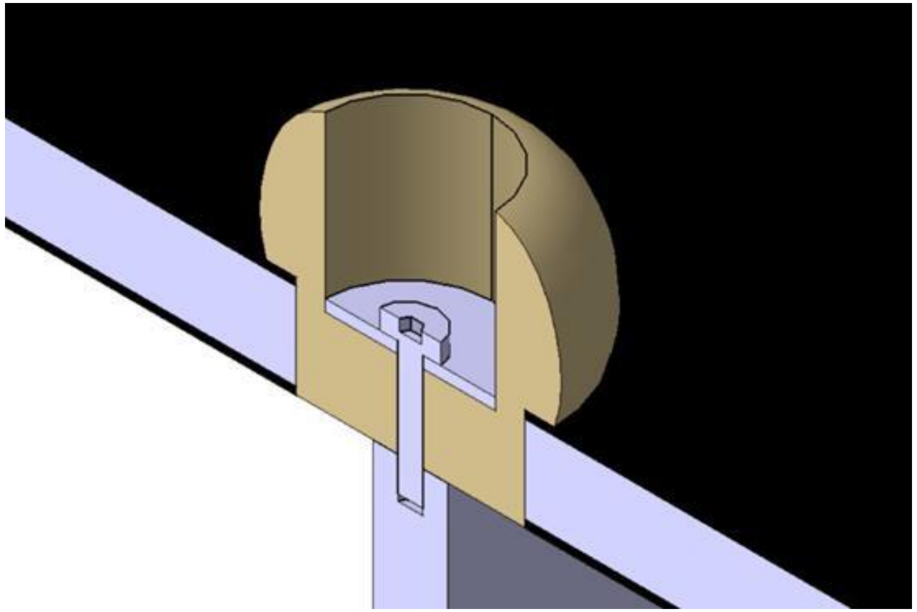
Lattice optimised geometry



Insert optimisation process



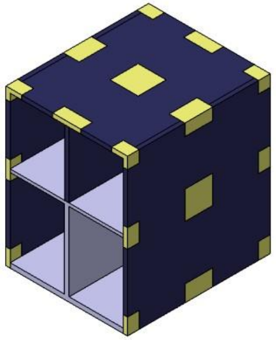
Starting point



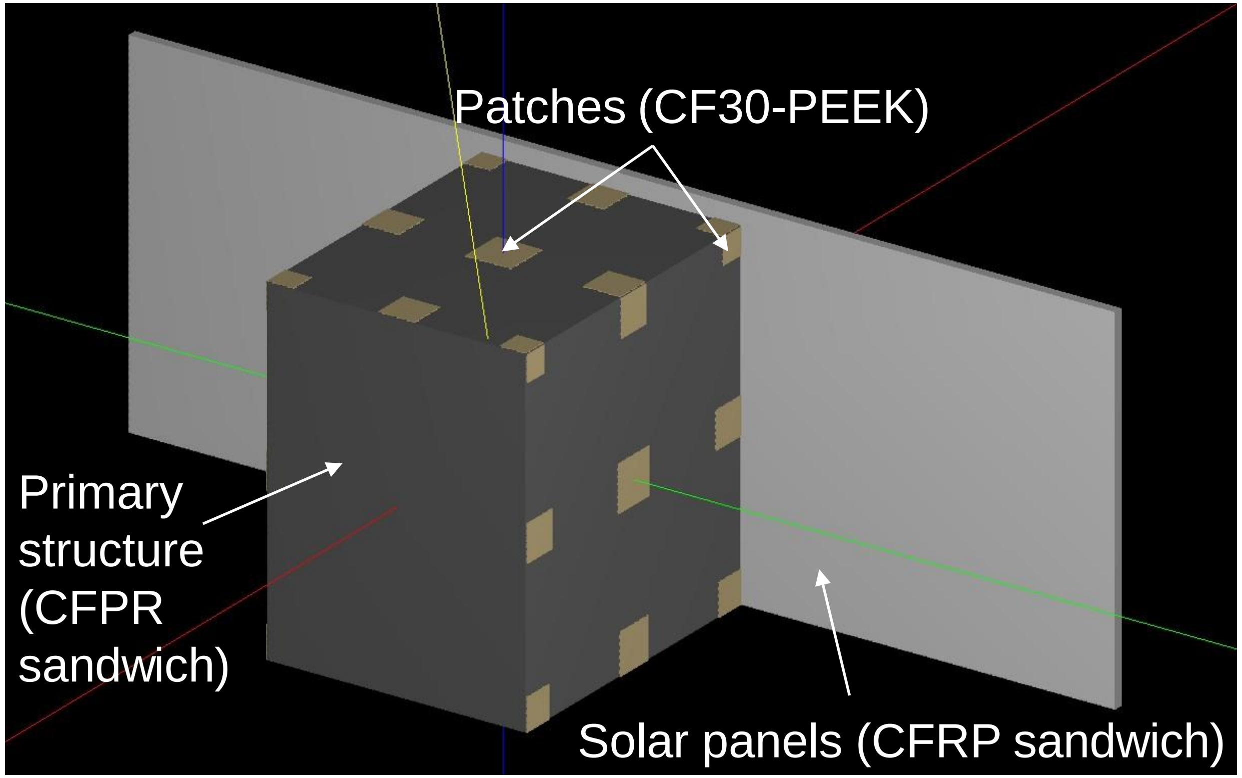
Final design
(shown without lattice infill for simplicity)

4. Re-entry analyses

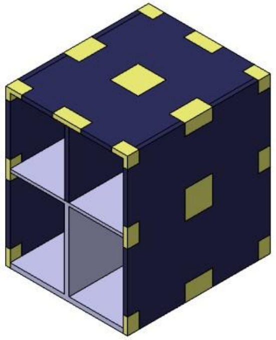
Re-entry analyses: Patches



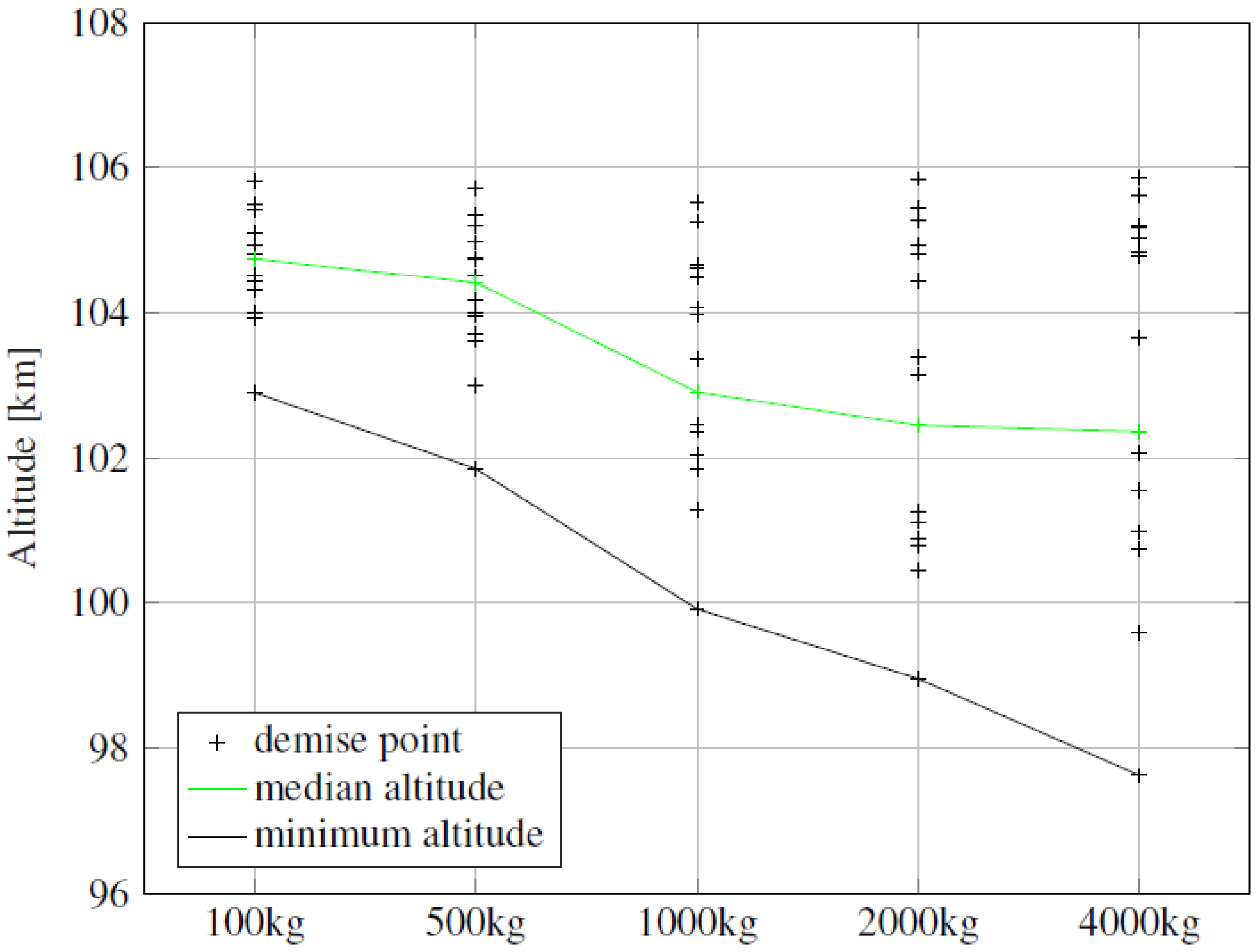
Patch design: Re-entry structural model with ESA-DRAMA



- ESA-DRAMA: Open source, re-entry survival and risk assessment (mitigation guideline compliance)
- Only upper FS and core of patches considered, lower FS does not need to demise for break-up
- Geometry needs to be simplified, especially patches
  ➔ Core mass scaled: $Q > m \times h_a / A_s$
- Analytical scale up ➔ 100 kg, 500 kg, 1000 kg, 2000 kg, 4000 kg satellite models tested
- FL orbital data used



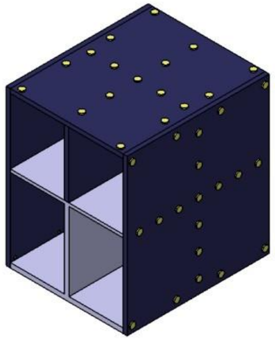
Patch design: Demise altitudes

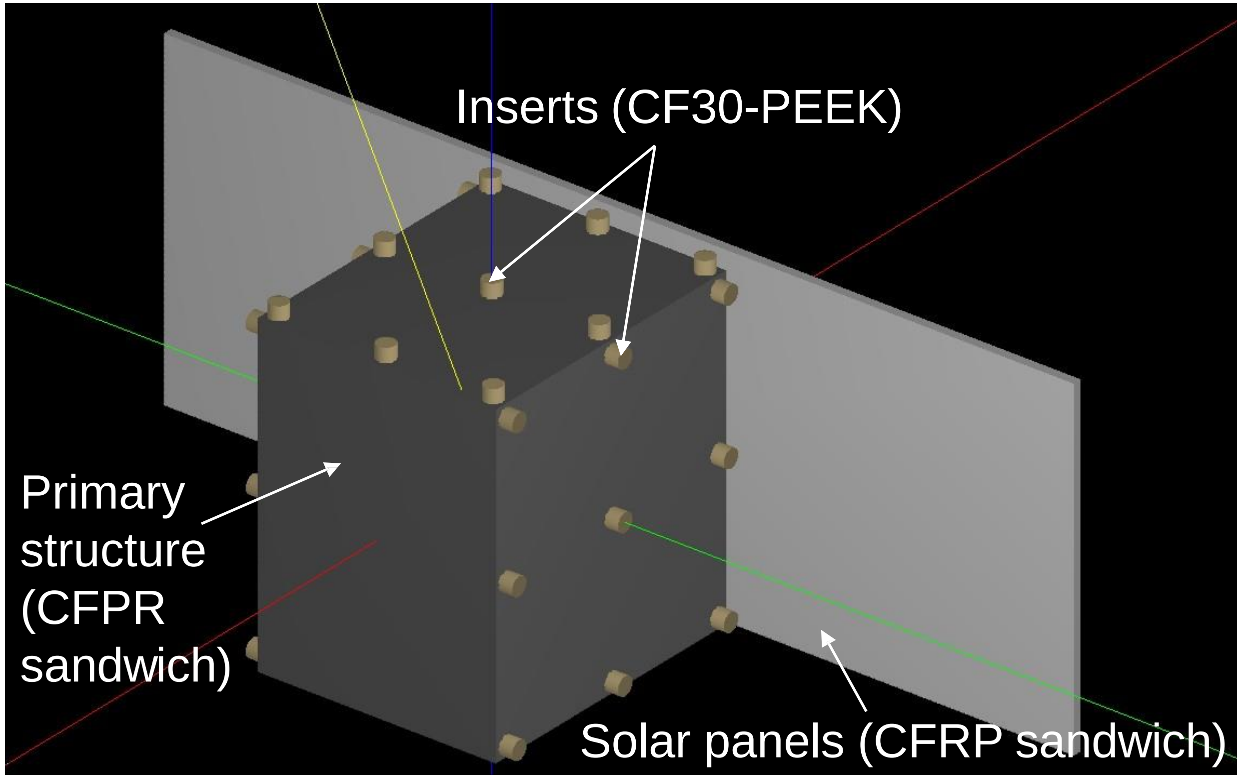


- Min alt.: All patches demised ➔ conservative break-up altitude
- Med. alt.: Approx. half of patches demised ➔ viewed as good estimate
- Thicker patches when scaled up ➔ reduction in break-up alt.

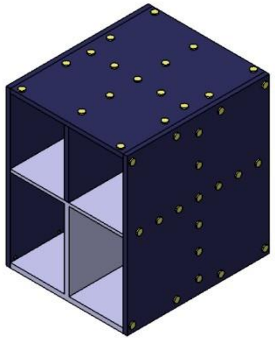
Re-entry analyses: Inserts

Insert design: Re-entry structural model with ESA-DRAMA

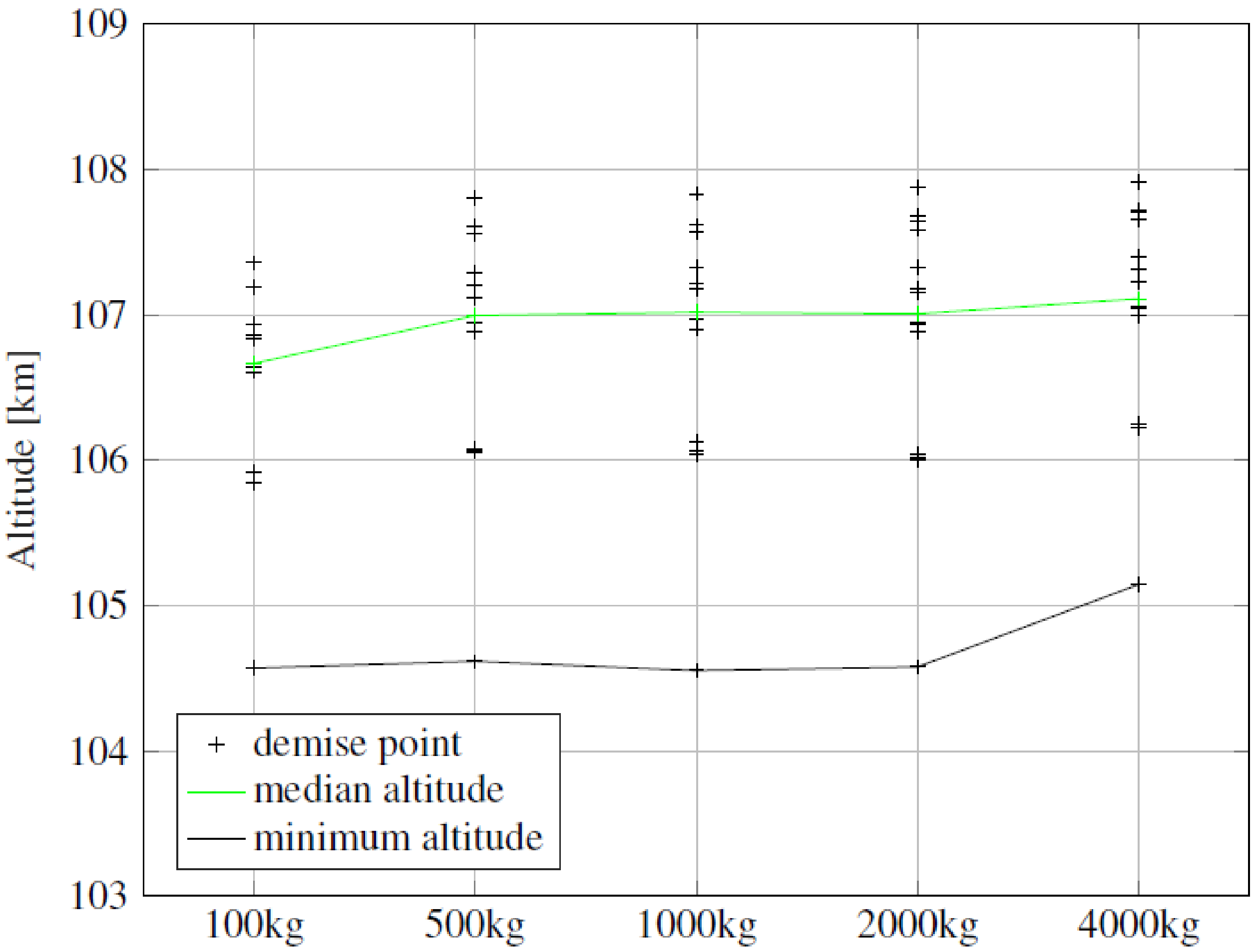




- Insert geometry in model corresponds approx. to geometry of dome protruding from structure
- Insert geometry is simplified, mass is scaled: $Q > m \times h_a / A_s$
- Analytical scale up ➔ 100 kg, 500 kg, 1000 kg, 2000 kg, 4000 kg satellite models tested
- FL orbital data used

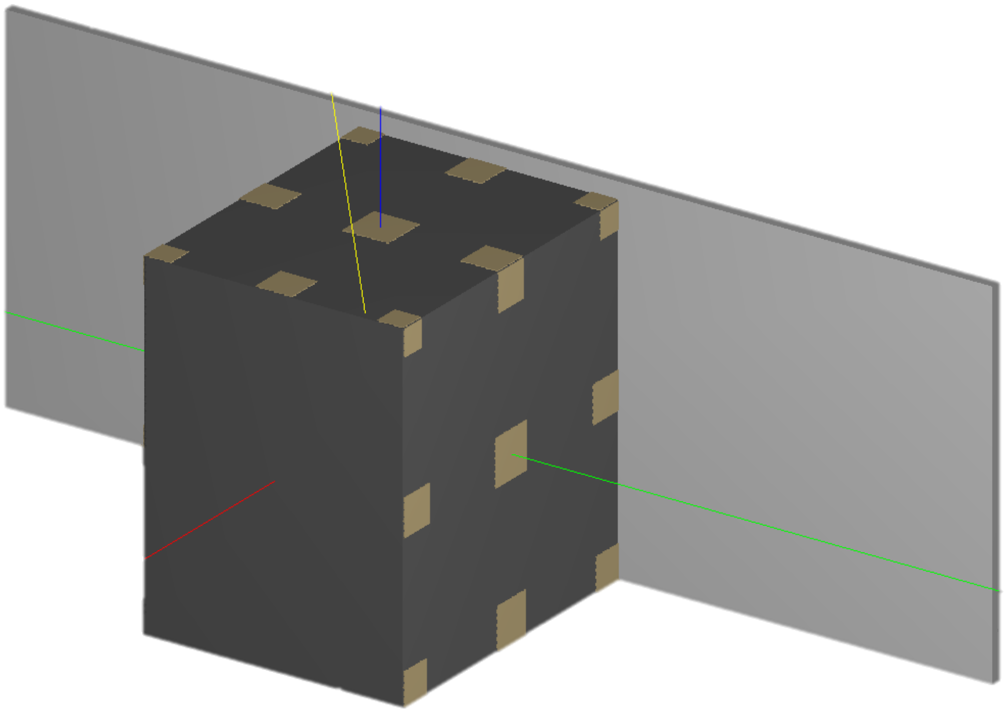


Insert design: Demise altitudes

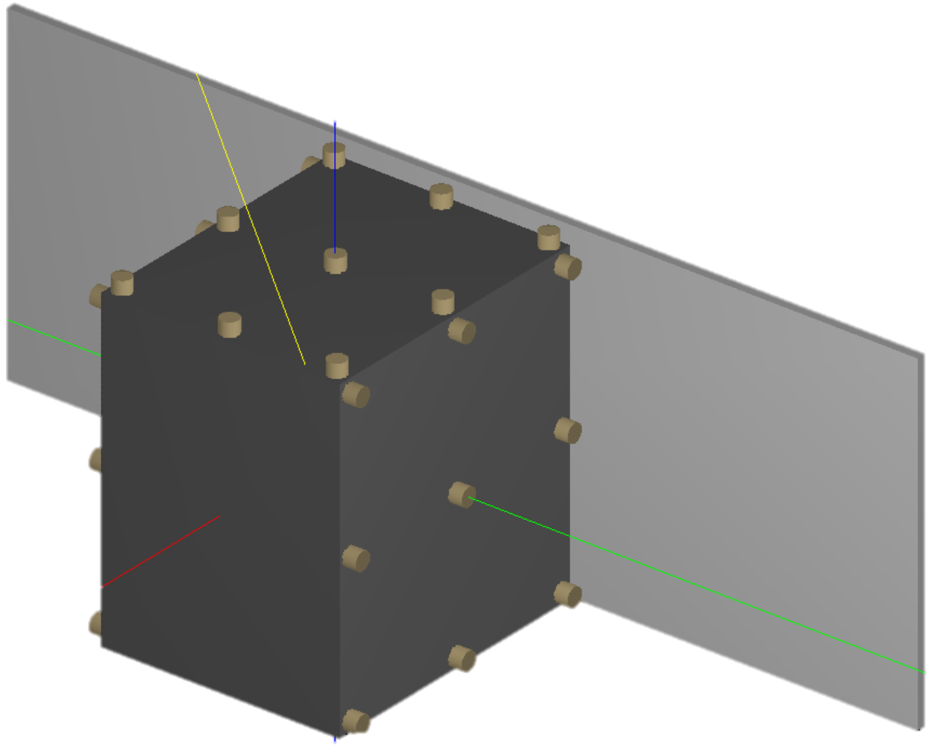


- All models break-up at over 104.5 resp. 106.5 km
- Break-up alt. near constant due to simplified scale up of insert geometry (less precise geometric model)

Break-up altitudes (median)



102 km
(Increase of 24 km, nominal 78 km)

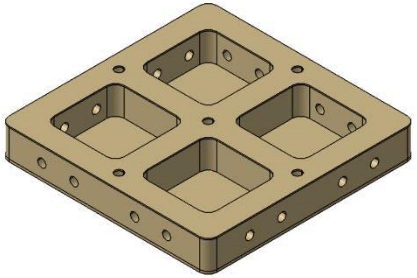


106.5 km
(Increase of 28.5 km, nominal 78 km)

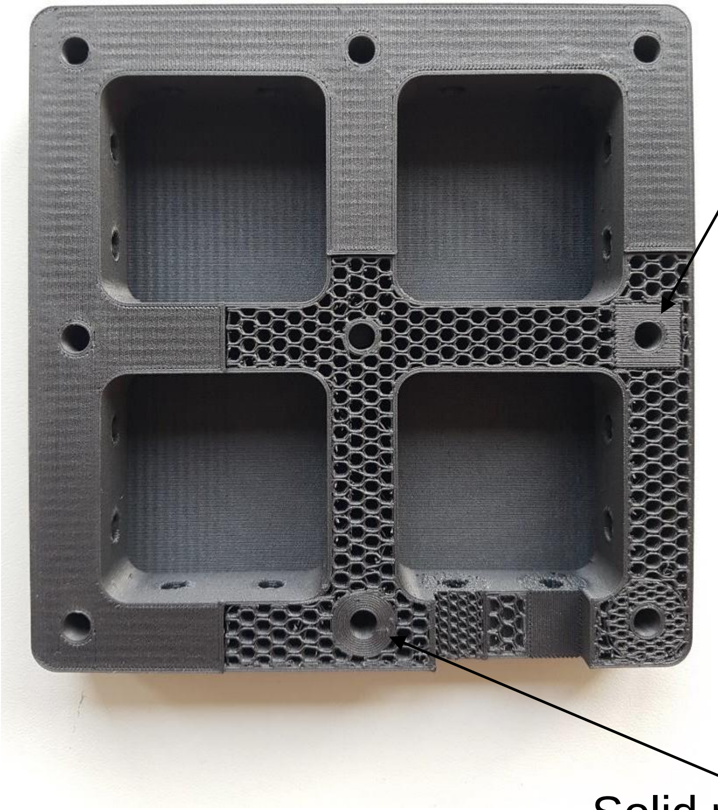
➔ ESA: Minimal risk if break-up above 95 km [6]

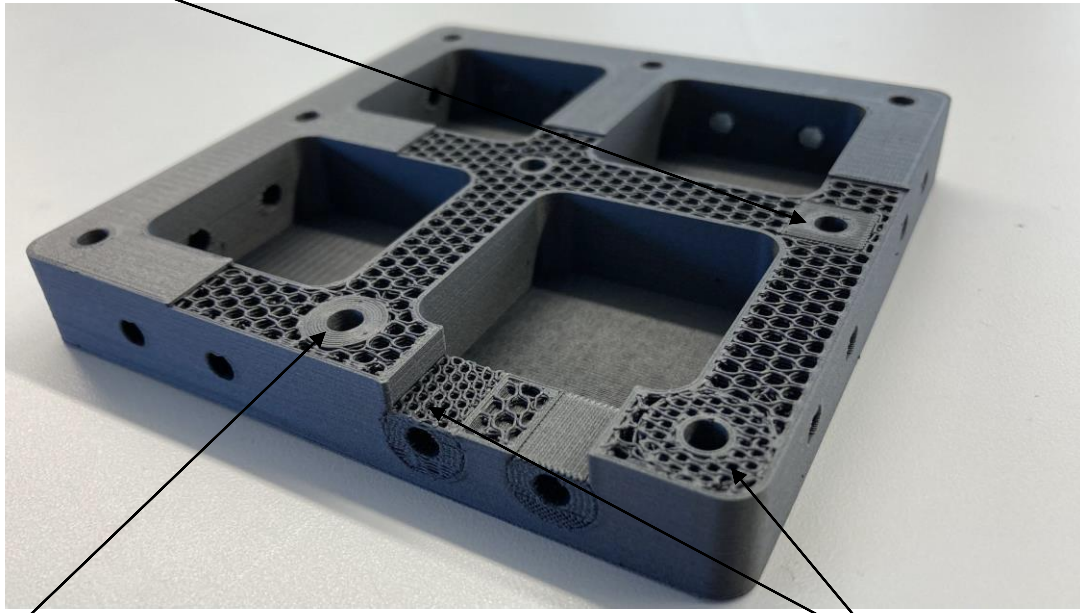
5. Demonstration model

Demonstration model



Solid material
(100% rectl. infill)





Inreased infill density

Solid material
(increased perimeters)

Link to demonstrator printing process:
https://www.linkedin.com/posts/dlr-bt_spacedebris-satellite-dlrbt-activity-6795616924253347840-6jO5

Conclusion and next steps

Conclusion:

- Two designs (Patches, Inserts) were developed end-to-end from concept to demonstrator
- Material characterisation CF30-PEEK ➔ Reliable material properties
- Structural analyses ➔ Both designs feasible
- Re-entry analyses ➔ Both designs strong increase in break-up altitude ➔ Risk minimisation
- Demonstrator ➔ Manufacturability
- Freedom of form of additive manufacturing most promising for demisability

Conclusion and next steps

Conclusion:

- Two designs (Patches, Inserts) were developed end-to-end from concept to demonstrator
- Material characterisation CF30-PEEK ➔ Reliable material properties
- Structural analyses ➔ Both designs feasible
- Re-entry analyses ➔ Both designs strong increase in break-up altitude ➔ Risk minimisation
- Demonstrator ➔ Manufacturability
- Freedom of form of additive manufacturing most promising for demisability

Next steps:

- Improve existing designs e.g. embedded pre-loaded springs
- Further validate designs with higher fidelity re-entry software (i.e. SCARAB) and experimentally (i.e. plasma WT)
- Investigate the potential of AM for subsystem demisability
- Subsystems and secondary structures made of 3D printed SiC-based ceramics and metals

Q & A

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