AetherSat-1: Design exploration of a CubeSat re-entry mission with an inflatable Thermal Protection System

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KU LEUVEN

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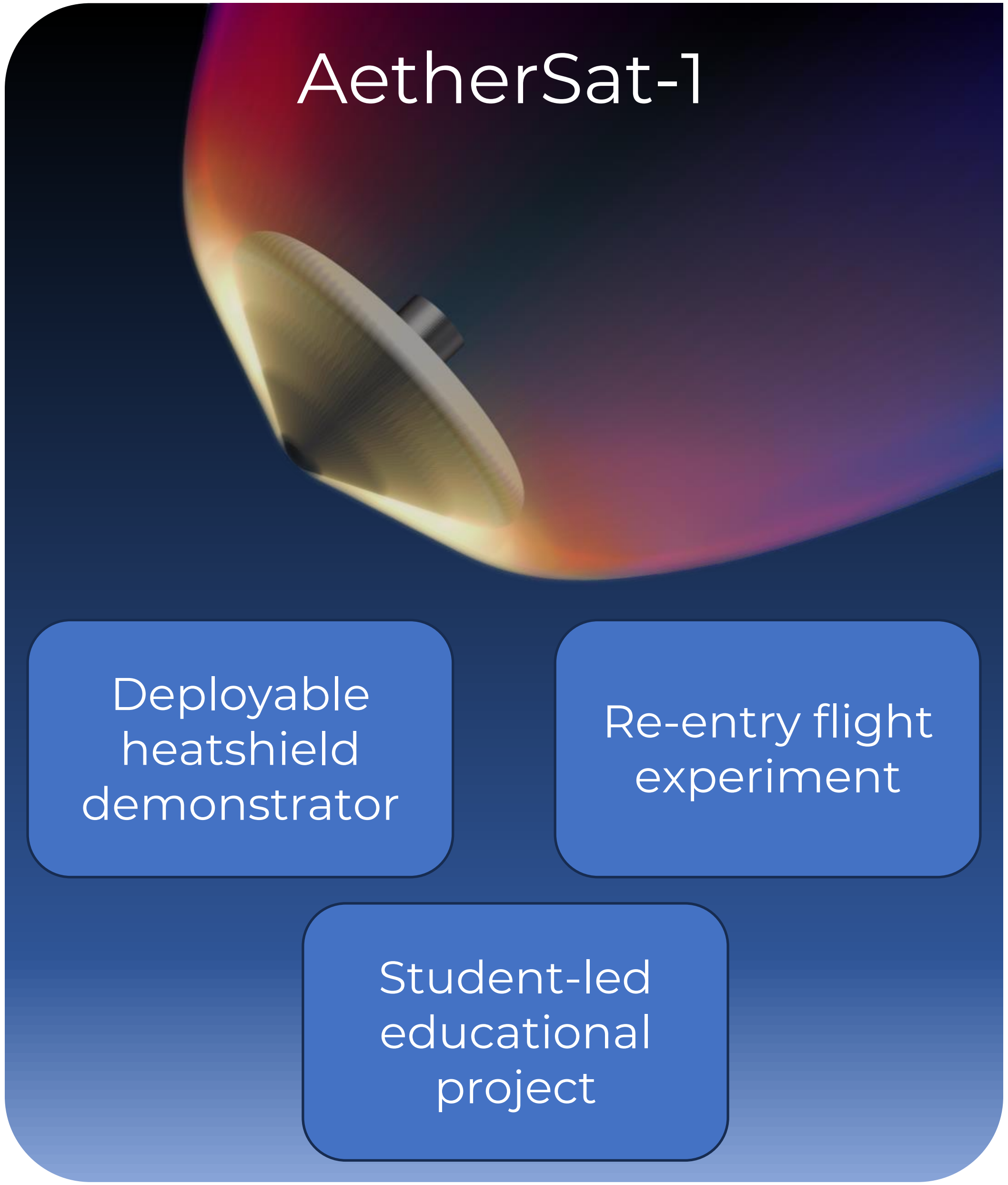
Towards a CubeSat platform for sample return from LEO

- **Launch costs:** decreasing rapidly
- But **downmass capacity** remains limited
  - Space manufacturing
  - Life sciences
  - Space exposure experiments
  - …
- **AetherSat-1:**
  - Taking a step towards a CubeSat re-entry platform
- Increased **knowledge of re-entry** phenomena could unlock
  - More efficient Thermal Protection Systems (TPS)
  - Better Design For Demise (D4D) assessment



Why use a deployable heatshield?

$$\beta = \frac{m}{C_D A}$$

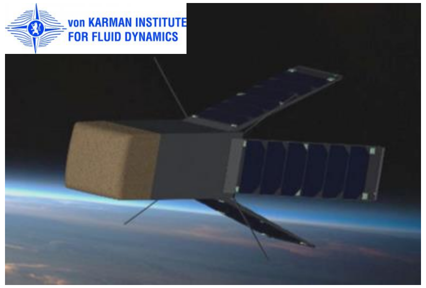
Mass

Drag coefficient

Frontal area

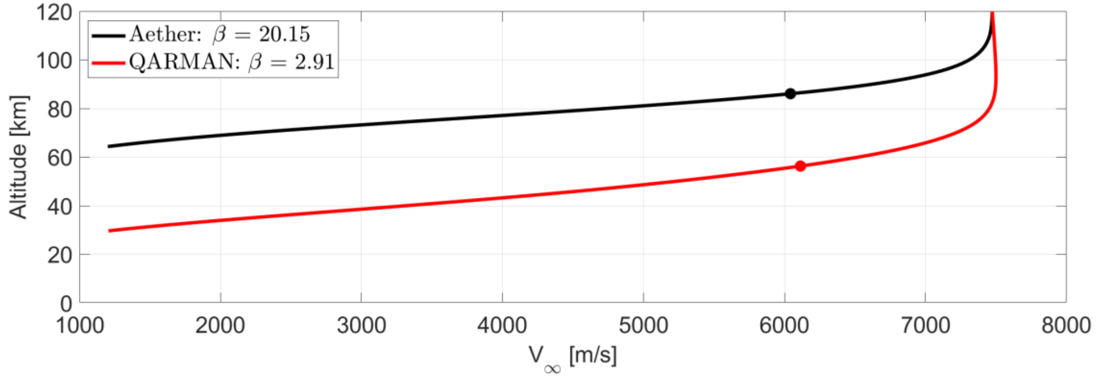
- Re-entry thermal loading dictated by **ballistic coefficient $\boldsymbol{\beta}$**
- Example: simulated entries of QARMAN vs. AetherSat-1
- AetherSat-1: $\boldsymbol{\beta = 20.15}$
- QARMAN: $\boldsymbol{\beta = 2.91}$

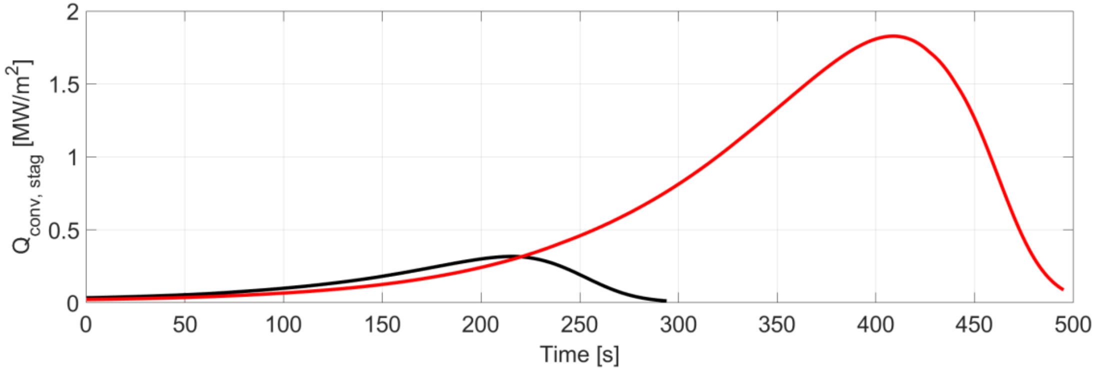
	QARMAN	AetherSat-1
Peak heat flux [MW/m²]	1.83	0.36
Integrated heat load [MJ/m²]	308.1	32.5
Altitude @ peak heating [km]	56.3	84.7
Max deceleration [g]	7.7	9.3



QARMAN (Qubesat for Aerothermodynamic Research and Measurements on AblatioN)

Same initial condition:





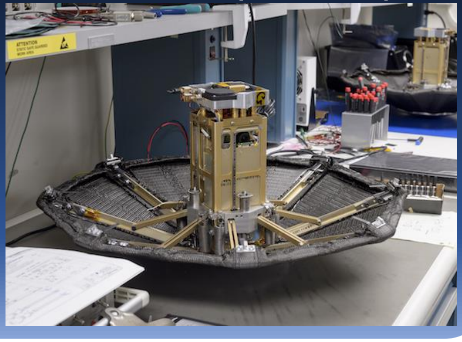
Deployable TPS concepts

- TRL of deployable heatshields: 4-5 in Europe, 6-7 in US
- Yellow indicates projects which are unflown

Rigid deployable

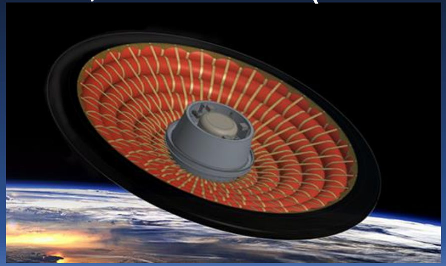
(mini-)IRENE (CIRA)

ADEPT (NASA)



Stacked torus

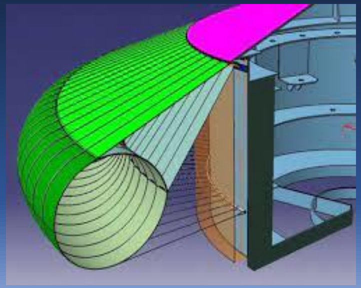
IRVE, LOFTID (NASA)



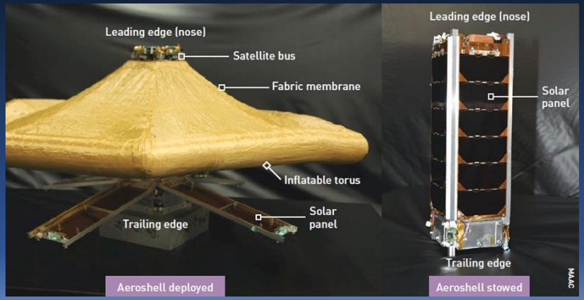
IRDT (ESA)

Tension cone

EFESTO (EU consortium)

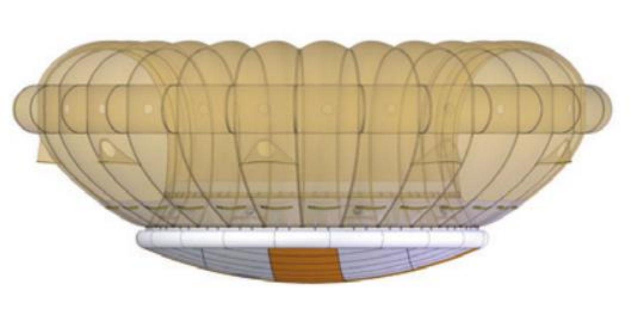


EGG (JAXA)



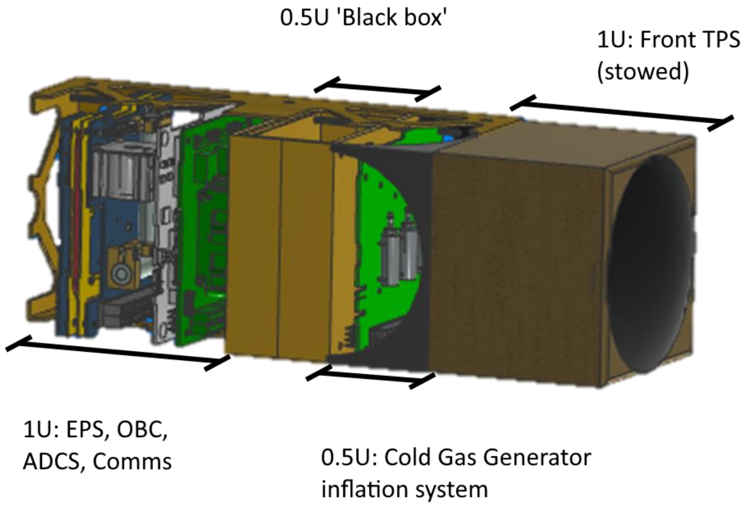
Isotensoid

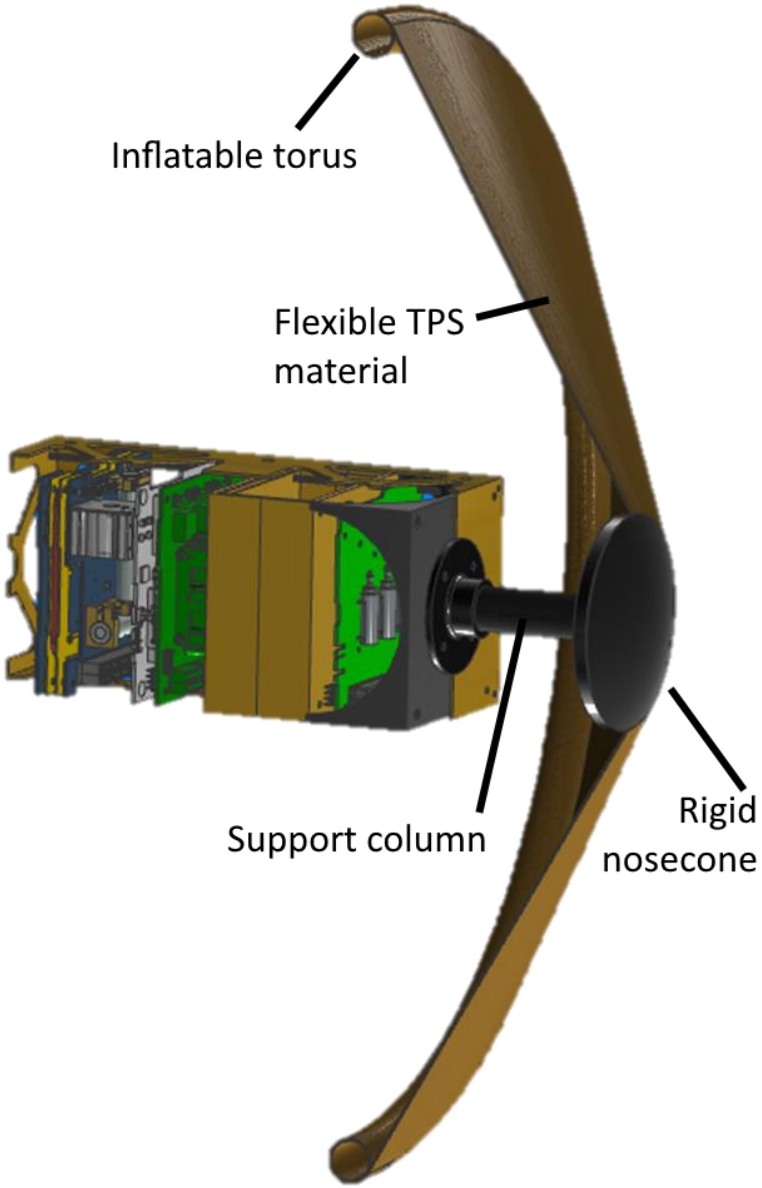
SIAD-E (NASA)



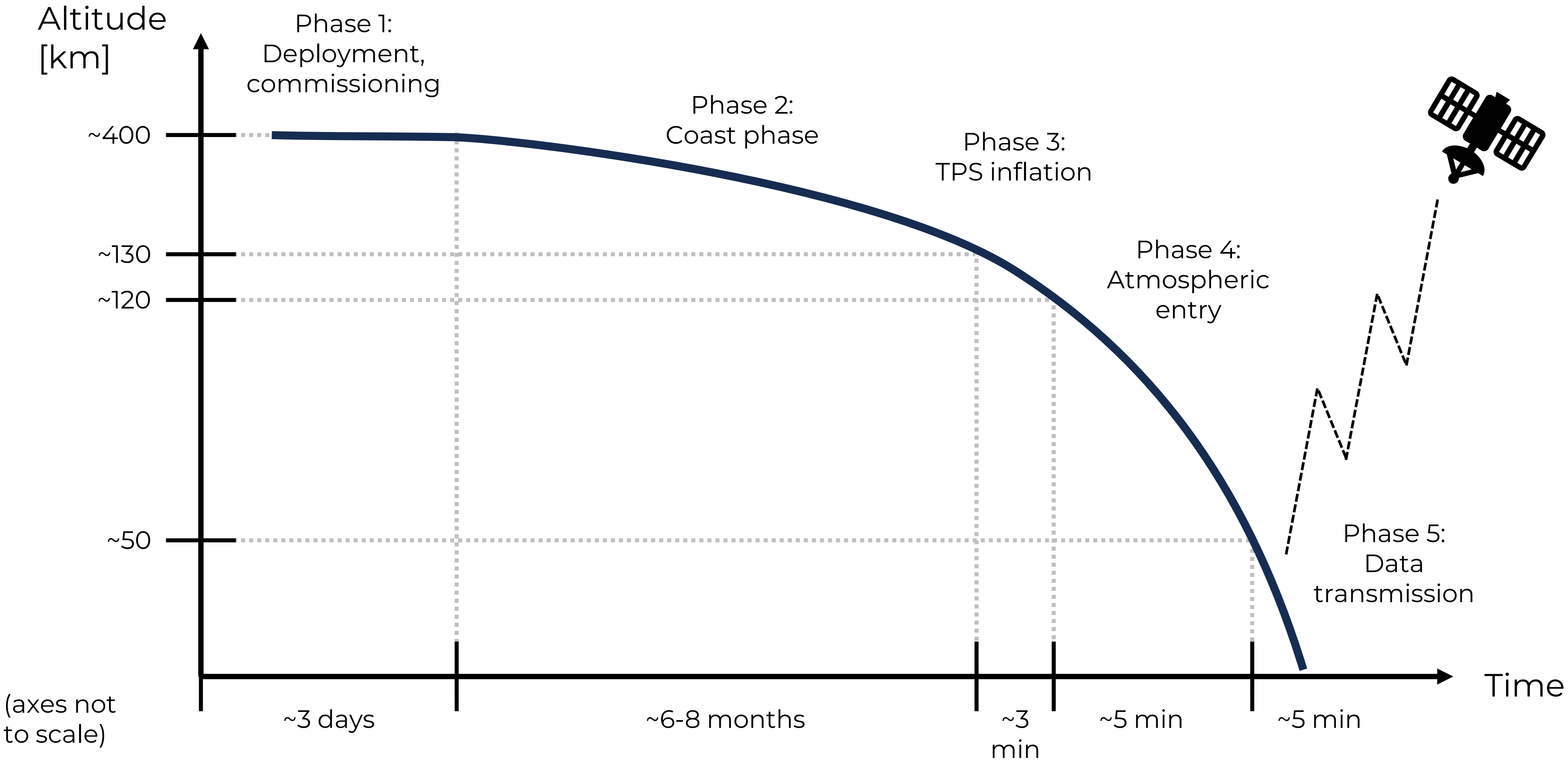
Tension cone design

- Aether team opted for a **tension cone design**:
  - ➢ Rigid deployable structure rejected: inflatable structure more compatible with 1U 'modular' design
  - ➢ Smaller inflated volume required vs. stacked torus
  - ➢ Lowest amount of fabric to pack into 1U volume



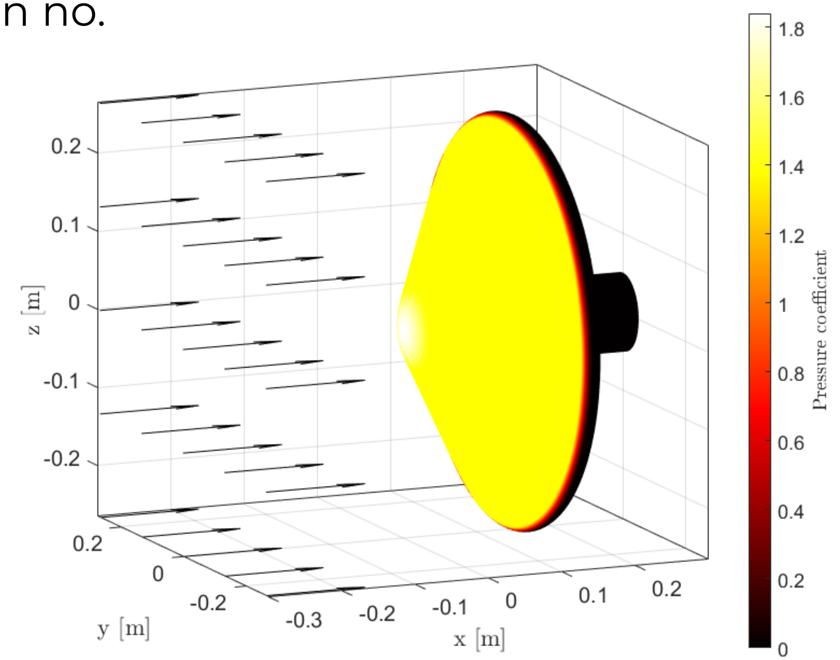


Mission profile

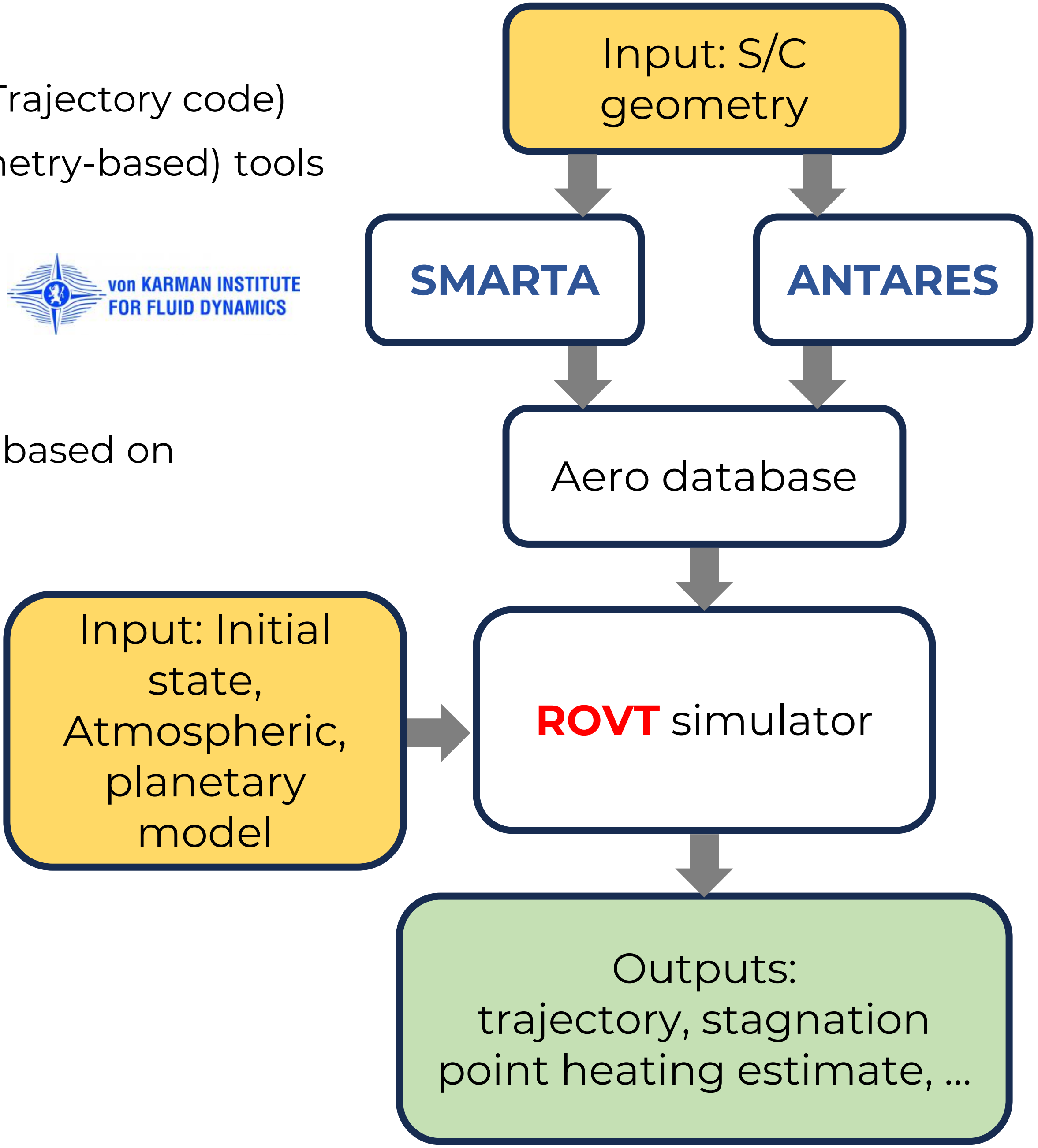


Analysis tools

- Trajectory analysis with **ROVT** (Royal Observatory and VKI Trajectory code)
- Aerodynamic database computed with engineering (geometry-based) tools
- **SMARTA** – free molecular flow regime
  - ➢ Panel method based on analogy with radiation problems
- **ANTARES** – hypersonic continuum flow regime
  - ➢ Modified Newtonian method
- Transition from SMARTA to ANTARES by bridging function based on Knudsen no.

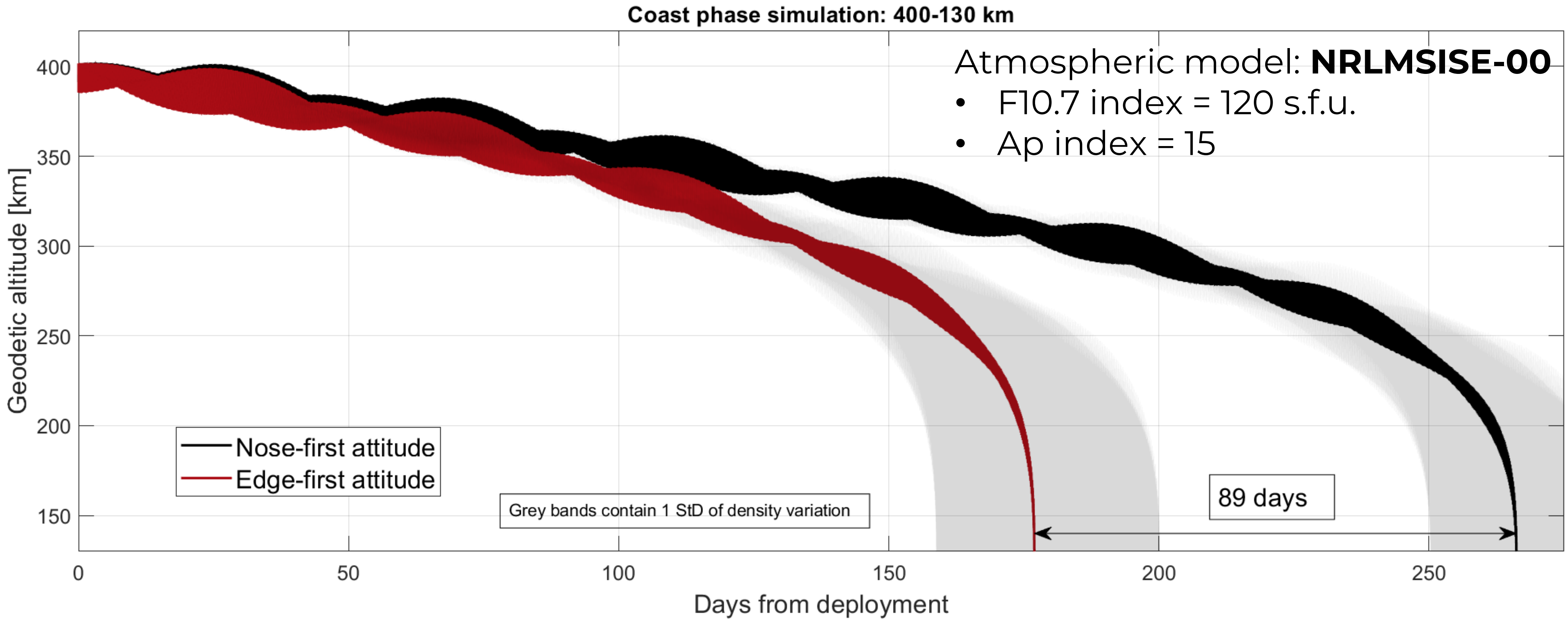


Pressure coefficients on the Aether geometry as determined by ANTARES



Coast phase – orbital decay estimates

Simulations of **undeployed geometry:** nose-first vs. edge-on attitude

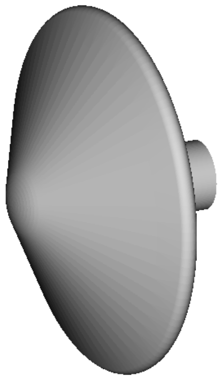


Proposed payload during coast phase: Sweeping Langmuir Probe for ionosphere measurements, cfr. to payload on PICASSO CubeSat (BIRA)

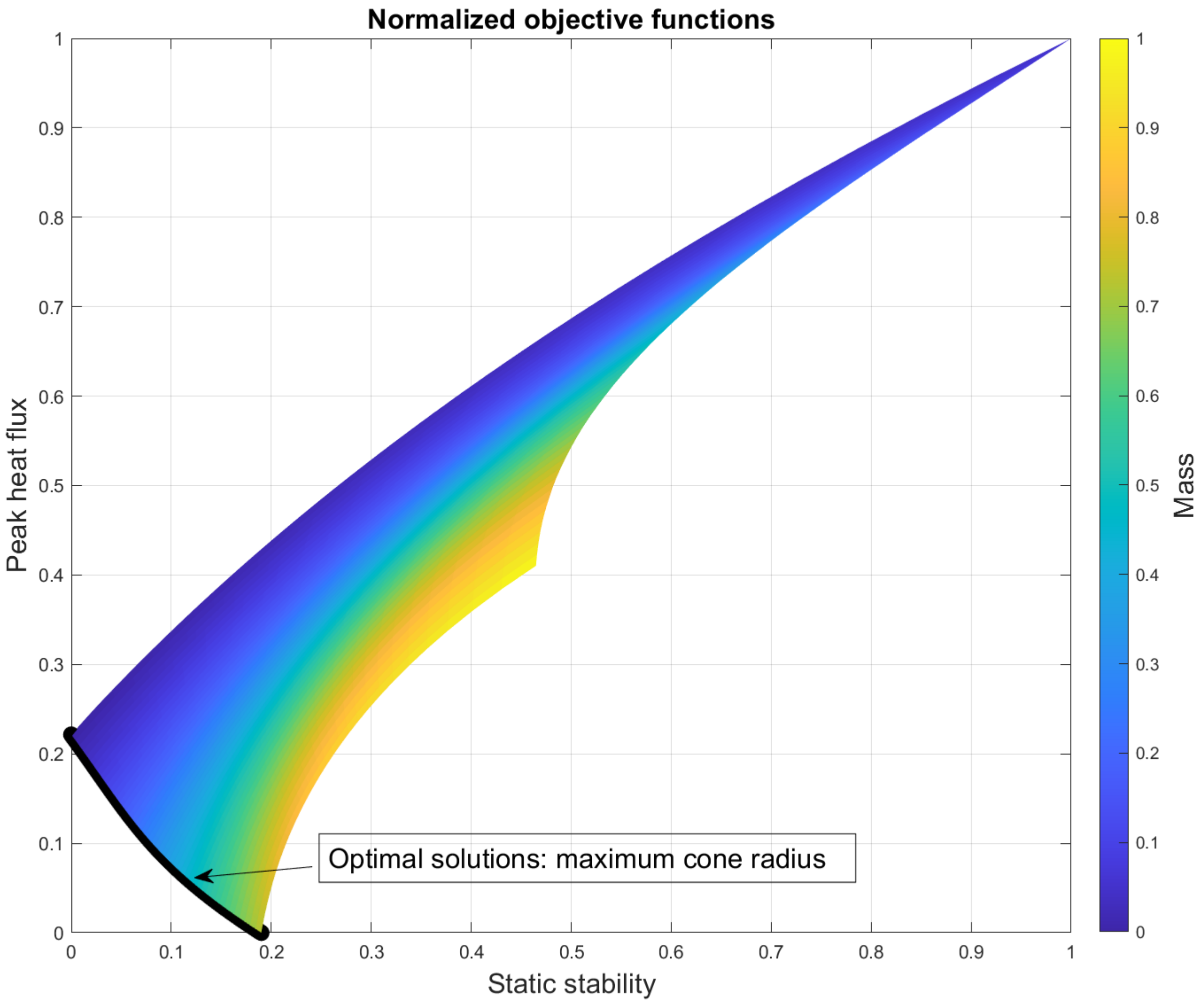
TPS shape optimization

- Optimization was performed through a **low-rank matrix decomposition** of each objective function with the **Adaptive Cross Approximation** algorithm
- This was done to limit the required number of ROVT simulations
- A **genetic algorithm (NSGA-II)** was used to explore the resulting surrogate model, leading to an optimal solution set
- The optimal set is 1-D: maximizing the cone radius with cone angle as a free parameter

- Resulting choice of heatshield:
  - ➢ 60° cone angle, 0.25m cone radius

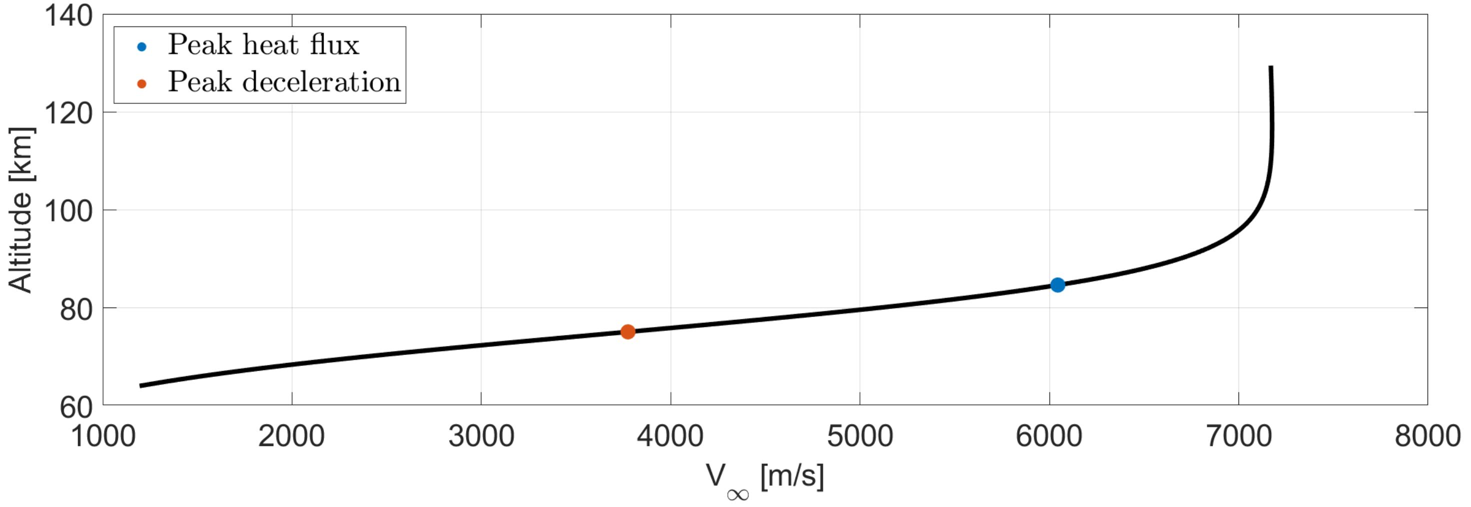


Input parameters	Cone angle [deg]	Cone radius [m]
Min	45	0.065
Max	75	0.25

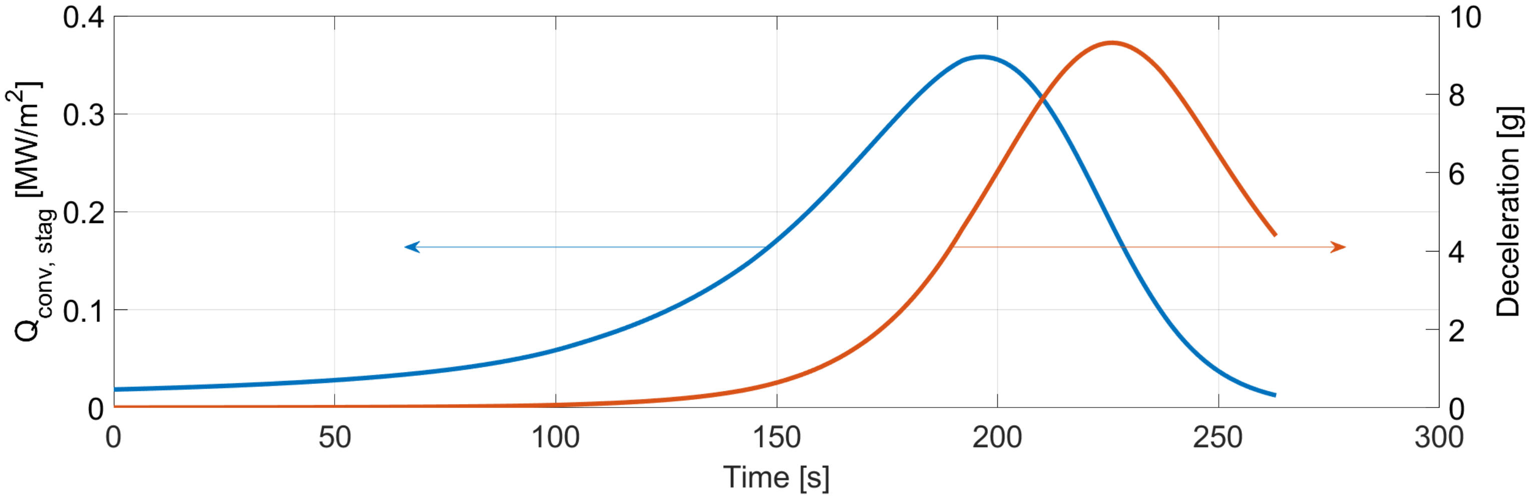


Atmospheric entry phase

- Optimal TPS shape
- Simulation start from end of rarefied simulation, until vehicle reaches Mach 4 (end of validity of ANTARES)
- Entry angle: -1°
- Total duration: ~5min



- Proposed payload during this phase: Monitoring of heatshield shape through **Fibre Bragg Grating strain sensors** embedded in the flexible structure



TPS surface heat flux, temperature estimates

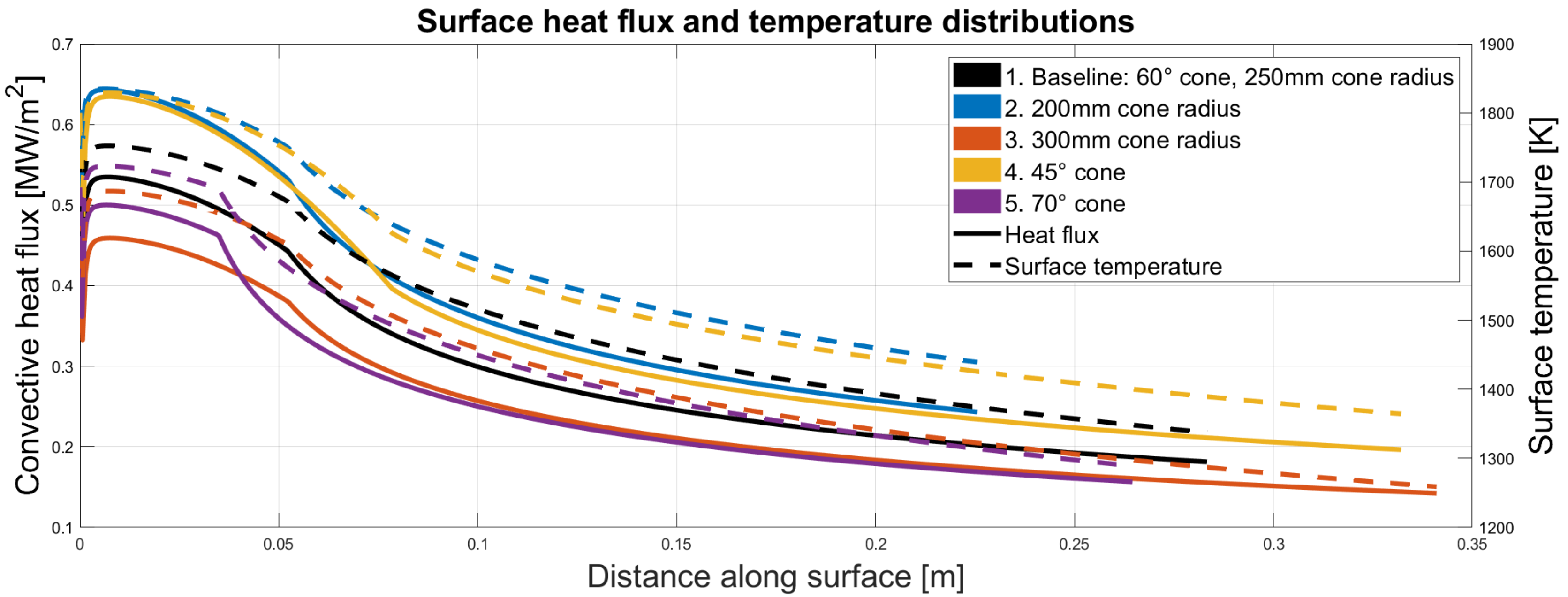
- Off-stagnation point, laminar heat flux expressions using reference enthalpy method:

$$\dot{q} = 0.22\rho_e u_e \left(Re_{\theta_L}\right)^{-1} (\rho^* \mu^* / \rho\mu) \times (H_{aw} - H_w) Pr_w^{-0.6}$$

$$\theta_L = 0.664 \left(\int_0^s \rho^* \mu^* u_e r^2 ds \right)^{1/2} \Big/ (\rho_e u_e r)$$

- Boundary layer edge properties assuming isentropic expansion from stagnation point + Modified Newtonian pressure distribution
- Surface temperature assuming radiative equilibrium at the surface: $\dot{q} = \epsilon\sigma T_{surf}^4$

		Low β variant	High β variant
T [K]	Nose region	~1600	~1800
	TPS fabric	~1300-1500	1400-1600
$\dot{q}$ [MW/m^2]	Nose region	~0.45	~0.65
	TPS fabric	~0.15-0.35	~0.25-0.50



Aether: a student-led educational project

- Since 2020
- Students can join the team full-time as part of 1 or 2-year postgraduate programme **'TechInVenT'**

Space Education

2023-2024 academic year:
- 10 full-time team members
- ~15 thesis students & volunteers
- **STEM promotion**, workshops in schools

Connecting students with industry

Many Aether alumni have gone on to work in the (Belgian) space industry

Thank you for your attention!

Many thanks to the partners of the Aether team:

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