Configuration design for a VLEO spacecraft with atmosphere-breathing propulsion

Institute of Space Systems

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Frame of this Work: RAM-CLEP

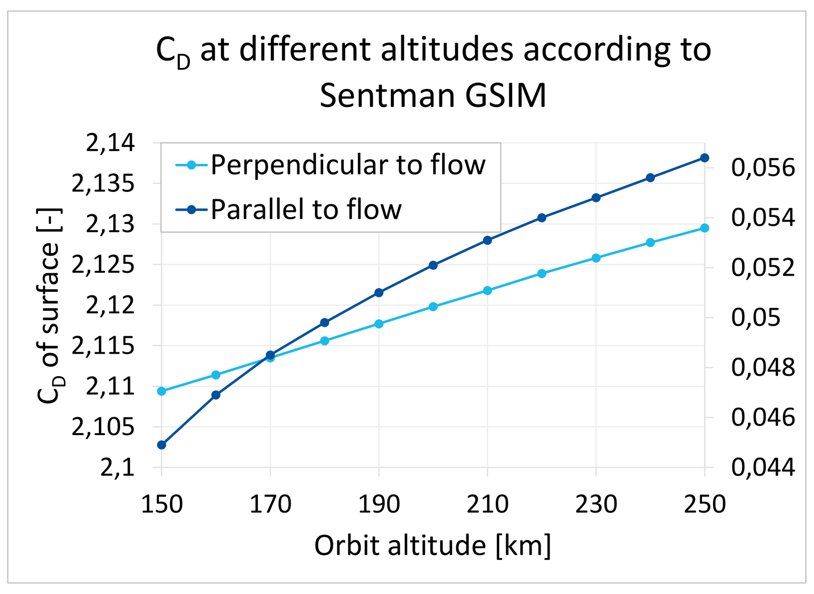
The work presented here was partly carried out in the frame of an ESA-funded project on Technology Enhancement of Cathode-Less Electric Propulsion (RAM-CLEP). The goals of this activity are (1) to mature the technology of components of an Atmosphere-Breathing Electric Propulsion System (ABEP), (2) to identify how the VLEO environment and the use of an ABEP system affect mission design, and (3) to identify how the VLEO environment and the use of an ABEP system impact satellite design. For the ABEP system, the intake and thruster developed at the IRS under DISCOVERER are baselined. This poster focuses on the latter part and describes studies carried out on a beneficial spacecraft configuration for VLEO satellite propelled by an ABEP system.
Further activities to be carried out under RAM-CLEP are shortly described in the "Outlook" section.

Methodology

Constraints
- Realistic specific impulse requirement for engine
- Geometrically fit optical payload
- Fit into launcher

Goal
- Minimization of required power

Challenges
- Preference to avoid drag simulations (allowing faster comparisons)
- Contribution of intake to drag unknown – previously treated as if spacecraft had a closed frontal surface



Approach
- Simplified calculation of drag using panel method/Sentman model and assuming only surfaces parallel or perpendicular to flow
- Introduction of factor β to represent different degrees of drag contribution by intake (0 to 1):

$$C_D = \frac{A_{\parallel}\, C_{D,\parallel} + (A_{\perp} + A_{\text{intake}}\beta) C_{D,\perp}}{A_{ref}}$$

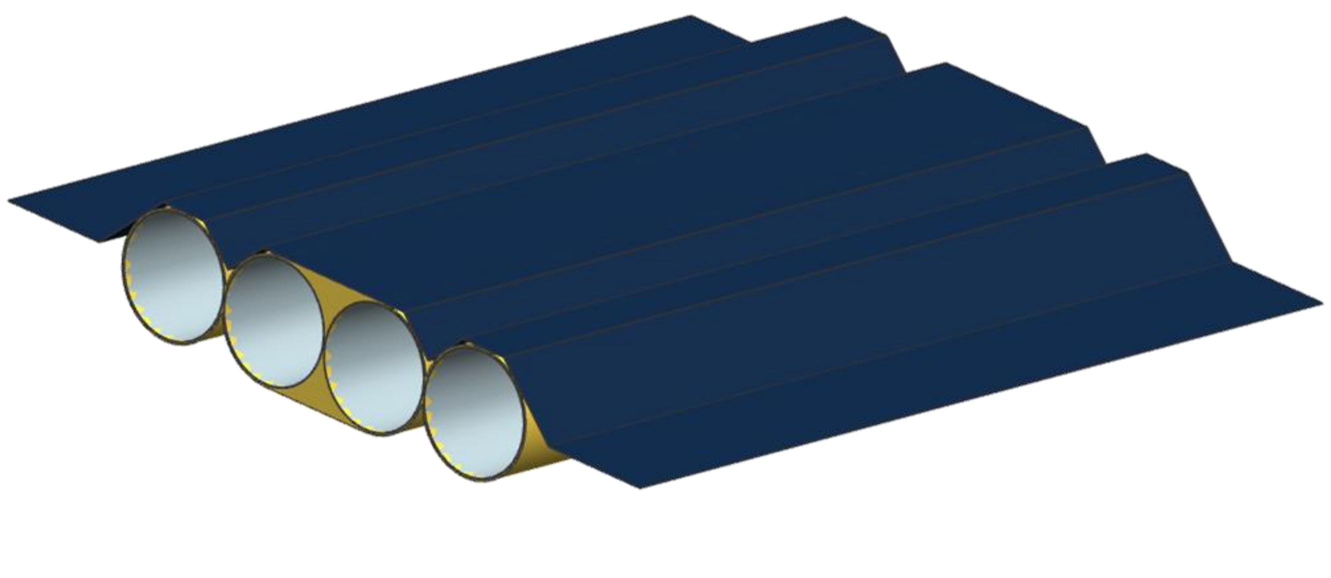
Verification
- Comparison with ADBSat & PICLas simulations
- < 1 % deviation in between results

Spacecraft, Mission, & Payload

Flight altitude
- 150 to 250 km

Spacecraft
- Diffusely reflecting spacecraft surfaces
- Energy accommodation coefficient: 1.0
- Maximal viable length (launcher): approx. 4 m
- Pre-selection of "slender" & "flat" body shapes

Payload compartment
- 390 mm x 270 mm x 270 mm (l x w x h) on nadir side of spacecraft

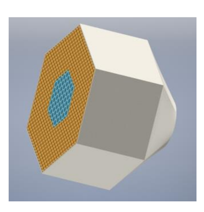


Exemplary flat body spacecraft configuration with four intakes

ABEP System

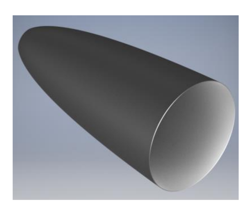
Helicon-based plasma thruster
- Realistic max. I_{sp}: ca. 2000s
- Required min. pressure: 0.12-0.3 Pa
- Thruster efficiency: ca. 0.2

Considered intakes
- Diffuse intake efficiency: 0.46
- Specular intake efficiency: 0.94



Specular intake ⟶

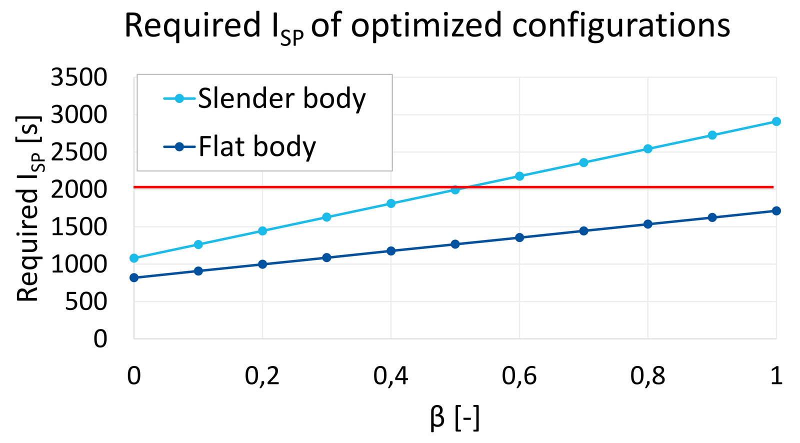
⟵ Diffuse intake



Results

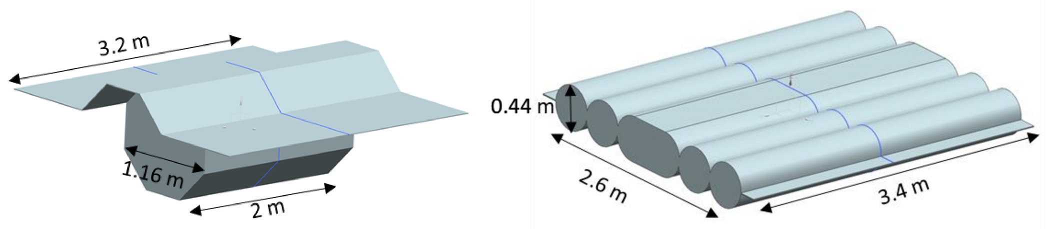
Required specific impulse as a limiting factor
- The specific impulse required from the thruster(s) constrains viable options for spacecraft configurations
- The required specific impulse is inversely proportional to the ratio of $A_{intake}*\eta_c/A_{frontal}$:

$$I_{SP} = \frac{1}{2}\frac{v(h)}{g}\frac{A_{frontal}}{A_{intake}\eta_c}C_D(h)$$



Limitation on specular intake diameter
- Available length of approx. 3 m for intake limits diameter to max. ~0.5 m => slender body only viable with diffuse intake

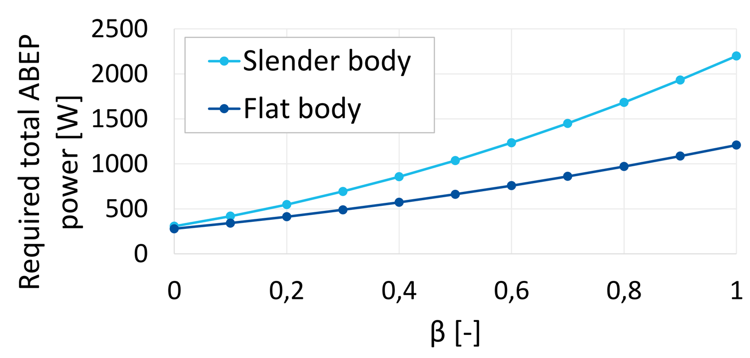
Optimizations of slender and flat body
- Shortened spacecraft body of slender body
- Slightly increased diameter of slender body
- Relatively large intake diameters of flat body
- 6 or 8 ABEP systems (intake + thruster) for flat body



C_D (wrt frontal area)	1.2 - 3.2	1.7 – 3.6
Drag @200 km	11 mN - 31 mN	14 mN - 29 mN

Conclusion

High achievable $A_{intake}/A_{frontal}$ in combination with specularly reflecting intakes clearly suggests flat body design over "classical" slender body with regard to total power required (see below)



Outlook

Further work to be undertaken within the RAM-CLEP project will include:
- Study of intake contribution to drag, multi-disciplinary optimization of flat body spacecraft, and preliminary system design for Earth Observation and Telecommunication applications
- Design & realization of thruster, intake, and PPU for ground tests
- Ground test of thruster & intake at IRS facilities using a particle flow generator (PFG)
- Development of simulation models for the PFG and the ABEP system
- Definiion of a roadmap for further development of the ABEP

Selected References

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