Plasma-based electric propulsion: the air-breathing concept

V. Giannetti[1, 2], E. Ferrato[1, 2], T. Andreussi,[1]

[1] *Institute of Mechanical Intelligence, Scuola Superiore Sant'Anna, Pisa, Italy*

[2] *Celeste S.r.l., Pisa, Italy*

Flying a spacecraft in Very Low Earth Orbit (VLEO), at an altitude below 400 km, would provide significant advantages[1], both in terms of payload performance and debris mitigation. However, the drag experienced at these altitudes due to the residual atmosphere must be continuously counteracted by a propulsion system, significantly limiting the lifetime of the satellite. For this reason, satellites do not typically operate in VLEOs.

In recent years, air-breathing electric propulsion has emerged as a potential enabling technology for long-duration space missions in VLEO. The concept relies on an intake placed in front of the spacecraft that collects the atmospheric gases and feeds them to a plasma-based electric thruster, capable of ionizing and accelerating the collected particles to compensate the atmospheric drag.

Several concepts have been proposed for air-breathing electric thrusters[2]; however, ground tests have highlighted difficulties in the efficient ionization of the VLEO atmosphere. This is because (i) molecular nitrogen and atomic oxygen are intrinsically more complex to ionize than typical Electric Propulsion (EP) propellants, and (ii) because of the relatively low pressure expected at feasible VLEO altitudes, $\sim 10^{-6}$ mbar.

In this work, we investigate the plasma generation in air breathing electric propulsion systems from a fundamental perspective. First, based on available atmospheric models[3], the collection and compression capabilities of rarefied air by a passive intake at orbital speed are evaluated using Monte-Carlo methods. With the availability of the expected particle density and composition in the discharge chamber, a reduced order formulation is then proposed to model the generation of air plasma, accounting for all main reactions involved. Finally, the developed model is used to assess the feasibility of plasma generation for systems' conditions representative of real VLEO operative scenarios.

---

[1] Crisp, N. H., et al. (2021). System modelling of very low Earth orbit satellites for Earth observation. Acta Astronautica, 187(June), 475–491. https://doi.org/10.1016/j.actaastro.2021.07.004.

[2] Andreussi, T., et al. (2022). A review of air-breathing electric propulsion: from mission studies to technology verification. Journal of Electric Propulsion, 1(1), 1–57. https://doi.org/10.1007/s44205-022-00024-9.

[3] Picone, J., et al. (2002). NRLMSISE-00 empirical model of the atmosphere:Statistical comparisons and scientific issues. Journal of Geophysical Research, 107(A12), 1468.