Application of Orbital Aerodynamics to Satellite Attitude and Orbit Control

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DISCOVERER
Revolutionizing Earth Observation with sustained operations at lower altitudes than the current state of the art.

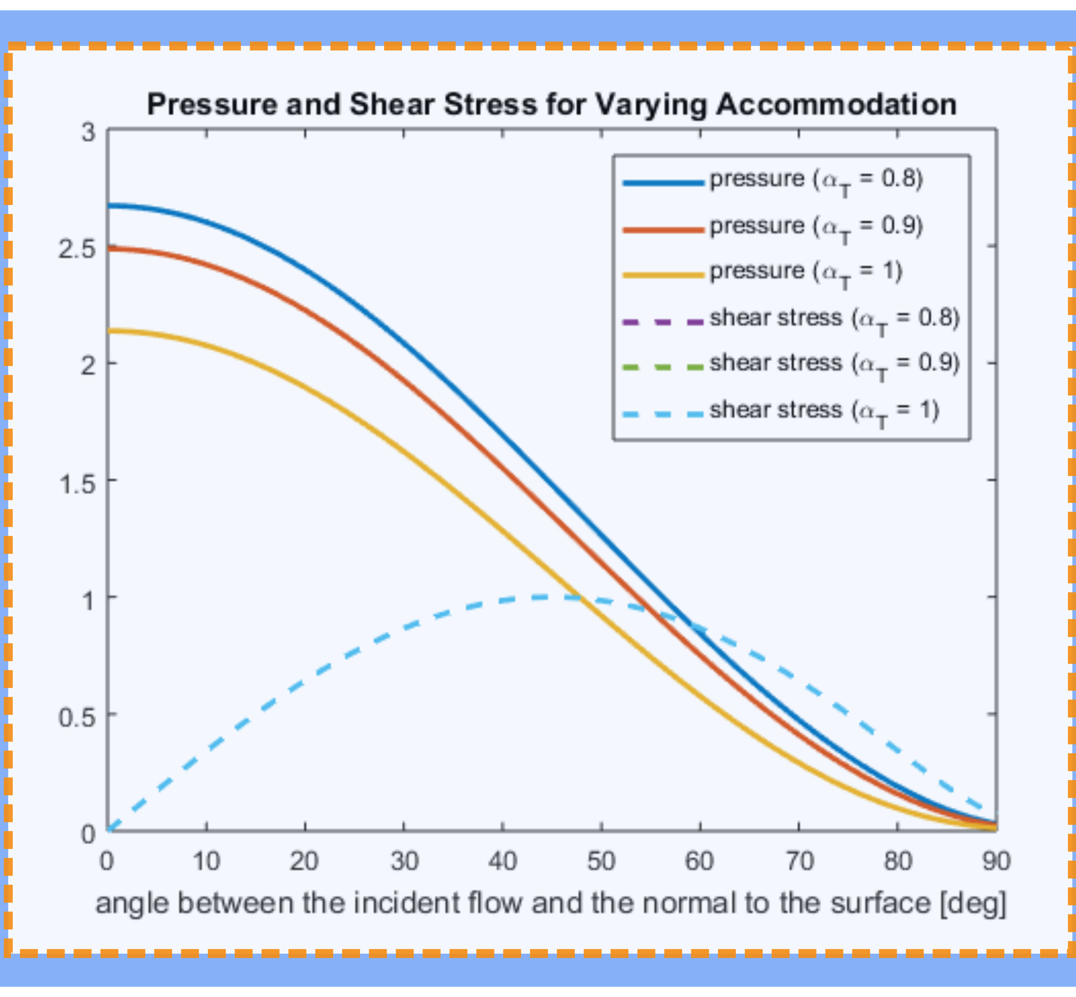
Background

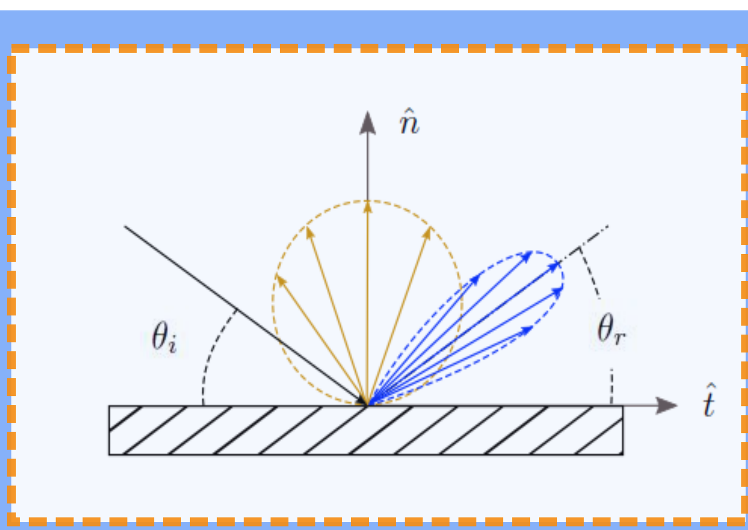
Satellites in VLEO experience increased aerodynamic perturbations resulting from the interaction between the external surfaces and the residual atmosphere.

Aerodynamic control methods can thus be developed to take advantage of the environment for:

1. Aerostabilisation;
2. Attitude Control and Momentum Management;
3. In-plane/Out-of-plane Orbital Manoeuvres.

On-Orbit Demonstration:
Aerostability & Drag-based Orbit Control Manoeuvres





Some sources of uncertainty however exist:

1. Density variations;
2. Gas-Surface Interaction (GSI);
3. Satellite relative velocity;
4. Reference area determination.

GSI models use a set of average phenomenological coefficients to define the amount of momentum (σ) and energy (α_T) exchanged with the surface:

1. Contaminated surfaces: diffuse scattering (unitary/nearly unitary accommodation coefficients);
2. Clean surfaces: quasi-specular lobal patterns (low accommodation coefficients).

Uncertain accommodation coefficients estimation

Uncertain aerodynamic forces estimation

The Plan

Review paper: Modelling Aerodynamic Forces and Torques in VLEO

1. Uncertainties in aerodynamic forces and torques estimation (upper atmosphere, GSI models, reference surface definition);
2. Results provided by gas-beam experiments on clean and contaminated surfaces;
3. Experimental-based and theory-based GSI models comparison;
4. Current challenges in GSI characterisation.

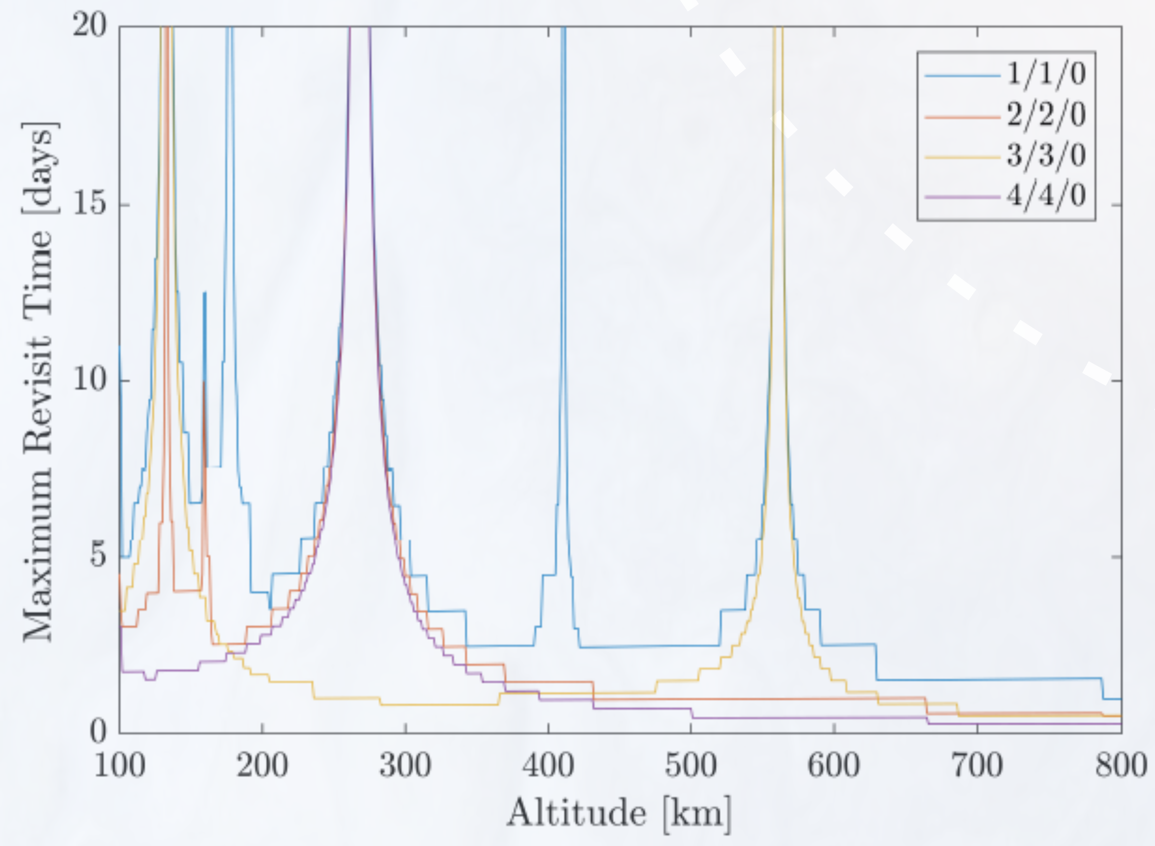
Aerodynamic Attitude and Orbit Control Manoeuvres Demonstration

Algorithms for orbit\attitude determination, control and data management for SOAR (3U CubeSat for orbital and aerodynamic research). The objective is to demonstrate on-orbit aerodynamic:

1. Reaction/momentum wheel desaturation;
2. Detumbling;
3. Coarse pointing performance;
4. Re-entry interface location control;
5. Modulation of the secular rate of the right ascension of the ascending node.

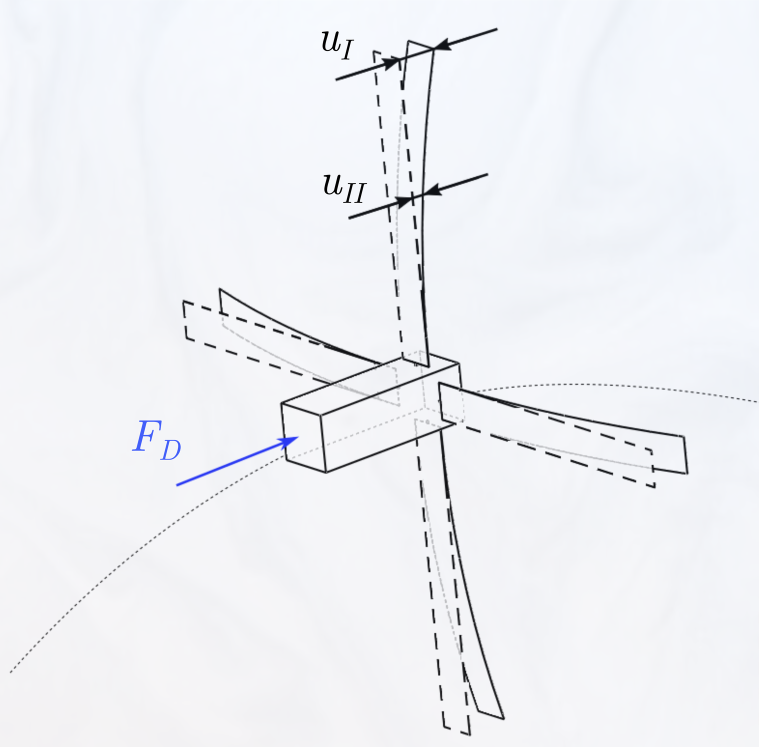
Application: aerodynamic correction of nodal regression rate drift in Sun-Synchronous orbits (SSO).

Specific SSO constellations configurations seem to provide temporal resolution performances comparable to those obtained at higher altitudes.



Aerodynamic Forces/Torques for Control Purposes in VLEO

Structural Flexibility Impact on Stability Characteristics



The increased aerodynamic forces may induce deformations on the external surfaces.

Consequent variation in the CoP - CoG relative distance

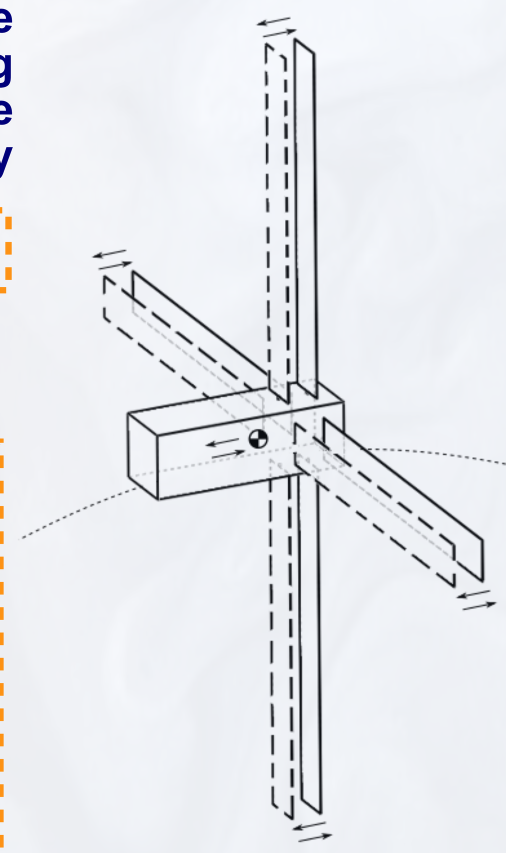
Additional torques affecting the dynamics of the satellite in orbit

Stability/Agility Variation through Centre of Pressure (CoP) - Center of Gravity (CoG) Relative Position

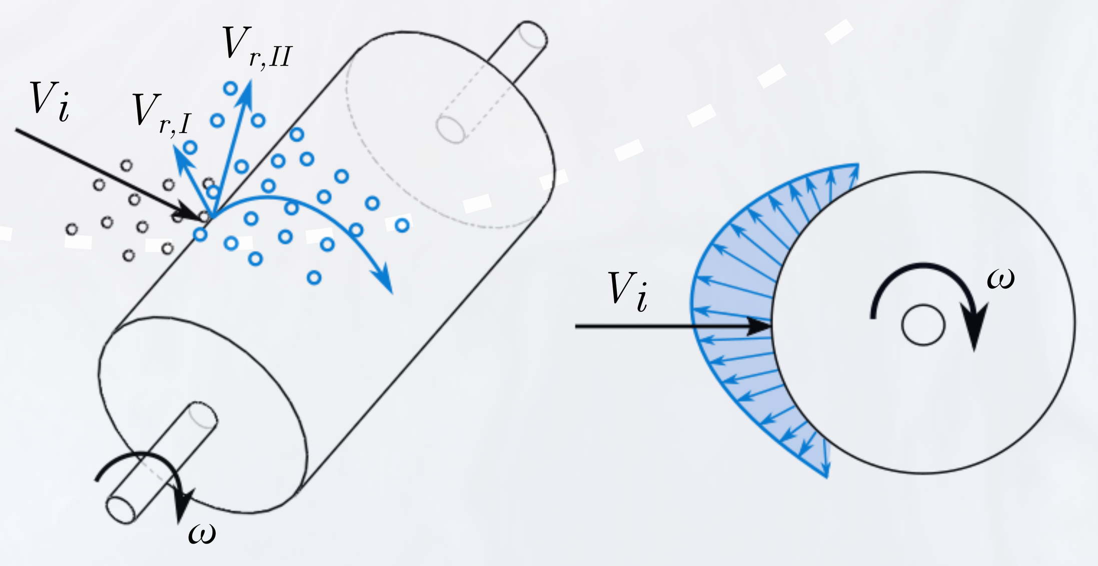
Aerodynamic torques can be changed in magnitude by varying the CoP - CoG relative distance with null impact on orbital decay

Movable aerodynamic surfaces

1. Robust aerodynamic control under varying environmental conditions;
2. Agility/stability variation achievable if required;
3. Aerodynamic Trim;
4. Efficient desaturation of momentum exchange devices.



Experimental Gas-Surface interaction Characterisation Through Rotating Surfaces



1. Scattering velocities and distributions characterisation;
2. Time scale variations of surface accommodation.
3. Aerodynamic properties of a rotating cylinder in Free Molecular Flow;
4. Inverse Magnus-like force experimental validation;

[1] D. Mostaza Prieto, B. P. Graziano and P. C. E. Roberts, "Spacecraft drag modelling", Progress in Aerospace Sciences, vol. 64, pp. 56-65, 2014. http://dx.doi.org/10.1016/j.paerosci.2013.09.001.
[2] N. H. Crisp, S. Livadiotti and P. C. E. Roberts, "A Semi-Analytical Method for Calculating Revisit Time for Satellite Constellations with Discontinuous Coverage", 2018. http://arxiv.org/abs/1807.02021.
[3] D. A. Vallado and W.D. McClain, "Fundamentals of Astrodynamics and Applications", New York, McGraw-Hill Companies Inc., 1997.
[4] K. I. Borg, L. H. Soderholm and H. Essen, "Force on a spinning sphere moving in a rarefied gas", Physics of Fluids, vol. 15, no. 3, pp. 736-741, 2003.
[5] J. R. Wertz, "Spacecraft Attitude Determination and Control", Astrophysics and Space Science Library, Springer Netherlands, 1978.

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