Aerodynamic Attitude Control in Very Low Earth Orbit

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DISCOVERER

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

Background

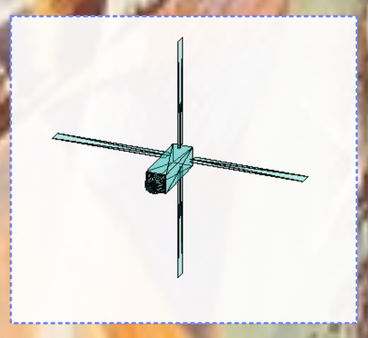
The enhanced aerodynamic environment experienced by satellites in VLEO (i.e. below 450 km) offers the opportunity to investigate the feasibility of exotic strategies employing aerodynamic torques to perform attitude control tasks.

Challenges

1. Density & thermospheric winds estimation;
2. Gas-surface interaction uncertainties;
3. Aerodynamic control authority variations with altitude;
4. Control law robustness;
5. Hardware & software limitations.

Geometry - SOAR

1. 3U CubeSat main body;
2. Aerostable feathered configuration;
3. Aerodynamic control panels extending at the rear of the satellite main body.



Proposed manoeuvres

1. Aerodynamic roll control combined with reaction wheels (RWs) pitch & yaw control;
2. Aerodynamic pitch & yaw control combined with RWs roll control;
3. Aerodynamic trim;
4. Management of the angular momentum stored in the RWs by means of aerodynamic torques.

Applied control strategies

Aerodynamic pointing & trim	Aerodynamic momentum management
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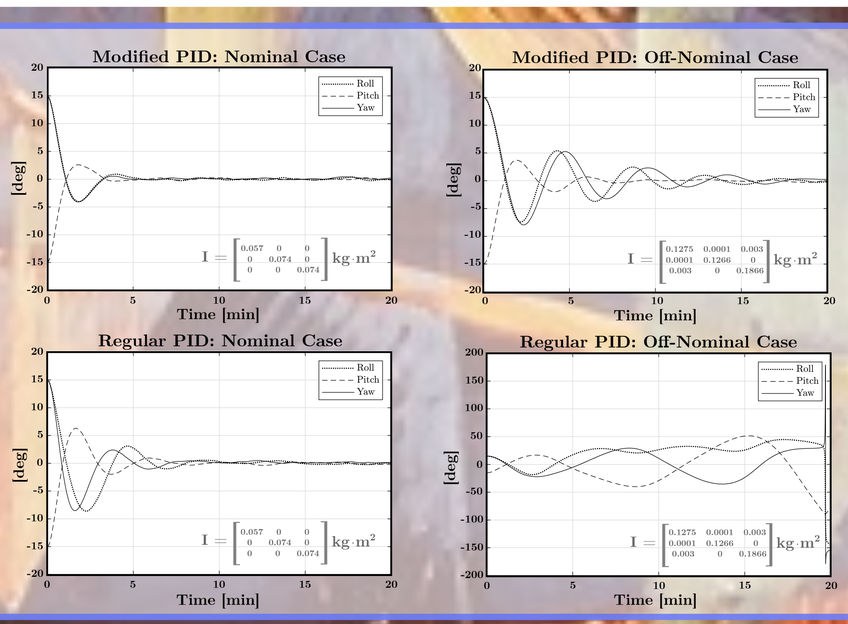
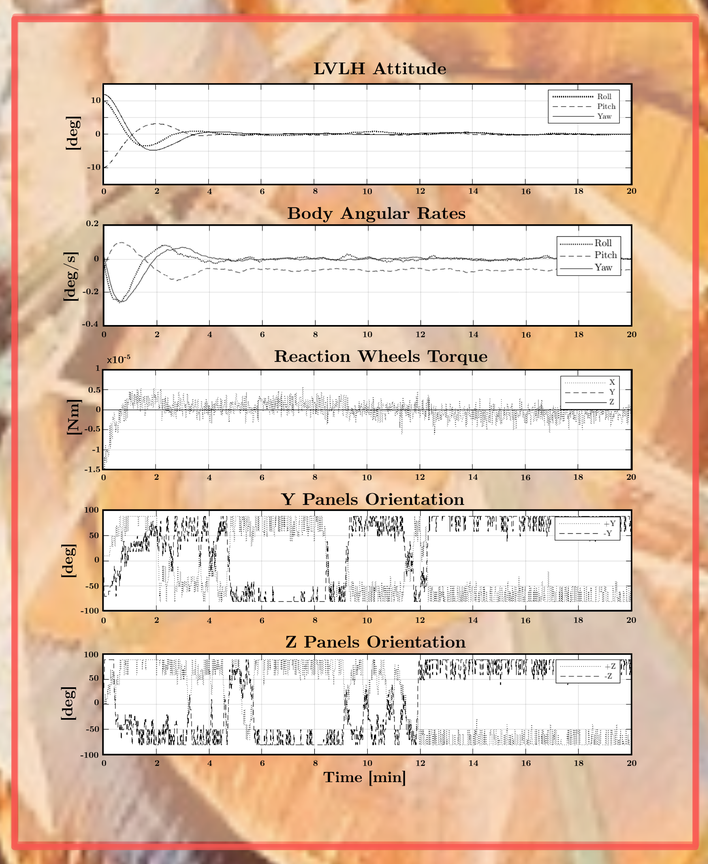
Modified PID & intelligent integrator [1,2]	Linear quadratic regulator

Robustness - Inertia matrix

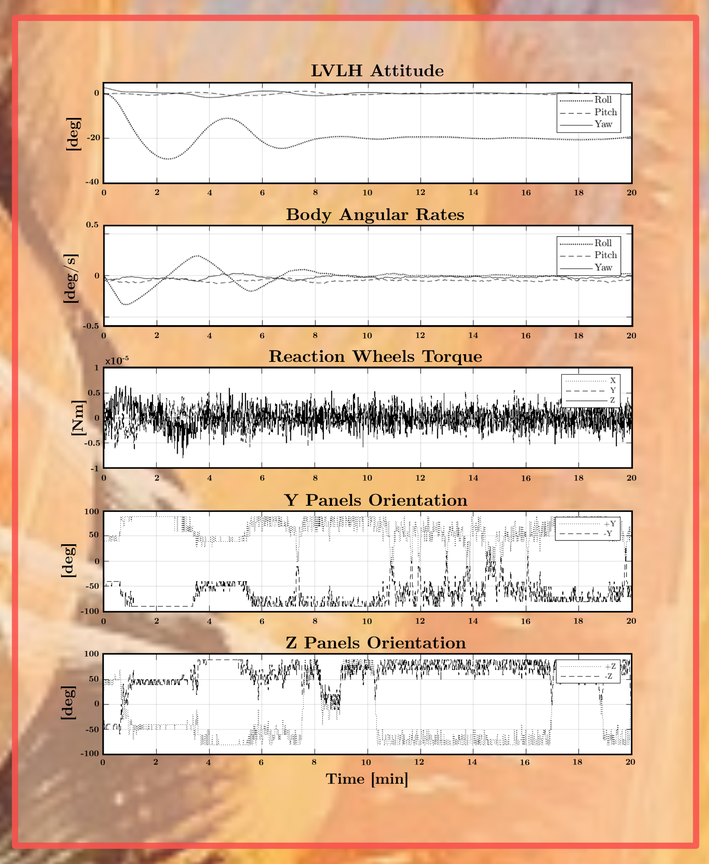


Results

Aerodynamic Pointing & Trim : Pitch & Yaw

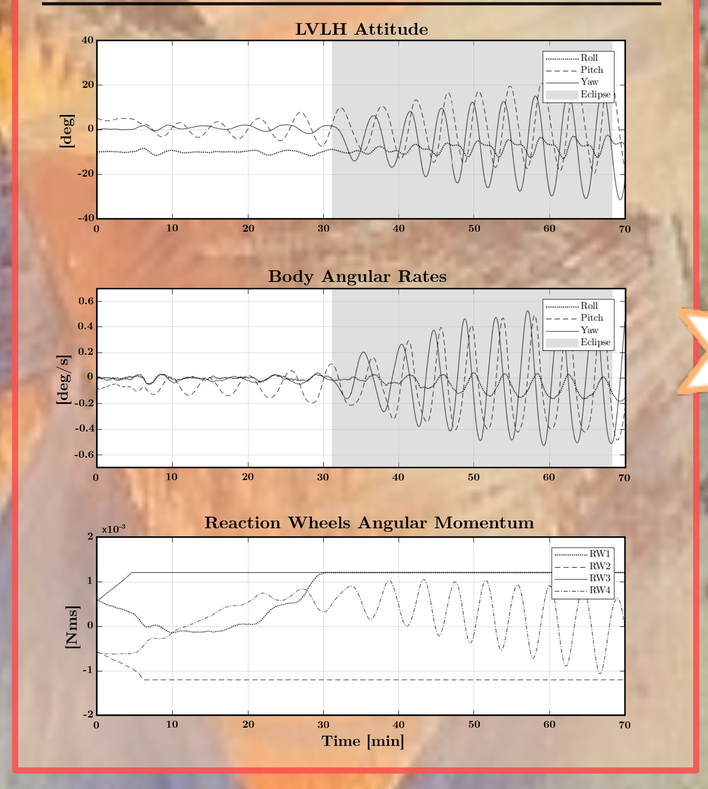


Aerodynamic Pointing & Trim : Roll

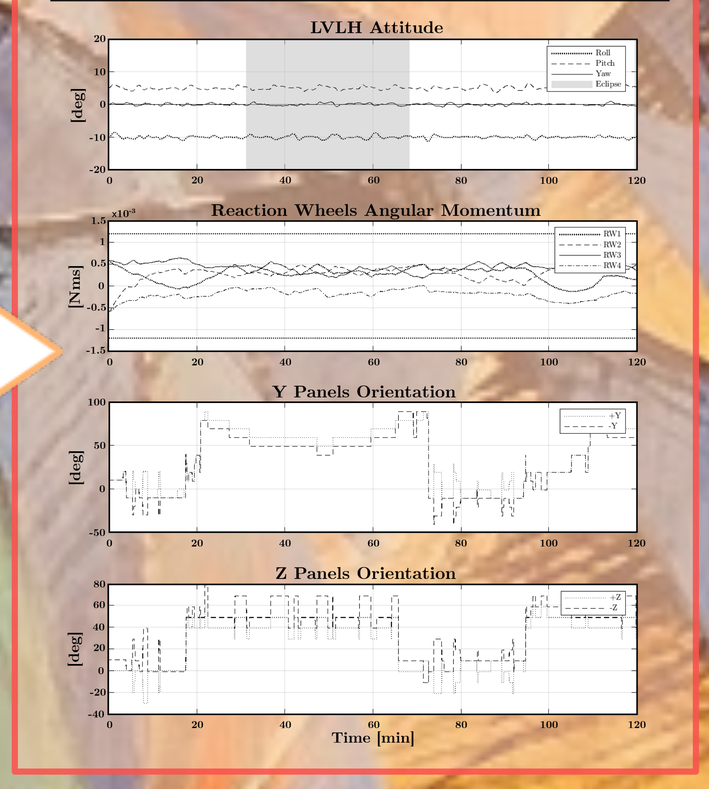


Aerodynamic Momentum Management

No Momentum Management



With Momentum Management



Assumptions

1. Discrete time domain implementation;
2. Environmental disturbances;
3. Accommodation coefficients linearly varying with altitude (0.9 to 1) - Sentman model;
4. Horizontal thermospheric winds;
5. Panels deflection rates: 30°/s;
6. Gyroscopes attitude error knowledge: standard deviation 1σ;
7. Disturbance introduced on total angular momentum by rotating panels;
8. Software limitations.

Possible applications

1. Small satellites: aerodynamic control to support pointing tasks when the control authority provided by conventional actuators is reduced;
2. To perform target acquisition below 250 km, where the control effort required is demanding and RWs saturate quickly;
3. To perform the momentum management task without interrupting the pointing task;
4. To counteract the perturbation introduced in yaw by atmospheric co-rotation, reducing RWs effort;
5. To achieve aerodynamic rejection of the environmental disturbances affecting the satellite.

[1] H. Bang, M. J. Tahk, H. D. Choi, "Large angle attitude control of spacecraft with actuator saturation", Control Eng. Pract., vol. 11, no. 9, pp. 989-997, 2003.

[2] B. Wie, H. Weiss, A. Arapostathis, "Quaternion feedback regulator for spacecraft eigenaxis rotations", J. Guid. Control Dyn. 12, pp. 375-380, 1989, doi: 10.2514/3.20418.

[3] F. L. Markley and J. L. Crassidis, "Fundamentals of spacecraft attitude determination and control", 2014.

[4] D. A. Vallado and W.D. McClain, "Fundamentals of Astrodynamics and Applications", New York, McGraw-Hill Companies Inc., 1997.

[Background] Giacomo Balla, "Mercury passing before the Sun", 1914, 120 x 100 cm, Oil Painting, Peggy Guggenheim Collection (on long-term loan), Venezia

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