National Aeronautics and Space Administration

Solar Radiation Pressure for Active Momentum Management

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Objectives

This project was aimed at investigating the use of solar radiation pressure and onboard spacecraft autonomy to provide reaction wheel momentum management capabilities. Using lessons learned from the MarCO spacecraft flight operations, a simulation was created to model the behavior of an example small satellite's guidance and control system while performing nominal mission behaviors. In particular, an inertial pointing task was to be used as a case study, since such pointing would occur for science observations and communications. An autonomous momentum management software was developed to determine the net system momentum and compute spacecraft attitudes that would provide the maximum momentum unloading should a sufficiently high system momentum be reached. Such a system can be further expanded with future research to a completely autonomous steering algorithm for long-term remote operation.

Background

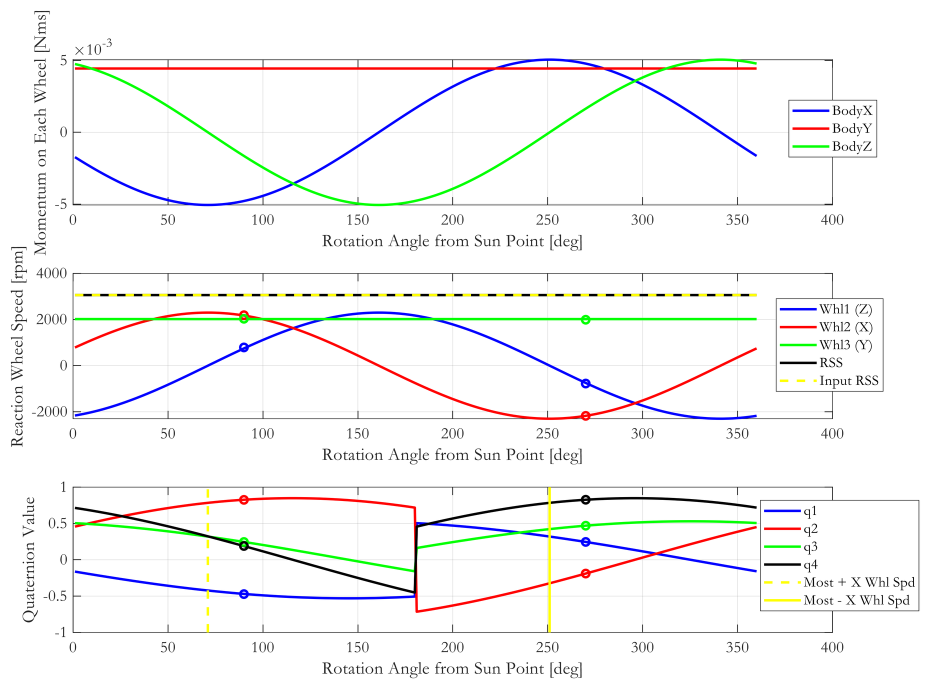
For many spacecraft, solar radiation pressure (SRP) poses one of the largest sources of disturbance torques in flight, being the dominant disturbance while in deep space. Typically relegated as a factor a guidance and control system must overcome, it nevertheless can also be used to a spacecraft's advantage. Spacecraft operating outside low Earth orbits typically rely on consumables like thruster propellant for managing momentum buildup from environmental and self-generated disturbance torques. Therefore, it is advantageous to make use of readily-available SRP to decrease the reliance on limited consumable supplies. Doing so can lengthen mission durations for a given consumable supply and reduce the burden on thruster systems. Additionally, by reducing the number of momentum management activities that are traditionally performed while in communication with the ground by performing them autonomously between other operational activities, more time can be spent maintaining power positivity, collecting data, or communicating with operators.

Significance/Benefits to JPL and NASA

This work resulted in the creation of a guidance and control simulation for developing and maturing the basis of a solar radiation pressure autonomy steering algorithm for managing system momentum buildup. The solar radiation pressure algorithm does not require a significant amount of computational processing time, and it relies on known spacecraft geometry and relative positioning of the spacecraft relative to the sun to function. Therefore, the algorithm may be used by spacecraft of all sizes to reduce the reliance on consumables for preventing high system momentum states. Further, the algorithm is designed to be run autonomously, freeing up communications time for increased data downlink

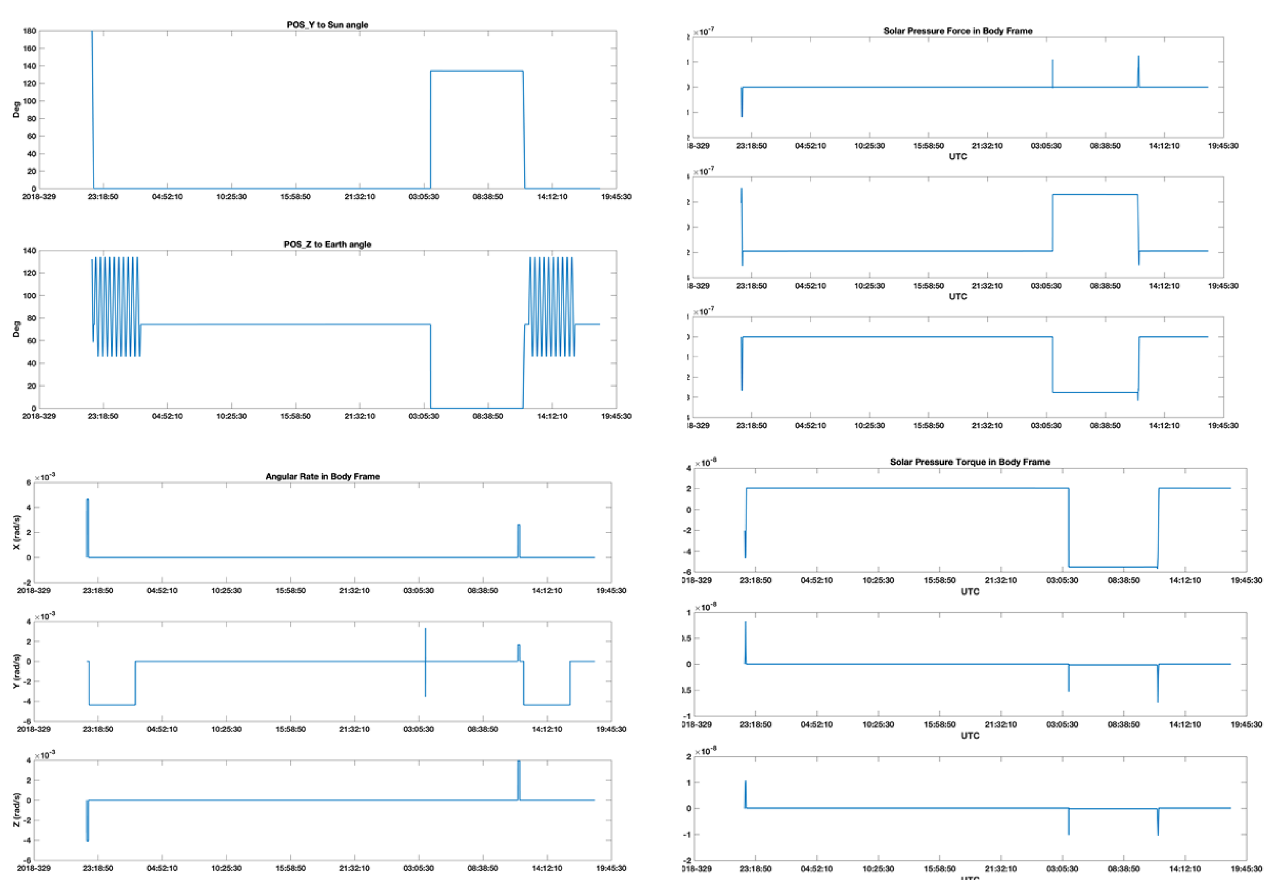
Approach and Results

The figure on the right shows an example of MarCO flight data (shown by circles) and how it could be used to determine a holding attitude at which SRP could decrease system momentum. While sun-pointing the solar panels, the stored momentum can be computed for any angle about the sunline. Since MarCO communication passes primarily increased system momentum in the X-axis wheel, this figure shows how an automated system with spacecraft state information could output a holding attitude (shown as yellow bars) for the spacecraft for adjusting system momentum as desired.

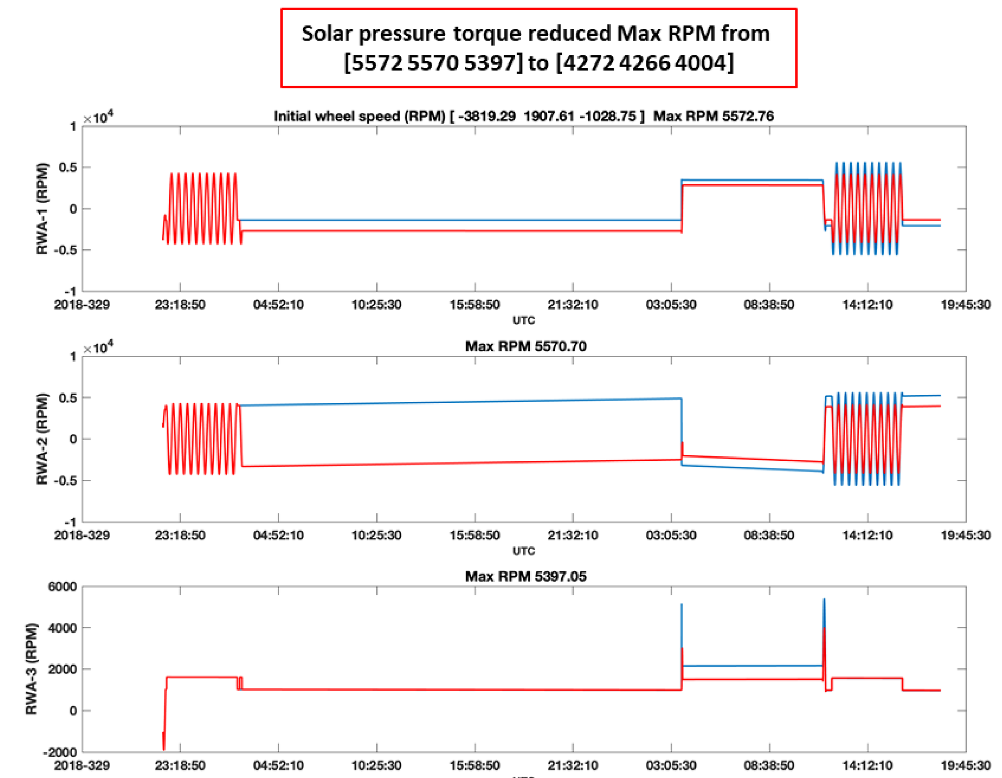


To create a full simulation of flight-analogous software operation and system autonomy, tools from the Europa Clipper mission were combined. In particular, by using the Clipper attitude commander for spacecraft attitude commanding, the Cassini RBOT ground tool for reaction wheel momentum and speed simulations, and the NAIF SPICE tool kit, it is possible to create a solver that can determine for a given spacecraft state and an operational constraint for the next communications pass how the spacecraft should orient itself to ensure system momentum remains sufficiently low. The SPK kernel for this simulation was from the MarCO A Mars flyby covering the 2018-NOV-25 21:59:12.474 to 2018-NOV-27 21:37:44.206, and the solver used parameters for MarCO reaction wheels, mass and inertia properties, and pressure surface model.

The left figure shows the sun position and spacecraft rotation rate over the course of an operational scenario, while the right figure shows the SRP force and torque acting on the spacecraft. First, after completing a detumble maneuver and sun search, the spacecraft executed a 0.25 deg/s roll about the sunline at 329T22:20. At 330T02:40, it stopped the sun-roll, maintained POS_Y to Sun, and slewed to the desired clock angle for momentum buildup. Next, at 331T03:40, it slewed to Earth with its primary vector being POS_Z to Earth and secondary vector being POS_X to Sun orthogonal. Lastly, at 331T11:40 it slewed back to POS_Y to Sun point with a continuous roll about the sunline.



This figure shows for each wheel speed subplot a blue curve and a red curve for this simulated scenario. The blue shows a nominal spacecraft momentum buildup as compared to the red, which shows the result of applying this SRP momentum management process. As a result of this autonomous process, wheel speeds prior to the start of the next activity have been reduced from by approximately 1000 rpm per wheel. This single example can be extended to other spacecraft, more operational constraints, and into complete steering algorithms with further development.



Algorithm

First, for a given initial system momentum, a change in the system momentum needed to perform a slew to a communications attitude is determined. Next, a time delta is computed for performing the momentum dump using SRP torque when the spacecraft is rotated to a target clock angle along the sunline. Next, the spacecraft performs the attitude hold at this momentum dump attitude to be completed before the scheduled next spacecraft activity.

$$\vec{H}_{system} = \vec{H}_0 + \vec{H}_{trq} = \vec{H}_{SC} + \vec{H}_{RWA}$$

$$\Delta\vec{H}_{desired} = T_b^i(t_1)\, T_{rwa}^b\, I_{rwa}(\vec{\omega}(t_1) - \vec{\omega}_{desired})$$

$$\Delta\vec{H}_{trq} = Pitch(\theta_{clock})\, T_b^i(t_2)\, \vec{\tau}_{solar}^b\, \Delta t$$

$$Find\ \theta_{clock}\ to\ align\ \ \Delta\hat{\vec{H}}_{trq}\ \ to\ \ \Delta\hat{\vec{H}}_{desired}$$

$$\Delta t \cong \Delta\vec{H}_{desired}\ ./\ Pitch(\theta_{clock})\, T_b^i(t_2)\, \vec{\tau}_{solar}^b$$

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