AN EFFICIENT METHOD TO DESIGN PREMATURE END-OF-LIFE TRAJECTORIES: AN ALTERNATE FATE FOR CASSINI

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Although the majority of the times a mission is terminated in a planned fashion, sometimes the degradation of power subsystems (solar arrays or thrusters) and onboard components or the lack of fuel in the tanks can force a premature disposal of the spacecraft. Per planetary protection and organic contamination control requirements, disposal of the vehicle cannot be done in any given way. These requirements, which are usually specific to the mission, are one of the driving factors in the design of controlled end-of-life trajectories.

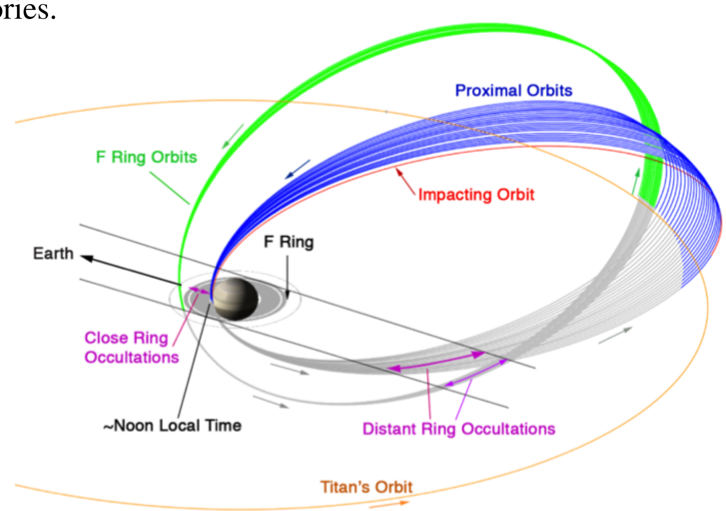

Figure 1. Cassini's Grand Finale Trajectory

Consider the highly successful Cassini mission, which continues to explore and collect valuable scientific data with unprecedented details of the Saturnian system for over a decade now. It is known that the spacecraft will inevitably run out of propellant in mid-to-late 2017. Several studies were carried out to design the most optimal – in terms of science return and fuel consumption – end-of-mission (EOM) scenario. Currently, the Cassini mission is proposed to end nominally with a series of 22 highly inclined (62 degrees), short period (6.5 days), ballistic orbits each passing within a few thousand kilometers of the cloud tops of Saturn, ultimately impacting the planet on September 15, 2017. The nominal EOM trajectory, encompassing the F-ring orbits (green), the Grand Finale orbits (blue), and the final orbit (red) culminating with Saturn atmospheric entry, is depicted in Figure 1. This end trajectory was incorporated in the final phase of the Solstice Mission after multiple tradeoff studies were carried out to ensure that, per planetary quarantine requirements and before the spacecraft runs out of propellant, the possibility of future impact with any of the icy moons was precluded. This particular design was selected by the different science disciplines because of its attractive geometry, which offers scientists an opportunity – otherwise unavailable – to study the intricacies of the planet's thermosphere as well as its complex ring system. However, this was certainly not the only available spacecraft disposal option. Several other end-of-life options were considered; the spacecraft could i) impact Saturn on a different path (short or long impact orbits with various inclinations) [1], ii) remain in the Saturnian system (long-term stable orbits) [2], or iii) entirely escape the Saturnian system (large heliocentric orbits). In any case, the design of such orbits is constrained by the requirement to prevent contamination of a pristine environment and avoid collisions with any moons, particularly Titan and Enceladus. Additionally, these orbits must be accessible from the Cassini reference trajectory with minimal ΔV usage and maintain their characteristics over long-term propagation under gravitational perturbations of the Sun, Jupiter, Titan, and other moons of Saturn.

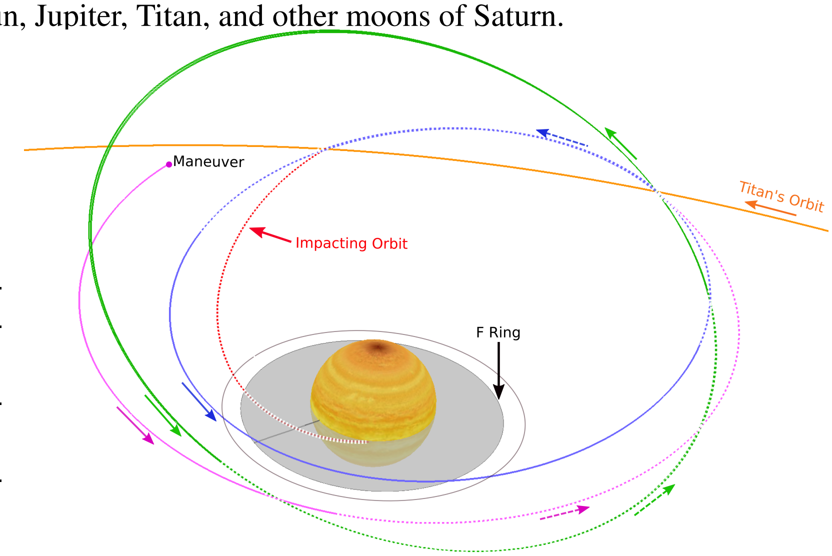

Figure 2. A Possible Alternate EOM Trajectory

But, what would happen if, hypothetically, the mission is to be ended prematurely? The current nominal EOM plan is tied to a particular initial state and time epoch and, thus, is not accessible from any other point along the reference trajectory. As the end-of-mission date approaches, both the uncertainty in usable propellant margins and the probability of spacecraft systems failure increase. If the spacecraft runs out of propellant, or one of the propulsion subsystems suddenly fails such that the engines become inoperable and we lose control of the spacecraft, we ought to have a solid plan in place to safely dispose of the vehicle and meet the planetary protection requirements. This hypothetical 'emergency' situation is different from the nominal design scenario in the sense that i) there is no input from the science teams taken into consideration (the priority is to safely dispose of the vehicle, not to collect science), ii) there are severe restrictions on the ΔV usage (not because of the availability of propellant, but because of the limited ability of maneuvering the spacecraft), and iii) a point solution must be quickly produced for any possible scenario, regardless of the selected initial state or the epoch along the reference trajectory. Thus, a robust method to efficiently design alternate EOM trajectories is presented in this paper. The methodology is primarily based on a hybrid approach that exploits two-body and three-body resonant and non-resonant flyby transfers combined with a numerical optimization scheme within a high fidelity simulation environment to produce viable terminating trajectories. For instance, consider an assumed premature EOM scenario and the corresponding sample impact trajectory generated using this technique in Figure 2. The spacecraft is flying on the reference path and at a given epoch, a maneuver is performed to transfer it to a disposal trajectory (magenta path). This ΔV-optimal 70-day transfer features a total of three Titan flybys: a resonant transfer (green), a non-resonant transfer (blue), and a third and final Titan flyby that puts the spacecraft on an impact path with Saturn (red). The design process along with the differential corrections algorithms will be detailed in the paper. Several different end-of-mission scenarios will be illustrated to demonstrate the capability of quickly computing a feasible end-of-life trajectory from any point along the current reference trajectory from now through mid 2017.

1. References

[1] C. H. Yam, D. C. Davis, J. M. Longuski, and K. C. Howell. "Saturn Impact Trajectories for Cassini End-of-Mission." Journal of Spacecraft and Rockets, DOI:10.2514/1.38760. 2008.

[2] C. Patterson, M. Kakoi, K. C. Howell, C. H. Yam, J. M. Longuski. "500-Year Eccentric Orbits for the Cassini Spacecraft within the Saturnian System." AAS/AIAA Astrodynamics Specialist Conference, AAS Paper 07-256. Mackinac Island, Michigan, August 19–23 2007.