Orbit and Attitude Coupling in the Full Higher-Fidelity Ephemeris Model within the context of the Geometric Mechanics Framework

A. Anderson, B. McCann, Dr. D. Canales Garcia, Dr. M. Nazari

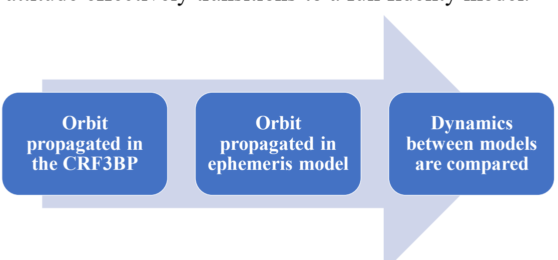
ABSTRACT: Predicting the orientation of spacecraft traveling within the Cislunar (Earth-Moon) region is necessary to ensure the success of future missions planned within that realm of space. This research looks to consider the coupling between translational and rotational motion to not only improve trajectory accuracy, but to also introduce the prediction of attitude in mission planning. Trajectories computed in the circular restricted full three-body problem (CRF3BP), previously proposed by the authors, allow for the spacecraft to be modeled as a rigid-body rather than a point mass. These are utilized as initial guesses for a full ephemeris model, where the gravitational field of perturbing bodies and the eccentricity of the Moon's orbit alter these trajectories. Initially, a simple, planar L2 Lyapunov orbit was selected, and it is shown that attitude can be predicted in a full ephemeris model, which is a novel contribution to astrodynamics.

Background

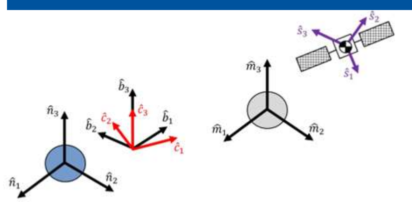
Considering the renewed interest in the Cislunar region in recent years, with more than thirty new missions planned by 2023 [1], ensuring mission success of paramount concern for the astrodynamics community. The dynamical environment in the Cislunar realm is complex, and the reduction to the circular restricted three-body problem (CR3BP) is an effort to simplify the mission design process. However, this reduction comes with the assumption of a point mass model of the spacecraft and gravitational primaries. Most missions possess some attitude requirements to ensure success, whether the application is for science [2] or surveillance [3]. The ability to predict attitude within the Cislunar region is instrumental in the planning of these missions.

Methodology

A thorough investigation about the attitude variation in a Lyapunov orbit around L_2 is performed for a spacecraft with mass and inertia characteristics of that of the International Space Station (ISS). The Lyapunov orbit is first computed in the CRF3BP, then transitioned in a full ephemeris model. For a given epoch, the addition of perturbations are assessed against the solution of the CRF3BP with the goal to see if the solution obtained in the CRF3BP for the attitude effectively transitions to a full fidelity model.



Simulation Details



The two dynamical models within this research utilize a variety of reference frames as defined in the figure on the left. The full ephemeris model uses SPICE toolkit data to obtain the location of the Earth, Moon and Sun at each timestep.

Spacecraft characteristics:

Spacecraft	Mass (kg)	Inertia (kg.m^2)
ISS	419725	$\begin{bmatrix} 10276978 & -1084837 & 597098 \\ -1084837 & 31940398 & -614081 \\ 597098 & -614081 & 40019058 \end{bmatrix}$

<u>2 cases for rotational initial conditions…</u>

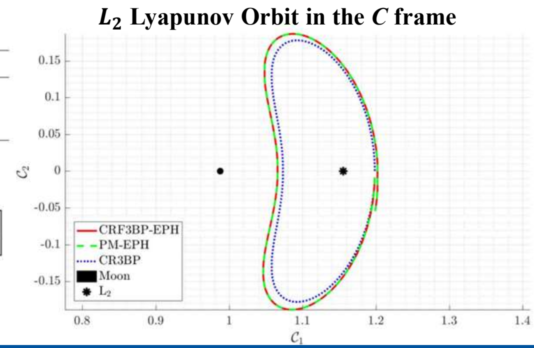
Nonzero rotational initial conditions:

$$R_{\mathcal{S}/\mathcal{M}} = \left(R_1\left(\frac{\pi}{5}\right) R_2\left(\frac{\pi}{3}\right) R_3\left(\frac{\pi}{7}\right)\right)^T = \begin{bmatrix} 0.4505 & 0.1076 & 0.8863 \\ 0.2169 & 0.9498 & -0.2256 \\ -0.8660 & 0.2939 & 0.4045 \end{bmatrix}$$

$$\omega_{\mathcal{S}/\mathcal{M}} = [0.001,\ 0.002,\ 0.003]^T \text{ rad/s}$$

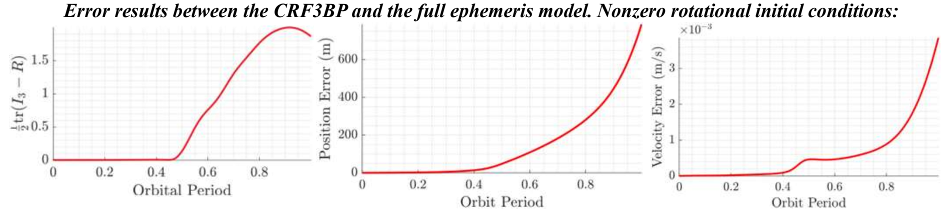
Null rotational initial conditions:

$$R_{\mathcal{S}/\mathcal{M}} = I_3 \qquad \omega_{\mathcal{S}/\mathcal{M}} = [1e-10, 1e-10, 1e-10]^T \text{rad/s}$$

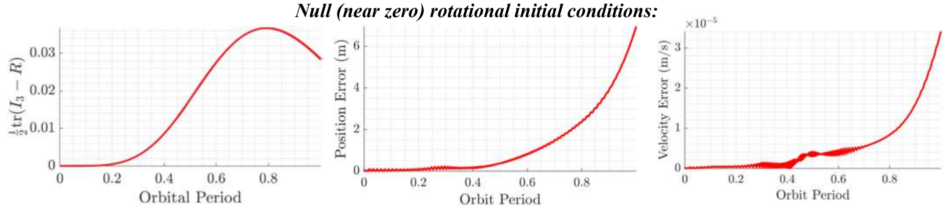


Rotational & Translational Results

Error results between the CRF3BP and the full ephemeris model. Nonzero rotational initial conditions:



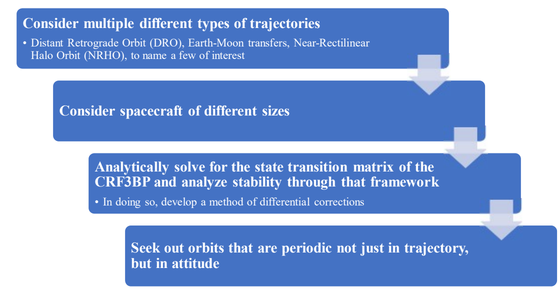
Null (near zero) rotational initial conditions:



Takeaway: Spacecraft orientation can be predicted in a full ephemeris model within some error!

Future Work

The ability to predict attitude in a full ephemeris model is a novel contribution in the field of astrodynamics. This research lays the foundation for several future projects. To name a few future avenues:



If you are interested in this research, as well as seeing its continuation in future papers, check out the Space Trajectories and Applications Research Group's website:

https://www.staresearchgroup.com/

References

A. Anderson, B. McCann, D. Canales, and M. Nazari, "Orbit and Attitude Coupling in the Full Higher-Fidelity Ephemeris Model within the context of the Geometric Mechanics Framework," 33rd AAS/AIAA Space Flight Mechanics Meeting, January 15-19, 2023.

See this work on ResearchGate, as published by AAS.

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