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INVESTIGATION OF INTERIOR MEAN MOTION RESONANCES AND HETEROCLINIC CONNECTIONS IN THE EARTH-MOON SYSTEM

Abstract

Understanding the dynamical structure of cislunar space beyond geosynchronous orbit is of significant importance for lunar exploration, as well as for design of high Earth-orbiting mission trajectories in other contexts. A key aspect of these dynamics is the presence of mean motion resonances. A number of prior spacecraft have been placed into stable lunar resonant orbits, such as NASA's TESS and IBEX, while some seemingly orbit in the unstable resonance regime (e.g. Russia's now-defunct Spektr-R).

Although libration point orbits have been studied extensively in the Earth-Moon system (e.g. Gomez et al. 2001 or Henry and Scheeres, 2024), the intricate nature of mean motion resonances, especially their stable and unstable orbit families and their overlapping heteroclinic connections, is less explored. The unstable orbits' stable and unstable manifolds can generate heteroclinic connections between different resonances, in which case the resonances are said to "overlap". A spacecraft following a heteroclinic connection will naturally change its semimajor axis due to the subtle influence of the Moon, without use of propulsion. The presence of such paths can be used beneficially for trajectory design, but could be potentially hazardous if unanticipated in mission planning.

While heteroclinic connections between resonances (Koon et al. 2000) are fundamental to understanding the evolution of a spacecraft's semimajor axis, they remain woefully understudied in the Earth-Moon system. Our paper presents two primary contributions: first, we compute and analyze several important resonant orbit families within the Earth-Moon system based on the planar circular restricted 3-body problem model. In this case, unstable resonant orbits are periodic and occur in 1-parameter families. Focusing on interior resonances 4:1, 3:1, and 2:1, we identify a number of bifurcations of these resonances' periodic orbit families. We find and describe relationships between unstable and stable prograde and retrograde resonant orbits.

Once the aforementioned resonant orbits are computed, we then compute their stable and unstable manifolds. This is done using a parameterization method combined with a Poincaré map at osculating orbit perigee, which has desirable properties for the analysis. Carrying out these computations across a range of Jacobi constants in the Earth-Moon system, we then visualize the computed manifolds. Key Jacobi constant values required for overlap of 4:1 and 3:1 resonances, as well as of the 3:1 and 2:1 resonances, are identified, thus characterizing the range of naturally attainable semimajor axis values for future distant Earth-bound or lunar spacecraft missions.