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LAGRANGIAN COHERENT STRUCTURES IN VARIOUS MAP REPRESENTATIONS FOR APPLICATION TO MULTI-BODY GRAVITATIONAL REGIMES

Abstract

In the absence of analytical solutions, trajectory design within multi-body gravitational environments is not always straightforward. An actual mapping of the design space can offer critical information in a convenient, reasonably intuitive form that may expose feasible, yet previously unknown, options. The Finite-Time Lyapunov Exponent (FTLE) has been demonstrated as an effective metric for revealing distinct, bounded areas within the flow. Much like the traditional Lyapunov exponent, the FTLE supplies information regarding stability and chaoticity. The computation of the FTLE is not contingent on any assumptions in the derivation of the system differential equations, and, thus, can be applied for systems modeled with various levels of fidelity. As a consequence, generating maps of FTLE across a given region serves as an excellent step in obtaining insight into the problem, and is frequently observed as striking visual representations of the structures in the flow. Specific features within an FTLE map have been identified as Lagrangian Coherent Structures (LCS) – effective transport barriers similar to invariant manifolds in autonomous systems. These concepts involving FTLE and LCS have developed over the past decade and only relatively recently has FTLE/LCS-based analysis been exploited in astrodynamics.

This analysis compares FTLE maps and the corresponding LCS in systems reflecting different levels of fidelity. Trajectory design typically proceeds from simple assumptions to a higher-fidelity ephemeris model. Similarly, maps also evolve. As examples, maps in the circular restricted three-body problem, a restricted four-body problem and an ephemeris model are investigated. Moreover, alternative variable representations are also examined for their relevance and effectiveness. Specifically, LCS in traditional phase-space maps as well as periapse maps are explored. For more direct comparisons between models and formulations, conditions are simulated to enable specific observations as the model evolves. With successively more complex dynamical environments for motion of a spacecraft, the FTLE maps reveal many comparable structures but, simultaneously, additional features emerge that might aid mission design. Some features of the maps and the associated trajectories indicating different behaviors are highlighted. Additionally, the advantages and disadvantages of the different variable formulations are noted. From results associated with the different models, as well as the different representations, it is apparent that the slight differences resulting from higher-fidelity models along with appropriately selected conditions, can sometimes render a trajectory less attractive or expose new options.