ABSTRACT

Trajectory Design for GENESIS Using a Dynamical Systems Approach

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Prepared for the
AAS/AIAA Astrodynamics Conference
Sun Valley, Idaho

August 4-7, 1997

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Introduction

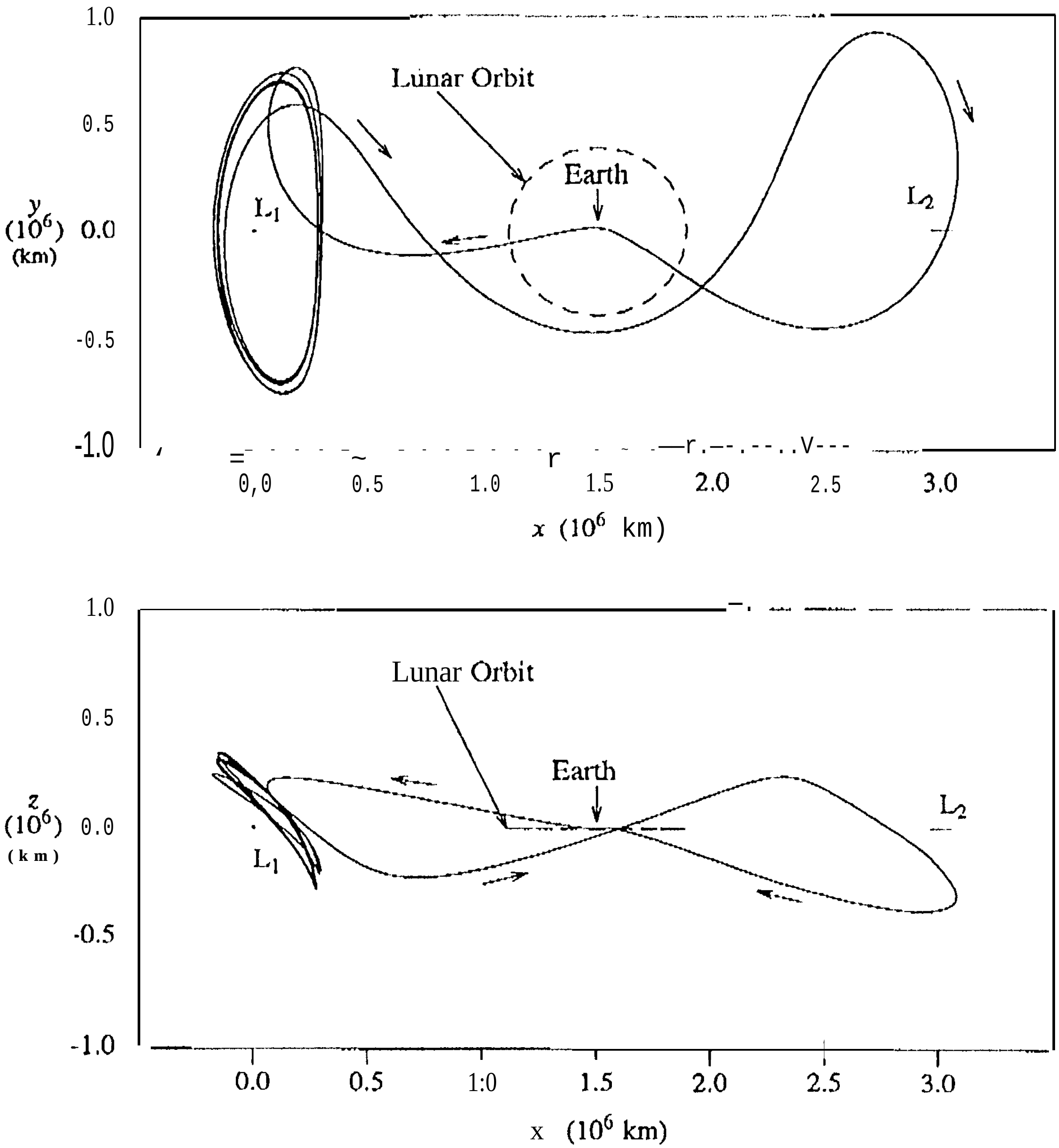
In the area of astrodynamics, the complex missions envisioned for the upcoming decades will demand innovative spacecraft trajectory concepts and efficient design tools for analysis and implementation, It is also increasingly apparent that accomplishment of many short- and long-term science and exploration goals will require a broader view that expands the range of options available. Much recent interest has focused on missions to the vicinity of the libration points in the Sun-Earth system, Spacecraft in orbits near libration points offer valuable opportunities for investigations concerning solar phenomena as well as solar and heliospheric effects on planetary environments. Current design capabilities for such missions have significantly improved in the last five years but are still limited, Libration point missions require a baseline trajectory concept derived from solutions to the three-body problem (not the traditional baselines rooted in the two-body problem and conics). Conventional tools simply do not incorporate any firm theoretical understanding of the multi-body problem and do not offer the flexibility to take further advantage of the dynamical relationships in producing alternative trajectory designs.

This work has focued on obtaining a clearer understanding of the fundamental, underlying dynamics associated with the trajectory design problem, with particular emphasis in multi-body regimes, where qualitative information is needed concerning sets of solutions and their evolution. Nonlinear dynamical systems theory is a key component in progress toward that objective. This type of analysis involves issues such as periodic orbits, stability, instability, quasi-periodic motion, asymptotic properties, structure of solution sets, escape, symmetries, and evolution of a dynamical system. Much insight has resulted from an investigation of halo orbits and Lissajous trajectories within this context. For halo orbits, in particular, study of the stability characteristics and the invariant manifolds associated with these periodic orbits has already served as a guide to generate natural pathways near the libration points. But the primary objective has been to *use* this information for trajectory design. Rather than rely solely on experience and previously determined solutions or propagate, somewhat blindly, until a useful trajectory appears, the goal is to knowledgeably select and compute trajectory arcs in the multi-body problem, The arcs can then be patched together for optimal results in complex trajectory design. Thus, the approach supports development of the necessary capabilities for actual mission planning, Of course, the possibilities expand tremendously if a dynamical systems approach should result in new classes of solutions. As a follow-up to a trajectory design investigated previously, it has now been applied in the design of the trajectory for the Jet Propulsion Laboratory's recent GENESIS mission.

Mission Design

$ome fundamental concepts from dynamical systems theory have already provided critical clues in generating the trajectory for an earlier mission concept, They have once again been exploited in generating trajectories for the current GENESIS mission. The mission concept is outlined as follows: depart the Earth on a direct transfer to an L_1 Lissajous trajectory; after some number of revolutions in the halo/Lissajous orbit, return to a specified Earth landing site for a dayside landing. A direct return on the day side from an L_1 orbit requires a prohibitive ΔV and, in some eases, may be impossible; a direct return from an L_2 Lissajous, however, will result in a dayside re-entry. This concept, and a candidate solution based on using the L_2 return option, was developed previously from insights offered through computations of the invariant manifolds associated with L_1 and L_2 halo orbits. The new mission, however, offered new challenges because of additional specifications and an increased flexibility that was necessary for the mission. These included investigations to consider tighter fuel budgets and tighter timing requirements. At the same time, more flexibility was necessary in launch dates and return strategies. Shown in Figure 1 is one trajectory design that resulted, Note that the path was constructed from a set of trajectory arcs that have been put together to meet the needs of the mission. (Generating a trajectory for a libration point mission by conceptualizing a series of arcs — each a "known" natural pathway in a *three*-body problem -- is not the standard sequence of steps in the design process for this regime.)

The details of the investigation and solution for the GENESIS trajectory offer additional information and insight concerning the issues raised through the new mission requirements. Along the way, some intriguing new options appeared as weU, Although not appropriate for GENESIS, they suggest alternative strategies that increase our understanding of the solution space and may prove useful for other missions.



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y (10^6) (km) 0.0
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Lunar Orbit
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L_2
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x (10^6 km)
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