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Ballistic Transfers Across the 1∶1 Resonance Around Vesta Following Invariant Manifolds

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Motivated by the challenging crossing of the 1∶1 resonance planned for the Dawn mission a general transfer design strategy is developed using the manifold structure of near-synchronous, unstable periodic orbits. Two families of transfers across the 1∶1 resonance at the asteroid Vesta demonstrate the approach. A family of low-inclination low-energy transfers follows the stable and unstable manifolds of the libration orbits near Vesta's equilibrium points (in a surface-fixed rotating frame). A high-inclination family of transfers arises similarly from the manifold structure of near-polar near-circular orbits. Ballistic resonance crossing transfers near Vesta are presented and characterized. This transfer design methodology applies well to any solar system body where the dynamics are dominated by gravitational acceleration from a nonspherical central-body potential.

Nomenclature

$\bar{C}_{\mathrm{nm}}, \bar{S}_{\mathrm{nm}}$	=	normalized spherical harmonic coefficients of the gravitational field
$D\phi_T(X_0)$	=	monodromy matrix (state transition matrix after one period) of a T periodic orbit with initial condition X_0
$\mathbf{F}(X)$	=	associated (Hamiltonian) vector field
$H(\tilde{\mathbf{r}}, \tilde{\mathbf{p}})$	=	orbiter Hamiltonian, also referred to as energy
h	=	arbitrary fixed value of the Hamiltonian (energy)
i, j, k, k_1, k_2, m, n	=	arbitrary integers
$J(\tilde{\mathbf{r}}, \dot{\tilde{\mathbf{r}}})$	=	first integral of motion for the Vesta orbiter dynamics in terms of position and velocity
P_n	=	Legendre polynomials
$P_{\mathrm{nm}}, \bar{P}_{\mathrm{nm}}$	=	associated Legendre and normalized associated Legendre functions
P_1, P_2, P_3, P_4	=	relative equilibria of the orbiter dynamics
$\tilde{\mathbf{p}} = (p_x, p_y, p_z)$	=	orbiter momenta in rotating, body-fixed Vesta centered frame
R_V	=	radius of the reference sphere associated with the spherical harmonic gravity field
(r, ϕ, λ)	=	radius, latitude and longitude of spacecraft in the Vesta centered, body-fixed frame
$\tilde{\mathbf{r}} = (x, y, z)$	=	spacecraft position vector in body-fixed, Vesta centered frame
Spec$A$	=	set of eigenvalues of matrix A
U, μ	=	Vesta gravitational field force potential and parameter
$\boldsymbol{V}^s, \boldsymbol{V}^u$	=	stable and unstable eigenvectors, respectively
$\mathbf{X} = (\tilde{\mathbf{r}}, \tilde{\mathbf{p}})$	=	spacecraft position and momenta in rotating, body-fixed Vesta centered frame
$\mathbf{Z}(h)$	=	zero-velocity surface
$\kappa(\mathbf{r}, h)$	=	implicit function defining the zero-velocity surfaces and allowable region of motion
λ^j	=	real part of jth eigenvalue
ξ^s, ξ^u	=	displacements along the stable and unstable eigenvectors, respectively
ϕ_t, θ	=	t advance mapping along a trajectory and phase along a periodic orbit
$\psi(\theta, \xi^u, \xi^s)$	=	parametrization of a stable — unstable manifold
$\boldsymbol{\omega}, \omega$	=	angular velocity vector of Vesta (relative to inertial space) and associated magnitude
ω_p^j	=	imaginary part of jth "in-plane" eigenvalue (with small z, p_z components)
ω_v^j	=	imaginary part of jth "out-of-plane" eigenvalue (with large z, p_z components)

I. Introduction

AS OF September 2011, NASA's Dawn mission has successfully inserted into orbit around the asteroid Vesta. Dawn's Vesta exploration plan calls for eventual transfer to the low-altitude mapping orbit (LAMO) at ~460 km radius [1,2]. The LAMO has an orbital period smaller than Vesta's rotation period, so that the spacecraft must cross the 1 : 1 resonance between the spacecraft orbit period and Vesta's rotation period using its low-thrust propulsion system. This transfer presents a mission risk, because chaotic dynamics in the region around the resonance could cause unplanned trajectory excursions that would negatively impact the mission. This study is motivated by this challenge; not to design Dawn's trajectory but to develop a general transfer design strategy for crossing this potentially hazardous region during future missions.

The chaotic motion associated with resonant orbit dynamics results from a repeating system configuration that allows small

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