Collinear point dynamics of a dumbbell satellite in fast rotation

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Abstract. For technically feasible tether lengths, the dynamics of fast rotating tethered satellites at the collinear points is reduced to an integrable problem depending on two parameters, one related with the tether's length and the other with the size of the orbit. The reduced dynamics maps orbits of the tether's center of mass onto points on the sphere, and shows how the tether length plays the role of a control parameter that can be used to mimic the relevant features of libration point orbits using orbits of a much smaller size than those spawned by the natural dynamics.

Introduction

The perturbed dynamics of dumbbell satellites in fast rotation with light tether of small dimensions, is formally analogous to the oblateness perturbation of a central attractor [1], whose modifications on the mass point dynamics are well known. Because of that, dumbbell satellites applications to mitigate orbital instabilities due to either the irregular nature of the Selenopotential or third-body perturbations have been proposed in which the length of the tether can be used as a control mechanism that, for instance, mitigates the strong instabilities affecting libration point (LP) orbits [2, 3]. The computation of LP orbits can be approached analytically when the nonlinearities remain at the level of a perturbation of the saddle $\times$ center $\times$ center dynamics stemming from the collinear points. Then, the integrals of the linearized dynamics can be extended to the whole problem by perturbation methods. Application of this technique to the Hill problem showed that the slow dynamics emerging from a LP can be reduced to an integrable problem whose phase space is the sphere [4]. Fixed points of the reduced flow on the sphere match periodic orbits of the Lyapunov, halo, and bridge-family types —the latter pertaining to the family that links planar and vertical Lyapunov orbits with a two-lane bridge of periodic orbits. Good approximations to these characteristic orbits can be obtained from high orders of the analytical perturbation solution without having to resort to the usual numerical continuation procedures.

Results and discussion

We apply the same analytical techniques to the dumbbell satellite model, and obtain a very simple one-degree-of-freedom Hamiltonian depending on two parameter. Depicting the intersection of different levels of this energy-type surface with the sphere is computationally inexpensive and provides an immediate insight on the dumbbell satellite LP orbits dynamics. The global description of the dumbbell satellite's slow dynamics about the LP is then obtained in the form of an atlas: Each sheet of the atlas corresponds to a point in the parameters plane, for which the phase space is given by the trajectories on the sphere (see Fig. 1 for reference). In this way we easily check how the dumbbell satellite in fast rotation modifies the classical LP orbits. In particular, it is shown how halo orbits can be twisted and narrowed about the vertical direction by increasing the tether's length, to the extent of making the halo to collapse into a vertical Lyapunov orbit, which in this way recovers stability, or how halo orbits can be additionally generated in regions in which the natural dynamics alone would prevent them to exist. Therefore, the use of a dumbbell satellite may provide interesting alternatives for mission orbit design.

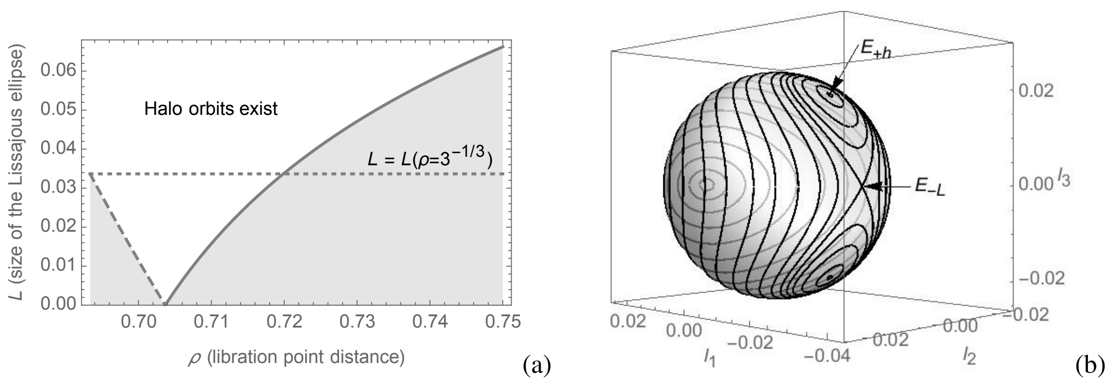

Figure 1: Sketch of the parameters plane (a), and sample flow in the light region where halo orbits exist (b).

References

[1] Peláez J., Lara, M. (2009) Dynamics of fast-rotating tethered satellites. *Publ. Real Acad. Ciencias Zaragoza* **32**:75-83

[2] Lara M., Peláez J., Bombardelli C., Lucas F.R., Sanjurjo-Rivo M., Curreli D., Lorenzini E.C., Scheeres D.J. (2011) Dynamic Stabilization of L_2 Periodic Orbits Using Attitude-Orbit Coupling Effects. In: Proc. 22th International Symposium on Space Flight Dynamics, São José dos Campos, Brazil, February 28 - March 4, 2011

[3] Lara M., Peláez J., Urrutxua, H. (2020) Modifying the atlas of low lunar orbits using inert tethers. *Acta Astronautica* **79**:52–60

[4] Lara M. (2017) A Hopf variables view on the libration points dynamics. *Celest. Mech. Dyn. Astron.* **129**:285–306