07/4201 DYNAMICS AND STABILITY OF TETHERED SATELLITES AT LAGRANGIAN POINTS

Type of activity: Extended Study (6 months, 35 KEUR)

Background and Motivation

The existence of equilibrium points in the circular restricted three body problem, known as Lagrangian or libration points, has been key to the success of many space missions in the past [1] and will likely play an important role for future space applications. A spacecraft placed at any of these points is able to maintain a stationary position relative to the main two gravitational bodies possibly with the need of small corrections depending on the system stability. Among the five Lagrangian points (L1,L2,..,L5) the collinear equilibrium points L1 and L2 are particularly attractive given their location and accessibility. Unfortunately both of them are unstable, which means a spacecraft to be kept at or orbiting around them will require correction manoeuvres typically to be performed at the expense of propellant mass. For instance a 3500 km Lissajous trajectory at the translunar L2 libration point in the Earth-Moon system requires an estimated deltaV correction on the order of 300 m/s per year [1]. A study by Giuseppe Colombo [2] first demonstrated the feasibility of controlling the unstable nature of the collinear Lagrangian points exploiting a varying-length tether system. The concept was later studied in more details by Farquhar [3,4]. This control scheme, which exploits the capability of dumbbell systems of shifting the centre of gravity position with respect to the centre of mass in a controlled manner, allows keeping the position of an artificial satellite close to the lagrangian points without using propellant. The major technological difficulty highlighted by Farquhar's analysis is the limited control authority associated with a gravity-gradient stabilised system. Misra et al. [5] later studied the problem with a different approach and included the possibility of using rotating tethered system of constant length to ease the stabilisation process. In the latter study the dynamics of a passive (constant-length) rotating dumbbell system were investigated without addressing possible control strategies. The need for further, more in-depth dynamic and control analysis of the system was highlighted.

More recently Pelaez and Scheeres [6] proposed to place electrodynamic tethers for permanent power generation at the Lagrangian points of the inner Jupiter moonlets (e.g. Amalthea). In that case, current control was proposed as the sole mean to stabilise both the position and the attitude of a constant-length non-rotating electrodynamic tether system placed in the vicinity of the unstable Lagrangian points of the moonlets. In this way a continuous power can be extracted from the orbital energy of the moonlet. The main difficulty of this approach were to accommodate both position and pendular motion control (tether pendular motion is generally unstable when electrodynamic forces are involved), and the lack of tether tension in the low gravity-gradient environment of Jupiter.

It is believed that this intriguing dynamical problem deserves a more comprehensive analysis encompassing the different stabilisation techniques (length control, rotation, electrodynamic forces) and exploring a wider range of orbital dynamics scenarios.

For instance, the benefit of a rotating tether with variable-length control has not yet been fully explored. Also the use of rotating electrodynamic tether systems (which are known to have a better control authority than non-rotating systems [7]) at the Lagrangian points of the giant planets has not yet been considered.

Research and Study Objectives

The aim of this study is to conduct a comprehensive analysis of the dynamics of tethered system at the Lagrangian points and explore promising applications of this concept.

1. Develop a comprehensive 3D analytical and numerical model to represent the dynamics of a rotating variable-length electrodynamic tether system (dumbbell model) placed in the vicinity of the collinear Lagrangian points of a generic orbital system or following a periodic or quasi-periodic orbit around these points. Both the tether and the environmental model are expected be kept as simple as reasonable (e.g. rigid tether, dipole magnetic model, etc.). Likewise, when electrodynamic forces are considered, a maximum amount of current will be assumed available without the need to model the tether current collection and the interaction with the plasma.
2. Non-electrodynamic tethers: evaluate the control capability of the system based on gravitational forces as a function of centre of mass location, tether length and attitude and the impact of the orbital and mass characteristics of the primary and secondary body.
3. Electrodynamic tethers: evaluate the control capability of the system based on the Lorentz force as a function of the parameters listed above as well as of the available current and investigate the performance of the system as a space power plant.
4. Stability analysis: Propose at least two control strategies to stabilise the dumbbell motion around the libration points assuming a spin-stabilised system, one for a non-electrodynamic tethers and one for electrodynamic tethers.
5. Based on the results obtained, promising applications of this concept in future mission scenarios will be evaluated.

While participating in all the above mentioned research packages, ACT researchers are prepared to play a substantial role in the development of the dynamical models representing the system dynamics and the applications analysis. Universities and research groups with no background in tether dynamics but with expertise in disciplines as dynamical systems, orbital dynamics and control theory are strongly encouraged to apply, as the ACT researchers are prepared to offer in-house expertise in tether dynamics and control.

References

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[3] Farquhar, R.W., "The Control and Use of Libration-Point Satellites", NASA TR R-346, September 1970. pp. 89-102

[4] Farquhar, R.W., "Tether Stabilization at a Collinear Libration Point", The Journal of the Astronautical Sciences, Vol. 49, No. 1, January-March 2001, pp. 91-106.

[5] Misra, A. K., Bellerose, J., and Modi, V. J., "Dynamics of a Tethered System near the Earth-Moon Lagrangian Points," Proceedings of the 2001 AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Canada, Vol. 109 of Advances in the Astronautical Sciences, 2002, pp. 415–435.

[6] Pelaez, J. and Sheeres, D.J., "A permanent tethered observatory at Jupiter. Dynamical analysis". AAS/AIAA Space Flight Mechanics Meeting Sedona, Arizona January 28 - February 1, 2007.

[7] Levin, E.M., "Dynamic Analysis of Space Tether Missions". Advances in The Astronautical Sciences, Vol. 126. American Astronautical Society, 2007.