# Control of orbital parameters of a dumbbell satellite using moving mass actuators

**Valery Pilipchuk**[*], Steven W. Shaw[**] and Nabil Chalhoub[*]
[*]*Mechanical Engineering Department, Wayne State University, Detroit, MI, U.S.A.*
[**]*Department of Mechanical and Civil Engineering, Florida Institute of Technology, Melbourne, FL, USA*

**Abstract**. Principles of a moving mass control of the orbital parameters of an artificial satellite are discussed based on the suggested design of the dumbbell shaped satellite. The purpose of the design is to implement a non-jet actuation through the variable geometry of the satellite associated with its internal degrees-of-freedom. Both massive parts of the dumbbell can spin and change their relative distance upon the orbital angle according to the suggested control algorithms. It is shown by analysis and simulations that this in an effective approach to altering orbital parameters.

## Introduction

A dumbbell-shaped satellite model enables the two-particle approach to be implemented for representing the dynamics of a rigid-body moving in a central gravitational field. Such modeling eases analytical manipulations with the differential equations of motion; thus, providing a clear way for designing control algorithms. In addition, the dumbbell model captures important dynamic properties of the so-called tethered satellite systems used in experimental investigations of space related exploitation of the Earth's magnetic field [1]. During the past decades, different spinning tethered systems were analyzed in connection with specific space missions, including the Momentum-Exchange/Electrodynamic-Reboost (MXER) project by NASA. The main purpose of the present work is to understand the extent to which orbital parameters of the satellite can be controlled through variations of the satellite geometry, namely, by the satellite length and the relative angles $\varphi$ of the two massive components with respect to the connecting rod (Fig.1a).

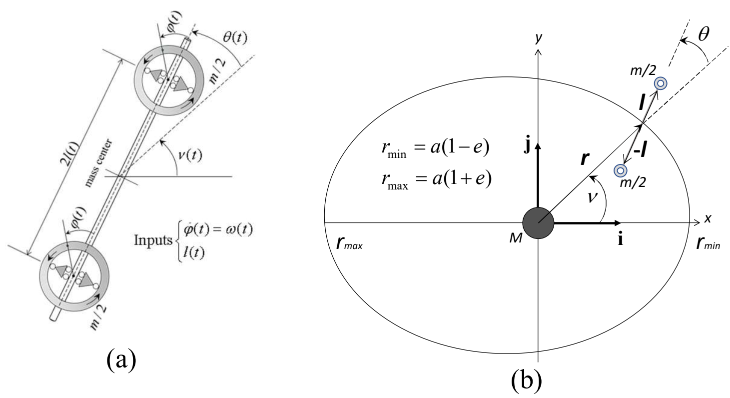


Figure 1: Planar dynamics of the dumbbell satellite with controllable inertial properties: (a) schematic of the satellite, and (b) the model coordinates with mass parameters and elements of the orbit in the inertial Cartesian frame [2].

## Results and discussion

It is shown that the total energy of the satellite, $\alpha(\nu)$, follows the target profile, $\alpha_d(\nu)$, with both increasing and decreasing intervals, if the satellite angle $\theta$ (Fig.1b) is guided by the prescribed dependence

$$\theta_d(\nu)=\frac{1}{4}\pi\left(1+\cos\left[\nu-\mathrm{sgn}(\alpha_d-\alpha)\frac{\pi}{2}\right]/\sqrt{1-\beta^2\sin^2\left[\nu-\mathrm{sgn}(\alpha_d-\alpha)\frac{\pi}{2}\right]}\right),$$

where $\beta$ is a smoothing parameter, such that, for $\beta=0$, the above equation yields a shifted cosine wave, whereas $\beta\to 1$ leads to a rectangular pulse train. Both classical PID and robust sliding mode control algorithms assume that the main control input is generated through the rotation of end masses, $\varphi(\nu)$. The total angular momentum conservation law guarantees the corresponding effect on the angular coordinate $\theta(\nu)$. The rate of change of the eccentricity per unit orbital cycle is found to be $de/dN=1.5625\times10^{-6}$ for the orbital parameters $a=13623.58$ km and $e=0.34456$, and satellite length 10 km, which is reasonable for tether structures. Such relatively minor effects may still be sufficient for long-terms non-jet corrections of orbits since the suggested actuators can use electric energy accumulated from solar panels over the extended operational period.

## References

[1] Beletsky V.V., Levin E.M. (1993) Dynamics of space tether systems. *Advances in the Astronaut. Sci* **83**.
[2] Pilipchuk V., Shaw S.W., Chalhoub N. (2022) Control of dumbbell satellite orbits using moving mass actuators. *Nonlinear Dynamics* **110**:1373-1391.