The Removal of Large Space Debris Using Tethered Space Tug

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At present, thousands of the space debris are located in the orbits. There are several technical solutions being proposed for space debris mitigation. One of the possible ways to remove the large space debris from the critical areas of near-Earth orbit can be the tethered space tug, which uses the thruster. One of the motivating applications of this work is transporting of space debris (non-functional satellites or upper stages of the rockets) from the orbit using a tethered space tug. A large space debris can strongly affects the motion of the debritor and the tether during the transportation, which can leads to the loss of control of the tethered system. There may be cases where the motion of the space debris can lead to the tether tangle or rupture. Therefore, the process of transportation must be analyzed in detail.

Proposed work studies the influence of the large space debris to the motion of the system (debris+tug) during the descent from the orbit. The *space debris* is a large passive nonfunctional spacecraft or an upper stage of the rocket as a rigid body. The active spacecraft or a *space tug* is considered as a mass point. The active spacecraft equipped with rocket thruster and connected to the passive spacecraft by a viscous-elastic weightless tether. The dynamics of a space transportation system composed of two bodies connected by a tether is considered. The spatial motion of the space transportation system is studied in the gravity field of the Earth under the action of the space tug thruster and a disturbance force due to the atmospheric drag (Fig. 1).

The equations of the center of mass of the system are written using osculating elements of the orbit. Particular attention is given to the investigation of the spatial motion of the space debris relative to the tether and relative to the space tug. The equations of the motion of the space debris obtained by using the direction cosines

The influence of the parameters of the system to its motion is investigated, including the moments of inertia of the space debris, the length and the properties of the tether, the thruster force of the space tug and the initial conditions of the motion. Correctness of the model is

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checked based on the definition of the center of mass of the system and the results of numerical simulations.

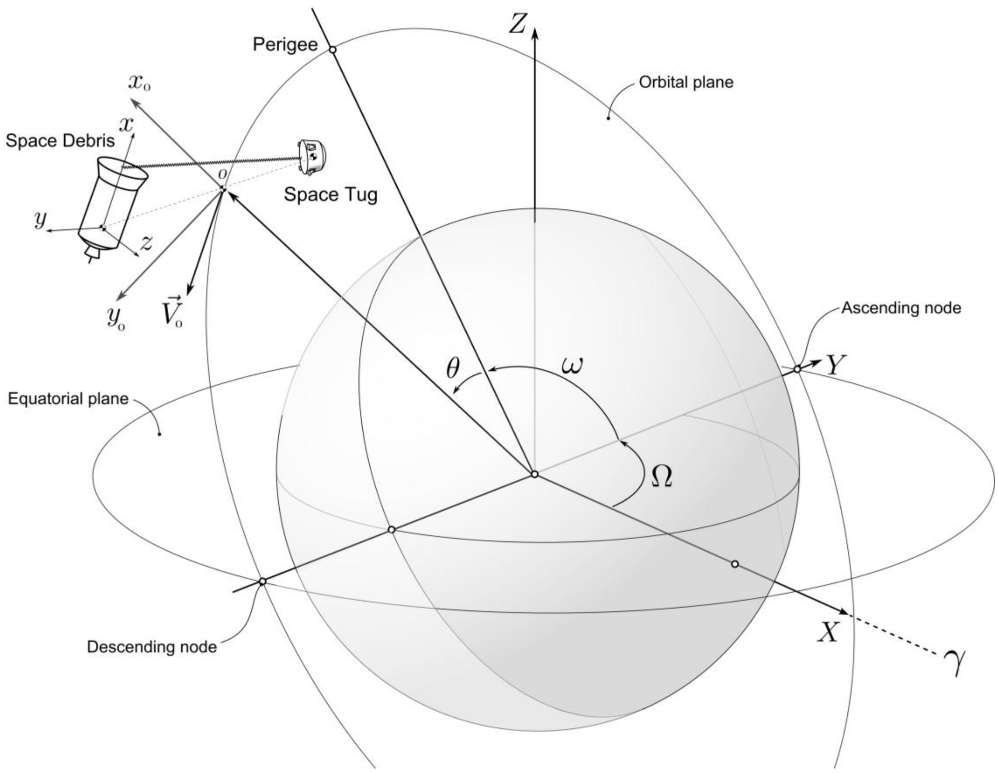
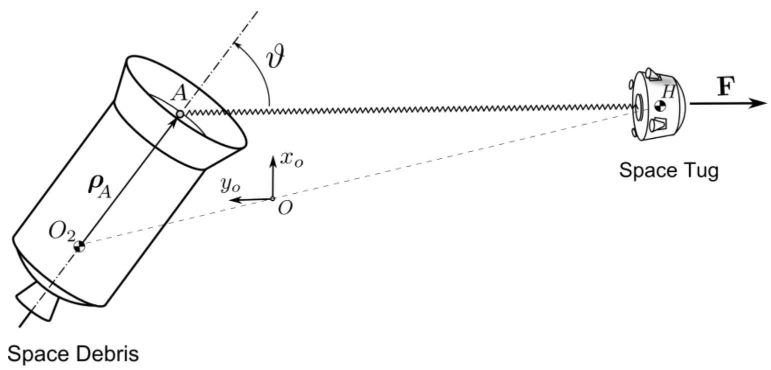


Fig. 1 The space tug and the space debris

Nine cases are considered. In the cases 1, 2, 3 and 4 we investigate the motion of the system with initially tensioned and initially slackened tether with different length and damping. We investigate the influence of the tether length and the tether damping to the attitude motion of the space debris. Initial positions of the space tug and the space debris are shown at Fig 2a. In the case 5 and 6 the influence of the space tug force is investigated. The motion of the system is considered for two values of the space tag thruster force. Initial positions of the space tug and the space debris are shown at Fig 2b for these cases and further.

a) Cases 1-4



b) Cases 5-9

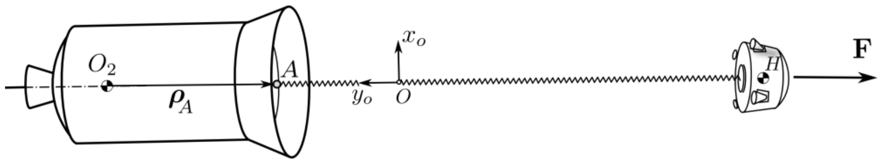


Fig. 2 The initial positions and the orientations of the space tug and the space debris

In the case 7 the attitude motion of the space debris with the oblate ellipsoid inertia is considered. In the case 8 we consider the plane motion of the system. In the case 9 we run full simulation of the descent process from the orbit with $h \approx 500\ km$ to the edge of the atmosphere $h \approx 100\ km$.

It is shown that the safe transportation process is possible when the space tug force vector coincides with the direction of the tether and the tether is tensioned. The amplitude of the oscillation of the passive satellite primarily depends on the properties of the tether. Slackness of the tether can lead to tether tangling due to the high amplitude of the oscillation of the passive satellite relative to the tether. For the particular system parameters the minimal height of the safe transportation exists below which the space tug can come into collision with the connected space debris. The space tug should keep sufficient level of the thruster force to eliminate the high amplitude oscillation of the space debris relative to the tether.

Additional references

[1] V. S. Aslanov, V. V. Yudintsev "Dynamics of towed tethered spacecraft in a central gravitational field". (In Russian). Vestnik SGAU (Samara State Aerospace University), 2 (33), 2012, pp. 9-16. http://termech.ru/sites/default/files/papers/Aslanov_Space_tug_tether_spacecraft_2012_SSAU.pdf

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