ATTITUDE AND ORBITAL DYNAMICS MODELING FOR AN UNCONTROLLED SOLAR-SAIL EXPERIMENT IN LOW-EARTH ORBIT

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ABSTRACT

Gossamer-1 is the first project of the three-step Gossamer roadmap, the purpose of which is to develop, prove and demonstrate that solar-sail technology is a safe and reliable propulsion technique for long-lasting and high-energy missions [1]. The development of the booms and the deployment unit is further described in [2], the sail design including the results of several development tests is given in [3] and [4].

As a pure deployment demonstrator, the Gossamer-1 spacecraft does not have an attitude control system. Therefore, its orbital and attitude dynamics are completely determined by the forces and torques in orbit. Furthermore, the sail is a non-rigid structure. The sails will billow and the booms will bend, depending on both the external forces and the internal tensioning forces. Compared to the deformation of the sail membrane, the deformation of the booms is small and was neglected. The shape of the sail changes constantly according to attitude and the corresponding loading, especially the aerodynamic drag and the solar radiation pressure. To get an idea of the sails deformation, an implicit finite element model with shell elements was implemented in ANSYS, considering the drag as pressure according to a Newtonian flow.

Our model considers a non-flat sail in a Low-Earth Orbit, affected by the gravitational force, the aerodynamic force in free molecular flow and the solar radiation pressure (SRP) force. The main challenges for modeling the solar-sail behavior arise from the continuously changing SRP force direction and magnitude, the eclipses, and the displacements in the sail, which affect all the parameters linked to the sail and the directions of the forces.

The SRP model has been taken from Ref. [5] and the eclipse model from Ref. [6]. The analytical model for drag in free molecular flow has been intensively studied in the last decades [7, 8] and has recently been statistically compared by Ref. [9] to very precise Direct Monte Carlo Simulations (DMCS), which is computationally too expensive to be included in our model. The analytical model for drag fitted the DMCS with significance and thus has been used.

The tumbling of the spacecraft has a direct impact on the thermal control design, the design of the power system, and the design of the communications system. Also, excessive spinning may result in the destruction of the sail. Furthermore, it is important to make sure that the sail will de-orbit in an acceptable amount of time. Therefore, it is important to understand the orbital and attitude behavior of the solar-sail spacecraft. In this paper, we describe the implementation of our solar-sail model and the results of our simulations.

The simulation results are also fundamental to understand the final optimal shape of the sail. Depending on the effect of the billowing on the spacecraft dynamics, it may be possible to loosen or necessary to tighten the sail with respect to the actual configuration.

1. References

[1] Geppert, U., Biering, B., Lura, F., Block, J., Straubel, M., and Reinhard, R. “The 3-step DLR-ESA Gossamer Road to Solar Sailing.” Advances in Space Research, 2010.

[2] Straubel, M., Seefeldt, P., Spietz, P., and Huene, C. “The Design and Test of the GOSSAMER-1 Boom Deployment Mechanisms.” “Proceedings of the AIAA SciTech, 2nd AIAA Spacecraft Structures Conference,” 2015.

[3] Seefeldt, P., Spietz, P., and Sproewitz, T. “The Preliminary Design of the GOSSAMER-1 Solar Sail Membrane and Manufacturing Strategies.” “Advances in Solar Sailing,” 2014.

[4] Seefeldt, P., Steindorf, L., and Sproewitz, T. “Solar Sail Membrane Testing and Design Consideration.” “Proceedings of the European Conference on Spacecraft Structures, Materials and Environmental Testing,” 2014.

[5] McInnes, C. R. Solar Sailing. Technology, Dynamics and Mission Applications. Springer, 1999.

[6] Montenbruck, O. and Gill, E. Satellite Orbits. Springer, 2005.

[7] Sentman, K. H. “Free Molecule Flow Theory and Its Application to the Determination of Aerodynamic Forces.” Tech. rep., Lockheed Martin, 1961.

[8] Hughes, P. C. Spacecraft Attitude Dynamics. Dover Publications, 2004.

[9] Hart, K. A., Dutta, S., Simonis, K., Steinfeldt, B. A., and Braun, R. D. “Analytically-derived Aerodynamic Force and Moment Coefficients of Resident Space Objects in Free-Molecular Flow.” “AIAA Atmospheric Flight Mechanics Conference,” American Institute of Aeronautics and Astronautics, 2014.