Control of a Space Vehicle Pulling a Debris

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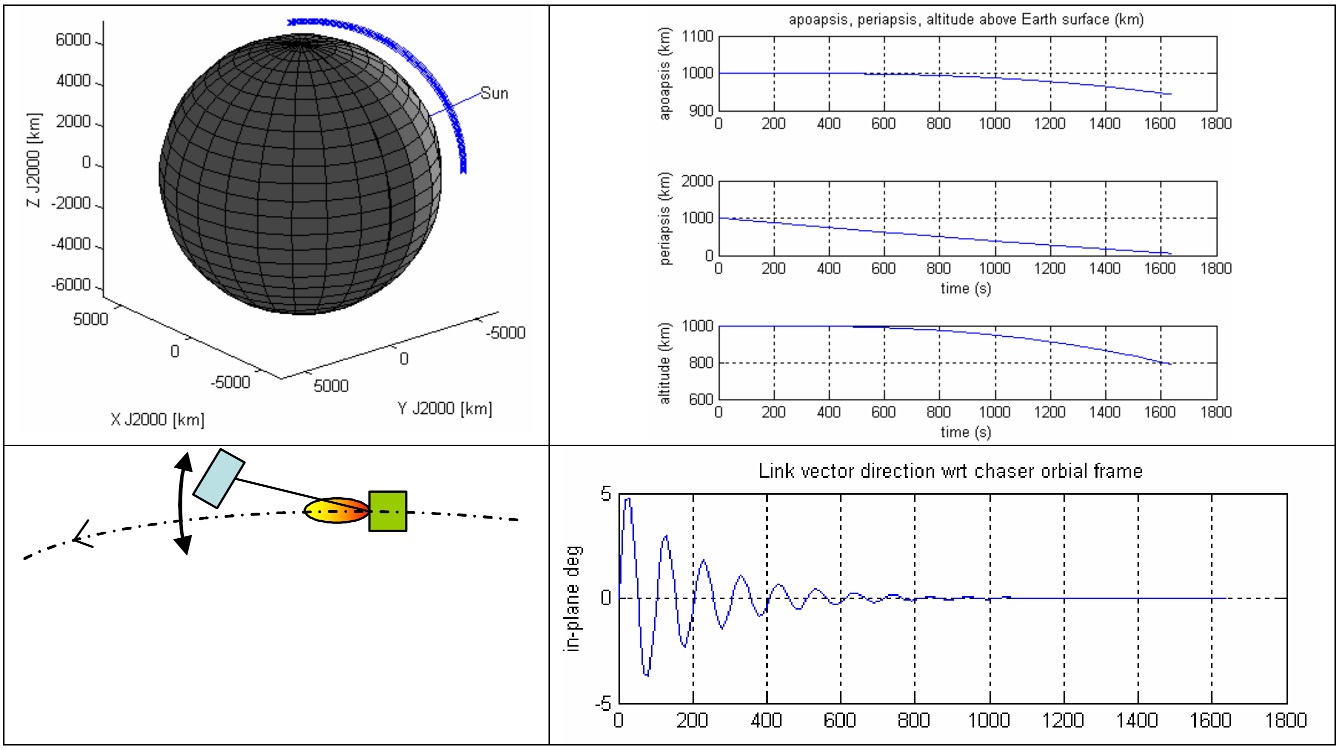
ABSTRACT

The multiplication of debris represents a risk for space operations. Among all the risk reduction actions studied by industrials and space agencies, this paper focuses on the following issue: the de-orbiting of an isolated debris with a dedicated debris removal vehicle. This vehicle is designed to be as cheap as possible. It uses a harpoon to capture the debris. Whenever possible, a bigger multi-debris vehicle will de-orbit all the debris whose orbital elements can be grouped. The control of the mono-debris vehicle has been studied in the frame of the OTV2 contract funded by CNES (Centre National d'Etudes Spatiales). This paper presents the challenges of the control action from the capture up to the end of the de-orbiting phase. Simulation results are also provided.

In the first section of the paper the main features of the vehicle, the debris and the mission are presented. The vehicle architecture is driven by a cost optimization care. The rendezvous system architecture is simplified to the maximum: optical navigation camera is considered as relative sensor and a set of chemical thrusters as actuators. The capture mechanism is composed of a harpoon attached to a flexible tether. Concerning the debris, two types of this one have been considered: a launcher stage and a satellite. Both debris types have a circular orbit around the Earth. The paper focuses on the capture phase and the de-orbiting phase. The capture phase comes after a debris inspection phase, whose objective is the determination of all the debris surfaces compatible with the harpoon and an estimation of the debris motion. During the inspection, the vehicle is on a fly-around periodic orbit. For the capture, the vehicle leaves this orbit to hold a relative position along the capture direction. The capture direction is the harpoon shooting direction and it is considered close to the debris velocity direction. It defines the initial conditions of the capture phase.

In the second section of the paper the control challenges during the capture and the de-orbiting phases are detailed. The capture itself is very fast because the harpoon ejection velocity is quite high. The control shall deal immediately with an assembly made of a vehicle, a flexible tether and a debris. The control shall avoid any wrapping of the tether around the debris, that could lead to a very complex modeling. The idea is then to start immediately the de-orbiting phase by applying a thruster force in the vehicle body reference frame, in order to pull the debris, to damp the transverse angular rates, to maintain the tether in tension and to de-orbit the assembly. Meanwhile the vehicle attitude is controlled in order to maintain the force opposite to the velocity vector and thus decrease the perigee, despite the disturbing torques applied by the tether on the vehicle body. The challenges at control level arise from the huge flexible mode induced by the debris attached to the tether, and from the uncertainties in the system, i.e., debris features, debris residual propellants, debris-tether attached point, debris solar arrays flexible modes.

The third section of the paper presents the high-fidelity simulator and some simulation/analysis results highlighting the feasibility of the mission. In the simulator, vehicle and debris attitude and position are modeled during the whole de-orbiting phase.



The perigee is lowered to 50km with a continuous 30mn long braking. The debris is pulled by a 100 meters long wire and oscillates behind the chaser. This preliminary simulation includes a full 6 dof dynamics of the chaser.

Figure: de-orbiting of a debris pulled by a flexible link