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On use of electrodynamic tethers for Saturn missions I

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Abstract

Exploring the moons of *Saturn*, particularly *Enceladus*, is an important goal of planetary science, the more so for search of life outside the Earth. Whereas use of *Electrodynamic Tethers* is readily possible for Jupiter [1], the case for the 3 other Outer Giant Planets, Saturn, Uranus and Neptune, presents issues, basically because their magnetic self-field B is grossly weaker, surface values being about 5% of the Jovian value; the efficiency of spacecraft capture (S/C-to-tether mass ratio) goes down as B^2 for low enough field. On the other hand, a possible gain by a factor of 2 in the efficiency arises from the low B value itself and the ensuing weak Lorentz drag, requiring no tether spin, as opposite the Jovian case, to keep it from bowing.

From the orbital point of view, capture is an essential issue for a tether mission to Saturn, because there will be only one opportunity for success. Once the tethered spacecraft is captured by the gravity of Saturn, a space tether could carry a spacecraft through the *neighborhoods* resorting to neither propellant nor power supply [2]. The basic scenario for the capture is described in [3] for the case of Jupiter; such analysis must be adapted to Saturn, but such adjustment is not trivial.

In the present work we consider ways to further increase the efficiency. First, moving from standard tether use of aluminium to beryllium, in case it could be made ductile enough, increasing the ratio between electrical conductivity and density by a factor of 1.8, an important parameter for efficiency. Additionally, ensuring that the length-averaged current in the tether is close to its short-circuit, upper-bound value, by choosing it long and thin enough; this raises no issues as in the Jovian case [1], again because of the very low Saturn field B.

Secondly, by introducing a gravity assist from some Saturn's moon. Table 1 shows some facts of the main moons. Titan, orbiting Saturn at $19.88 R_S$ with mass $2.366 \cdot 10^{-4} M_S$, as against moon Ganymede, orbiting Jupiter at $15.0 R_J$ with mass $0.79 \cdot 10^{-4} M_J$, is the more promising.

Table 1: Main moons of Saturn

Moon	Mass	Orb. radius	Eccent.
Tethys	$1.086 \cdot 10^{-7} M_S$	$4.888 R_S$	0.0001
Dione	$1.926 \cdot 10^{-6} M_S$	$6.225 R_S$	0.0022
Rhea	$4.056 \cdot 10^{-6} M_S$	$8.694 R_S$	0.0002
Titan	$2.366 \cdot 10^{-4} M_S$	$19.88 R_S$	0.0288
Iapetus	$3.175 \cdot 10^{-6} M_S$	$58.73 R_S$	0.0293

Assuming a Hohmann transfer to Saturn, the goal is to turn the initial hyperbolic trajectory —relative to Saturn— into an elliptical one with negative keplerian energy. Such depletion of energy is performed by the electrodynamic drag provided by the tether with the help of some flyby around Titan. We use some of the ideas described in [4] for the Giant Jupiter adapting them to the Saturn planet.

This simple model must be tested considering impact trajectories from Earth to Saturn using the *circular restricted three body problem*. The CRTBP permits to obtain with more precisión the arrival velocity to the sphere of influence of Saturn, one of the main parameter of the analysis.

The main figures of the Saturn Orbit Insertion (SOI) of the Cassini S/C are: $\Delta V = 626.8$ m/s, duration 5780.5 s, fuel consumed 841.5 kg and average thrust during the maneuver 443.1 Nw. In the case considered in this work, the gravity-assist maneuver aims to facilitate and to guarantee the capture and is quite different from the gravity-assist maneuvers around Titan performed in the Cassini mission.

References

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