Aerocapture as an Enabling Technology for Planetary Missions

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Aerocapture uses atmosphere of a planetary body to achieve orbit insertion

Aerocapture is an atmospheric maneuver where aerodynamic forces are used to transfer a spacecraft from a hypersonic orbit to a targeted capture orbit. Aerocapture provides large mass benefits over all-propulsive maneuvers that are typically used to enter capture orbits. Additionally, aerocapture is a quick maneuver where the spacecraft enters the target orbit within a few maneuvers versus similar aero-assist maneuvers like aerobraking, where the vehicle enters the desired orbit incrementally from a highly elliptical orbit and usually takes a longer time.

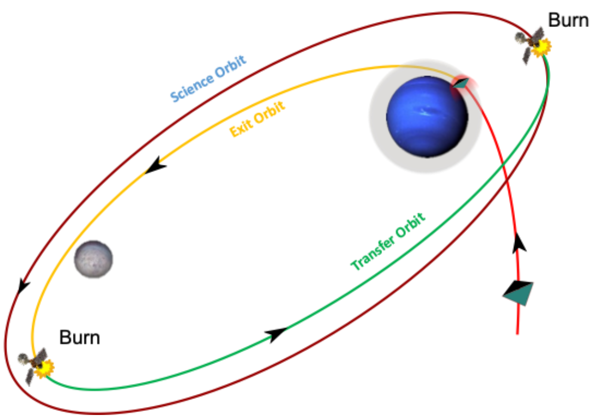

Fig. 1. Aerocapture concept of operations [1]

An aerocapture maneuver consists of one atmospheric portion of flight followed by two or more propulsive maneuvers. The vehicle approaches in a hyperbolic trajectory with the periapsis deep in the planetary atmosphere. The atmospheric drag decreases the speed of the vehicle below escape velocity, while the vehicle maneuvers to the correct apoapsis and wedge angle of the target orbit. After exit, a periapsis raise maneuver at the first apoapsis and an apoapsis correction maneuver at the next periapsis is conducted. The vehicle may also have to adjust the longitude of the ascending node and inclination angles.

Aerocapture provides orbit insertion system for SmallSats without large propellant mass

Small satellites (SmallSat) are a revolutionary paradigm shift for planetary science missions, as miniaturized scientific instruments in spacecraft with dimensions less than 100 cm and 180 kg can tackle important scientific questions. However, a fast, orbit insertion mechanism still requires large chemical propellant masses due to the realities of the rocket equation.

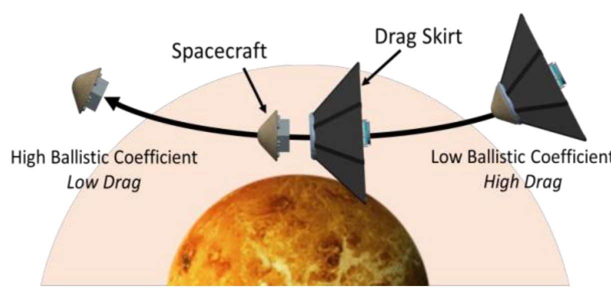

Fig. 2. SmallSat using deployable entry vehicles [2].

Aerocapture can alleviate the volume and mass penalties of traditional orbit insertion systems by using a lighter aeroshell, such as deployable shown in Fig. 2, that can achieve orbit insertion with significant mass savings compared to an all-propulsive solution.

Aerocapture enables large missions, especially to the Ice Giants, with increase in on-orbit mass and decrease in cruise time

The benefits of aerocapture are destination dependent, but some of the largest mass savings occur for Uranus and Neptune. Due to the large hyperbolic velocities of interplanetary trajectories approaching Uranus and Neptune, large amount of propulsion (approaching 1000 m/s of ΔV) must be used to put a spacecraft in science orbits around these planets. For Uranus and Neptune, the propellant mass fraction for the orbit insertion can be 40-60% of the total system mass. Aerocapture can reduce the propulsion needs by dissipating energy in the sizable atmospheres of Uranus and Neptune without a significant mass increase due to the need of an aeroshell. In fact, past studies by NASA have shown that the on-orbit mass can increase by approximately 40% using aerocapture versus fully-propulsive orbit insertion [1].

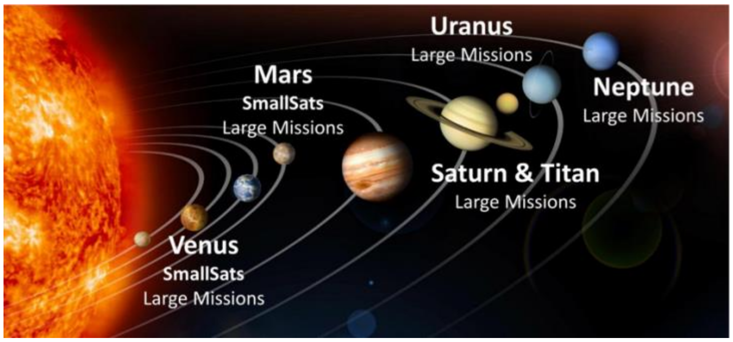

Fig. 3. Potential for Aerocapture usage in the Solar System [2].

This mass savings could be used to reduce the launch vehicle requirements or add additional science instrumentation. Since the vehicle will dip into the planetary atmosphere and will have a low initial periapsis altitude, aerocapture naturally allows mission designers to target science orbits with low periapsis altitudes, which are useful for ranging and remote sensing operations.

Additionally, aerocapture performance is relatively insensitive to increases in hyperbolic excess velocity, the interplanetary trajectory can be designed to arrive at the Ice Giants faster, reducing the interplanetary transit time and operations cost by as much as 3-5 years (15-30%).

Aerocapture together with gravity assist unlocks Enceladus, Titan, and Saturn missions

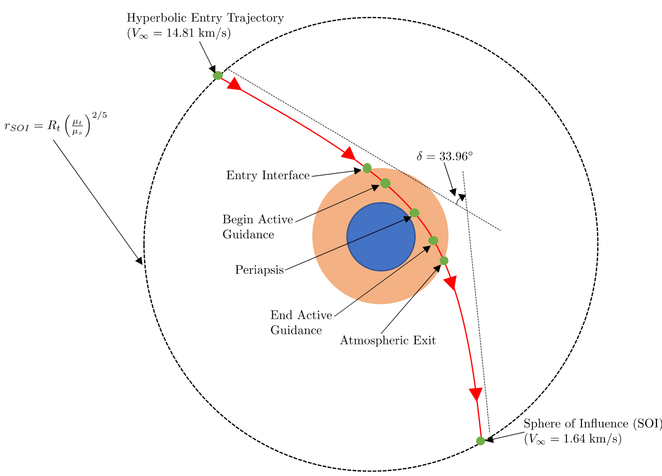

Fig. 4. Aerogravity assist at Titan [3].

Aerogravity assist maneuver, where the atmospheric drag and gravity of a planet-sized body are used to provide the ΔV and turn angle needed for an orbit insertion about another celestial object, would be best suited for missions to the Saturnian system, especially an Enceladus mission. Past studies have considered Titan as the planetary body whose atmosphere and gravity could be used to decrease the velocity of the interplanetary trajectory to attain a Saturn capture orbit with flybys to study Enceladus, although a Saturn-based aerocapture could attain similar results. With modern guidance and control techniques along with Thermal Protection System (TPS) improvements in the last two decades, there now exist ways to conduct aerocapture and aerogravity assist at the Saturnian system and many other planetary bodies throughout the Solar System.

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