EPSC Abstracts
Vol. 5, EPSC2010-454, 2010
European Planetary Science Congress 2010

The interplay of trajectories and propulsion techniques: expanding the horizons for Titan science

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Abstract

1. Introduction

Since mid-2004, data from the Cassini/Huygens (CH) mission show Titan as a destination of great scientific interest. This interest is spread over an Earth-like mix of science disciplines: an interior; a crust with a diverse surface; large bodies of liquids; a dense, mostly-nitrogen neutral atmosphere with active, surface-altering meteorology; and an upper atmosphere that interacts with sunlight and the local magnetosphere. Organic chemistry is a cross-cutting theme in all these disciplines. Methane is a significant component of the atmosphere and is thought to constitute a significant fraction of the surface lakes and seas. There might also be a subsurface reservoir of methane and other organic liquids or solutes in a porous upper crust. In the upper atmosphere, solar and magnetospheric energy sources drive chemistry that produces an abundance of more complex organic species, some of which rain down on Titan's surface, where there is potential for further organic chemistry. At Titan, the potential for scientific investigation is as rich as it is for Earth.

This abundance of scientific research avenues in a large range of diverse environments means that scientific exploration of Titan could employ a large range of different spacecraft platforms. Some of the platforms considered to date include flyby vehicles, orbiters, entry probes, balloons, airplanes, helicopters, landers, rovers, buoys, boats, even submarines. Of these, an orbiter is usually ranked among the top priorities for future Titan mission concepts. But this has been tempered somewhat in the past by concerns about the difficulty of delivering significant payloads to Titan orbit.

2. Delivering a spacecraft to Titan's vicinity

As a Saturn satellite, the transfer to Titan at ~9.5 AU from Earth is not easy. No spacecraft has gone directly from Earth to Saturn because the energy required makes the mass capability of even large launch vehicles too small. The Voyager and Cassini/Huygens spacecraft that visited the Saturn system did so using gravity assists, sometimes with leveraged chemical propulsion. All those spacecraft used Jupiter gravity assists as a critical energy boost toward Saturn. But Jupiter gravity assists to Saturn are available only in 2- to 3-year windows centered nearly 20 years apart. Fortunately, electric propulsion techniques are becoming available that could fill the gaps.

Electric propulsion, first used for station-keeping, has now been used as the primary propulsion systems of multiple spacecraft, including NASA's New Millennium Program Deep Space 1 to comet Borrelly (1998-2001), ESA's SMART-1 to orbit Earth's moon (2003-2006), and NASA's Discovery Program DAWN, launched in 2007 and currently in flight to orbit asteroids Vesta and Ceres. The 2008-2009 joint NASA/ESA study of the Titan Saturn System Mission (TSSM) showed that solar electric propulsion (SEP) systems of reasonable size, coupled with the proper trajectories, could allow delivering significant mass to Saturn on Atlas-class launch vehicles, without a Jupiter gravity assist [1]. This greatly expands the suite of potential launch opportunities for Titan missions.

3. Beyond flybys: staying in Titan's Vicinity

Although flybys have achieved breakthrough science at Titan, some high-priority science objectives require spending a great deal of time in the near vicinity of Titan; hence the high priority for an orbiter. Prior to 2008, most mission architects thought that for some time aerocapture would be the only practical means of achieving orbit at Titan, because the propulsive delta-V required for the trajectories known at the time was prohibitively high. Since then, ground-breaking work at JPL on "leveraged propulsion" trajectory techniques applied to Titan and the Saturn system has uncovered trajectories that deliver significant mass into Titan orbit without aerocapture. These techniques were incorporated into the TSSM trajectory, allowing a mission concept with much Cassini/Huygens heritage [1]. This does not imply that there are no benefits to aero-assist techniques at Titan, but it does mean there are other, currently more mature, alternatives.

Aero-assist techniques and aerocapture are not one and the same. Another aero-assist technique, aerobraking, has great potential at Titan for both better engineering performance (more mass into a low circular orbit) and science not possible otherwise. The TSSM study showed that at Titan, where spacecraft in near-circular orbits are limited to altitudes above 1000 km, an aerobraking orbiter could penetrate to altitudes of 600 km, possibly even less [1]. This opens the possibility of *in situ* measurements in a region where important chemistry is thought to occur, but lack of data thwarts verifiable modeling.

4. Presentation summary

This presentation will describe the various propulsion and trajectory techniques available for Titan science mission concepts, and discuss relative advantages and disadvantages for the science those missions address.

Acknowledgement

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the United States' National Aeronautics and Space Administration.

References

[1] Reh, K., Erd, C., Matson, D., Coustenis, A., Lunine, J., and Lebreton, J-P., and the TSSM Study Teams: Titan Saturn System Mission Joint Summary Report, joint NASA/ESA publication, 19 Jan. 2009; available at http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=44033#