National Aeronautics and Space Administration

Architectural Elements for a Future Mission to Titan/Enceladus

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The Titan Saturn System Mission Study, completed in 2008, developed one implementation of a mission that would expand on Cassini/Huygens tantalizing discoveries at Titan and Enceladus, covering the widest range of planetary science disciplines – Geology, Geophysics, Atmospheres, Astrobiology, Chemistry, Magnetospheres – in a single NASA/ESA collaboration

Science Goals & Objectives

The TSSM SDT summarized mission science in three Goals:

Goal A: Explore Titan, an Earth-like System

- What is Titan's climate like?
- How does it change with time?
- What can it teach us about Earth's climate?

Goal B: Examine Titan's Organic Inventory – A Path to Prebiological Molecules

- What kind of organic chemistry goes in Titan's atmosphere, in its lakes and seas, and underground?
- Is the chemistry at the surface mimicking the steps that led to life on Earth?
- Is there an exotic kind of life—organic but totally different from Earth's—in the methane/ethane lakes and seas?

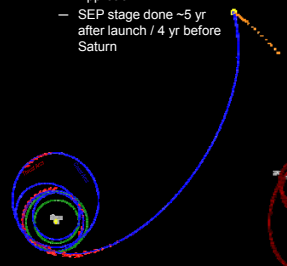
Goal C: Explore Enceladus and Saturn's Magnetosphere – Clues to Titan's Origin and Evolution

- What is the source of geysers on Enceladus?
- Is there life in the source water of the geysers?

Mission Design

SEP-Augmented Interplanetary Trajectory

- 2020 EVEE, SEP trajectory
  - 9 yr FT to Saturn
  - Sep-2020 to Sep-2029
  - 1613 kg s/c to Titan
  - 830 kg ISEs on Saturn Approach
  - SEP stage done ~5 yr after launch / 4 yr before Saturn



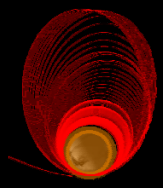
Saturn Tour

- Tour Consists of Three Phases After SOI:
  - In-Situ Element Delivery
    - Montgolfiere delivered on 1st Titan flyby
    - Lander delivered on 2nd Titan flyby
  - Enceladus Flybys
    - 7 Enceladus close flybys
  - Final Slow-Down
    - Reduces Titan V_∞ from 4 km/s to 0.9 km/s for efficient Titan orbit insertion.

Red denotes Ion Engine thrusting

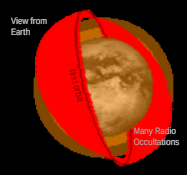
TOI and Aerobraking

- Titan orbit insertion into initial 750 km by 15,000 km ellipse.
- Aerobraking reduces ellipse over two months while sampling atmosphere down to 600 km.
  - ~200 passes
  - ~200 m/s delta-v savings

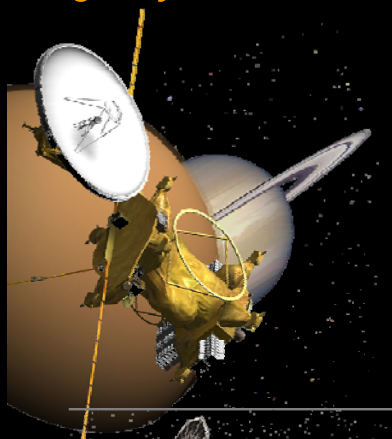


Circular Orbit

- Aerobraking phase is followed by a 20 month mapping phase:
  - 1500 km, circular orbit
  - Near-polar (85º inc)
  - Orbit plane varies from ~11:30 am to ~9 am am over 6 month mapping period



Flight System



SEP Flight Configuration

Orbiter

The TSSM orbiter was designed as a three axis stabilized spacecraft. The flight system includes an articulated 4m high gain antenna (HGA) using 35 W RF Ka band TWTAs for high rate science data downlink. Accommodation is provided for the two *in situ* elements at attach points along the body of the spacecraft. Five Advanced Stirling Radioisotope Generators would power the spacecraft, providing about 540 W of electrical power at end of mission. The launch mass of the flight system including the full ESA *in situ* payload and contingency is 6187 kg with respect to the Atlas V 551 capability of 6259 kg to the required launch C3.

Orbiter Planning Payload – 165 kg
HiRIS – 1-6 micron hi-resolution imager and spectrometer
TiPRA – Penetrating radar and altimeter
PMS – Polymer mass spectrometer
SMS – Sub-mm sounder
TIRS – Thermal Infrared Spectrometer
MAPP – Magnetometer and plasma Pkg.
RSA – Radio science augmented by accelerometry

SEP Stage

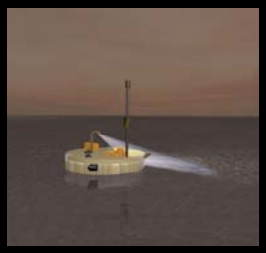
The TSSM flight system incorporated a Solar Electric Propulsion stage for use in the inner solar system. This stage provides extremely efficient ΔV capability over a purely chemical propulsion system for that portion of the mission where solar energy is abundant. The SEP stage is integrated into the launch vehicle adapter and contains three NEXT ion thrusters (two operating and one spare) powered by CEV-derived 15 kW ultraflex solar arrays.

In situ Elements

Montgolfière *In situ* Element

The European Space Agency in collaboration with CNES was to provide a montgolfière (hot air balloon) for exploration of Titan from a nominal altitude of 10,000 m. Buoyancy would be provided by the thermal output of an integral Multi-Mission Radioisotope Thermoelectric Generator, enabling the montgolfière to drift with Titan's winds to provide atmospheric and surface science data over wide swaths of Titan's surface.

Montgolfiere Planning Payload – 22 kg
BIS – Balloon Imaging Spectrometer
VISTA-B – Imaging System for Balloon
ASI/MET – Atmospheric Structure Inst./Meteorology Pkg.
TEEP-B – Titan Electric Environment Package
TRS – Titan Radar Sounder
MRST – Radio Science using S/C comm. system
MAG – Magnetometer
TMCA – Titan Montgolfiere Chemical Analyzer



Lander *In situ* Element

The European Space Agency was also to provide a lander for detailed surface analysis. This battery-powered lander would be targeted to one of the recently discovered methane lakes.

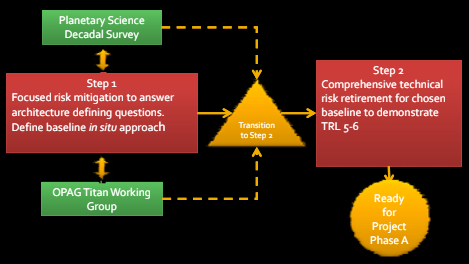
Lander Planning Payload – 23 kg
TLCA – Titan Lander Chemical Analyzer
VISTA-L – Titan Probe Imager (+ lamp)
ASI/MET – Atmospheric Structure Inst./Meteorological Pkg.+ electrical properties
SPP – Surface Properties Package + Acoustic Sensor Pkg. with Acoustics and Magnetometer
LRST – Radio Science using S/C Telecom System

Path forward

- NASA science panel confirmed that in situ elements are needed for a credible flagship mission to Titan
  - Science rated Excellent; science implementation – rated low risk; mission implementation – rated high risk
- The most significant technical risks identified will need to be mitigated to enable a future mission
  - Balloon deployment and inflation upon arrival at Titan
  - Balloon packaging and thermal mgmt. inside the aeroshell
  - Interface complexity between balloon, RPS and aeroshell
  - Integration of the NASA provided MMRTG into balloon
  - In situ sampling and instrument systems, including chemical analyzers

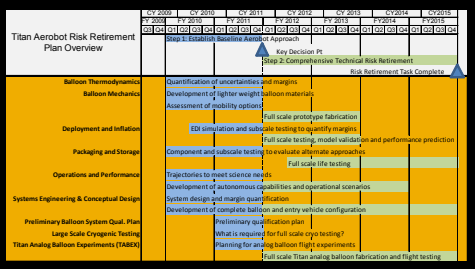
- A multi-year risk reduction effort is being pursued
  - Plan leverages JPL, APL, Caltech, CNES and NASA Wallops Flt Facility expertise

Two-step Risk Reduction Approach



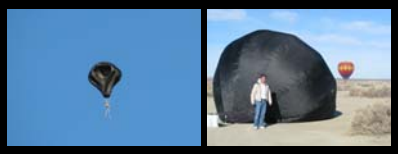
Two-step approach maintains alignment with ongoing Planetary Science Decadal Survey and focused investment strategy

Tasks and Schedule



Defining questions are answered early, allowing further definition of baseline approach and cost effective focus on retiring major risks

Risk Reduction Progress



Successful aerial deployment and inflation test on 4.5 m balloon (300-400 meter altitude)

Indoor propane-heated flight of 9 m prototype montgolfiere balloon

CFD modeling of Titan montgolfiere balloon thermodynamics (left), cryogenic testing of 1 m diameter balloon by by Julian Nott (lower right) and comparison of buoyancy vs heat transfer data

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