Preliminary Results of the Advanced RPS Mission Studies Team

Outer Planets Advisory Group (OPAG)

Boulder, Colorado

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RPS Mission Studies Team Members

Team

- Rob Abelson - Team Lead / Titan Orbiter Study Lead
- Tibor Balint –Titan Rover Study Lead
- John Elliott – Mission Architect
- Michael Evans – Mission Architect
- Jackie Green - Manager
- Jim Shirley – Science Advisor
- Tom Spilker – Science Advisor / Mission Architect

Resources

- Ajay Misra – NASA Headquarters
- Bill Nesmith – RPS Technology
- Kip Dodge – RPS Technology
- Bob Wiley – Department of Energy
- Beckie Richardson - Department of Energy
- Bill Otting – Rocketdyne
- Jack Chan – Lockheed Martin
- Team X - Concurrent Engineering Design Team
- Radioisotope Power Conversion Technology (RPCT) NRA
- Jeff Hall – JPL
- Many Others……

Solar System Exploration

Introduction

Solar System Exploration

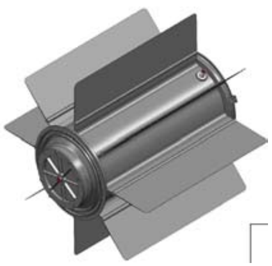
- The RPS mission studies team is investigating the mission enabling/ enhancing characteristics of a range of potential new advanced radioisotope power systems (ARPS).

- Focused, limited-budget ($25k) studies were performed to assess the mission benefits and trades of ARPS technology for various missions concepts.

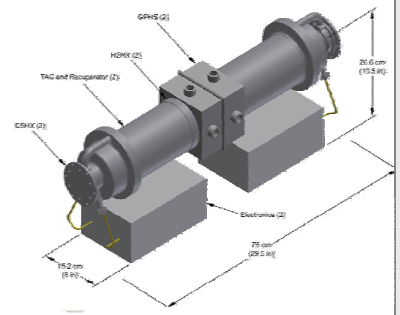
- Four ARPS technologies considered:
  1. Advanced Radioisotope Thermoelectric Generator (RTG)
  2. Advanced Stirling generator
  3. Thermophotovoltaic (TPV) generator
  4. Brayton generator.

- All four ARPS technologies were funded by NASA in 2004 for research and development.

- Study results used to assist NASA in identifying need for ARPS technology and power system requirements.

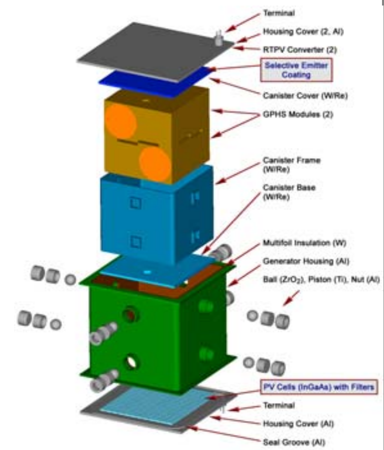


Adv. RTG



Brayton

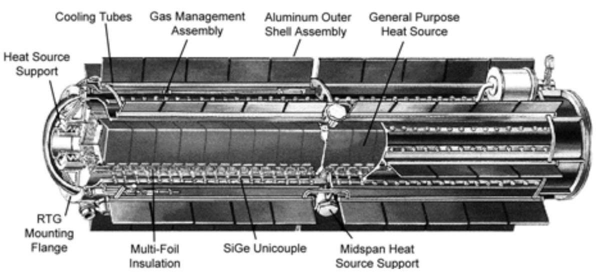
Adv. Stirling



TPV

Background - RPS 101

Existing RPS



GPHS RTG

Power: ≥285 We (BOM)

Efficiency: 6.8%

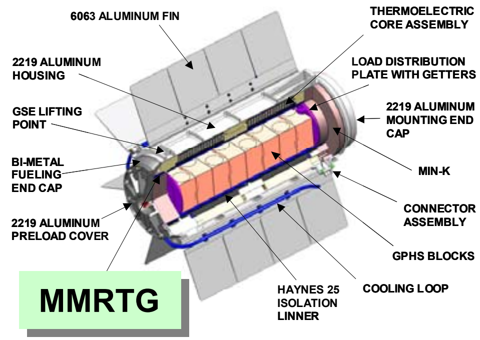
Specific Power: 5.2 We/kg

Missions Supported:

- Galileo (2 RTGs)
- Cassini (3 RTGs)
- Ulysses (1 RTG)
- Proposed Pluto-KB (1 RTG)

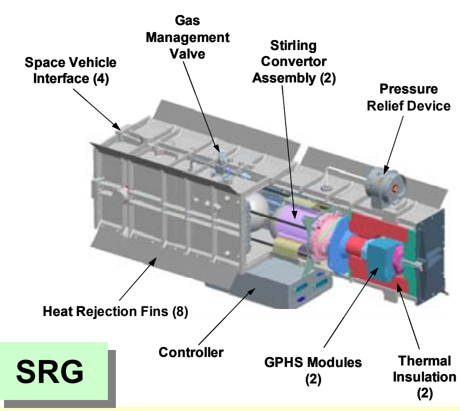
One unit remaining after Pluto-KB. *May* have enough spare parts to build a second unit.

Standard RPSs
(Available starting 2009 to 2011)



MMRTG

Power: >110 We (BOM)
Efficiency: 6.2% to 6.3%
Specific Power: 2.9 We/kg

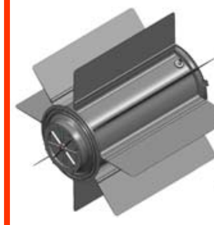


SRG

Power: >110 We at BOM
Efficiency: 21 to 24%
Specific Power: 3.0 to 3.4 We/kg

Advanced RPSs
(Potentially available ~ 2014 to 2015)

Conceptual Designs

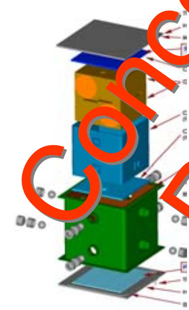


Adv RTG

Power: ~110 We
Efficiency: ~9%
Sp: ~4.3 We/kg

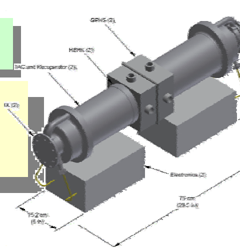
Adv. Stirling

Power: ~80 We
Efficiency: ~32%
Sp: ~5.9 We/kg



TPV

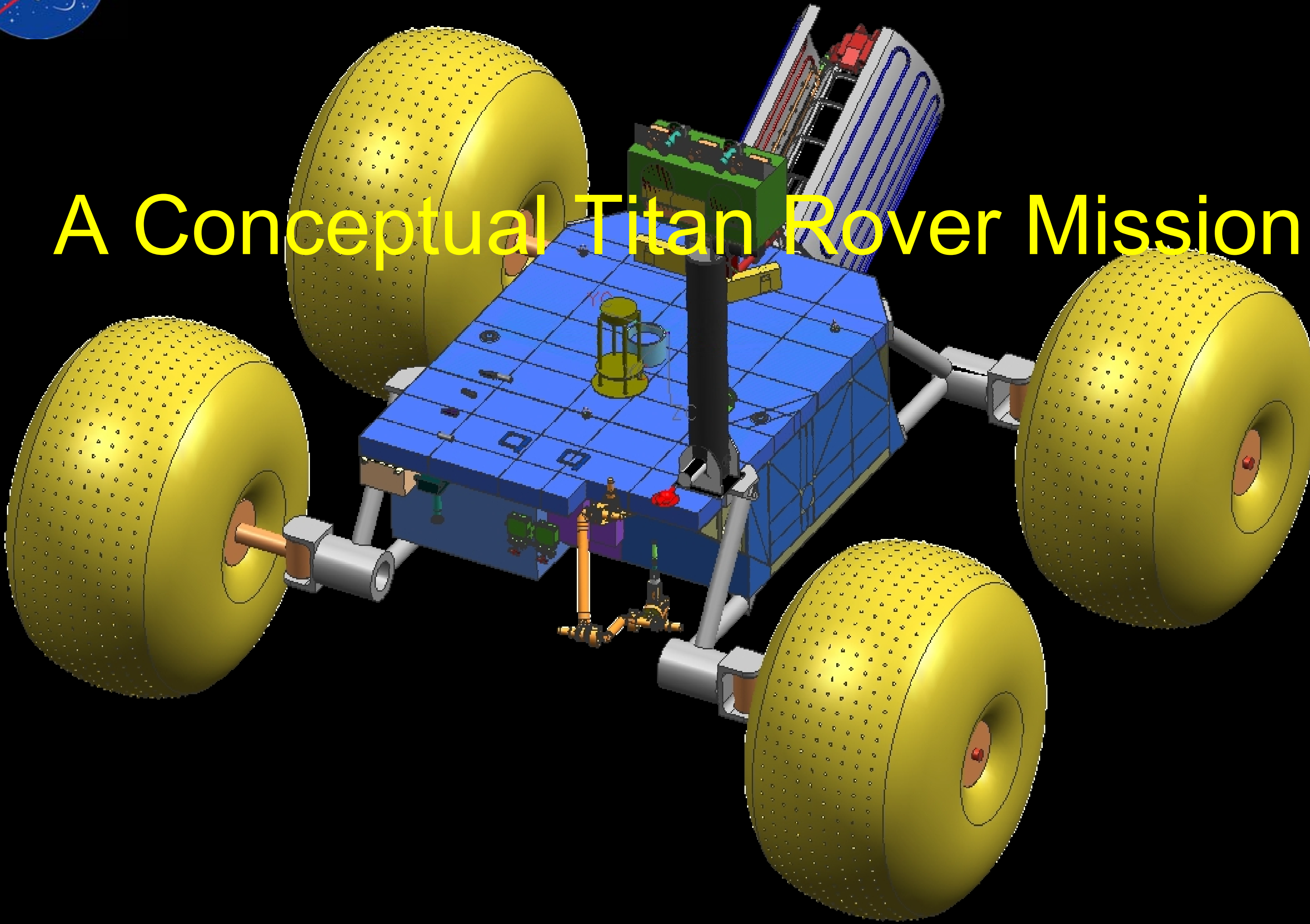
Power: ~110 We
Efficiency: ~15%
Sp: ~6.3 We/kg



Brayton

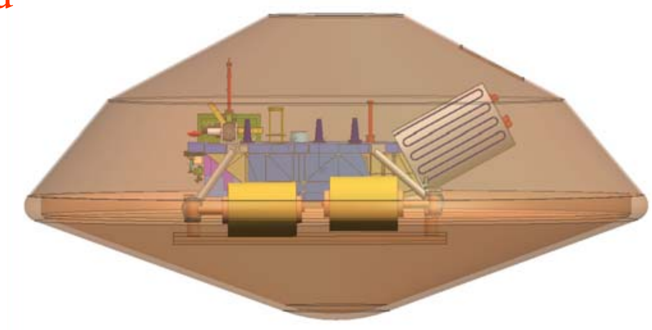
Power: ~110 We
Efficiency: ~22%
Sp: ~3.8 We/kg

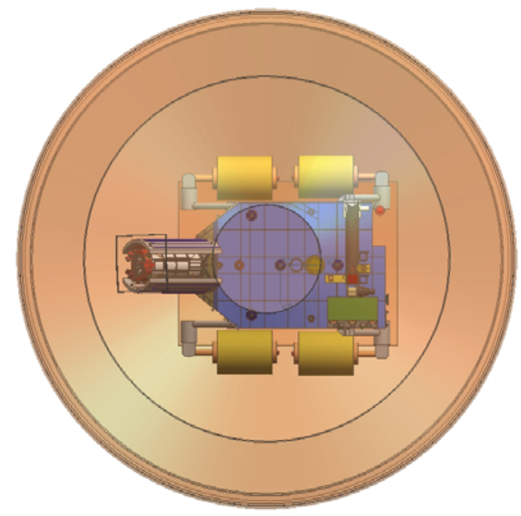
A Conceptual Titan Rover Mission



Study Parameters and Assumptions

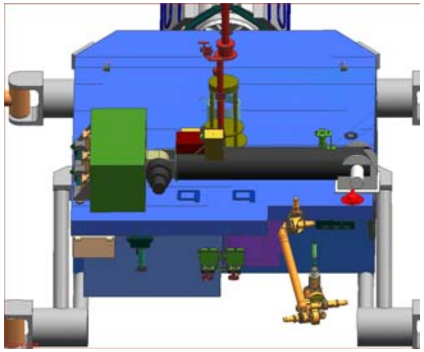
- Goal was to design a simple and credible rover mission concept for Titan in-situ exploration using Advanced RPS.
- Use flight & design heritage when possible
  (e.g., MSL (rover); Viking (aeroshell/landing); Team-P fetch rover sampling mechanism)
- Launch date: 2015 *(with technology cutoff in 2012)*
- Launch vehicle: Atlas 501 w/5m fairing
  (Delta IV-H was also assessed, but resulted in an oversized mission)
- Aeroshell: 4.5 m *(Viking heritage)*
- Trip time: 7.6 years *(with EJ gravity assist)*
- MSL class rover with inflatable 4 wheels *(D_{wheel}=1.5 m)*
- Surface operation: 3 years
- Dual string design

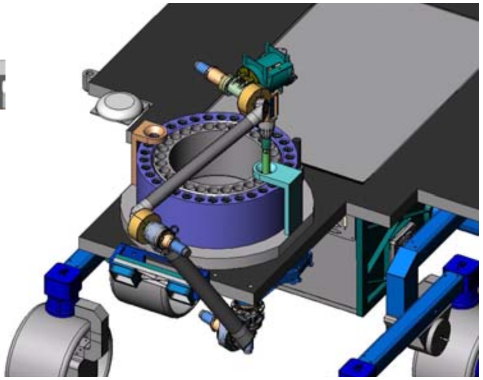


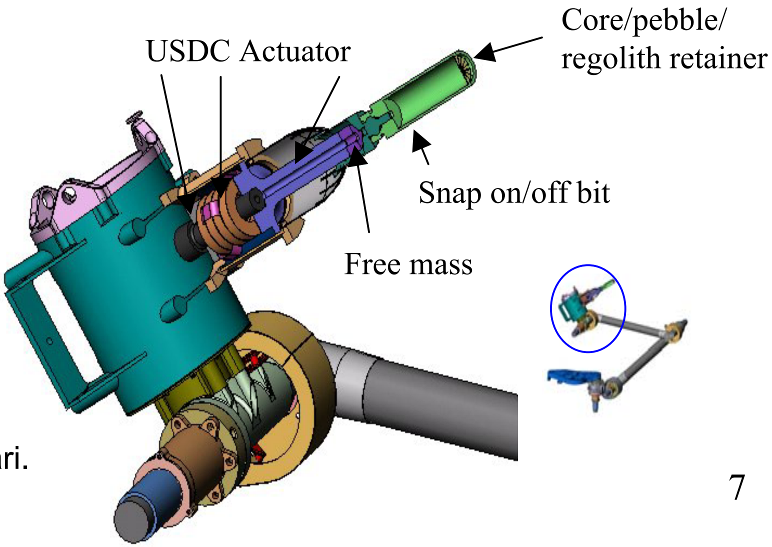


Representative Science Objectives

- Objective 1:
  Determine the composition of Titan's surface materials.
- Objective 2:
  Characterize the organic chemistry taking place at Titan's surface.
- Objective 3:
  Describe the interactions between the surface materials and the atmosphere.
- Objective 4:
  Describe the morphology of Titan's surface.
- Objective 5:
  Describe the surface meteorology







Science goals as recommended in the Post-Cassini/Huygens Titan Study Science Team Final Report (4/12/2001) led by Leslie Tamppari.

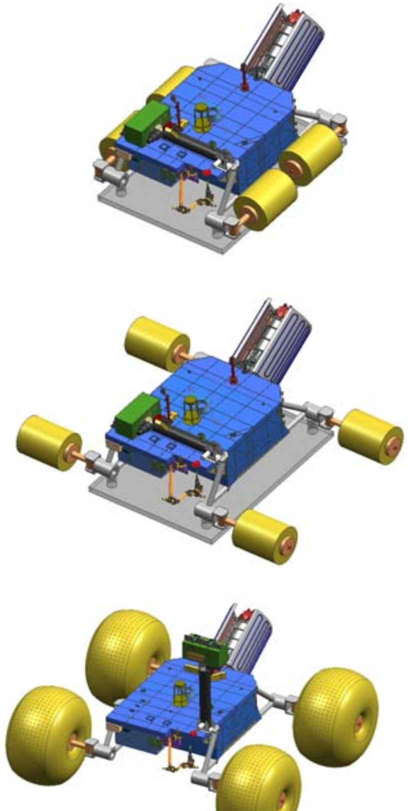
Strawman Instrument Suite for the Titan Rover

Instrument	Mass	Volume	Power	Data	Heritage	Comments
Met Package	**0.7 kg**	11x16x6cm	800mW	57.4 kbit/day	Marsnet Study	Including wind sensor, pressure, temperature
Radiation Monitor	**2 kg**	20x10x5	3 W	10 kbit/day	MARIE	Scaled down. Energy resolution needs to be specified to measure 13C
Acoustic Monitor	**0.1 kg**	5x5x1	150 mW	100 kbit/day	MPL Mars Microphone	Assumes slightly larger capability than mars microphone
Sampling Camera/ Microscope	**0.5 kg**	5x5x5	200 mW	1 Mbit/analysis	MPL RAC	Could be extended to MECA-type AFM
Chemistry Package (GCMS/ES-IMS /CE etc.)	**20kg**	50x50x30	40W for 5 hrs/analysis		WAG - based on Huygens GCMS	Exact mix of techniques tbd
Raman Spectrometer	**1.5 kg**		3 Whr; 2-5 min/sample			Replaced Miniature Chemistry Package on original list
Panoramic Camera	**5 kg**		3W		IMP	
LIBS	**1.4 kg**		2 W			
Ultrasonic Corer	**6.8 kg**		20 W			Taken from Wayne Zimmerman's MSR Fetch Rover study

Total instrument payload: ~38kg, not including the 30% contingency required by design principles; nor the mast, drill & sample collection system mass

Solar System Exploration

Mass Breakdown



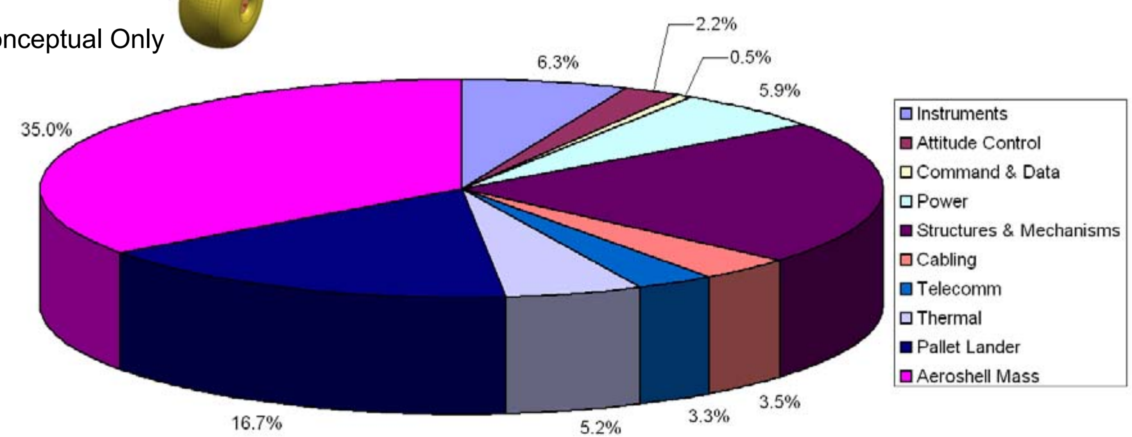
Conceptual Only

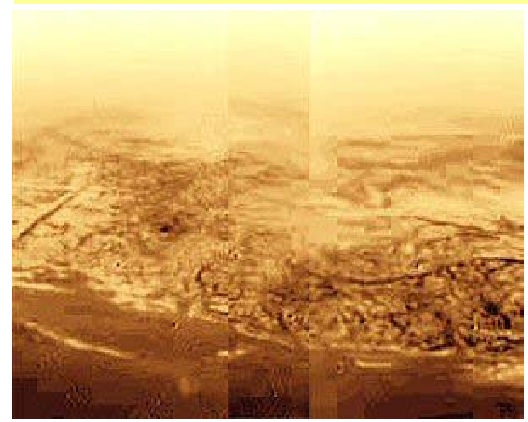
Element	Mass (kg)	Mass (kg) w/ 30% cont.
Instruments (Payload) Total	38	49
Attitude Control	13	17
Command & Data	3	4
Power	35	46
Structures & Mechanisms	128	167
Cabling	21	27
Telecomm	19	25
Thermal	31	40
Bus Total	251	326
Rover Total (Dry)	**289**	**376**

Element	Mass (kg) w/ 30% cont.
Rover Total (Wet)	**376**
Soft Lander (with 30% contingency)	130
Landed Mass	506
Aeroshell Mass	272
Entry Mass	**778**

Atlas 501 ($C3=25.7 km^2/s^2$):
Launch Capability: 1455 kg
Remaining mass for cruise stage and DSM: ~677 kg

Delta IV-H ($C3=25.7 km^2/s^2$):
Launch Capability: 5733 kg



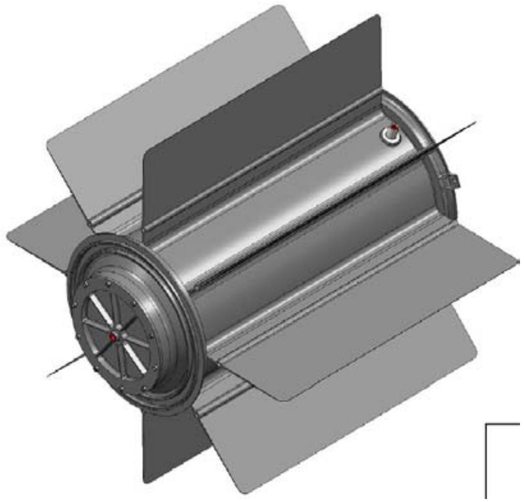


Robert Abelson, JPL, June 2005

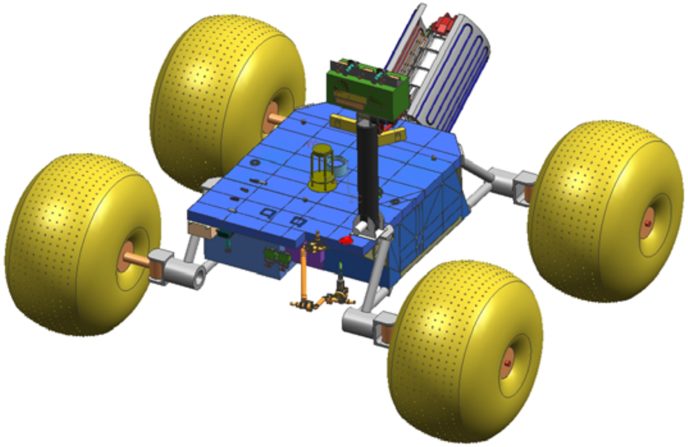
This information is pre-decisional and for discussion purposes only.

Conceptual Advanced RPS for Titan Rover

- The conceptual Advanced RTG convertor is used as the baseline ARPS.
- Power output: ~112 We/1250 Wt (at BOM)
- # of GPHS Modules: 5
- Efficiency: ~9%
- Specific Power: ~4.3 W/kg.
- Mass: 26 kg
- Require 1 Advanced RTG for the Titan Rover mission
- Brayton, Advanced Stirling, and TPV considered, but offer lower mass advantages and/or greater integration challenges compared with Advanced RTG.



Conceptual Advanced RTG

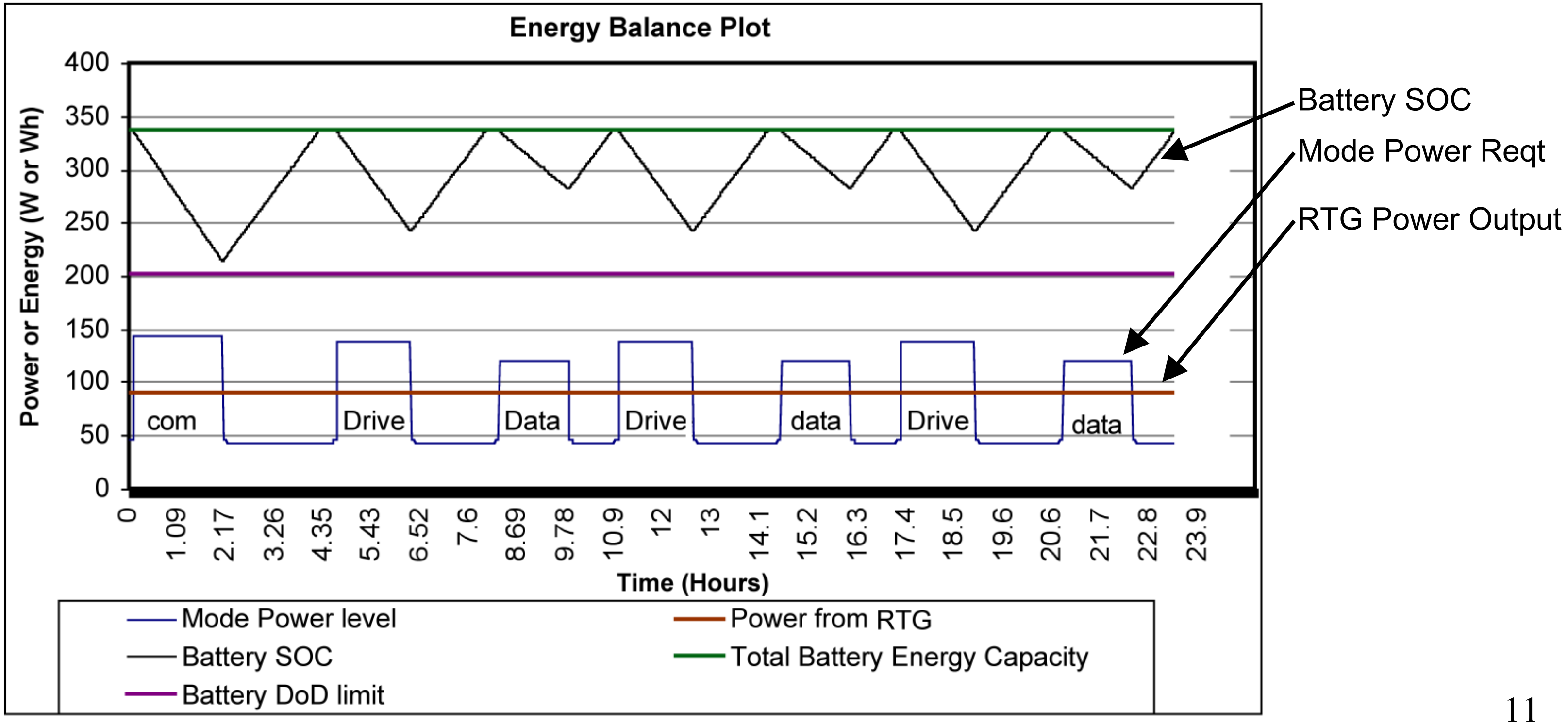


Integration of Advanced RTG with the Conceptual Titan Rover

Solar System Exploration

Power and Duty Cycle

- ARPS provide continuous power over the mission lifetime with a gradual power degradation (~1.6% for Advanced RTG)
- Adv RTG Power Output: ~90 We (after 10 years)
- Hybrid power system with secondary batteries (12Ah)
- Peak Power is High Science mode: 147 We
- 3 x 1.7 hrs drive sessions & 3 x 1.55 hrs science & 2 hrs telecom per day



Titan Rover Operations (continued)

Item	Comments
Traverse	1.5 m diameter wheels (4) with inner tire; Material: PBO (polybenzoxaxole)/Xylon; Could traverse up to ~150 m/hrs; up to ~0.5 km/day; & up to ~500 km/3-years (dependent on science and mission requirements; surface environments; and navigation/autonomy):
Data volume	Rover Science Data Volume: ~28.8 Mbits of science data is downlinked per day
Communications	On rover: 8.4 GHz X-band 0.5 m 2 axis articulated HGA; Emergency LGA; Direct-to-Earth comm. thus landing location limited to the pole region; Assumed 180x12m DSN antenna array:
Autonomy & Navigation	Requires autonomous hazard avoidance; HGA pointing for DTE; Trajectory request uploaded from Earth (direction/distance), rover follows suit and avoids obstacles; No orbiter; All-sky camera; Pointing requires 3600 arcsec of control & 1800 arcsec knowledge to DTE comm.; Use input from IMU/PanCam/accelerometer and cameras to navigate
Structures	MSL chassis; Sampling arm with drill and sample carousel; Arm would carry ultrasonic corer inside a rotatable pod; PanCam style 1.5m mast, stereo+2 nav.cam; all-sky cam
Thermal design	7.6 year cruise phase – RPS excess heat removal from aeroshell (5GPHS, 1250Wt) Virtually finless RPS on surface (94K); Utilize RPS waste heat for WEB
Extreme environments	Radiation: Jupiter flyby 30-200kRad w/o shielding; Ionizing Dose: 10 Krad TID behind 100 mils of aluminum with an RDM of 2 Cold: 94K on the surface; flexible materials / actuators / joints on arm, mast Tholin: could stick to lens, optics
Planetary protection	Not addressed in this limited scope / small budget study

RPS Trade for the Titan Rover

- The conceptual Advanced RTG was assess to provide the best combination of mass savings and integration simplicity relative to other RPS systems.
  - Would save ≥30 kg in mass relative to using the Standard MMRTG due to higher ARPS specific power and system-level “ripple effects”.
  - Would save ≥50 kg in mass relative to using Standard SRG (which would require a redundant unit following current design principles).
  - The mass savings is proportional to the number of RPSs required for the mission, that is, vehicles requiring more power would see even greater mass savings using ARPS.
- The Brayton, Advanced Stirling, and TPV would be preferred (in decreasing order) for the Titan Rover mission.

Titan Rover Summary

- This study assessed the feasibility of an MSL-class Titan rover concept.
- Would perform characterization of Titan's surface composition, morphology, meteorology, organic chemistry, and the interactions between surface materials and the atmosphere.
- The conceptual Advanced RTG is the baseline Titan Rover ARPS - provides the best combination of mass savings and integration simplicity relative to other RPS systems.
  - Resulting mass savings could be used to increase rover payload, add additional design margin, etc.
- Technology challenges and tall poles include:
  - Direct to Earth communications (assumed the upgraded DSN with 180x12m antennas)
  - Extreme environments issues, such as materials for the cold (94K) surface operations incl. inflatable wheels, actuators, joints; sticky tholin deposits on imaging systems
  - Autonomy and Navigation issues

A Conceptual Titan Orbiter with Probe Mission

Introduction

- Cassini-Huygens has provided us significant new information on surface topography, composition and atmosphere characteristics of Titan.
- However, Cassini-Huygens represents only a beginning for the exploration of Titan.
- Only ~20% of the surface of Titan will have been mapped by the end of the nominal Cassini-Huygens mission.
- Large gaps in knowledge will remain in key scientific areas
- This study details a conceptual Titan orbiter mission that would provide full global topographic coverage, surface imaging, and meteorological characterization of the atmosphere.

Focus on Atmospheric Dynamics

- The present mission study focuses on critical Titan science objectives that are not well addressed by the investigations of the Cassini mission.

- Titan's massive atmosphere plays an extremely significant role for Titan's surface processes, because it is the source of the organics that are expected to be present, and because it actively modifies the surface via meterological processes, particularly precipitation.

- A dual-frequency radar investigation can provide insights into atmospheric dynamics and meterological processes that cannot be obtained in any other way. As an added bonus, such an instrument may also function in an altimetry mode, to allow *complete* mapping of the surface topography of this interesting moon.

- The following science objectives reflect this emphasis on atmospheric dynamics and meterology:

Solar System Exploration

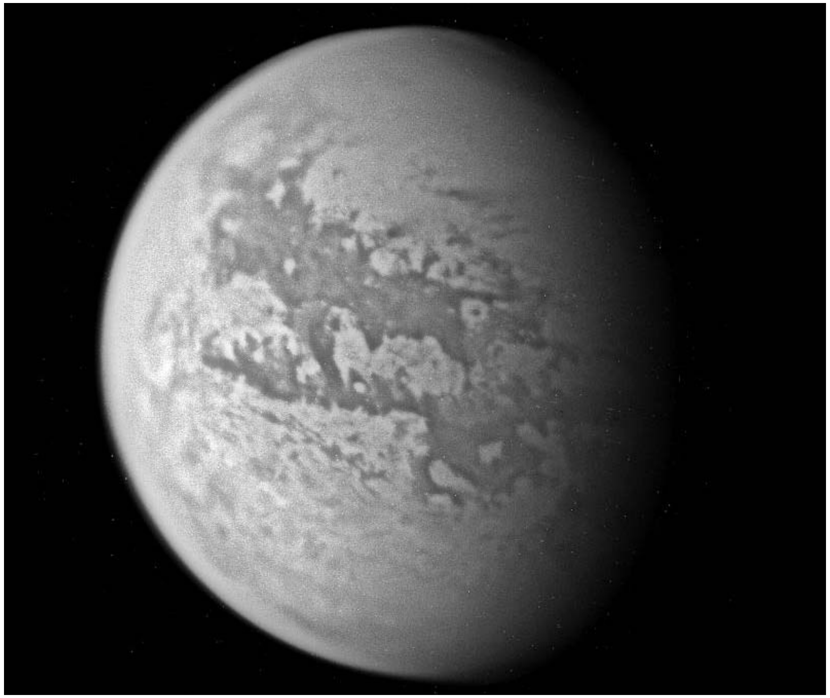
Representative Orbiter Science Objectives

- **Objective 1:** Understand the meteorology and dynamics of the atmosphere.
- **Objective 2**: Resolve the global topography of Titan; Understand the results of meteorological processes and the effects of fluid flows over the surface; and Understand the crustal structure and strength of crustal materials.
- **Objective 3:** Characterize the atmospheric composition of Titan, its variability with latitude and solar phase angle, and characterize the interaction of Titan's atmosphere with Saturn's magnetosphere.
- **Objective 4:** Obtain global imaging coverage of the surface of Titan.

Science goals as recommended in the Post-Cassini/Huygens Titan Study Science Team Final Report (4/12/2001) lead by Leslie Tamppari

Mission Parameters

- The Titan Orbiter mission is assumed to launch in 2015.
- The Orbiter would spend a minimum of two years at Titan to perform detailed global mapping of Titan's:
  - Surface topography
  - Cloud structure and dynamics,
  - Precipitation rates, and
  - Atmospheric composition.



- A "bolt-on" probe would be included to perform in-situ measurements.
  - Lander science goals and detailed design not addressed in this study.
- The baseline power requirement would be ~1 kWe at EOM, driven by a high power radar instrument that would provide 3-dimensional measurements of atmospheric clouds, precipitation, and surface topography.

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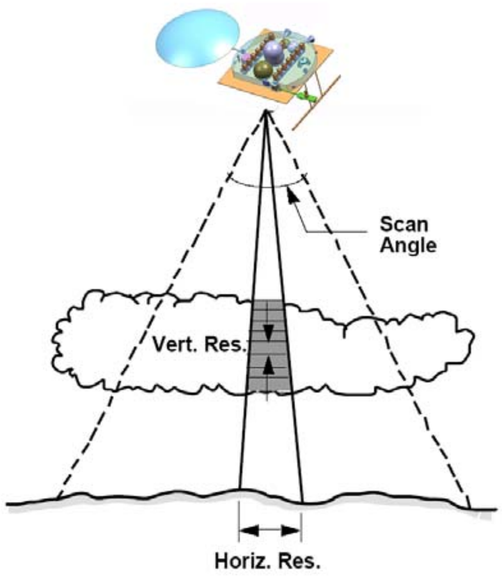
Strawman Science Instruments

Instrument Name	Purpose	Science Objectives Addressed	Heritage
1.Cloud/Precipitation Radar Altimeter	Radar Altimetry mode for global topographic mapping; atmospheric 3-d imaging of clouds and precipitation	Objective 1, to understand the meteorology and dynamics of the atmosphere; objective 2, to resolve the global topography of Titan.	New
2. Infrared Spectrometer	Obtain global infrared (~1.8 to 5 um) surface imaging and measure atmospheric composition	Objective 3, to characterize the atmospheric composition of Titan, and its variability; Objective 4, to obtain global imaging coverage of Titan's surface.	Mars CRISM
3. Wide-angle imager	Public Outreach - (Near IR, imaging at ~ 980 or ~ 2200 nm)	Contributes to objectives 1, 3, and 4 by providing wide-area context images for interpreting the higher resolution radar, near-ir, and mass spectrometer compositional data.	Multiple Missions
4. Radio Science Subsystem	Requires two frequencies (e.g., Ka and X-band) - USO	Contributes to understanding of the state of Titan's interior, which is relevant to the scientific questions addressed by objective 2 (surface topography).	Cassini
5. Synthetic Aperture Radar	High-resolution radar mapping of surface morphology and surface properties	Objective 2, to resolve the global topography of Titan, to understand the fluvial and other processes that modify Titan's surface.	Cassini
6. Ion and Neutral Mass Spectrometer	Measures upper atmospheric chemistry and quantifies magnetospheric interactions.	Objective 3, to characterize the atmospheric composition of Titan, and its varibility with latitude and with time.	Cassini

Titan Cloud/Precipitation Radar and Altimeter (TCPRA)

- Mission design driven by the TCPRA instrument proposed under the High Capabilities Instruments for Planetary Exploration (HCIPE) program.
  - TCPRA instrument proposed by Eastwood Im (JPL), Stephen Durden (JPL), and Ralph Lorenz (U of A)
- Would be used for global measurements of the 3-D structures of the atmospheric clouds, precipitation, and surface topography of Titan.
- 4-m Antenna
- 35 GHz and 94 GHz dual-frequency radar instrument.
- Average Power: 1.2 kWe
- Data Rate: 10 Mbps
- Mass: 400 kg

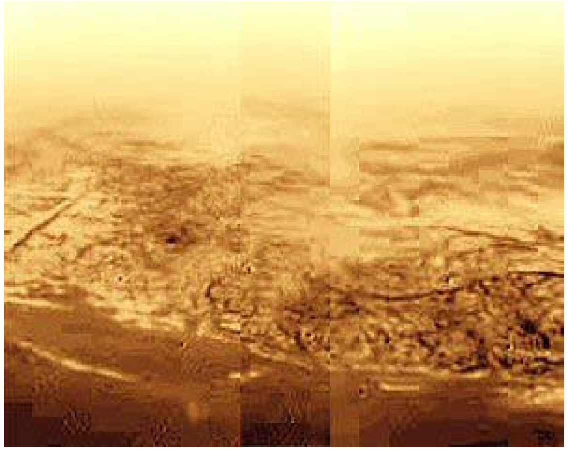


Parameter	35 GHz	94 GHz
Antenna Diameter (m)	4	
Beamwidth (°)	0.14	0.05
Scan Angle (°)	±15	±7.5
Swath Width (km)	770	370
Horizontal Res (km)	3.4	1.3
Cloud/Precip Vertical Res (m)	250	250
Cloud/Precip Bandwidth (MHz)	3	3
Altimetry Vertical Res. (m)	10	10
Altimetry Bandwidth (MHz)	18	18
PRF (kHz)	3	3
Doppler velociy precision (m/s)	0.7	0.7
Data Window Size (km)	50	50
Pulse Length (us)	10-40	10-40
Peak Power (kW)	3	2
Min. dBZ after averaging	0	-17
Data Rate (Mbps)	10	
Mass (kg)	400	
Required s/c power (kW)	1.2	

Solar System Exploration

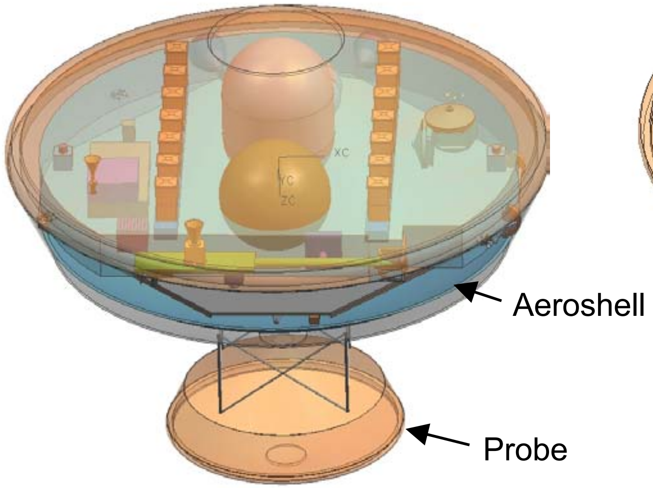
Mission Architecture

- The spacecraft is assumed to launch in 2015 with a C_3 of 25.7 km^2/s^2 using an Earth-Jupiter gravity assist (EJGA).
  - Would arrive at Titan ~2022 (7.6 years later).
- The Titan Orbiter spacecraft would consist of an orbiter stage, an aeroshell, and a deployable "black box" probe.
  - The details of the probe were not explored in this study; only the available mass was determined based on the launch mass margin.
- The orbiter stage housed within the lifting body aeroshell at launch, with the Probe mounted externally to the backside of the aeroshell.
  - Use of aerocapture provides significant mass savings versus the use of conventional chemical propulsion to perform Titan orbital insertion.
- The 2015 launch date would permit a large delivered mass to Titan (~5000 kg) using a Delta-IV Heavy launch vehicle (LV).

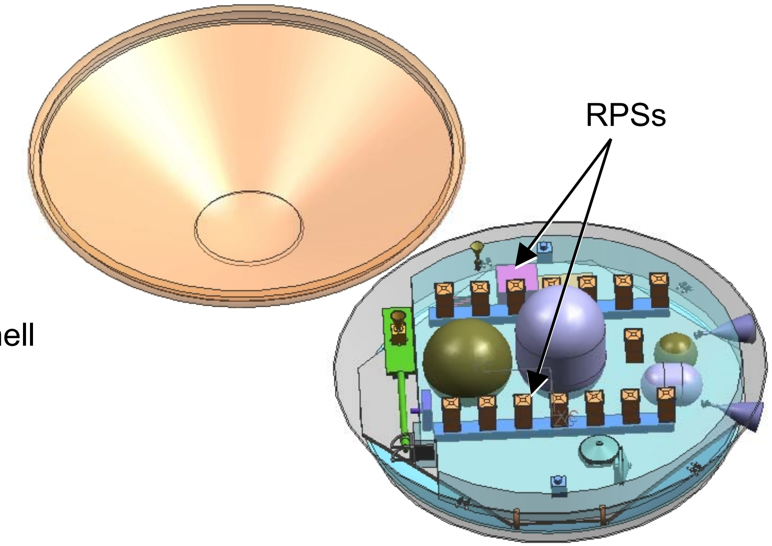


Conceptual Spacecraft Configuration

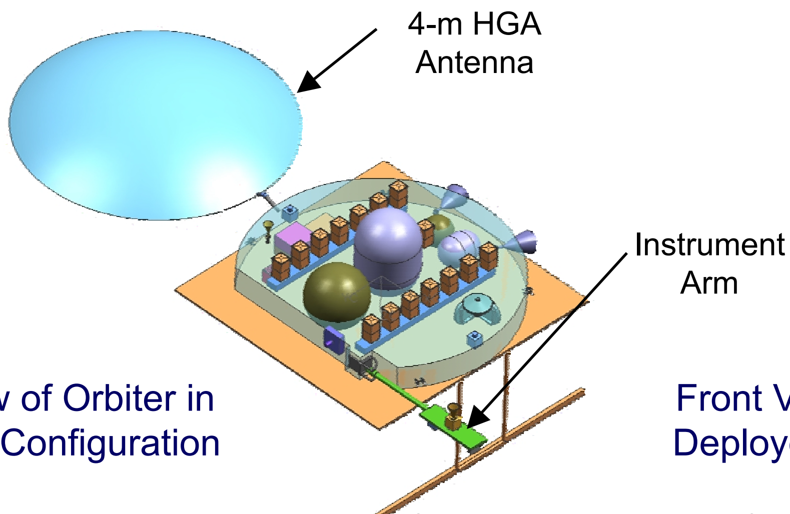
Orbiter and Probe within LV Fairing



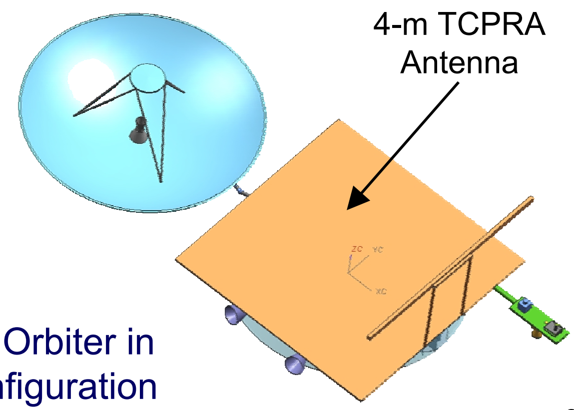
Detail of Orbiter and Probe



Aeroshell Open During Cruise
(Probe Not Shown)



Rear View of Orbiter in Deployed Configuration



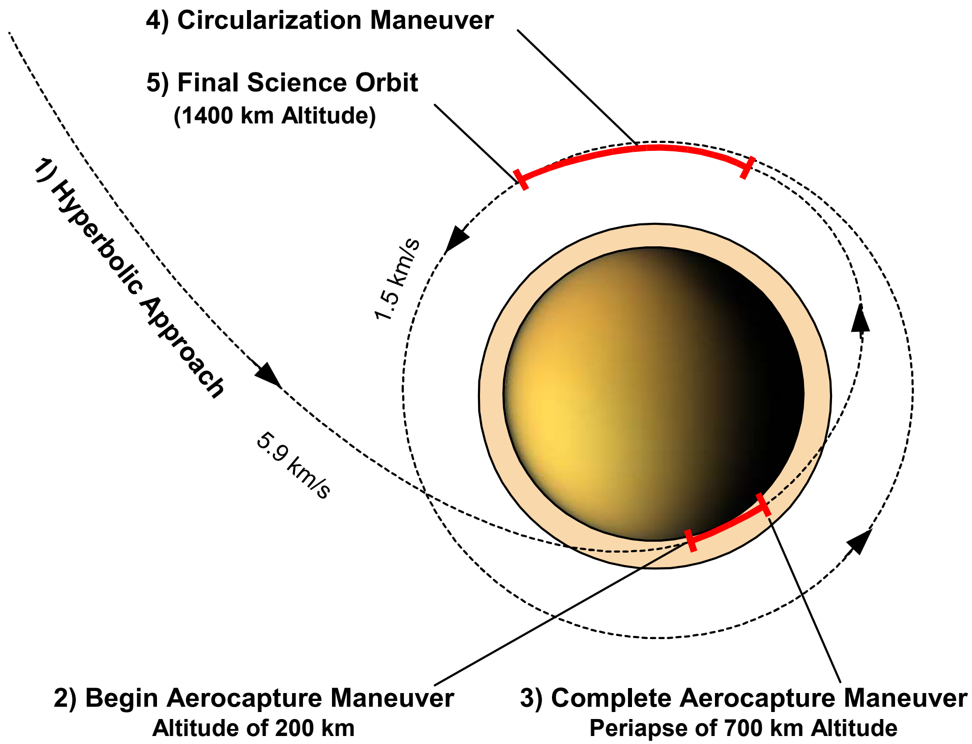
Front View of Orbiter in Deployed Configuration

This information is pre-decisional and for discussion purposes only.

Conceptual Illustrations Only

Mission Architecture

- During the cruise phase, the aeroshell would be opened permitting passive thermal control of the RPSs (Can radiate to deep space.)
- As the spacecraft approaches Titan, the probe would be released from the aeroshell and enter Titan's atmosphere directly.
- Prior to aerocapture, the aeroshell would be closed and locked. At this point, the RPS heat would need to be stored using phase change material (PCM).
- The Orbiter would enter Titan's atmosphere with a periapse of 200 km, maneuver to a periapse of 700 km (using its lifting body aeroshell), and exit with an apoapse of 1400 km.
- Following aerocapture, the Orbiter would be deployed from the aeroshell.
- Subsequent engine firings would circularize the spacecraft orbit to 1400 km.



Solar System Exploration

Delta V and Power

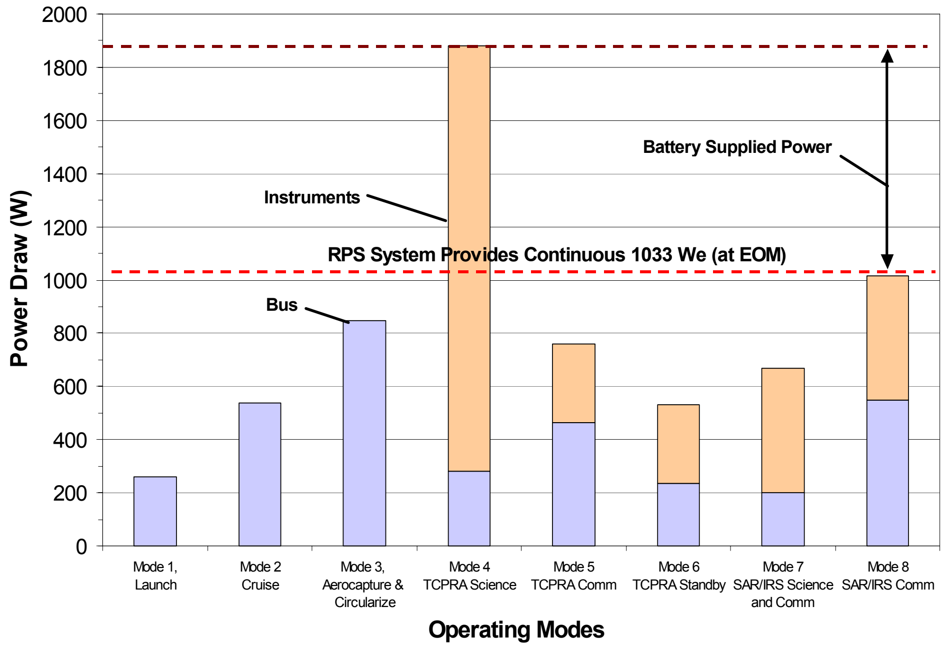
Activity	Delta V (m/s)	Prop Mass (kg)	Description
TCMs	10	17	Trajectory correction maneuvers during cruise phase.
Deep Space Maneuvers	706	1070	Deep space maneuvers during cruise phase.
Approach, Earth and Jupiter	45	61	Trajectory corrections during Earth and Jupiter Approach
Orbiter Maneuver during Probe Release	30	35	Avoidance maneuvers during the deployment of the “black box” probe.
Bank Angle Control	20	39	Orbiter attitude control during Titan aerocapture maneuver
Periapse Raise and Cleanup	76	52	Delta V required for orbit circularization and cleanup maneuvers following aerocapture maneuver.
Atmospheric Drag Compensation	1	1.2	Periodic atmospheric drag compensation to maintain 1400 km elevation during 2 year science mission.
Oxidizer and Residual Propellant	0	22	Holdup volume / residual margin of propellant and oxidizer.
Total Delta V	**888**	**1297**	

Delta V

- Total Delta V is ~890 m/s.
- Corresponds to ~1300 kg of propellant (82%).
- DSMs account for majority of delta V.
- Atmospheric drag at Titan (@1400 km) is small; requires ~1 m/s for a 2 yrs.

Power

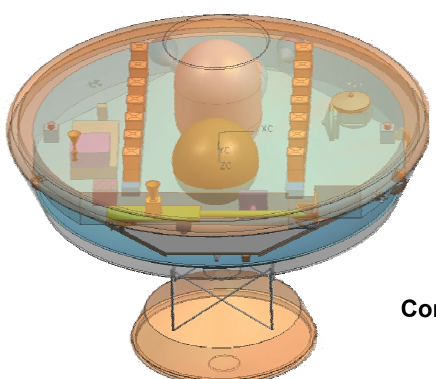
- Max Power Draw: 1880 W
  - Occurs during TCPRA Operation
- RPS Power @EOM: 1033 W
- # RPSs: 15 (Includes one spare)
- Batteries: (3) Li-Ion secondaries
  - Used to cover peak loads incurred during TCPRA Radar Operation.
  - Are recharged during other lower power operating modes.



Mass Estimates

- Injected Mass Capability: ~5730 kg on Delta IV-H.
- Instrument Mass: 626 kg
- Orbiter dry mass: 2130 kg
- Orbiter wet mass: 3425 kg
- Available Mass Margin for a Probe System: ~690 kg
  - Probe: 480 kg
  - Probe support structure: 210 kg

Subsystem	Mass, (kg)		
	All Units w/o Margin	Margin, %	All Units w/ Margin
Orbiter Stage (Dry)	**1662**		**2129**
Orbiter Stage (Wet)	**2958**		**3425**
Instruments	**481**	**30%**	**626**
TCPRA	400	30%	520
CRISM	28	30%	36
Small Wide-Angle Imager	3	30%	4
Radio Science Subsystem	1	30%	1
Cassini SAR	41	30%	53
INMS	9	30%	12
ACS	**34**	**25%**	**43**
C&DH	**10**	**30%**	**13**
Structures and Mechanisms	**361**	**30%**	**469**
S/C Adapter	**37**	**30%**	**48**
Power	**254**	**30%**	**330**
Li-Ion Battery System	25	30%	33
Advanced Stirling RPSs	210	30%	273
Power Conditioning and Balance	18	30%	24
Cabling	**99**	**30%**	**128**
Thermal	**104**	**25%**	**135**
Telecom	**125**	**20%**	**150**
Propulsion	**136**	**20%**	**165**
Propellant and Pressurant	**1297**	**0%**	**1297**
System Contingency	**22**	**0%**	**22**
L/V Adapter	**324**	**0%**	**324**
Probe	**337**	**30%**	**482**
Probe Support Structure	**145**	**30%**	**207**
Aeroshell	**1292**	**0%**	**1292**
Total Launch Mass (Dry)	**3760**		**4434**
Total Launch Mass (Wet)	**5057**		**5730**

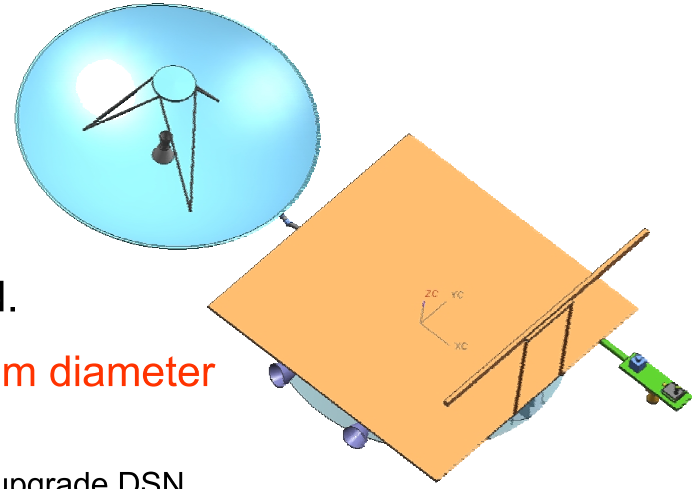


Conceptual Only

Robert Abelson, JPL, June 2005

Telecom

- High rate Ka-band link at Titan.
- Deployed 4-m diameter HGA..
- 2.3 Mbps downlink data rate at 10.5 AU.
- 125-W (RF) transmit power at 32 GHz Ka-band.
- Assumes upgraded DSN, consisting of 180 12-m diameter antennas arrayed together.
  - Existing DSN would limit data rate to ~1/10th that of the upgrade DSN.



Conceptual Only

Thermal

- RPS heat used to maintain operating temperatures of subsystems.
- Use of loop heat pipes increases system reliability (no moving parts).
- Phase change material (PCM) used to store heat during aerocapture maneuver.
  - Advanced Stirling requires least amount of PCM (~40 kg) due to greater conversion efficiency.
  - Advanced RTG requires greatest amount of PCM (~150kg) due to lower conversion efficiency.

RPS Configuration	Total # of GPHS Modules	Thermal Power, We (BOM)	Thermal NRG Generated in 1 hr, kJ	Required PCM Mass, kg
Advanced Stirling	15	3750	13500	41
Brayton	22	5500	19800	59
TPV	36	9000	32400	97
Advanced RTG	55	13750	49500	149

RPS Trade Study for the Titan Orbiter

- Trades were performed on RPS type versus spacecraft mass to assess the amount of mass available to support a "bolt-on" probe.
- Four advanced RPS systems and two standard RPSs were considered.
- All of the advanced RPSs allowed for a viable Titan Orbiter.
  - However, only two permitted a probe ≥375kg (i.e., JIMO class lander)
  - The advanced Stirling permitted the largest probe size (~690 kg)
- The Standard SRG provided a viable Titan Orbiter without a probe.
- The Standard MMRTG exceeded the LV launch capability – not viable.

RPS Type	Mass, kg					
	Orbiter, Dry (No Aeroshell, Adapter or Probe)	Propellant and Pressurant, kg	Orbiter, Wet (No Aeroshell, Adapter, or Probe)	Aeroshell	LV Adapter	Additional Remaining Mass Margin
Advanced Stirling	2129	1296	3425	1292	324	**689**
Advanced Brayton	2357	1307	3663	1366	324	**377**
Advanced RTG	2450	1311	3760	1396	324	**250**
Advanced TPV	2538	1314	3852	1425	324	**129**
Standard SRG	2458	1311	3769	1400	324	**236**
Standard MMRTG	2814	1316	4131	1555	324	**-280**

Advanced RPS would enable the addition of a JIMO-class probe.

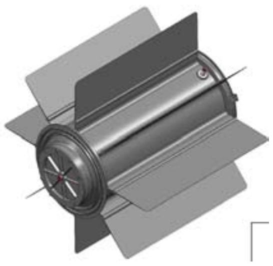
Titan Orbiter Summary

- The Titan Orbiter mission would provide a valuable follow-on to Cassini Huygens.
- Would perform detailed global measurements of Titan's: a) Surface topography, b) cloud structure and dynamics, c) precipitation rates, and d) atmospheric composition.
- The spacecraft is designed around the high power Titan Cloud and Precipitation Radar Altimeter (TCPRA).
  - Drives the power requirement of ~1 kW (EOM) and data rate requirement of 2.3 Mb/s.
- The Titan Orbiter would use a lifting body aeroshell for aerocapture into Titan Orbit (enabling technology).
  - Significantly reduces prop mass, but need to store RPS heat during aerocapture.
- The higher efficiency of dynamic Advanced RPSs significantly reduces the mass of PCM required for heat storage during aerocapture.
- This mass savings, along with the greater specific power of ARPS, provides additional mass margin compared with Standard RPS systems.

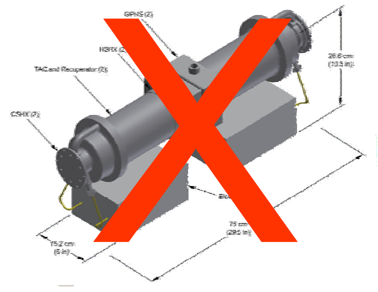
Advanced RPS could enable a $\geq$375 kg "bolt-on" probe for the Titan Orbiter mission.

Conclusions

- Advanced RPSs are enhancing, and potentially enabling for the Titan rover and orbiter concepts considered herein.
- ARPS would enhance a Europa Orbiter mission, and enable a long-duration Venus lander or rover.
- The mass benefit of ARPS increases for missions with higher power requirements.
- In 2004, four ARPS technologies were being developed by NASA.
  - Advanced RTG, Advanced Stirling, Brayton, and TPV
- In 2005, NASA budget reductions resulted in the cancellation of two ARPS programs (Brayton and TPV).
- Currently, only Advanced RTG and Advanced Stirling are being funded, but at a reduced rate.
- Further budget reductions, or loss of the ARPS program, would significantly constrain the capabilities of future missions.

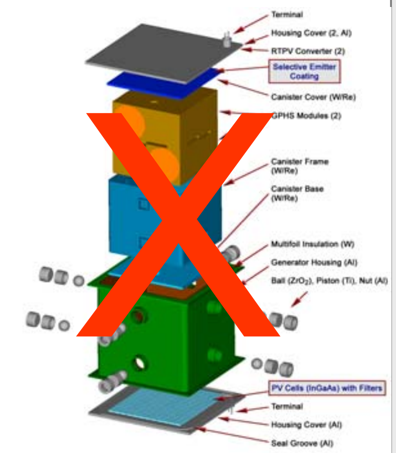


Adv. RTG



Brayton

Adv. Stirling



TPV

Need science community support to ensure that NASA continues to make advanced RPS development a high priority.