A Conceptual Titan Orbiter Mission Using Advanced Radioisotope Power Systems

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Abstract. With the remarkable success of the Cassini-Huygens mission, considerable new knowledge has been obtained regarding the surface topography, composition and atmosphere characteristics of Titan. However, Cassini-Huygens represents only a bold beginning for the exploration of Titan, as only ~20% of the surface of Titan will have been mapped by the end of the nominal mission. Large gaps in knowledge will remain in key scientific areas including global surface topography, atmospheric and surface composition, precipitation rates, and the density, thickness, and formation processes of clouds. This study details a conceptual follow-on Titan orbiter mission that would provide full global topographic coverage, surface imaging, and meteorological characterization of the atmosphere over a nominal 5-year science mission duration. The baseline power requirement is ~1 kWe at EOM and is driven by a high power radar instrument that would provide 3-dimensional measurements of atmospheric clouds, precipitation, and surface topography. While this power level is moderately higher than that of the Cassini spacecraft, higher efficiency advanced RPSs could potentially reduce the plutonium usage to less than 1/3rd of that used on the Cassini spacecraft. The Titan Orbiter mission is assumed to launch in 2015. It would utilize advanced RPSs to provide all on-board power, and would employ an aeroshell to aerocapture into Titan orbit. Additionally, a 500 kg "black box" deployed probe, with unspecified science instrumentation, was included in the design. The advanced Stirling RPS was selected due to its projected high specific power and higher conversion efficiency, resulting in the ability to include a 500 kg probe.

INTRODUCTION

This paper describes a conceptual orbiter with probe mission to Titan that would be enabled using advanced radioisotope power systems and aeroshell technology. This study was performed to assess the feasibility of a Titan orbiter mission using a realistic science-driven payload matched to the science goals of the Decadal Survey of the National Academies. The Titan Orbiter mission would be a follow-on to Cassini-Huygens, and a potential precursor to a dedicated rover or aerobot mission once full surface mapping had been completed. The technology cutoff date for this mission was assumed to be 2011, with a launch date of 2015. The Titan Orbiter spacecraft would consist of an orbiter stage and a deployable probe - the details of the probe were not explored in this study. The orbiter stage would initially be housed with a lifting body aeroshell (Figure 1) used for aerocapture at Titan, with the Probe mounted externally to the backside of the aeroshell. Aerocapture was selected for this mission study due to the significant mass savings obtained versus the use of conventional chemical propulsion to perform Titan orbital insertion. The 2015 launch date is significant in that it permits a large delivered mass to Titan (~5000 kg) using a Delta-IV Heavy launch vehicle (LV). Besides its heavy lift capability, this LV was selected for its 5-m diameter fairing,

which is required to accommodate the large 4-m radar instrument antenna and 4-m Ka/X-band high gain antenna. The Titan Orbiter would launch to a C_3 of 25.7 km^2/s^2, and use Earth and Jupiter flybys to maximize launch mass and minimize trip duration to Titan.

During the cruise phase, the aeroshell would employ a clamshell configuration that would be opened during cruise, permitting direct exposure of the RPSs to deep space (Fig. 2). This permits passive thermal control of the RPSs and precludes the need for an auxiliary set of externally mounted radiators were the aeroshell to remain closed during the cruise phase.

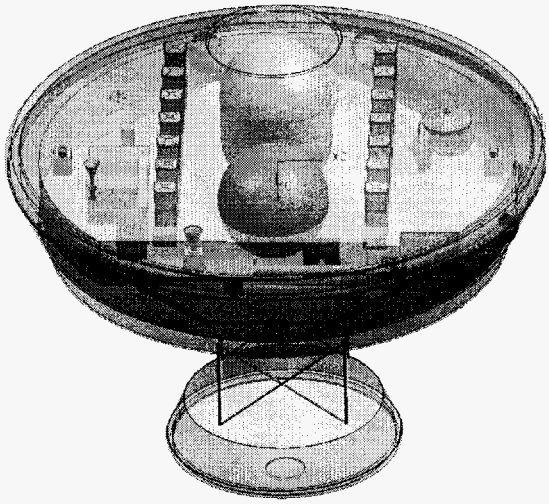

FIGURE 1. Titan Orbiter Spacecraft within Protective Aeroshell and externally Mounted Probe

As the spacecraft approaches Titan, it would be maneuvered to properly orient the probe for release from the aeroshell. Once released, the probe would continue independently and enter Titan's atmosphere directly. The subsequent probe entry, descent, landing, and science mission were not addressed in this study, however, many options could be considered for a 500 kg probe. As the Orbiter approached Titan's atmosphere, the aeroshell would be closed and locked in preparation for aerocapture into a polar orbit. Once closed, the heat of the RPSs would be stored using phase change material (PCM). The spacecraft would enter Titan's atmosphere with a periapse of 200 km altitude, maneuver to a periapse of 700 km using its lifting body aeroshell, and exit with an apoapse of 1400 km. The duration of the aerocapture maneuver is estimated at ~15 minutes, and the total time between closure of the aeroshell and subsequent reopening is estimated at one hour for purposes of sizing the thermal control system. Upon completion of aerocapture, the Titan Orbiter would be deployed from the aeroshell, and the RPSs thereafter allowed to passively radiate to deep space. Subsequent engine firings would be performed to circularize the spacecraft orbit to 1400 km.

Upon reaching its final circular polar orbit, the Titan Orbiter would deploy its high-gain antenna (HGA) and the corners of the radar instrument antenna (Figure 3), which had been folded and stowed under the HGA since launch (Figure 2). Following instrument checkout and calibration, the nominal 2-year science mission would commence. Science would be collected in two distinct modes – the first geared towards radar mapping of Titan's surface topography atmosphere, clouds, and precipitation using the Titan Cloud/Precipitation Radar and Altimeter (TCPRA). The requirements for this mode are a nominal 25% duty cycle, meaning that the TCPRA would take measurements for 25% of each orbit (from the equator to the pole or vice versa) and use the remainder of the orbital period for downlinking the data to Earth and recharging its batteries for the next orbital period (the peak power draw of the TCPRA exceeds the steady state power output of the RPSs, thus secondary batteries are required). The power level and duty cycle of the TCPRA instrument are the key drivers for the ~1 kWe (EOM) power requirement of the orbiter. A shorter duty cycle could reduce the required number of RPSs, but at the expense of reduced coverage during each orbital period. All other instruments would be kept in a standby state during this mode of

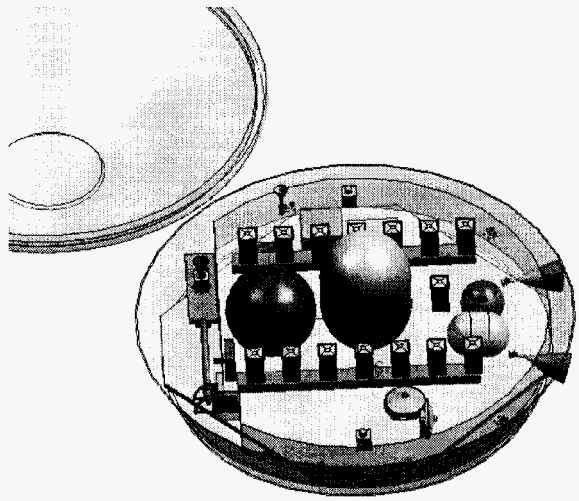

FIGURE 2. Titan Orbiter Spacecraft with Aeroshell Opened During the Cruise Phase (Probe Not Shown)

operation. The second science mode involves the operation of the Orbiter's SAR, IR surface mapper, and radiometer. The TCPRA would be placed in standby state during this mode of operation. Changes in science modes could be performed as determined by the mission science team, and were tentatively assumed to occur once a week for this study. The orbiter has a tight pointing requirement based on the IR Mapper's field of view, and assessed at 16 arcsec of control, 6 arcsec of knowledge, and 0.5 arcsec/sec of pointing stability

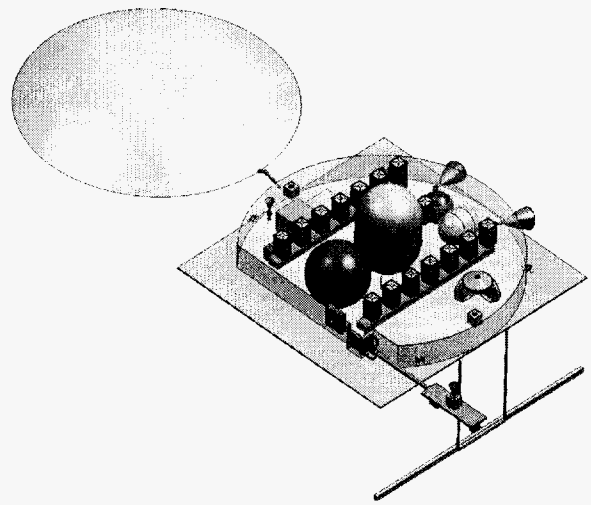

FIGURE 3. Illustration of the Back Side of the Titan Orbiter in its Fully Deployed Configuration

SCIENCE GOALS

Saturn's large satellite Titan is the only body in the solar system other than the Earth that has a substantial atmosphere dominated by molecular nitrogen. The similarities and differences of atmospheric processes on the Earth and Titan are of considerable interest to the scientific community. In addition, the prebiotic organic chemistry expected to be found at Titan's surface is of great interest for scientists concerned with the origins of life. The National Research Council's Decadal Survey [1] identified Titan as the second highest-priority target for future missions to the outer solar system, after Europa. The first Cassini Orbiter observations of Titan have only increased the level of interest. Follow-on missions to the Saturn system to explore Titan's mysteries in more detail are being studied both in the U.S.A. and in Europe. Some of the most critical objectives for future missions to Titan can only be addressed from lander or rover platforms. The surface composition, the distribution and nature of surface organics, and the present-day chemical interactions of the surface and atmosphere are among these. The thick, smoggy atmosphere of Titan makes it difficult to study these phenomena from orbit. There are also a number of key Titan science objectives that can only be addressed by an orbiter mission. Among these objectives are the desire to understand the dynamics of the atmosphere, including the meteorology of clouds and precipitation on Titan; the desire to measure and understand the global topography and the distribution of geomorphic landforms across the body; the desire to understand the atmospheric composition and its interactions with Saturn's magnetosphere; and the need to obtain global imaging coverage of the surface. The present mission study focuses on these four potential orbiter mission objectives.

SCIENCE INSTRUMENTS

The most unique and powerful instrument of the Titan Orbiter payload is the Titan Cloud/Precipitation Radar and Altimeter (TCPRA) [3]. The dual-mode radar (35 and 94 GHz frequencies) allows for imaging both clouds (35 GHz) and precipitation (95 GHz) simultaneously, enabling the 3-dimensional imaging of convective weather systems. Based on a number of proven technologies from Earth observing systems, the TCPRA could resolve atmospheric clouds and precipitation with 250 m vertical resolution over a 50 km altitude window. This would provide completely new insights into the dynamics and circulation of Titan's atmosphere. In altimeter mode, TCPRA could acquire surface height measurements with 10 m vertical resolution. This fulfills the objective of obtaining global topographic coverage of Titan that could not be achieved during the Cassini Mission. The TCPRA is a high-capability instrument, requiring an average of 1.2 kWe. Its large mass (400 kg) and high data rate (10 Mb/s) are dominating factors for overall spacecraft design.

The Titan Orbiter would carry a near-infrared spectrometer (IRS) similar to that used on the Mars Reconnaissance Orbiter, but optimized for the Titan environment and requirements. The composition of Titan's atmosphere is revealed by this instrument. The abundances of the various atmospheric species may be estimated by the depths of the individual absorption features observed. A synthetic aperture radar (SAR) similar to that on Cassini would be included in the Titan Orbiter payload to provide radar imaging and altimetry that complements and extends the radar altimetry performed by the TCPRA. Surface properties such as roughness and material dielectric constant affect the returned signal, allowing scientists to obtain additional key information about surface roughness and other properties. Titan's atmosphere is relatively thicker (or deeper) than that of the Earth,

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due to the lower surface gravity. The Titan Orbiter would be placed in a science orbit with altitude 1400 km to avoid excessive atmospheric drag. At this altitude the ion and neutral mass spectrometer (INMS) would be able to continuously monitor high-altitude neutral atmospheric composition, while also resolving ions produced by the interaction of Saturn's magnetosphere with Titan's atmosphere. The Titan Orbiter would also carry a wide-angle camera, for context imaging and for obtaining spectacular views of Saturn and its rings and satellites during the orbiter mission. Although no dedicated instrument package is included on the orbiter for gravitational mapping, standard radio science techniques applied to the frequency shifts of the downlink signal will allow improved information on the gravity field and internal distribution of mass of Titan to be obtained during this mission.

ADVANCED RPS CHARACTERISTICS

The baseline Titan Orbiter mission uses advanced Stirling RPSs for all electrical power generation. Other advanced RPS options were also considered for this mission study (i.e., Advanced RTG, TPV and Brayton) [2]; however, the higher efficiency and specific power of the advanced Stirling system yielded the lightest overall Orbiter configuration and, subsequently, enabled the inclusion of a 500 kg probe. Each advanced Stirling RPS is assumed to generate 80 We at BOM with a conversion efficiency of 32% (Table 1) [2]. A single 250 Wt (BOM) GPHS module would be used for this RPS design. Thermal control would be performed via heat rejection from the Stirling housing and small external fins, and via an integrated cooling loop that interfaces with the Titan Orbiter spacecraft cooling system for maintaining spacecraft operating temperatures and for energy storage during the aerobraking maneuver. An active vibration compensator is assumed to limit vibration levels associated with the single convertor system. A total of fifteen advanced RPSs would be used on the Titan Orbiter spacecraft, generating 1200 We at BOM and ~1100 We after 10 years.

TABLE 1. Advanced Stirling RPS Performance for Titan Orbiter Mission

Advanced RPS Parameter	Value
Number of Adv. Stirling RPSs	15
Number of GPHS modules per RPS	1
Total Number of GPHS modules	15
Total Thermal Power at BOM, Wt	3750
Conversion Efficiency	32%
Electrical Power per RPS at BOM, We	80
Total Electrical Power at BOM, We	1200
Degradation Rate per year	0.8%
Mission Duration, Years	10
Electrical Power at EOM, We	**1107**

DATA AND COMMUNICATIONS

The Titan Orbiter mission would be divided into separate cruise and science phases. During the cruise phase, data volume would generally be limited to health and status information of key subsystems, and the resulting data volume would be relatively low. During the science phase, however, the data volume would be significant, particularly during operation of the TCPRA instrument, which drives the data storage and communications design of the vehicle. The TCPRA has an estimated raw data rate of 10 Mb/s, generating about ~42 Gb per orbital pass using a 25% duty cycle. Lossless data compression is used (e.g., Rice or Huffmann methods) to reduce the stored data volume by a factor of 2.25, corresponding to ~18.6 Gbits per orbit. A solid state recorder (SSR) is used to store this data during TCPRA operations, and play it back during the subsequent 2.5 hour downlink mode each orbit. A 100% memory margin is included in the SSR design to guard against missed or failed downlinks, permitting storage of two orbit's worth of TCPRA data. Data storage during the second science mode (SAR/IRS) is 6.7 Gb/orbit raw and ~3 Gbits/orbit compressed, which is well within the capability of the 40 Gb SSR design.

The Orbiter would use a deployable 4-m Ka/X-band high gain antenna (HGA) that is nominally stowed during the cruise phase and deployed once in orbit about Titan. During the cruise phase, an articulated X-band medium gain antenna (MGA) would be used for downlinking nominal engineering and optical navigation data. Two X-band low-gain antennas (LGAs) are included for omni-directional communication with Earth during launch and near-Earth operations. An upgraded Deep Space Network (DSN) of 180 12-m diameter antennas is assumed in this study, and is consistent with the concepts currently being considered for development in the 2015 and 2020 timeframe. The Titan Orbiter would not start its science mission until ~2023, and thus could use the existing DSN during the cruise phase while the upgraded DSN was constructed and checked out. The Titan Orbiter would have a nominal communications window of 1.16 hours per orbit while operating in the TCPRA Science Mode, corresponding to ~13 hours per Earth day in this mode. In the less stressing SAR/IRS science mode, the communications window is 0.4 hrs per

orbit, or ~2 hours per Earth day. The 4-m Ka/X-band HGA would use redundant 125-W(RF) amplifiers at 32 GHz to transmit data at 2.3 Mbps at a maximum range of 10.5 AU from Earth. The HGA is assumed to be 50% efficient and requires 0.02 degree pointing accuracy. The articulated 0.2-m (20 dBi) Ka/X-band MGA would include redundant 35-W and 200-W (RF) transmitters to provide dual rate data downlink during cruise phase and for emergency events. The 200-W(RF) transmitter provides 1.2 kbps downlink at 10.5 AU distance from Earth (using the upgraded DSN), and would be used for playback of Op-Nav telemetry. The 35-W (RF) transmitter would be used for emergency downlinks, with a maximum data rate of 10 bps at 10.5 AU range distance.

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THERMAL

The Titan Orbiter would use a combination of passive and active thermal control systems to maintain operating and survival temperatures during the mission. A key challenge of the orbiter thermal control system is the rejection of the heat from the RPS power systems. A key advantage of the advanced Stirling-based RPSs is its higher power conversion efficiency relative to other RPS concepts, translating into less heat required to generate the same power level. The fifteen advanced Stirling systems required to power the spacecraft cumulatively generate 3750 W of thermal power at BOM. Effective management of this heat is critical during all phases of the mission. While on the launch pad, cooling of the spacecraft would be supplied by on-pad resources (i.e., chillers). During launch and up through fairing jettison, cooling would be accomplished by phase change of the residual pad cooling fluid. Once the spacecraft was free and clear from the fairing, the clamshell-style aeroshell would open (Fig. 2), permitting the RPSs to radiate directly to deep space using their integrated radiators. (The concept of an opening/closing aeroshell is not new, as both the Genesis and Stardust missions used a back shell that could perform this function. However, in their case, the open back shell was used to expose the science collection plates, and was subsequently closed for aero-entry at Earth.) During the ~8 year cruise phase, the RPSs would be passively cooled, with loop heat pipes used to transfer some of their heat to warm spacecraft subsystems. Additionally, the RPSs would be physically located around the propellant tanks to provide radiative heating of the fuel and oxidizer, thus reducing the required power needed for electrical heaters.

Just prior to aerocapture at Titan, the aeroshell would be closed, requiring that the RPS thermal energy be stored for approximately one hour. In order to effectively manage this heat, a phase change material (PCM) system would be used in conjunction with passive heat pipes. PCMs are effective, flight proven materials for maintaining prescribed temperature levels, and have been successfully used on numerous space missions [4]. Water was selected for its relative high heat of fusion (333 kJ/kg) and well-known thermophysical properties [4]. In general, the heat storage capability of a PCM is proportional to its heat of fusion and the quantity of material. Approximately 40 kg of PCM is required using advanced Stirling RPSs. Thermal control of the aeroshell would be performed via ablation of the phenolic-impregnated PICA structure and radiative heat transfer from the aeroshell surface to deep space.

Once the aeroshell has been jettisoned following aerocapture, the RPSs would be exposed to deep space permitting passive thermal control as during the cruise phase. Passive thermal management would be maintained using a combination of MLI, thermal surfaces, thermal conduction controller, passive heat pipes. Active thermal control would include electric heaters (mainly for propulsion elements and other temperature sensitive elements). A shunt radiator would be used to reject excess electric generated energy (this radiator is sized to be capable of rejecting the entire electrical load if required).

PROPULSION

The total delta V requirement for the Titan Orbiter mission is ~890 m/s, with approximately 710 m/s allocated to Deep Space Maneuvers, and the balance used for trajectory correction maneuvers, orbit circularization and cleanup burns following aerocapture, and reaction wheel desaturation and drag makeup while in Titan orbit. The total mass of propellant (fuel, oxidizer and pressurant) is estimated at ~1300 kg (Table 2). All thrusters and propellant systems are integrated on the Titan Orbiter spacecraft to reduce unnecessary redundancy and decrease mass. The Titan Orbiter propulsion system consists of separate high, intermediate, and low-thrust engines. The high thrust system is comprised of two bi-propellant 450-N HiPAT™ thrusters (Isp of ~325 s) using hydrazine (N_2H_4) and nitrogen tetroxide (NTO). The intermediate-thrust system is comprised of eight 90-N MR-120 monoprop thrusters (Isp ~226 s), and the low-thrust system comprised of sixteen Aerojet 0.7-N MIT monoprop thrusters (Isp~210 s). Sepa-

rate pressurization tanks are used for the bi-propellant and monopropellant systems. The aeroshell would include penetrations in its back-side, permitting the Orbiter-based thrusters to operate with the aeroshell in place (i.e., during the cruise and aerocapture phases of the mission). The propulsion system is assumed to utilize existing heritage technology, and as such, would be inherently low risk. All thrusters have functional redundancy including a backup main engine, four back-up MR-120 engines, and eight back-up MIT thrusters

TABLE 2. Delta V Estimates for the Titan Orbiter

Activity	Delta V (m/s)	Prop Mass (kg)
Trajectory Correction Maneuvers	10	17
Deep Space Maneuvers	706	1070
Approach, Earth and Jupiter	45	61
Maneuvers during Probe Release	30	35
Bank Angle Control	20	39
Periapse Raise and Cleanup	76	52
Atmospheric Drag Compensation	1	1.2
Oxidizer and Residual Propellant	0	22
Total Delta V	**888**	**1297**

POWER

The Titan Orbiter would nominally require ~1030 We at EOM in order to meet the science and mission objectives of this study. This corresponds to fourteen advanced Stirling RPSs (each generating 80 We at BOM). Consistent with NASA/DOE design principles [5], a redundant Stirling RPS would be added, yielding a total of 15 Stirling RPSs for this concept. The spacecraft power system would be located on the Orbiter – there are no power requirements for the aeroshell, and the "black box" probe is assumed to be self powered. To meet the peak energy demands of the TCPRA instrument and communications modes, secondary batteries are required and would be recharged during low-power system activities.

The Titan Orbiter has eight mutually exclusive operating modes corresponding to key sequences and activities during the mission. The modes are designed to maintain the energy balance of the Orbiter power system. The power modes are divided into three distinct transit-phase modes and five science-phase modes. The three transit-phase modes are *Launch*, *Cruise* and *Aerocapture & Circularize*. The five science-phase modes are *TCPRA Science*, *TCPRA Communications*, *TCPRA Standby*, *SAR/IRS Science and Communications*, and *SAR/IRS Communications*. The TCPRA Science mode is the peak power driver of the mission, requiring a total of ~1900 We (including 30% contingency) for the entire spacecraft. As the end-of-mission RPS power level is 1033 We, batteries are required to make up the balance of electrical power (867 We) used during this mode. Three 30 A-hr lithium-ion batteries are baselined for this mission, which includes one redundant unit. The total battery mass is ~33 kg (with 30% contingency), and is sized by the energy requirements of the TCPRA Science mode. A single-string nickel-hydrogen battery system was studied, but not selected as it was >18 kg heavier than the lithium-ion system. The batteries are nominally used only during the TCPRA Science mode to cover peak power usage. The power requirements of all other modes are within the capabilities of the RPS power system, and thus would not utilize the stored energy.

TABLE 3. Mass Estimates for the Titan Orbiter

System	Mass w/ Contingency, kg
Orbiter Stage (Dry)	**2129**
Orbiter Stage (Wet)	**3425**
Instruments	**626**
Attitude Control System	**43**
Command and Data Handling	**13**
Structures and Mechanisms	**469**
Spacecraft Adapter	**48**
Power	**330**
Cabling	**128**
Thermal	**135**
Telecom	**150**
Propulsion	**165**
Propellant and Pressurant	**1297**
System Contingency	**22**
Launch Vehicle Adapter	**324**
Probe	**500**
Additional Unallocated Mass	**189**
Aeroshell	**1292**
Total Launch Mass (Dry)	**4434**
Total Launch Mass (Wet)	**5730**

MASS

The total wet mass of the baseline Titan Orbiter spacecraft, including the aeroshell and probe is ~5730 kg with contingency. The Orbiter dry mass, excluding aeroshell

or probe, is ~2130 kg (Table 3). The propellant and pressurant mass is ~1300 kg, with the majority of the fuel used to perform Deep Space Maneuvers (706 kg). The baseline Titan Orbiter instrument suite weighs 626 kg including 30% contingency, and is dominated by the 520 kg TCPRA instrument used to perform detailed topographic altimetry and resolve atmospheric clouds and precipitation.

The aeroshell mass is estimated at ~35% of the approach mass at Titan [6], and is estimated to be ~1300 kg. The approach mass is minimized by deploying the probe prior to aerobraking. For comparison purposes, a purely chemical propulsion system (i.e., no aeroshell) was studied for the same size spacecraft. Such a system would weigh >6000 kg more (assuming a two-stage propellant system) than the baseline spacecraft using an aeroshell, placing it beyond the reach of existing launch vehicles (The mass savings using a single stage propellant system is even greater at >10,500 kg). Clearly, aeroshell technology is enabling for the Titan Orbiter mission.

The minimum probe mass requirement of 500 kg was selected to adequately cover the mass of the probe itself and its associated support structure. The combination of the Delta IV-H launch vehicle and baseline Stirling-based Titan Orbiter provides enough injected mass capability to enable the addition of a 500 kg probe, and ~200 kg additional unallocated mass that could be used for an increased capability probe, more orbiter instruments, or for system growth.

SUMMARY AND CONCLUSIONS

The Titan Orbiter mission would provide a logical follow-on to Cassini Huygens, performing detailed global measurements of Titan's surface topography, cloud structure and dynamics, precipitation rates, and atmospheric composition. The baseline spacecraft is designed around the high power Titan Cloud and Precipitation Radar Altimeter (TCPRA), which drives the power requirement of ~1 kW (EOM) and data rate requirement of 2.3 Mb/s. The Titan Orbiter would be enabled by a lifting body aeroshell for aerocapture into Titan Orbit. The use of the aeroshell reduces the required propellant mass by over 7000 kg, making it possible to use the Delta IV-H launch vehicle. The baseline Titan Orbiter uses 15 Advanced Stirling generators to produce all on-board power, corresponding to 15 GPHS modules, or ~1/3rd of the fuel used by the Cassini spacecraft. The higher efficiency of the Advanced Stirling generator would be a key benefit to the Titan orbiter mission from the perspective of fuel availability and in that less heat is produced, thus minimizing the amount of phase change material required to store the RPS heat during the ~1 hour aerocapture maneuver. The higher specific power of the Advanced Stirling (~5.9 We/kg), and its relatively small fin size are other key factors that helped to minimize system mass and overall system volume for this design. The Advanced Stirling RPS was the only advanced RPS studied that could provide enough mass savings to enable the inclusion of a ≥500 kg probe [2]. In conclusion, the Titan Orbiter mission is designed to address the key scientific goals of the Decadal Survey, and could be enabled by advanced RPS technology and a lifting body aeroshell.

NOMENCLATURE

BOM	Beginning of Mission
DOE	Department of Energy
DSN	Deep Space Network
EOM	End of Mission
GPHS	General Purpose Heat Source
HGA	High Gain Antenna
INMS	Ion and Neutral Mass Spectrometer
IR	Infrared
IRS	Infrared Spectrometer
LGA	Low Gain Antenna
LV	Launch Vehicle
MIT	Minimum Impulse Thrust
MGA	Medium Gain Antenna
NASA	National Aeronautical and Space Administration
PCM	Phase Change Material

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RF	Radio Frequency
RPS	Radioisotope Power System
RTG	Radioisotope Thermoelectric Generator
SAR	Synthetic Aperture Radar
SSR	Solid State Recorder
TCPRA	Titan Cloud/Precipitation Radar and Altimeter
TPV	Thermophotovoltaic
We	Watts (Electric)

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