An SLS Launched Titan Balloon Spacecraft Mission

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Abstract- This paper describes the delivery of a spacecraft to Saturn's moon Titan. Once captured at Titan and deployed, a Zeppelin type spacecraft would ride the moon's stratified and dynamic wind currents, operating for several years. The inflatable spacecraft and science package would flyover and survey large segments of the surface of Titan including its poles, mountains, valleys and liquid lakes. The NASA Space Launch System (SLS) is capable of injecting a 24.1-mt payload to an injection energy (C3) of 29 km2/s2, required for launch in 2035. Flight time to Saturn will be 7.8-years. Carried with the spacecraft will be trailing tethers, deployable probes, and drones that descend through the clouds and the various layers of the atmosphere to the surface. The SLS Block 1 vehicle successfully flew its first mission in late 2022. The SLS is being upgraded to the new Block 2 configuration with the addition of a new large Exploration Upper Stage (EUS). The EUS will substantially increase SLS payload capability, making robust, high science outer planet missions like this mission to Titan a reality

1. Nomenclature

EUS Exploration Upper Stage
SLS Space Launch System
ITIM Interplanetary Trajectory Injection Maneuver
EGA Earth Gravity Assist
DSM Deep Space Maneuver
JGA Jupiter Gravity Assist
R_S Saturn Planetary Radius
C3 Injection Energy km2/s2
DLA Declination of The Launching Asymptote
Vhp Saturn Excess Speed (velocity hyperbolic)
dVEGA delta Venus Earth Gravity Assist
PM Propulsion Module

2. Introduction

The NASA Space Launch System (SLS) can deliver dual inflatable Zeppelin type spacecraft and science packages to the atmosphere of Titan. This Titan mission fulfils two roles: First it serves as a scientific platform for the investigation of Titan. Second, it will serve as a technology demonstrator for later, more ambitious missions to explore the atmospheres of the gas giant planets Jupiter, Saturn and the Ice giant planets Uranus and Neptune. Titan exploration from the balloon system would include terrain mapping the surface, study of its magnetic field, surveys of volcanic activity, studies of the conditions at the poles, as well as atmospheric studies; including those done by trailing tethers, deployable probes, and/or drones that descend through the clouds and various layers of the atmosphere to the surface. The SLS flew successfully in 2022; it is being upgraded to a more capable Block-1B configuration featuring the new Exploration Upper Stage (EUS). The EUS, in development now, is the largest upper stage ever produced; with this upgrade the SLS can inject 24.1-mt to Saturn/ Titan in the year 2035. This is significantly more payload than any other launch vehicle can launch to Titan.

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3. Interplanetary Mission

For missions travelling beyond Jupiter to the outer solar system, it is more efficient to incorporate a Jupiter gravity assist if available. The minimum injection energy (C3) to enter an Earth-Jupiter direct transfer is approximately 90 km^2/s^2. For this science mission that we propose, the 90 km^2/s^2 launch energy is excessive and can be reduced by a simple addition to the interplanetary trajectory. To lower the required launch C3, we chose to add a delta Venus Earth Gravity Assist (ΔVEGA) loop. This loop is an Earth-Earth transfer taking 2 years' time where the spacecraft flies by Earth again post launch gaining velocity before heading to Jupiter. The Earth flyby is established by conducting a Deep Space Maneuver (DSM) after launch that targets the necessary Earth altitude to encounter Jupiter. The Jupiter Gravity Assist (JGA) finally propels the spacecraft on to Saturn. For this mission, a Jupiter encounter with a low DSM Δv is not available before 2034, so only dates thereafter are considered as candidate launch opportunities.

Saturn contains numerous moons and its famous ring system, all of which must be accounted for when targeting a periapsis radius above the planet. A gap exists between the rings, along with four large inner moons of Mimas, Enceladus, Tethys, and Dione and the target of Titan. Our aim point pierces this gap prior to capture. For this mission, we are targeting a 20x50 R_S capture orbit, where 20 R_S is just inside Titan's orbit. The Saturn arrival excess speed was also limited to less than 5-km/s. This constraint reduced the total mission Δv at the cost of increased duration. For technological and operational simplicity, our mission will use propulsive capture, rather than aerocapture, to slow down upon entering the Saturn planetary system. A series of successive burns, described in a later paragraph on mission analysis results, will lower the initial apoapsis while maintaining periapsis to match Titan's near circular orbit as well as reduce the relative inclination realized at Saturn capture. A final post-capture maneuver will be performed to circularize to the precise near-Titan orbit from which atmospheric entry will be performed.

Launch Date	7/25/2034	12/9/2035	10/10/2036
Titan Arrival Date	4/4/2043	5/28/2043	4/1/2043
Trip Time (years)	7.8	7.8	6.5
Launch C3 (km^2/s^2)	29.231	28.817	81.39
DSM Δv (m/s)	737	654	341
Earth Flyby Altitude (km)	319	319	n/a
Correction burns (m/s)	12	12	12
EGA Equivalent Δv (m/s)	*7390*	*7486*	*n/a*
JGA Equivalent Δv (m/s)	*9576*	*7145*	*7145*
Saturn Capture Δv (m/s)	2,686	2,686	2,686
Plane Change Δv (m/s)	722	655	722
Align to Titan's Orbit (m/s)	31	31	31
Titan Circularization (m/s)	1,075	1,075	1,075
Final Guidance Maneuvers	15	15	15
Total Propulsive Δv (m/s)	**5,278**	**5,128**	**4,882**

Table 1: Mission Δv Breakdown 2034, 2035, 2036

4. Mission Analysis Results

Using the trajectory methodology described in section 4, three launch opportunities have been identified. The first launch date occurs in summer 2034, the second is in winter 2035, and the third is summer of 2036.

The first two launch opportunities, 2033 and 2035, are consecutive year launch dates provide the opportunity to incorporate redundancy into the mission plan by designing the spacecraft around the 2034 mission. The goal would be to plan the mission around the earlier summer 2034 departure date (column 1 Table 1), with a spacecraft design that has the delta-v potential of this earlier and somewhat higher delta-v opportunity. If contingency plans must be realized, the 2035 mission 16 months later (column 2 Table 1) would provide a backup departure date with a spacecraft design that would have sufficient delta-v margin to perform this somewhat less energetic backup mission.The Earth launch phase of the mission entails two parts: an ascent to Earth orbit via the SLS, and then an Interplanetary Transfer Injection Maneuver (ITIM) via EUS. The C3 provided by the EUS for both Earth departure windows are close in launch energy (~29 km2/s2),

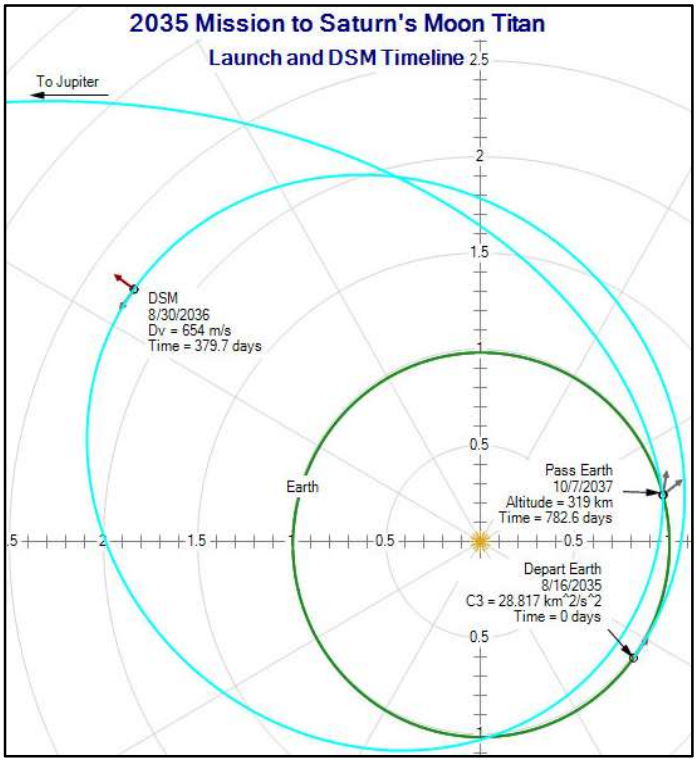


Fig. 1: Titan Spacecraft ΔVEGA & DSM Trajectory 2035

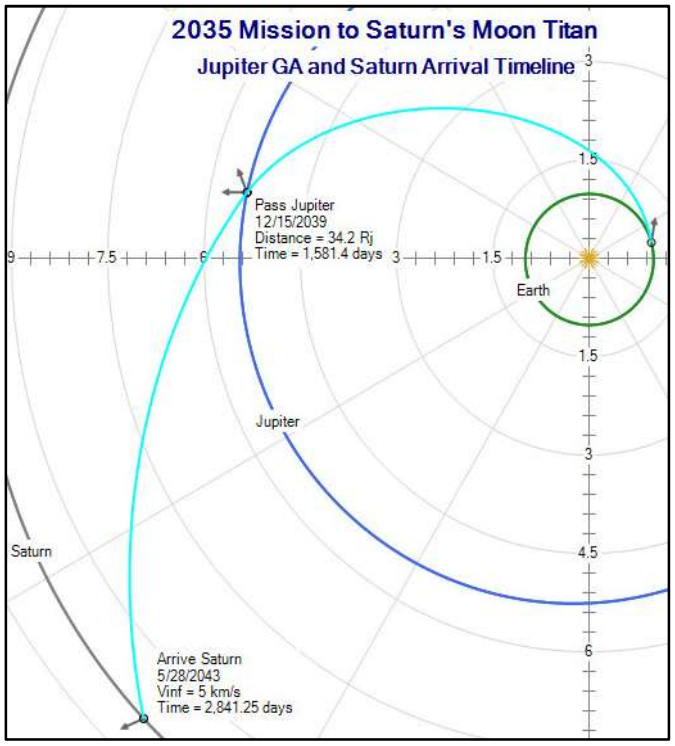


Fig. 2: Spacecraft Post JGA

In the mission analysis section below, we only provide an exposition of the lower energy 2035 mission, but Table 1 does include the higher energy 2034 mission data as well. The SLS block-2 can inject 24.1-mt to this C3; trip time to Saturn is 7.8 years.

From Fig. 1 at Earth departure, the ITIM places the spacecraft on an intermediate Earth Gravity Assist (EGA) phasing orbit. The Earth departure burn achieves a C3=28.8 km2/s2 (Table 1). This EGA phasing orbit includes a DSM of 654-m/s that occurs approximately 380 days after ITIM and at the apoapsis of the EGA phasing orbit that lies well beyond the average Mars solar orbital distance.

This DSM sets up the target conditions for the non-powered Earth flyby. This Earth flyby occurs 782.6 days after ITIM and provides a delta-v equivalent of 7,390-m/s that propels the spacecraft toward Jupiter, setting the stage for the JGA maneuver that will in turn target the Saturn planetary system.

From Fig. 2, the JGA phase of the mission consists of the post EGA trajectory that encounters Jupiter at just over 1581 days after ITIM. The JGA occurs at approximately 34.2 Jupiter radii (2,373,534-km altitude) with a non-propulsive equivalent Δv of 7145-m/s provided by Jupiter's gravity. The post JGA trajectory, the Saturn rendezvous phase of the mission, sets the spacecraft on a rendezvous with the Saturnian system at approximately 2841 days after ITIM with a Saturn excess speed (Vhp) that was constrained to no greater than 5-km/s. Given the Saturn approach excess velocity vector declination, it was not possible to achieve a Saturn capture orbit that was in-plane to the Titan orbit. The Saturn capture orbit was chosen as a 20x50 Saturn radius (R_S) elliptical orbit and incurred a Δv cost of 2,686-m/s. A plane change Δv of 655-m/s was required to achieve the Titan orbit inclination. Aligning the orbit closely to the Titan orbital parameters cost 31-m/s in Δv, while the circularization cost 1075-m/s. A small Δv will be required to target a precise Titan atmospheric entry.

Once in the prescribed Titan orbit, the spacecraft utilizes its heat shield and aerodynamic braking for reducing its altitude; after reaching the appropriate altitude for inflation, the heat shield is jettisoned. After inflation, the Helium storage pressurant bottles (now emptied) are dropped. What remains is the balloon with its science package underneath (Fig. 7); this is the final configuration that will ride the air currents of Titan. For comparison purposes, a third launch opportunity was evaluated (that does not use an EGA) to determine the effect of shorting the trip time. This launch, in

August of 2036, only utilizes a JGA and hence has a shorter trip time (6.6 years), but requires a higher ITIM (C3=81.4-km2/s2). The SLS Block 2 can inject 8.1-mt to C3=81.4. Although an EGA is not used, a 341-m/s DSM is still required to provide the appropriate Declination of The Launching Asymptote (DLA). The arrival and capture dV's remain the same as those for the 2034 mission, as the 3 trajectories evaluated were constrained to a 5-km/s Saturn arrival Vhp.

5. Propulsive Stages for Arrival & Capture

For the lower C3 (28.8) EGA + JGA missions departing in 2033 and 2035, a Titan Balloon Spacecraft, and its propulsion modules are launched together on the SLS. The Spacecraft has its own Propulsion Module (PM), and two other separate In-space Transfer Stages; the first is a PAM D2 solid rocket motor that does the DSM burn and the second is a separate In-space Stage that does the Saturn arrival burn. The PAM D2 Stage (Fig. 3), with an engine specific impulse (Isp) of 282 sec, masses 3.66-mt. After Saturn capture, the In-space stage is dropped, and the Spacecraft's PM does the remaining plane change, alignment, Titan circularization and final guidance maneuvers (Table 1). Element masses are given in Table 2.

The Spacecraft's Titan maneuvering PM (7.1-mt) and the Saturn arrival In-space Stage (7.1-mt) are near identical stages; using identical storable propellant propulsion systems with engine Isp of 321 sec. Masses include 5% margin on propellant. The Titan spacecraft proper masses 2.13-mt; this mass includes the balloon, inflation storage bottles, heat shield and science /avionics/ power mass. The complete mass for the system, injected by the SLS, is 19.9-mt. Payload attach fitting mass is 1.17-mt; SLS launch margin is 3.03-mt (15% of injected mass, Table 2).

SLS Payload (kg)		
Titan Ballon Spacecraft	**9,194**	
Spacecraft proper (kg)	2,130	
Titan Maneuver PM dry mass	726	
Propellant	6,338	
Saturn Capture Propulsion Stage	**7,046**	
Dry mass (kg) with adapter	844	
Propellant	6,202	
Deep Space Maneuver Stage (PAM D2)	**3,663**	
Inert Mass with adaptor	461	
Propellant	3,202	
Total System Mass (kg)	**19,903**	
Payload Attach Fittings	1,165	
Launch Margin	**3,032**	15.2%
Launch Vehicle Capability	**24,100**	

Table 2: Titan 2035 Mission Mass Statement



Fig. 3: PAM DII Solid Stage for DSM

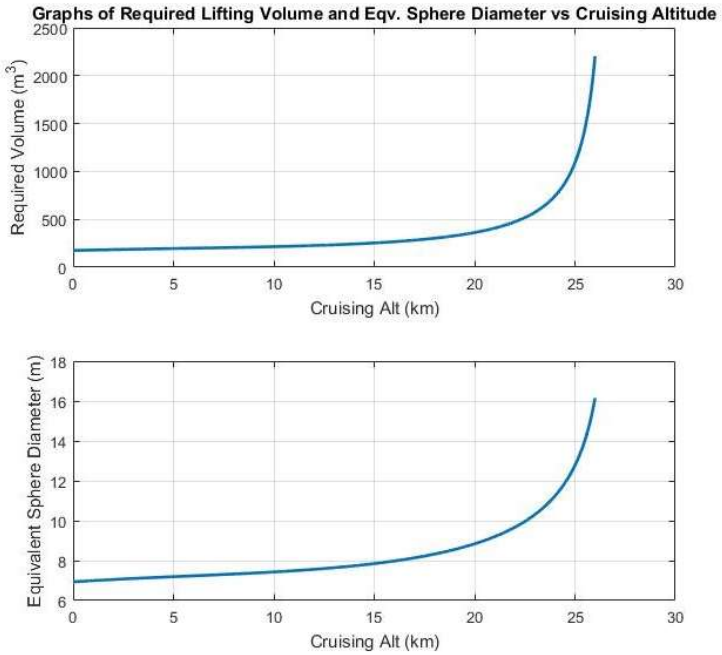


Fig. 4: Titan Balloon Required volume (m3) & Equivalent Sphere Diameter (m) vs Titan Cruising Altitude (km)

6. Balloon Volume

After arrival at Titan the Spacecraft's PM is jettisoned and the balloon is deployed and atmospheric current riding flight begins. Required Titan Balloon volume in cubic meters vs Titan cruising altitude in km is given in Fig. 4 top; Fig. 4 bottom, shows balloon Equivalent Sphere Diameter in meters vs Titan cruising altitude (km) for the launched in 2034 or 2035 spacecraft listed.

These volumes are the values necessary to keep the hardware mass at cruising altitude, that is, for the final spacecraft configuration after the heat shield and Helium storage tanks are jettisoned.

For cruising Titan at an altitude of 5-km, required balloon volume is about 150-m3, and equivalent sphere diameter for this volume is about 6.8-m. For cruising at an altitude of 20-km, required balloon volume is about 400-m3, and equivalent sphere diameter is about 8.8-m.

7. Aerocapture Options

In this paper, we have focused on an all-propulsion approach to reaching Titan orbit, leading to a substantial post-launch △v in excess of 5-km/s at a mission duration of 7.8 years. Although several factors influence the size of the post-launch △v, the most influential factor is mission duration through its effect on Saturn arrival hyperbolic excess speed. It was shown in Fig. 5 that the △v needed to capture into the selected Saturn capture orbit can be reduced by 1.0-km/s by increasing the fight time to 10 years. Less influential factors include the strategy used to transition from the Saturn capture orbit to the Titan orbit and the design of the heliocentric trajectory from Earth launch to Saturn capture orbit.

To achieve larger savings in post-launch △v, one may employ aerocapture, which is attractive at Titan because of its dense, predominantly nitrogen atmosphere. As yet, no mission has employed aerocapture and is often considered a high-risk choice. However, multiple authors [1, 2] argue that the risk is overstated. They point out that aerocapture should be easier to accomplish than aerobraking, which has been employed on many missions to circularize from a highly elliptic orbit. The arguments for this position are twofold: (i) aerocapture operates at lower altitudes where the atmosphere is denser compared to higher altitudes employed by aerobraking, which has larger pressure and density variations and uncertainties, and (ii) the entry corridors for aerocapture at the lower altitudes are larger than those for aerobraking and, therefore, are less demanding of the navigation system. They argue that aerocapture is achievable now with no further technology developments.

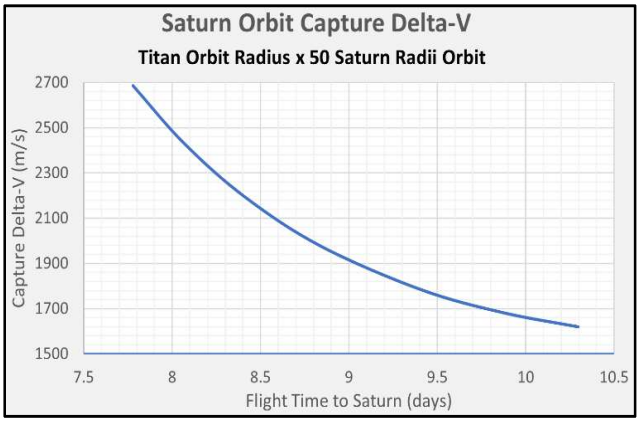


Fig. 5: Saturn Orbit Capture dV vs Flight Time

To assess the potential benefit of aerocapture, we refer to a NASA Technical Report of a detailed 2014 study performed at NASA Goddard Space Flight Center [1]. This report described a mission launched in February 2022 and arriving in the Saturn system in January 2031. Rather than enter a Saturn capture orbit, the arrival of the spacecraft was timed such that the

incoming heliocentric trajectory tangentially approached Titan's orbit about Saturn and directly entered Titan's atmosphere to achieve capture into a highly elliptic orbit prior to exiting the atmosphere. This is followed by multiple passes through the atmosphere to reduce the eccentricity. For this case the total post-launch $\triangle v$ was 666 m/s, which compares to the approximate 4-km/s $\triangle v$ required for the 10-year all propulsion case described above. Assuming a specific impulse of 320 seconds, the propellant mass fraction for the aerocapture option is 0.19 while that for the all-propulsion option is 0.72. To evaluate the effect of this $\triangle v$ saving, one must consider the mass of the aeroshell needed to achieve capture. This remains to be determined as the first aeroshell for a spacecraft of this size is yet to be designed and built. However, preliminary studies[1] suggest that reasonable aeroshell mass fractions will be well within the range that would make the aerocapture option quite attractive.

8. Science

Because Titan's atmosphere and landscape has the high potential of changing in response to seasonal variability, a long duration science-gathering platform capable of obtaining observations from a wide variety of locations is desired. As discussed shortly, we are proposing a lighter-than-air vehicle to perform these measurements. While restricted from carrying the heaviest of scientific instruments, a mobile aerial platform has the advantage of surveying unreachable terrain using various altitudes while not disturbing the surface. The available survey targets can vary widely from vast landscapes high above the surface for mapping to very low to the ground where minor features and topography can be easily observed with imaging cameras and even samples collected. These wide-ranging observations are impossible to realize for a rover or fixed heavy lander.

8.1 Atmospheric Science

Fundamental atmospheric properties like temperature, pressure, and density along with observed wind patterns, clouds, and precipitation will help to anchor complex global atmospheric circulation models used to simulate how Titan's atmosphere behaves. Predicting rainfall across the wetter portions of the moon, potentially across seasons, can assist geologists and hydrologists to map land erosion/evolution and the changing size of large lakes and seas like Kraken Mare. Similarly, gaining a greater understanding of wind patterns can help predict the migration and growth/retreat of the great sand dunes around the equator. Learning more about how arid regions on Titan evolve over time can give insights about how Earth's at-risk regions will react to desertification from a changing climate. Finally, samples can be taken of the atmosphere at different cruising altitudes to study the composition and atmospheric mixing. Sampling the atmosphere can identify airborne organic molecules that may form in the clouds, coalesce with liquid methane/ethane into droplets, then rain across the surface providing evidence of particulate transport across the moon in addition to rivers and watersheds.

8.2 Terrain Mapping and Sampling

Perhaps the most fascinating science data that an aerial platform can potentially gather will be detailed terrain maps, high resolution multispectral images, and direct surface samples. Scanning the terrain with in-situ LIDAR or RADAR will generate much higher resolution maps than available from Titan orbit, therefore enabling the study of Titan's distinct regions in unprecedented detail from macro scale geologic processes like surface deposition, uplifting, tectonic forces, cryovolcanism and weathering, as well as identifying watersheds where precipitation drains into rivers. Mountains and ridges as well as valleys can be precisely mapped to gauge their exact dimensions and future landing site candidates scoured for hidden hazards. Multispectral imaging can identify surface features in high resolution from a distance thereby assisting mission scientists identify the best candidates for future mapping and sample collection without having to peer through the dense atmosphere from orbit. These images can also serve as valuable data sources about surface composition and mineral content. Finally, because our vehicle is lighter-than-air, it has the potential to float on the lakes and oceans. This could allow direct sampling without posing a hazard to vehicle operation.

9. Titan and Its Atmosphere

Titan is the largest moon of Saturn at 5,152 km in diameter and is unique in the solar system as a non-planetary body containing an extensive atmosphere, liquid transport cycle, and an evolving terrain shaped by active atmospheric and potentially geologic processes. The orange, haze-covered moon has been described as one of the most Earth-like bodies in the solar system and was studied by the Cassini/Huygens mission from 2004 until 2017. Huygens descended to the surface for a brief period in early 2005 studying the atmosphere and surface near its landing site.

Titan orbits Saturn in a near circular orbit at a distance of a little more than 1.2 million km, or 3.2 Earth-Moon radii. With almost zero inclination relative to Saturn, Titan experiences the same 7 Earth-year long seasons as its parent planet. Saturn has an obliquity of 26.7° making seasons highly varied. Located far from the Sun's warmth, the typical surface temperature on Titan hovers around 93.7K or -291°F. Interestingly, temperature does not seem to correlate

with solar exposure with measurements of the night side temperature being warmer than the day side temperature, suggesting more complex processes may be ongoing that are worth investigation. Any liquid present is not water due to the frigid temperature, but instead liquids are composed of hydrocarbons, mainly methane and ethene. The solid surface is a mix of water ice, hydrocarbon solids, and potentially ammonia and methane ices.

9.1 Titan Atmosphere

The atmosphere is almost exclusively nitrogen with other trace gases, but this does not preclude the existence of complex atmospheric processes such as wind currents, cloud formation, and precipitation. Titan's atmosphere can be easily broken up into layers in a near identical manner to Earth based on a temperature profile trend giving rise to a clearly defined troposphere, stratosphere, etc. Due to its significant atmosphere compared to other solar system bodies, Titan exhibits dynamic wind patterns that are primarily driven by solar forcing that vary with the seasons. Within the lowest layer, wind speeds have been estimated to vary between 0 and 134 mph as a function of altitude. Strong jets with super rotation, whereby the atmosphere rotates faster than the surface underneath it, is present in the stratosphere which contributes to the movement of airmasses around the moon. Perhaps the most exciting feature of the atmosphere is the presence of a precipitation cycle. Moisture made up of hydrocarbons evaporates, condenses, and eventually rains back onto the surface. This falling moisture helps shape the surface in an Earth-like manner causing surface flows and landscape particulate movement. Precipitation and runoff consolidate into rivers, lakes, and seas primarily in the northern hemisphere.

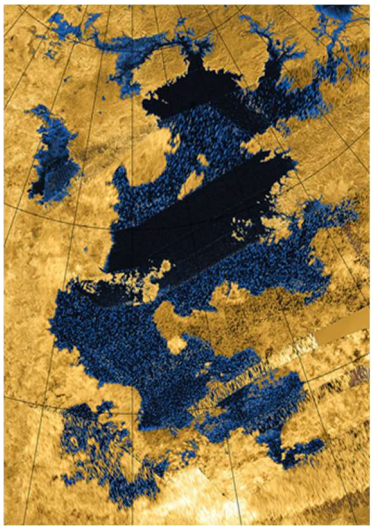


Figure 6. Synthetic RADAR Image of Kraken Mare. Credit NASA/JPL-Caltech/Space

9.2 Titan Terrain

Surface liquid is normally unheard of at any solar system location other than Earth, however Titan is again unique in that regard. The northern hemisphere hosts the largest lake on the moon, Kraken Mare (Fig. 6) and RADAR reflectivity measurements from Cassini estimate it to be around 500,000 km^2 in size which is about double the surface area of all 5 US Great Lakes added together with a depth likely exceeding 300 m (1,000 ft).

RADAR measurements were also used to scan and classify the moon's terrain. Titan's surface landscape is especially diverse and shares similar characteristics to Earth. Large wind-blown dune seas straddle the equatorial regions with rock-strewn plains primarily filling up the mid latitudes. As stated previously, hydrocarbon lakes reside near the north pole, but smaller liquid features can be found across the moon. The lack of craters in comparison to other airless bodies is partially explained by the extremely dense atmosphere that causes small to medium size meteors to disintegrate or breakup upon entry. There is also potential evidence for multiple types of surface renewal by geologic and atmospheric processes like cryovolcanoes emanating from the subsurface water ocean and wind and precipitation erosion. Mountainous regions are also present and not explicitly delineated in Figure 3, but typically range between 200 and 2,000-m in height. Water ice forms the foundation of these mountain ridges where it can be as hard as rock at the extremely cold surface temperatures on Titan.

Huygens was operational for around 3.5-hrs on Titan's surface before ceasing operations due to limited battery power which greatly restricted the temporal resolution of its stationary measurements. The combined Cassini and Huygens mission was limited in observing the moon in any detail for at most 44% of Titan's solar year starting after the winter solstice and ending a few months past the summer solstice. This limitation means there are still many desirable observations of the atmosphere and surface that remain and which simply cannot be done with remote Earth instruments in comparable detail.

10. Discussion

Aerial vehicles are ideal for planetary surveying due to enabling numerous surface locations without regard to terrain constraints, performing LIDAR or RADAR mapping of interesting features, characterization of atmospheric phenomena like cloud formation, wind patterns, and the liquid transport cycle. Associated properties like composition, temperature, density, and pressure can be sampled at multiple altitudes, all of which are all required to anchor atmospheric global circulation models.

Titan makes an excellent flying location for air vehicles due to the lower surface gravity and denser atmosphere than Earth. This, combined with existing planetary wind patterns discussed in Section 9.1 makes any kind of lighter-than-air vehicle ideal for exploring the moon. To float the same payload mass at ground level on Titan requires only

about 25% of the lifting volume than on Earth. A flying blimp type vehicle (Fig. 7) would be the most economical means to gather not only data on the atmosphere but also survey the sometimes-rugged terrain while utilizing the wind patterns for locomotion and therefore does not need a dedicated propulsion system.

There is little fundamental difference between a blimp designed to fly on Earth and the "current rider" design we propose herein. Helium will be used as the lifting gas due to its low molecular weight and stability during interplanetary transit compared to a better performing lifting gas like hydrogen. While Titan's atmosphere lacks free oxygen so flammability is not a concern, long duration storage of helium in composite pressure vessels makes it the ideal lighter-than-air choice until deployment at the moon.

Although our vehicle will rely on wind currents, that doesn't mean there will be no control capability. The cruciform tail configuration grants the blimp control authority along the roll, pitch, and yaw axes to remain stable and pointing as directed by the onboard software in response to sensor field of view requirements or prevailing winds. By pumping local atmospheric gases in or out of 2 ballast tanks called "ballonets", pitch can also be maintained as desired if the contained air mass is different between the volumes providing redundancy to the tail fins. Changing the total mass of the vehicle with a fixed volume of lifting gas allows the blimp to ascend or descend on command as a positive side effect of pitch control. This provides huge benefits as it allows the vehicle to catch the right wind stream as a function of altitude to relocate to another science region or drop down nearer to the ground for close-in observations of surface features and perhaps even performing direct sampling of lakes or seas.

The heart of the current-rider blimp will be the science and electronics gondola. The gondola will be suspended below the lifting envelope an identical configuration as Earth analogues, with clear views of the surface beneath. Because sunlight hardly reaches Titan, with the atmosphere blocking a further 90% of any received light, electrical power will need to be generated via radioisotope thermal generators (RTGs). The waste heat from the thermal-electric conversion can also be recycled to heat electronics to their minimum operating temperatures against Titan's frigid environment. The RTGs can last for a long duration thereby enabling a multi-year science gathering mission.

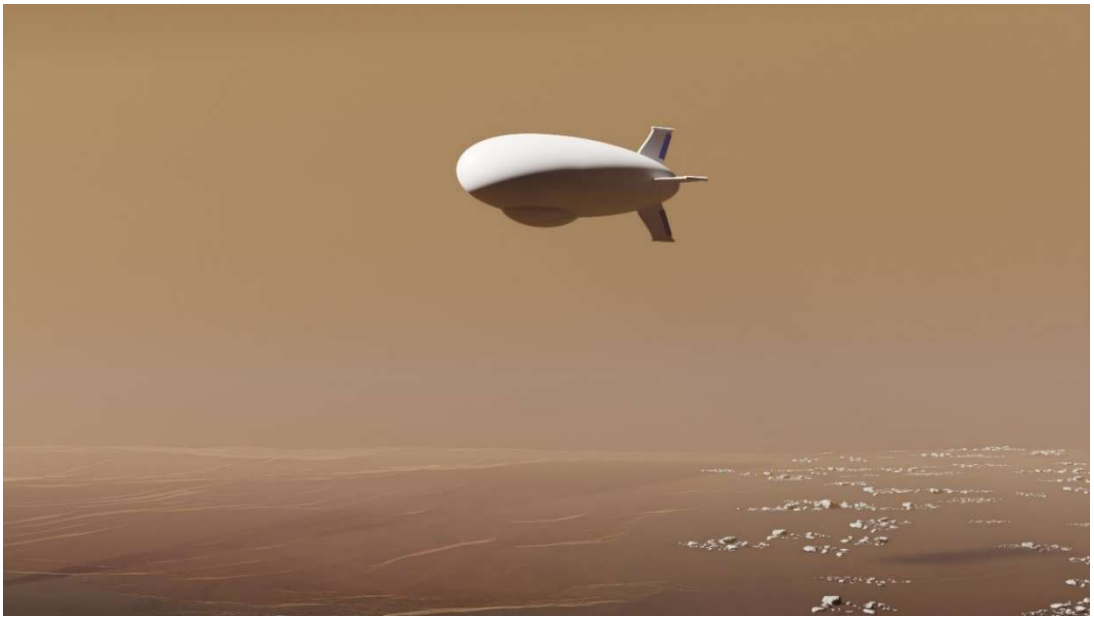


Figure 7. Notional Titan Current-Rider Blimp

11. Conclusions

This paper presents a mission concept for an aerial long duration balloon system that rides the dynamic wind currents of Titan. This system would be capable of exploring large segments of the surface, gather data from the atmosphere, and provide opportunities for short duration surface probes. The mission might also serve as a technology demonstrator for more ambitious missions to the atmospheres of the gas giant planets. The large throw mass and payload volume of the SLS provides a game-changing capability for the exploration of worlds with extreme environments.

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