A SURFACE SCIENCE PARADIGM FOR A POST-HUYGENS TITAN MISSION

Wayne Zimmerman, Jet Propulsion Laboratory
wayne.f.zimmerman@jpl.nasa.gov
Dr. Jonathan Lunine, University of Arizona
jlunine@lpl.arizona.edu
Dr. Ralph Lorenz, University of Arizona
rlorenz@lpl.arizona.edu

ABSTRACT

With the Cassini-Huygens atmospheric probe drop-off mission fast approaching, it is essential that scientists and engineers start scoping potential follow-on surface science missions. This paper provides a summary of the first year of a two year design study [1] which examines in detail the desired surface science measurements and resolution, potential instrument suite, and complete payload delivery system. Also provided are design concepts for both an aerial inflatable mobility platform and deployable instrument sonde. The tethered deployable sonde provides the capability to sample near-surface atmosphere, sub-surface liquid (if it exists), and surface solid material. Actual laboratory tests of the amphibious sonde prototype are also presented.

1. TITAN SCIENCE

Since the discovery of a methane atmosphere around Titan by Gerard Kuiper in 1944, Titan has attracted much exobiological interest. In the 1970s, before spacecraft reconnaissance established surface conditions with certainty, much of this interest centered around the possibility that the greenhouse effect of a thick atmosphere could permit hospitable surface conditions. The Voyager 1 encounter in 1980 showed that while the atmosphere was a familiar one in some respects (1.5 bar, mostly molecular nitrogen), the surface temperature of 90K was far too low for liquid water [2]. Many organic compounds have been detected in Titan's atmosphere. These form as a result of the recombination of molecular fragments produced by methane (and nitrogen) photolysis. Ultraviolet solar radiation is primarily responsible, although irradiation by electrons in Saturn's magnetosphere is an additional energy source. The ultimate fate of these compounds is to condense at or near the base of Titan's stratosphere and be deposited as liquids or solids on the surface [3]. Titan's photochemistry is of keen interest for modelers of atmospheric chemistry. However, by itself it goes but a little ways towards addressing the origins of life, a key goal of astrobiology and of Titan exploration. If there is to be any chemistry relevant to pre-biotic synthesis on Titan it must be occurring on or near the surface, acting on the products of stratospheric chemistry and powered by sources other than direct solar ultraviolet radiation. ***Thus, we must go to the surface and analyze the organics there in order to explore organic systems that might be direct precursors to life.*** Titan's atmosphere is essentially bereft of oxygen or oxygen-containing compounds like water. Even the most abundant (CO) is present only at a few tens of ppm. Although the early Earth similarly lacked molecular oxygen, carbon dioxide was an important or even dominant constituent of its atmosphere. The lack of oxygen-bearing compounds in Titan's atmosphere is a crucial point for two reasons. First is that the chemistry that sustains life on Earth is mediated in liquid water - it requires liquid water as a solvent. Second, virtually every organic molecule of biochemical interest contains some oxygen (that means every amino acid - and therefore every protein and enzyme - every sugar, every fatty acid, and DNA itself). Were there no way to incorporate oxygen into the chemical chain in the atmosphere then the organics that made in Titan's atmosphere would be sterile nitriles and hydrocarbons. On the other hand, experiments have shown that tholins and nitriles are readily hydrolyzed by liquid water into amino acids; e.g., Titan tholin yields about 1% amino acids by mass on hydrolysis [4]. Hence, if the accumulating organics on Titan's surface are exposed to liquid water, an entirely new step in chemical synthesis is introduced. ***It is of keen astro-biological interest to find locations on the surface that bear evidence of past episodes of liquid water.***

Although we do not yet understand the nature of Titan's surface very well, it is clear that organic products of methane photochemistry must have been deposited on the surface over geologic time. By inference, Titan is thought to be half rock and half water-ice based on the Voyager-derived density and cosmic abundance considerations. Rock-ice moons surveyed in the Jupiter system similar in size to Titan show partial or full differentiation that migrates water-ice to the surface. Hence, two key ingredients for life (i.e., organic molecules and water in the form of ice) almost certainly exist today at the surface of Titan**---*scientists need to identify ways to investigate the chemical/ice nature of the Titan surface.*** Although the surface temperature of Titan at 90K is too cold to support liquid water in steady state, sources of transient liquid water at the surface of Titan might include cryo-volcanism (extrusion of liquid water or--more plausibly--water ammonia solutions on the surface) or medium- to largesized impacts. Such impacts would gouge out craters in the water ice crust of Titan and leave behind approximately 1% by volume melt water [5]. If ammonia is present, complete refreezing of the liquid water would take up to 10^4 years [6]. We have no experience with the products of aqueous organic chemistry on such long timescales, or large spatial scales, yet such materials may lie preserved by deep freezing in the near-surface crust of Titan.

2. STRUCTURE OF THE TITAN DESIGN STUDY

The overall design study architecture started with the definition of desired science measurements, which were then networked into various implementation options, starting with launch/cruise, payload insertion, payload delivery to the surface, culminating in a surface/sub-surface sample acquisition and delivery system design. The overall system approach taken included the following steps:

1. Team based science requirements definition;
2. Science measurement-to-instrument mapping/ instrument payload definition;
3. Use of a cadre of functional design models that assess thrust, power/thermal, communication, and EDL requirements for different flight architectures needed to deliver the science payload, and;
4. Development of surface sampling robotic/ mobility kinematic/dynamic design models to implement the actual mission;

Once the overall science mission goals were defined and a potential instrument suite scoped, the first model developed was the optimal manner in which to launch and inject the desired payload (e.g., we examined the array of launch vehicles that might be available, examined possible fuel savings from Earth/Venus orbital assist, and then determined the cruise/EDL orbital mechanics needed to get us there). This design effort determined exactly how the science payload would be placed on the Titan surface. The results of this modeling work also defined disjoints between the desired science-driven mass and volume of the science payload vs. what the launch/orbital mechanics models say we could inject with the array of launch/cruise options available. Depending on desired launch windows, these two potentially conflicting parameters usually required an iterative approach to establish the “likely” subset of phased launch options and instrument suites. The surface component of the flight architecture was derived from examining an array of surface options for delivering the science payload, followed by developing functional models of the surface system The surface system dynamic models also encompassed communications, thermal control, power, structural analysis, materials, avionic/ mechanical component selection, navigation/ buoyancy and cooperative control (i.e., lander or aerial platform, science instrument/mobility/ sampling platform). The results of this analysis were used to size the surface power system as well as define the power conversion mechanism (e.g., one large RTG vs. many mini-radioisotope power sources or thin film boost batteries). Ultimately, the separate subsystem modeling results were iteratively worked to establish a complete trade-space science/surface system configuration envelope which was bounded by mass, power, and volume. Once fed back into the space transport and orbital mechanics models, a “likely” subset of system design(s) was developed which fell within the constraint envelope for “near-term” and “far-term” missions. The technology “tall poles” were filtered out of this solution subset.

3. RESULTS OF THE DESIGN/TRADE-SPACE ANALYSIS

Science Measurements and Supporting Instrument Suite

The science measurements discussed in the previous section are expanded here. We wish to understand the make-up of the atmospheric column close to the surface as a function of organic compounds present, densities, temperature, pressure. It is essential to perform complete gas/liquid/solid analysis of constituents, particularly examining make-up of tholins and possible presence of chirality. We also wish to perform a complete physical study of the subsurface liquid column in a shallow crater lake. This includes analyzing the liquid column as well as bottom material since it may be ancient deep material brought to the surface by an impact event. Again, temperature, pressure, opacity/particle suspension, and chemical properties will be studied. Last, we wish to perform shallow subsurface (<5cm depth) analysis of crater rim solid icy conglomerate material bordering shallow lakes. Measurements include physical characteristics of the rim area (microscopy/far field images, hardness), chemical make-up, presence of H20, and trace mineralogy.

The minimum science instrument payload deemed necessary to make the above measurements includes:

- Engineering sensors like temperature/pressure sensors, acoustic ranging (provides liquid depth), pH/conductivity/ dielectric, and turbidity measurements using off-angle LED’s;
- Micro-scopic/near field imagers mounted in the shell of the sonde;
- Gas Chromatography coupled with a mass spectrometer (GCMS) to measure organic and chiral signatures (considered top priority);
- Either a Raman mass spectrometer or ion-micro electrodes for analyzing minerals/bulk material (if we can meet volume constraints);

Launch/Cruise/Entry Results

The tradeoff analysis looked at different launch and cruise options for getting the total surface payload to Titan. For the near term, it appeared that the most viable launch option was an Atlas 551, coupled with solar electric propulsion (SEP) and passive aerocapture at Titan. Use of a single or double Venus gravity assist greatly added mass margin to the total system. While an orbiter was considered useful as both a communication relay and global positioning system (GPS), it was found that the mass of the orbiter taxed the ability to deliver the desired science payload (~100kg, 3 sondes + instruments @ 33kg ea.). Therefore, the option of finding a trajectory and entry latitude which would enable a direct-to-earth (DTE) communication link was also examined. In this case, the aerial platform would be used as a large antenna for the DTE connection. The net results of the Atlas 5 vs. Delta 4 tradeoffs are summarized in Table 1.

One critical variable considered in the tradeoff analysis was the trip time. The science team all concurred that it was essential to keep the trip time in the 6-7 year range in order to maximize the science return as a function of the scale of the mission relative to cost. It was felt that this time period would frame the mission as a more cost effective alternative given the grand scope of the proposed in-situ science element. The last critical variable was the entry velocity. Since a passive aerocapture (AC) system saved considerable mass, it was necessary to pick a trajectory and entry vector which kept the entry velocity in the 5-7km/sec range—well within existing aeroshell material strength limits. Fig 1 shows the actual mass breakdown for the Atlas 5/SEP option considered optimal.

The total system mass was slightly over 5000kg which allowed injection of the aerial platform and 100kg science payload to the surface, with approximately 30% mass margin which is typically desired in the early phase of mission design.

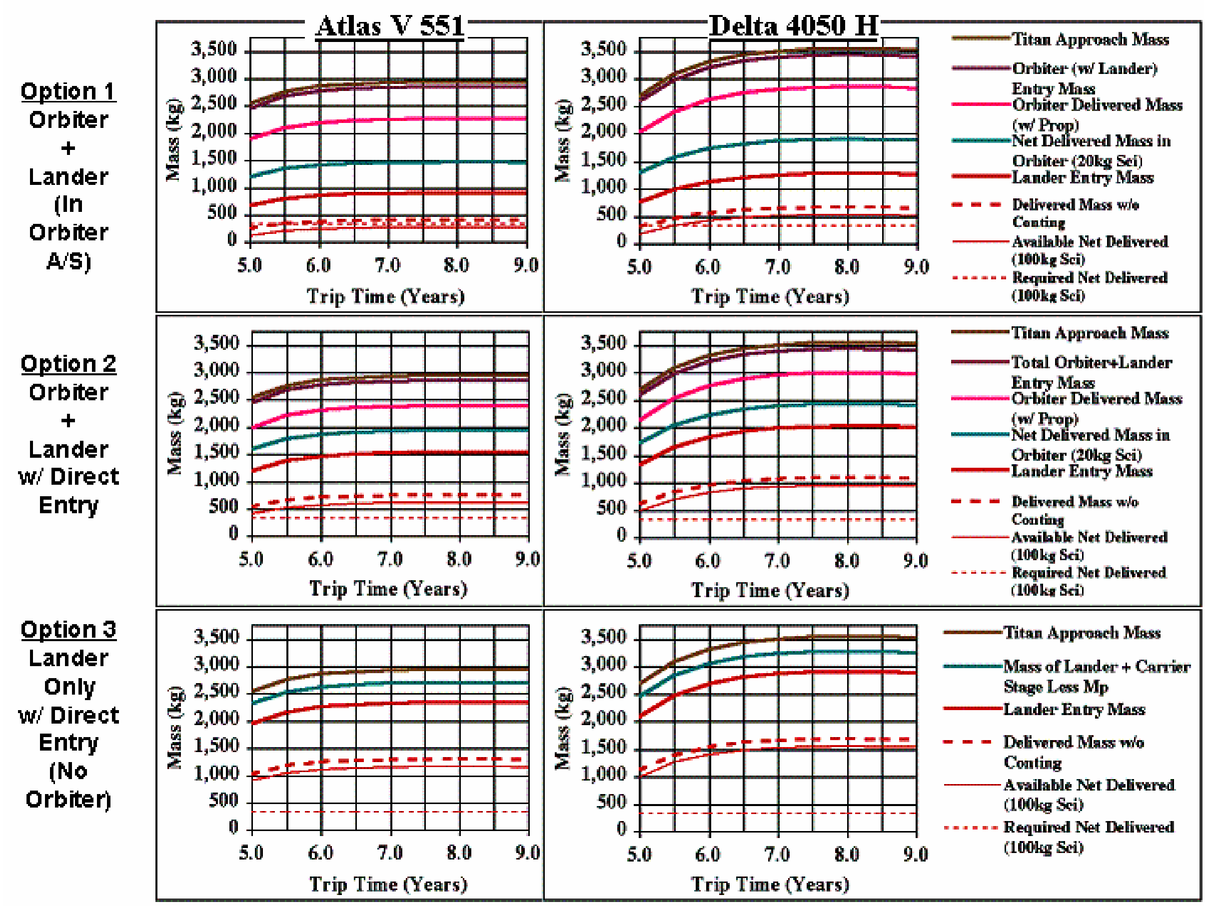
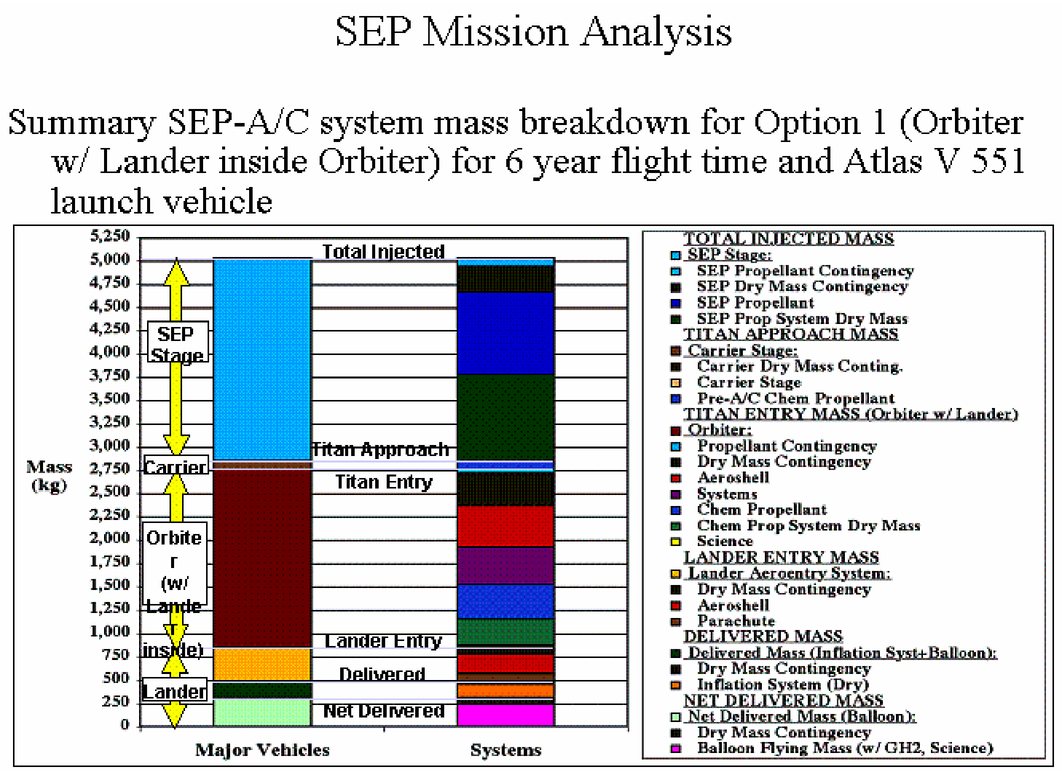


Table 1. Comparison of Injected Payload Capacity as f(launch vehicle, trip time)



SEP Mission Analysis

Summary SEP-A/C system mass breakdown for Option 1 (Orbiter w/ Lander inside Orbiter) for 6 year flight time and Atlas V 551 launch vehicle

Fig 1. Final Atlas 5/SEP/Aerocapture Configuration Offering Best Trip Time and Highest Injected Payload Mass

Results of Communication Subsystem Trades

The above section made reference to the large mass penalty paid by carrying a relay orbiter. While it was understood that the orbiter relay capability and global positioning system (GPS) capability for tracking the surface system were critical, it was also understood that a surface mission of this scale would benefit greatly by reducing mass as much as possible. By reducing mission complexity and mass, cost could also be substantially cut. The trade-space analysis for this subsystem concentrated first on making sure we could still fit within a total launch capacity envelope using the classical approach of both an orbiter and surface package. This was successful as shown in the previous section. The final trade-space analysis then focused on getting rid of the orbiter and using a quad-dipole patch antenna array mounted on the aerial platform for a direct-to-earth (DTE) link. Since the aerial platform would experience natural drift due to surface winds (not large at 1km altitude), the final patch array design used a "max signal strength" polling/switching control system to home in on Earth. The design effort paid off as shown in Table 2. By setting the entry trajectory for touchdown at 85degrees N. latitude, 22W of transmit power enables 1kbps to be transmitted for 8hrs while Earth is above the horizon. This was a significant finding.

Table 2 DTE Comm Architecture

1- **Mission time**- 2016, no orbiter (mass savings of 600kg), quad-dipole patch array mounted on the gondola of an aerial platform, transmit altitude at 1km above the surface, transmit zone on Titan at >80 degrees latitude;
2- **Direct-to-Earth** (70 m DSN antenna) link from the balloon will require ~ 22 W transmitted power (~ 65 W DC power) with 35 cm patch arrays – based on a worst case DTE range of ~ 1.65 X 10^9 km;
3- **Operation** at latitudes above 85 degs allows Earth to be in direct view of the aerial pltform;
4- **Max DTE link availability** is 8 hours/day when Earth is rotated toward Titan
5- **Result**- The above 85degN option provides an 8hr/day transmit window at 1000bps data rate, and provides a max data volume/day of ~3.6 Mbytes/day based on worst case range analysis—this is a very reasonable data return at fairly low power with a significant reduction in launch mass;

Results of Power/Thermal Subsystem Trades

The design and trade-space analysis for the power and thermal control subsystems were tightly coupled. The power subsystem design considered both a dual string and single string architecture. The single string architecture was considered the likely implementation due to mass/volume constraints. However, it was understood that for a mission of this scale, we needed to consider redundancy as a viable alternative. It was for this reason that the science payload was designed to include 3 sondes with internal instrument packages. This redundancy would allow 2 sondes to fail and still meet the mission goals. The single string architecture considered internal redundancy from the standpoint of employing not only the tether supplied power from the aerial platform 100We radioisotope power source (RPS), but also employing rechargeable secondary batteries trickle charged off a single RPS general purpose heat source (GPHS) with thermo-electric converters mounted in the nose of the sonde. Fig 2 provides the general power architecture for the sondes.

Fig 2 shows the use of staged voltage regulators vs. DC-DC converters. This selection was made because extreme low temperature DC power converter technology is maturing at a very slow rate. However, low temperature voltage regulator technology is well developed and offers the advantage of less mass and volume with better low temperature performance. The most significant design element of this architecture was the realization that the many of the instruments in the surface/subsurface payload could not survive the extreme 90K Titan environment without staying warm. Further, although tether loses over the tether length of ~100m at 90K were minimal, the 100We aerial platform power source could not deliver sufficient power to operate the sonde/ instruments and power the aerial platform as well. An elegant low mass solution was required. After considering vacuum bottle approaches, use of a GPHS/thermo-electric conversion system in the sonde nose, we finally closed on a hybrid thermal solution. The problem with the vacuum bottle approach was that the sonde wall had to have at least a 2cm vacuum gap between the outer wall and inner wall. This reduced the internal volume of the sonde down to a point where the instrument payload would not fit. While the GPHS solution provided sufficient heat to keep the sonde warm while allowing the probe internal volume to be adequate for the science payload, it was determined that the sonde could overheat when suspended in the Titan atmosphere. Not only did the design complexity increase for radiating the heat to the atmosphere, but additional heat pipes were needed to remove the heat during the long cruise phase. The final solution was a combination of a small vacuum gap (5mm) coupled with use of a phase change material (e.g., water) which would convert to super-heated vapor when heated by the 100We (1250Wt) aerial platform RPS. This thermal jacket, augmented by only 20We of aerial platform power, allowed the sonde to maintain an internal temperature of 0-10degC (ideal operating temperature for the electronics) for up to 7hrs of surface mission time---more than adequate to obtain surface/sub-surface samples. Spot heat could be used for select instrument components.

Probe Power Subsystem Block Diagram

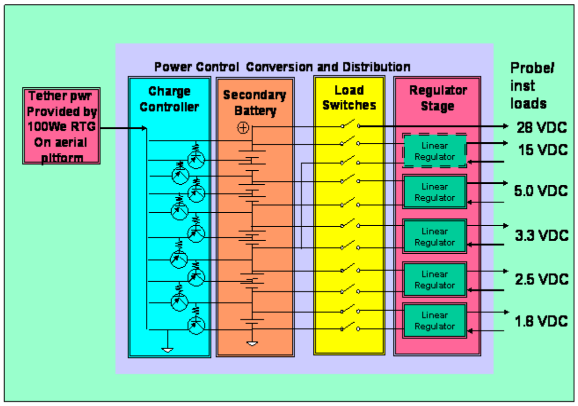


Fig 2 .Sonde/Instrument Power Architecture

Surface Mobility/Instrument Delivery and Sample Acquisition Results

Section 1 described the desired science measurements. Given the science requirement to sample atmospheric+liquids+solids over a region, we expanded our design/trade-off envelope to look at multiple sampling/in-situ analysis options—in all cases the vehicle would be deployed off an aerial platform. The reason an aerial platform was picked was two fold:

1. Titan has a significant atmosphere which makes use of an aerial platform attractive;
2. Being an icy body, the topography and potential orgainic sludge of Titan is expected to be challenging for a long range rover type vehicle and, perhaps, too constraining for a stationary lander (i.e., the landing site only offers a single location which may not allow access to other more interesting sites like hovering over a methane lake);

The overall surface mission concept is shown in Fig 3. The surface system design effort looked at small harpoon sampling devices fired from a tether when in proximity to the liquid or solid environment, followed by retrieval/delivery of a small sample canister to a sample transfer/distribution facility on the gondola. We also examined a passive drop sonde lowered via tether from the aerial platform to the surface, in which the sonde center of gravity (c.g.) is offset from the long axis of the probe. By off-setting the c.g., the probe automatically orients itself so the sampling mechanism always faces the surface. The last option we examined was a limited mobility amphibious vehicle capable of operating in all three environments.

Fig 3 illustrates the aerial platform deployment, survey, and sampling phases of the in-situ surface mission. Two primary surface instrument delivery options were considered:

1. The aerial platform does an aerial survey of a large area first before selecting a prime science target (i.e., a cratered organic lake with rich rim deposits of organic precipitates and mineralogy)---three sondes are separately deployed (one tethered for analyzing the atmospheric column, one free swimming for subsurface liquid column analysis, and one crawler for crater rim solids analysis)—multiple harpoons could also be deployed which retrieve/transfer sample to the aerial platform gondola instruments;
2. The aerial platform carries one tethered deployable sonde or harpoon suite which samples the atmospheric column, samples the liquid lakes, and samples the crater rim material as the aerial platform moves from site to site.

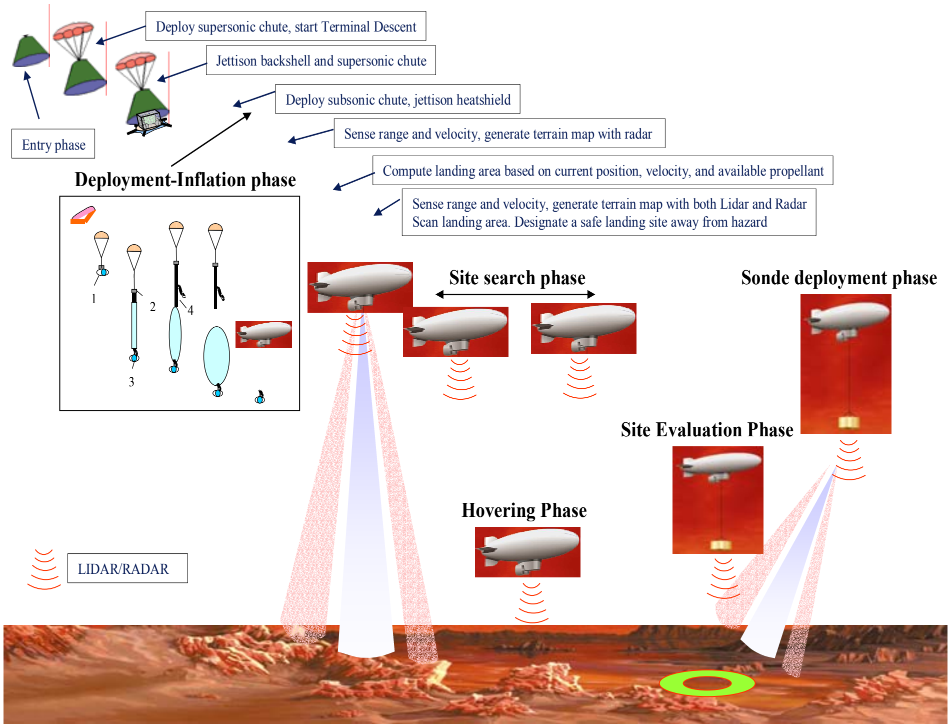


Fig 3. Aerial Platform Deployment/Survey Scenario

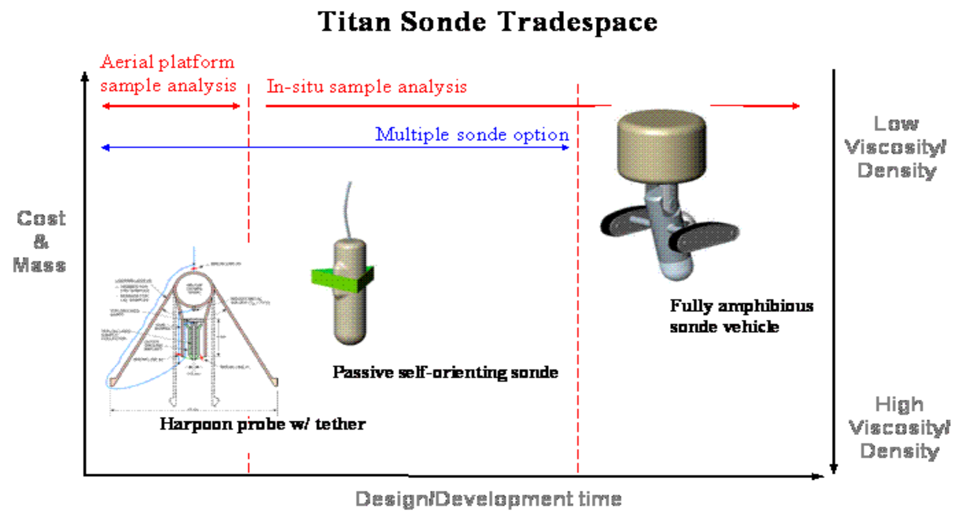


Fig 4. Sample Acquisition Options

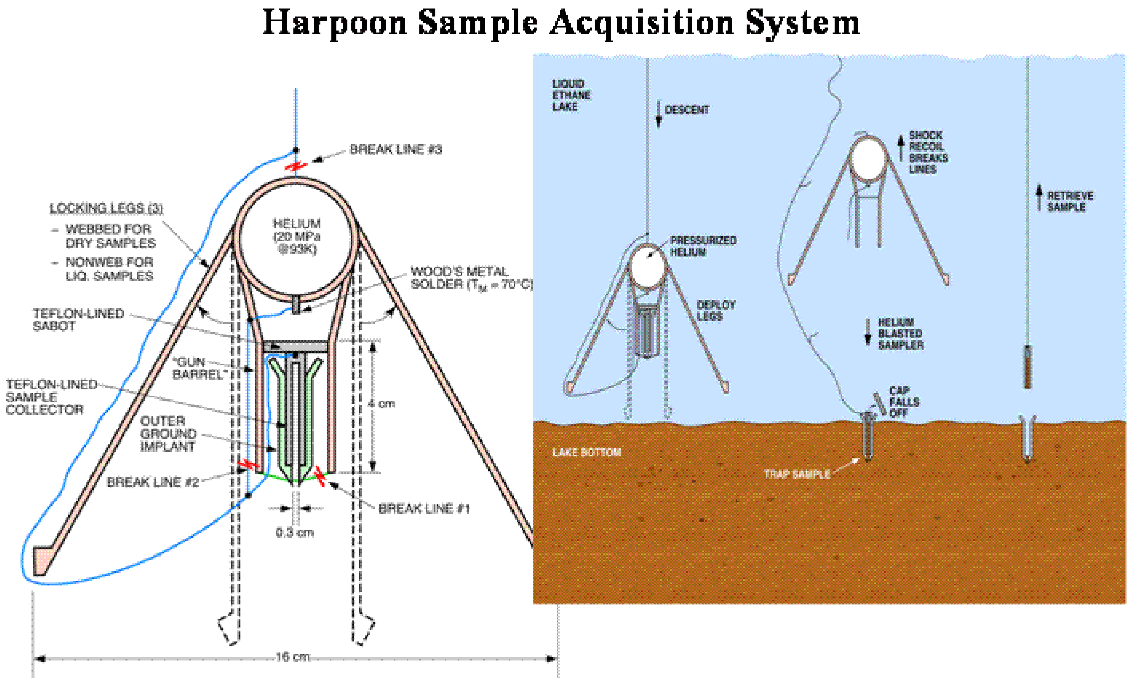


Fig. 5. Harpoon Close-up w. Retrieval System

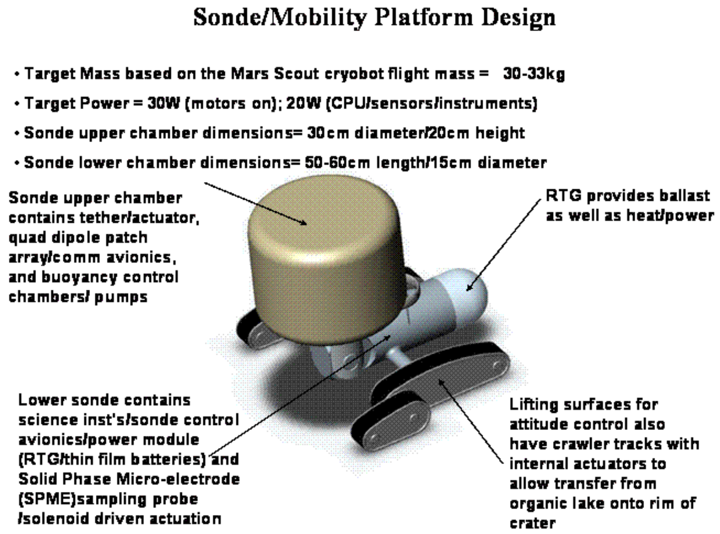
Fig. 4 summarizes the key variables associated with the three sampling options. The harpoon's primary advantage is that it can accommodate high viscosity medias. Its disadvantage is that off-normal impacts and/or extremely hard surfaces, degrades its sample acquisition performance. Also, once the device is fired, it cannot be reused. This means that many devices, all requiring tethers, must be carried on the gondola. Both the passive and active sondes can be deployed into all environments, can be reused, but will have difficulty in viscous mediums.

The harpoon concept is shown in greater detail in Fig. 5. The device is lowered via a tether to the surface and/or subsurface. Pyros are used to drive the center sample chamber into the material where it is trapped and sealed. The umbrella shown in Fig 5 reacts rebound forces in liquid mediums so that the sample chamber thrust force stays vectored in the direction of the sampling surface. Research was done to identify cryo-liquid class pyros for both the sample chamber and for jettisoning the rebound umbrella/housing after the impact event. Once the sample is collected, the sample chamber is reeled back up to the aerial platform where it is then transferred to the instrument suite mounted in the gondola. It should be noted that the combined mass of the harpoon system was within 1-2kg of the mass of a single integrated sonde---essentially the same.

Both the passive sonde and active sonde are the same in terms of deployment by tether and internal electronics/science payload. Only the amphibious sonde is discussed here.

The amphibious sonde design was pursued first since it represented the worst case payload element in terms of design complexity. The design effort included functional design, dynamic simulation, and development/test of the first prototype. Considerable work has already been done in the area of mole penetrators. The JPL cryobot developed and tested in a glacier above the Arctic Circle on the island of Svalbard [2001, 7] was a form, fit, and functional prototype vehicle which used a cyclic passive nose heating and active water jetting approach for penetrating ice sheets and managing dust/debris in the ice. The science payload was completely integrated into the vehicle housing, where sampled melt-water was passively ingested and circulated across an ion-micro-electrode array. A 3x magnification imager was mounted normal to the long axis of the probe in the electronics bay of the probe housing. This configuration allowed the probe to image ice/debris layers as it descended. The probe was also capable of steering by selectively turning off nose heaters and turning on opposing aft shell heaters. The sonde design developed in this study drew heavily on the heritage of the cryobot while extending its capability by adding the feature of mobility in both liquid as well as on solid surfaces like the rim of a Titan crater lake.

The current science requirements only require 2-5 cm penetration depths of the solid icy surface on Titan. If liquid methane lakes exist, the probe is only required to sample meters in depth close to the crater rim, with emphasis placed on getting a small sample from the



Sonde/Mobility Platform Design

- Target Mass based on the Mars Scout cryobot flight mass = 30-33kg
- Target Power = 30W (motors on); 20W (CPU/sensors/instruments)
- Sonde upper chamber dimensions= 30cm diameter/20cm height
- Sonde lower chamber dimensions= 50-60cm length/15cm diameter

Sonde upper chamber contains tether/actuator, quad dipole patch array/comm avionics, and buoyancy control chambers/ pumps

RTG provides ballast as well as heat/power

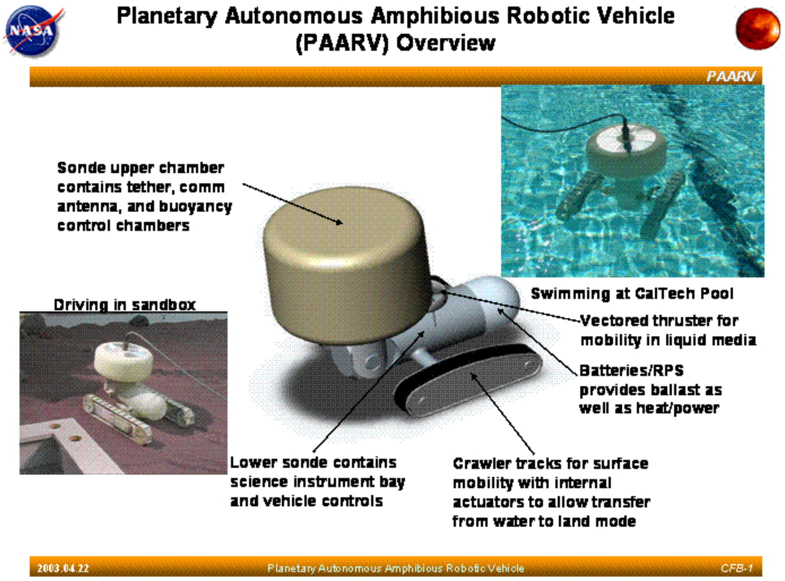
Lower sonde contains science inst's/sonde control avionics/power module (RTG/thin film batteries) and Solid Phase Micro-electrode (SPME)sampling probe /solenoid driven actuation

Lifting surfaces for attitude control also have crawler tracks with internal actuators to allow transfer from organic lake onto rim of crater

Fig 6. Planetary Autonomous Amphibious Robotic Vehicle (PAARV)

bottom of the lake. To do this with a simple system which could meet the volume constraints of the sonde (i.e., 15cm dia, 60-90cm length) we decided to look at solid phase micro-extraction (SPME) needles which adsorb sample onto a thin porous coating,, retract into a chamber where the needle can be interrogated for bulk material inorgnics, and then heated to release the organic volatiles. The SPME is mounted in the belly of the sonde where it can be deployed/retracted via solenoid or spring action close to the surface. The complete system is shown in Fig 6.

The above design has been prototyped and tested in the laboratory. This system is shown in Fig 7. The reader should note that this first version was primarily built to test its actual dynamic response against the kinematic/dynamic modeling results. No instruments were placed on-board and the active buoyancy control system was not incorporated due to limited funding. The vehicle was teleoperated and tested in soil (the coarse Mars stimulant in the Planetary Robotic Vehicle Laboratory, JPL) and in a pool (the CalTech swimming pool). The tests showed good vehicle maneuverability in deep, heavy soil. In the pool environment, we learned that as we changed vertical orientation (pitch), subsequently changing the c.g., the vehicle was somewhat sensitive to the degree to which it could pitch and still remain stable, particularly in the presence of waves. It will be necessary to build in lower buoyancy control chambers near the nose , or provide the ability to extend a telescoping mass to maintain stable vertical equilibrium. The vehicle is shown maneuvering in the sandbox and pool in Fig 7.



Planetary Autonomous Amphibious Robotic Vehicle (PAARV) Overview

PAARV

Sonde upper chamber contains tether, comm antenna, and buoyancy control chambers

Driving in sandbox

Swimming at CalTech Pool

Vectored thruster for mobility in liquid media

Batteries/RPS provides ballast as well as heat/power

Lower sonde contains science instrument bay and vehicle controls

Crawler tracks for surface mobility with internal actuators to allow transfer from water to land mode

2003.04.22 Planetary Autonomous Amphibious Robotic Vehicle CFB-1

Fig 7. PAARV Being Tested in the Mars Sandbox and CalTech Pool

4. TECHNOLOGY ASSESSMENT

One of the key outputs of the Titan design analysis was to obtain a clear understanding of what we know, what we can comfortably predict in terms of launch mass/volume, and how a large scale in-situ science mission might be accomplished. Of particular importance was identification of the technology uncertainties and gaps. This first year effort identified the following critical technologies as enabling for a post-Huygens in-situ science mission:

- Ultra-light weight aerocapture/aeroshell materials;
- High efficiency SEP solar cell technology;
- High efficiency NEP/high-yield radioisotope materials;
- Extreme cold sensors/electronics/batteries
- Extremely high resolution micro-wet chemistry instruments;
- Extremely high resolution, low volume GCMS;
- Understanding the physics of cryogenic related failures/accurate failure projection models;
- GN&C w/o orbiter (surface beacons, Titan celestial nav, micro-satellites for GPS);
- Steerable phased patch array DTE comm using MEMS/nano-device technology;
- Structural/electronics packaging for extremely tight volumes;
- Cryogenic balloon materials;
- Packaging for long cruise soaks and cryogenic deployment;
- Solid Phase Micro-Extraction sample acquisition/ control devices;
- Solids/residue purging technologies for instruments/transfer ports;
- Icy organic sample acquisition and transfer via controlled adsorption/ desorption;
- Subsurface mobility propulsive mechanisms for dense cryo-organic liquids;
- Cryo-genic actuators/valves/seals;
- Cryo-tether materials (low shape memory/non-fracturable fiber-optics);
- Passive/amphibious mobile sondes for organic lake/crater rim sampling;
- Micro-harpoon impactors for dense icy materials (impact reaction mechanisms, cryo-liquid pyro mechanisms, low voltage/ high pressure micro tanks and valves;
- Autonomous control/fault tolerant-redundant S/W architectures;

5. SUMMARY AND CONCLUSIONS

The results of this initial study phase are significant. The following key findings were products of the design effort:

- We identified a Titan mission design that meets the science team requirements, based on a realistic payload/mass that can be injected down to the Titan surface (i.e., launch 5028kg total payload in 2011 and arrive 2017);
- We looked at near/far term launch capabilities of Adv SEP and NEP---NEP alone can deliver same payload but takes 2x as long to get to Titan (i.e., 11yrs);
- We determined that a hybrid launch/cruise system composed of an Atlas 551(Chem)+SEP+aerocapture entry looks best for the optimal:
  - Injected mass;
  - Trip time (keeping trip times ~6yrs +/-1yr per rqmt levied by science team);
- We completed the orbital insertion analysis/packaging with final mass breakdowns (total of 5028kg, 2600kg of injected mass, 100kg of science payload);
- We developed sonde and harpoon surface and sub-surface sampling designs that allow sampling of the atmospheric column, liquid lakes, and crater rim solid material;
- We developed a power and functional control architecture for the surface system (60W peak);
- We determined a way to remove the requirement for an orbiter, and developed a viable DTE communication concept using a patch array mounted on the aerial platform;
- We delineated the aerial platform/sonde design interfaces and developed dynamic models for sonde hydrodynamics;
- We developed a thermal control concept for the surface mobility/instrument delivery sondes to enable reliable surface and sub-surface operations for minimum power (20We after 5hrs).

6. ACKNOWLEDEMENTS

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors would like to acknowledge the following Titan team members for their respective contributions to this research activity: Dr. P. Beauchamp- JPL, Dr. J. Beauchamp- CalTech, Dr. R. Hodyss- CalTech, Dr. N. Sarker- UofA, Dr. M. Smith- UofA who participated on the Titan science team. Special acknowledgment also goes to the engineering support team composed of T. Sweetser- Orbital mechanics, P. Timmerman- Power, R. Frisbee/M. Noca- Propulsion, E. Satorius/E. Archer- Communications, J. Jones/J. Hall/B. Dudik- Aerial platform/Harpoon sampling system, C. Bergh /W. Fang /E. Kulczycki- Sonde electronic/mechanical design, G. Woodward- Probe deployment/functional operation simulation, S. Chao /A. Sengupta- Survivable systems analysis, M. Quadrelli- S/W control architecture (aerial platform to sonde(s), sonde-to-sonde), and last, additional mission design support from NASA Langley (F. Stillwagen, S. Krizan, E. Dyke, orbiter/aero-capture/simulation), and NASA Glenn (M. McGuire, NEP option).

7. REFERENCES

1. Chau, Quadrelli, Zimmerman, "Search for Life Chemicals & Resources on Titan," NASA, Code R Revolutionary Aerospace Concepts, RASC, January 2003.

2. Lorenz, R. D. and Mitton, J. 2002. *Lifting Titan's Veil*, Cambridge University Press, Cambridge.

3. Yung, Y. L., Allen, M. A., and Pinto, J. P. 1984. Photochemistry of the atmosphere of Titan: comparison between model and observations. *Astrophysical Journal Supplement Series* **55**, 465-506.

4. Khare, B. N., Sagan, C., Thompson, W. R., Arakawa, E. T., Suits, F., Callcott, T. A., Williams, M. W., Shrader, S., Ogino, H., Willingham, M. W., and Nagy, B. 1984. The organic aerosols of Titan. *Advances in Space Research* 4, 59-68.

5. Artemieva, N. and Lunine, J. I. 2003. Cratering on Titan: Impact melt, ejecta, and the fate of surface organics. *Icarus* 164, 471-480.

6. Lunine, J. I., Lorenz, R. D., and Hartmann, W. K. 1998. Some speculations on Titan's past, present and future. *Planetary and Space Science* 46, 1099-1117.

7. Zimmerman, W., et.al., “The Mars North Polar Cap Deep Penetration Cryo-Scout Mission,” 2002 IEEE Aerospace Conference, Session 2.07, Big Sky, Montana, March 9-16, 2002.