National Aeronautics and Space Administration

Titan In Situ Exploration Concepts at JPL

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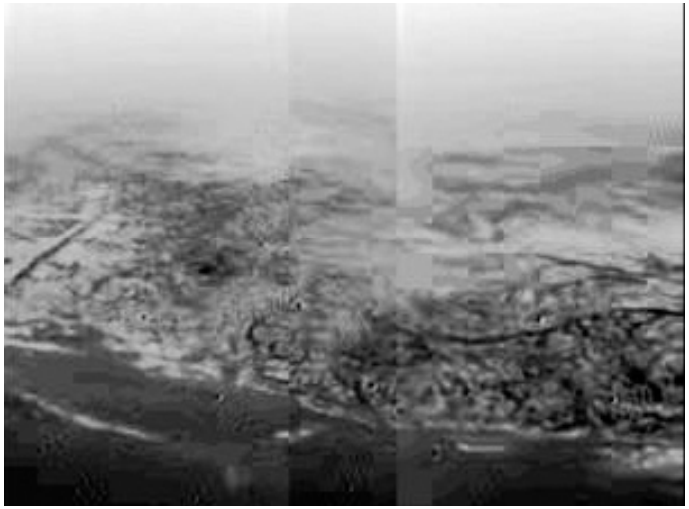
Overview

- The Titan environment is very well suited for exploration by buoyant (balloon) vehicles:
  - The dense atmosphere (4.5x higher than on Earth) allows for large payloads carried by compact vehicles
  - The atmosphere is clear below 10 km allowing for high resolution imaging
  - Huygens measured very low wind speeds near the surface, allowing for slow overflights and/or station-keeping by self-propelled aerobots
  - The 90 K cryogenic temperature would allow for hot air ("Montgolfiere") balloons with MMRTG-like ~2 kW heat inputs (on Earth it takes 50 – 100 kW of heat because of the much greater radiative heat losses)
- That last advantage has been exploited in the baseline Titan mission architecture by including a wind-driven RTG-Montgolfiere balloon
  - This kind of balloon would fill with ambient atmosphere making it highly tolerant of defects in the balloon envelope
  - Flight lifetimes of a year or more should be possible, allowing for the circumnavigation of Titan given the expected prevailing winds



Huygens aerial view of Titan

Titan Montgolfiere balloon concept

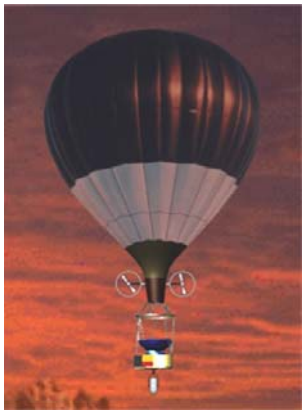
Titan Aerobot Baseline Options

Montgolfiere (Hot air) Balloon

Wind-driven

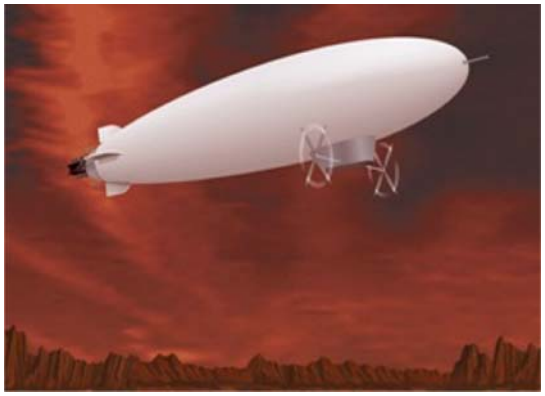
- Buoyancy would be produced by RTG-heated ambient atmosphere
- Altitude control via gas venting
- Moves with the winds
- Limited trajectory control via different wind directions at different altitudes
- Could acquire surface samples
- No loitering or station-keeping
- Essentially unlimited lifetime

Self-propelled



- Same as wind-driven Montgolfiere except for addition of 1 or more propellers for augmented trajectory control and station-keeping under some conditions.

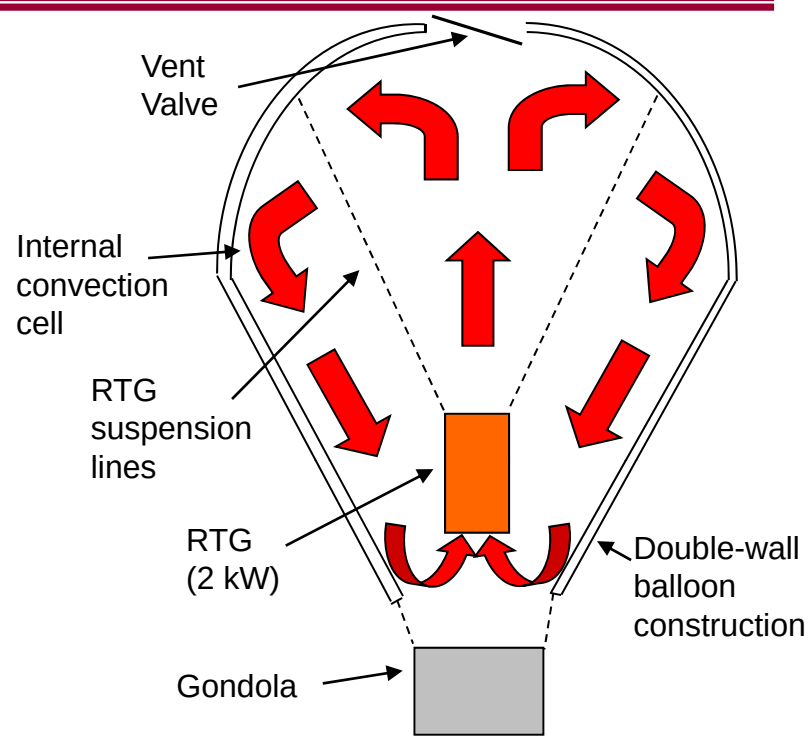
Self-propelled Blimp

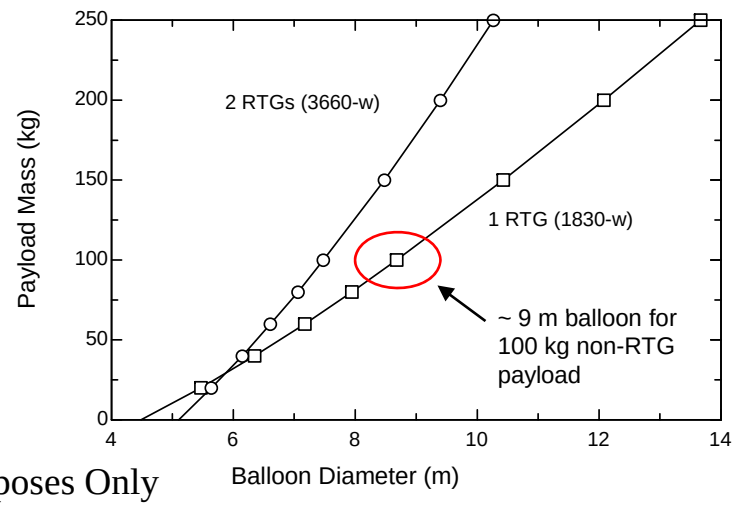


- Buoyancy produced by hydrogen gas
- Altitude control primarily via propulsion
- Propellers would generate 1-2 m/s flight speeds for precise trajectory control
- Loitering and station-keeping possible under expected Titan wind speeds
- Could acquire surface samples
- Lifetime limited by loss of hydrogen, but some replenishment possible from atmospheric methane

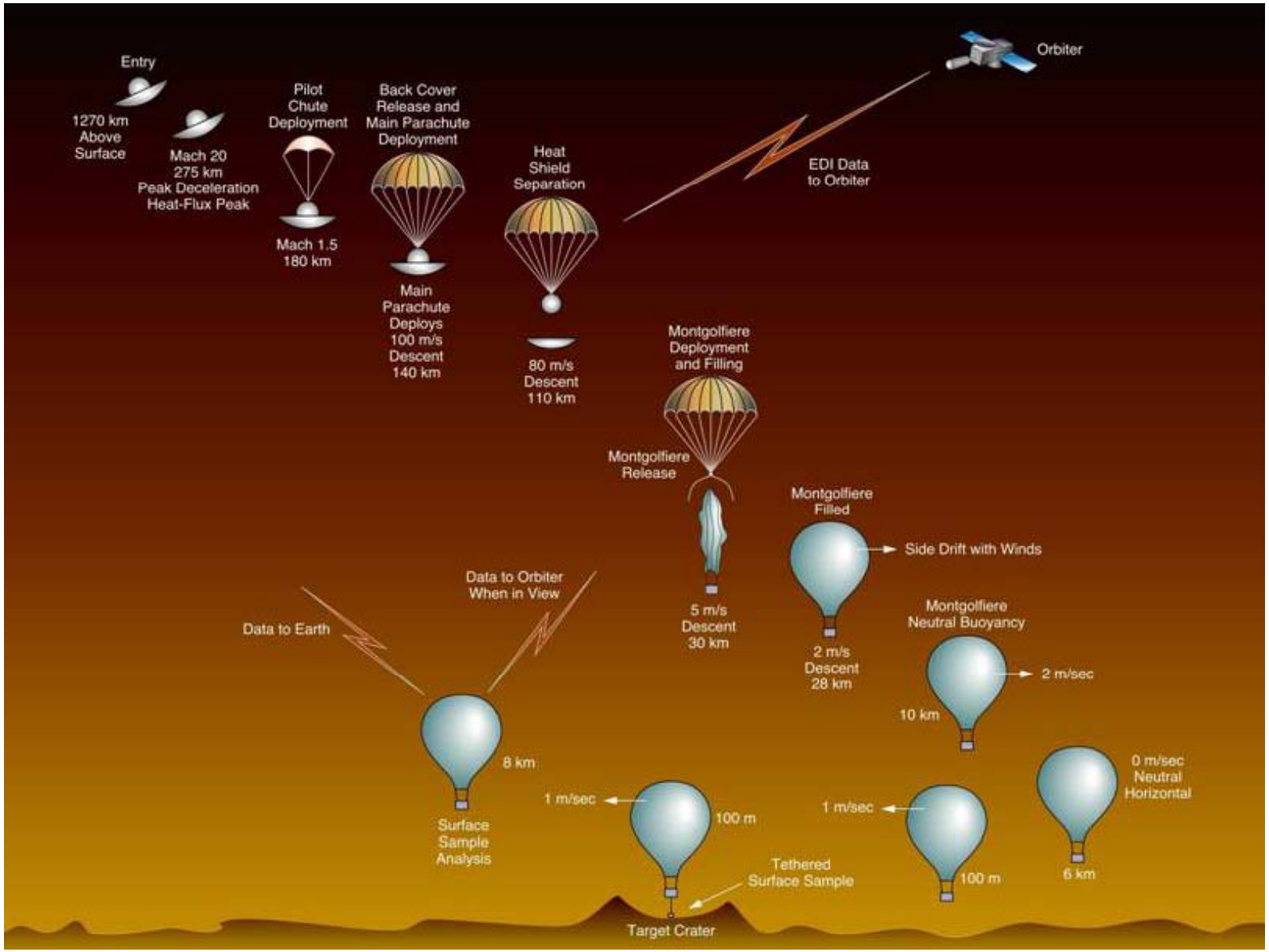
Baseline Balloon Description

- A hot air Montgolfiere balloon produces buoyancy by heating up ambient atmosphere to reduce its density
- At Titan, we would expect a 2 kW RTG thermal source to generate internal temperatures of ~20 K above ambient (110 K vs 90 K)
  - This would be sufficient to float a 100 kg payload (beyond the RTG) with a ~9 m balloon using a double-walled construction
  - The RTG would be located inside the balloon to minimize gas leakage out the bottom
- The balloon would include a valve at the apex to modulate buoyancy and achieve altitude control
  - An 0.5 m diameter valve will produce a ±0.5 m/s ascent/descent rate
  - Altitude control over a 0 to 10 km altitude range should be possible
  - Valve would normally held closed by metal springs; provides a fail-safe (closed) condition in the event of actuator failure



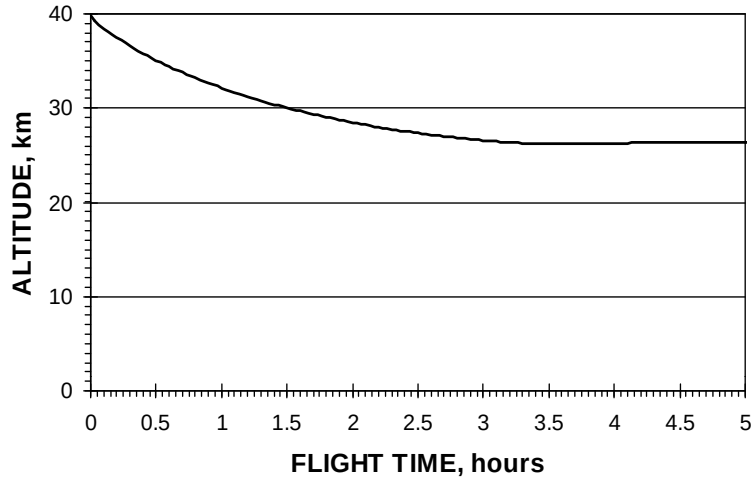


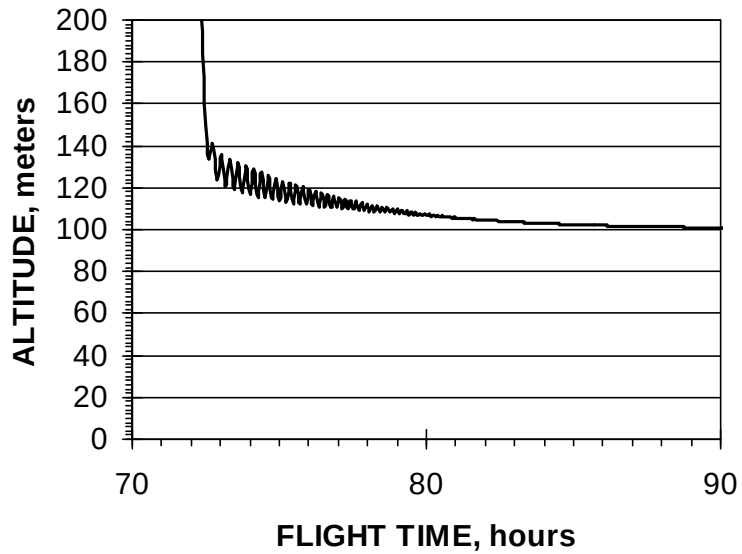
Titan Montgolfiere Deployment Scenario



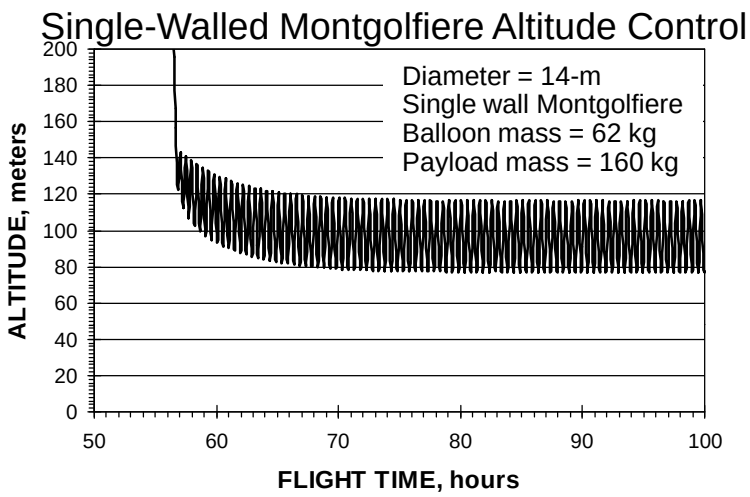
Balloon Altitude Control

- Analyses indicate that the balloon would deploy, inflate and achieve neutral buoyancy in approximately 3-4 hours
  - This is easily tolerable given the very slow parachute descent times (~3 m/s)
- The nominal exploration scenario would have the balloon moving with the winds at a 10 km altitude
  - For close-up surface observations, the balloon could descend to the surface in approximately 5-6 hours by simply opening the vent valve
  - Simulations show that even crude controllers could maintain altitude to within ± 5 m in the absence of turbulence
- The balloon could be fitted with a rope ("snake") that would hang below the balloon and off-load weight to provide for a "soft" landing in the event of an altitude control problem near the surface

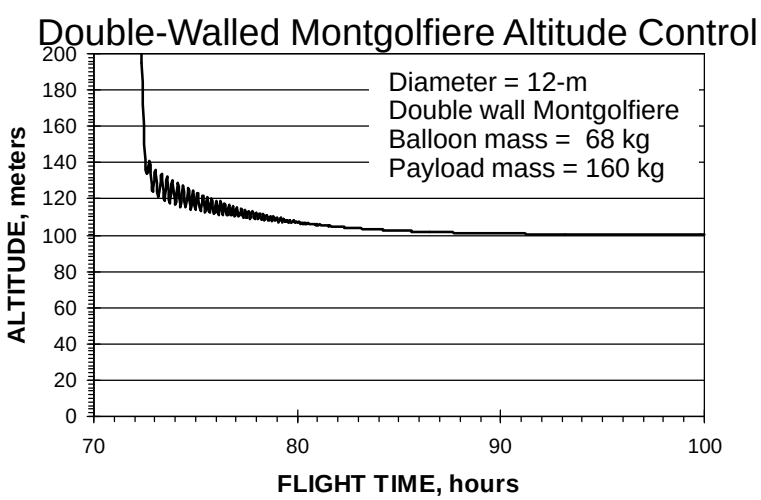


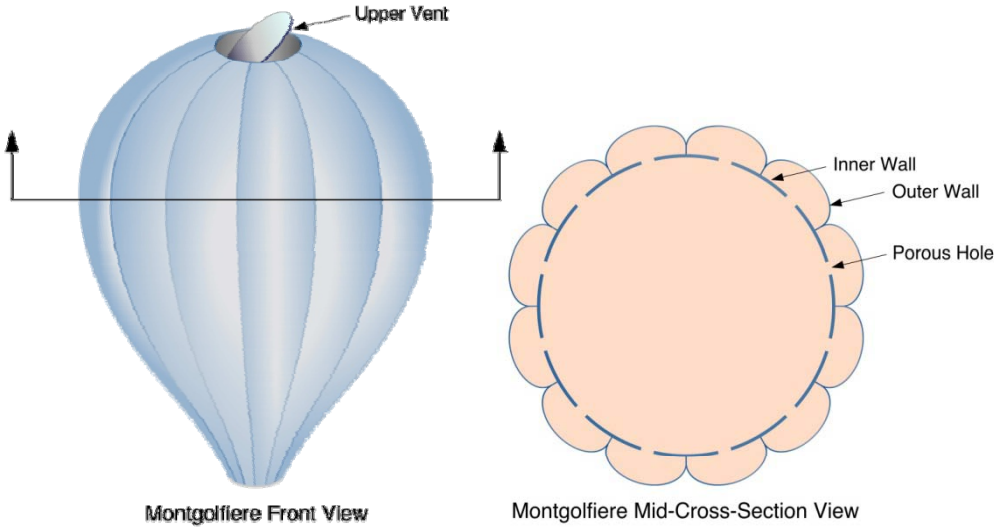


Titan Montgolfiere Thermal Analyses



- Both single-walled and double-walled RPS Montgolfieres could function well on Titan.
- Double-walled Montgolfieres could hold tighter altitude control and could be smaller (12-m vs. 14-m diameter)
- Double-walled Montgolfieres could safely ascend and descend at speeds of 1 km/hr. This corresponds to a 15 degree hazard avoidance angle with surface winds ~1 m/sec





Single vs. Double RPS Power System

- A single, 2000-watt RPS-heated, double-walled Montgolfiere balloon envelope could be about 12-m diameter and would have a mass of about 68 kg.

- A two-RPS, double-walled Montgolfiere balloon envelope(4000-watts) could be about 8-m diameter and would have a mass of about 30 kg.

- Both of these systems would be capable of ascending to over 20 km above the Titan surface, well above our planned ceiling of 10-km altitude.

Balloon Technology Status (1)

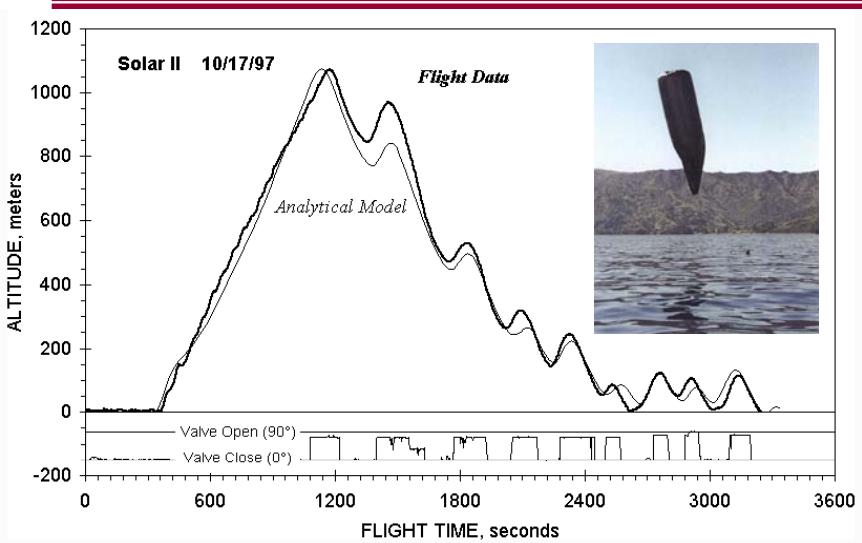
- JPL has been working Montgolfiere balloon technology since the mid-1990s and has invested substantial resources since 2002 to mature a broad spectrum of Titan-specific aerobot technologies centering on the key problems of:
  - The 90 K cryogenic Titan environment requires alternate balloon construction materials, payload thermal protection and balloon thermodynamic design modifications
  - The remoteness of Titan from Earth (2+ hours round trip light time) precludes human piloting and requires significantly autonomous operations
  - An aerobot must be folded up for the trip to Titan and then automatically deployed and inflated upon arrival.
- Progress has been made in many areas to build confidence in the viability of both Montgolfiere and powered blimp vehicles for Titan

Successful development of 93 K balloon material

4.3 m blimp tested at 93 K (2005)

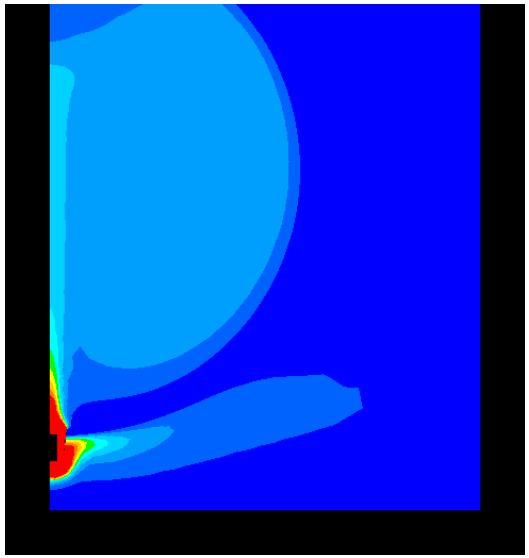
13 m blimp leak test (2006)

Balloon Technology Status (2)

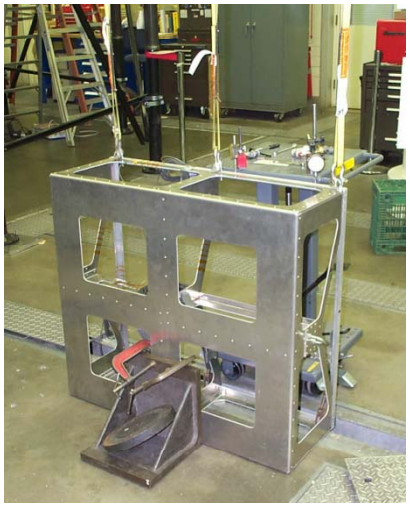


Earth solar Montgolfiere altitude control flight tests (1997)

JPL autonomy flight tests (2002-2006)



Montgolfiere CFD analysis (2004)



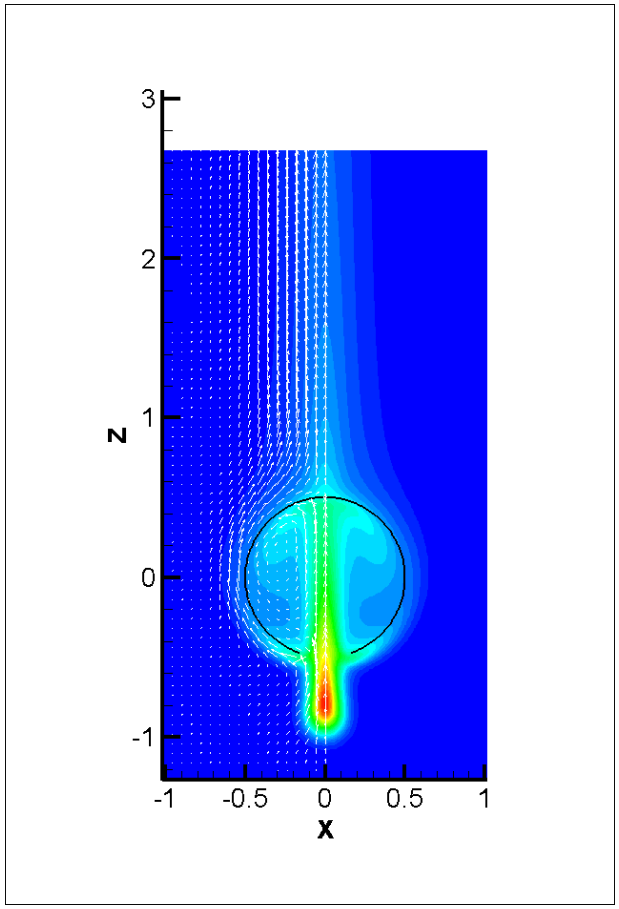
Gondola structural mockup static load test (2004)

Aerial deployment & inflation test (2006)

Caltech CFD analysis of Titan Montgolfiere Balloon

- JPL has started a collaboration with Prof. Tim Colonius of Caltech to conduct computational fluid dynamics (CFD) simulations of Titan Montgolfiere balloons
- The objective of this work is to verify and/or refine the heat transfer models used to design the balloon
- We expect to publish the first results at COSPAR later this summer

Example shows single-walled spherical balloon with external heat source below.



Technology Development Plan

- JPL and its partners have formulated a Titan Aerobot Technology Development Plan to guide future work and achieve TRL 6
- The plan includes both Montgolfiere and self-propelled blimp concepts to provide backup options to the Montgolfiere baseline in this study
  - These options provide improved functionality such as self-propelled site targeting, surface sample acquisition, station-keeping and direct-to-Earth telecom
- The starting point for the plan was the identification of key technical risks and development of exit criteria that must be achieved in order to achieve TRL 6
  - The Top Risk List is presented on the next slide
- Risk mitigation tasks have been formulated and cost estimates generated
  - Because of prior component development work, these tasks are dominated by sub-system and system prototyping and model validation experiments
- The plan is broken into two steps: Phase 1 consists of mostly room-temperature experiments, Phase 2 focuses on cryogenic subsystem and system testing
- It is estimated that 4-5 years will be required to complete the two-phase technology development plan with a total cost of $50M (including development of a new cryogenic testing facility for Phase 2)
  - This cost is reflected in the overall mission budget
  - The presumption is that upon completion of this technology development effort the Titan balloon technology will be at TRL 6 and ready to support a project PDR

Balloon Technology Top Risk List

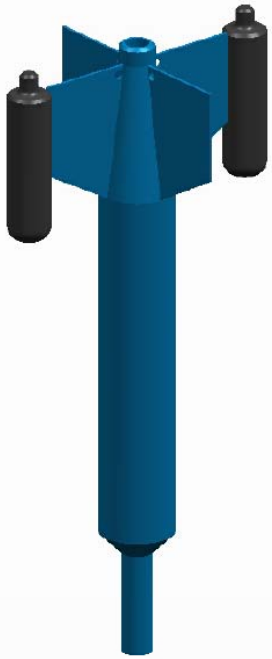
- Some of the risks are common to both main aerobot options (Montgolfiere balloon, self-propelled blimp) and some are particular to one or the other
- Some risks require new, large scale cryogenic testing and hence will not be retired until the completion of Phase 2 of the technology develoment effort as noted

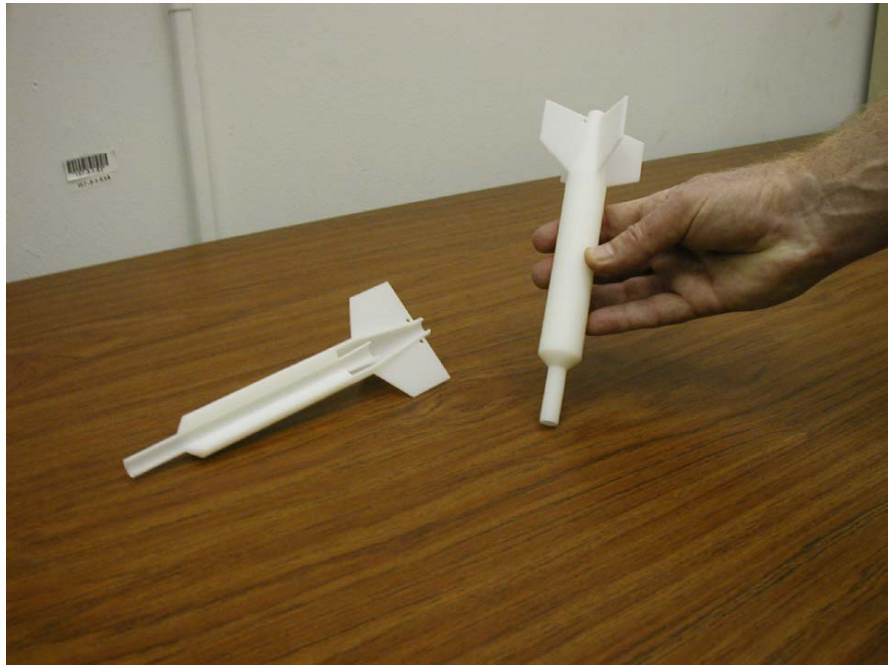
Rank	Risk	Which Architecture?	When retired?	
			Phase 1	Phase 2
1	Heat loss to cryogenic environment exceeds design limits on Montgolfiere balloon.	Montgolfiere	X	
2	Balloon and/or ballonet leak rate is larger than replenishment capability.	Blimp		X
3	Titan winds do not allow for significant wind-only targeting of science investigation sites.	Montgolfiere	X	
4	Lack of sufficiently large cryogenic test facilities	Both	X	
5	Aerial deployment and inflation severely damages aerobot.	Both		X
6	Inability to localize position on Titan to sufficient accuracy.	Both	X	
7	Manueverability/control is insufficient to safely accomplish surface sample acquisition operations.	Blimp		X

Baseline Montgolfiere Sample Acquisition and Handling

A tethered harpoon would be used to acquire ten samples (1-2 grams each) of surface ice from 100-m altitude above the surface. The samples would be pulled back up to the gondola for scientific analyses.

Cameras could be installed on the fins of the harpoon, or they may be dropped separately and simultaneously with the harpoon. Temperature control of the cameras would require small heaters if they are attached to the harpoon.

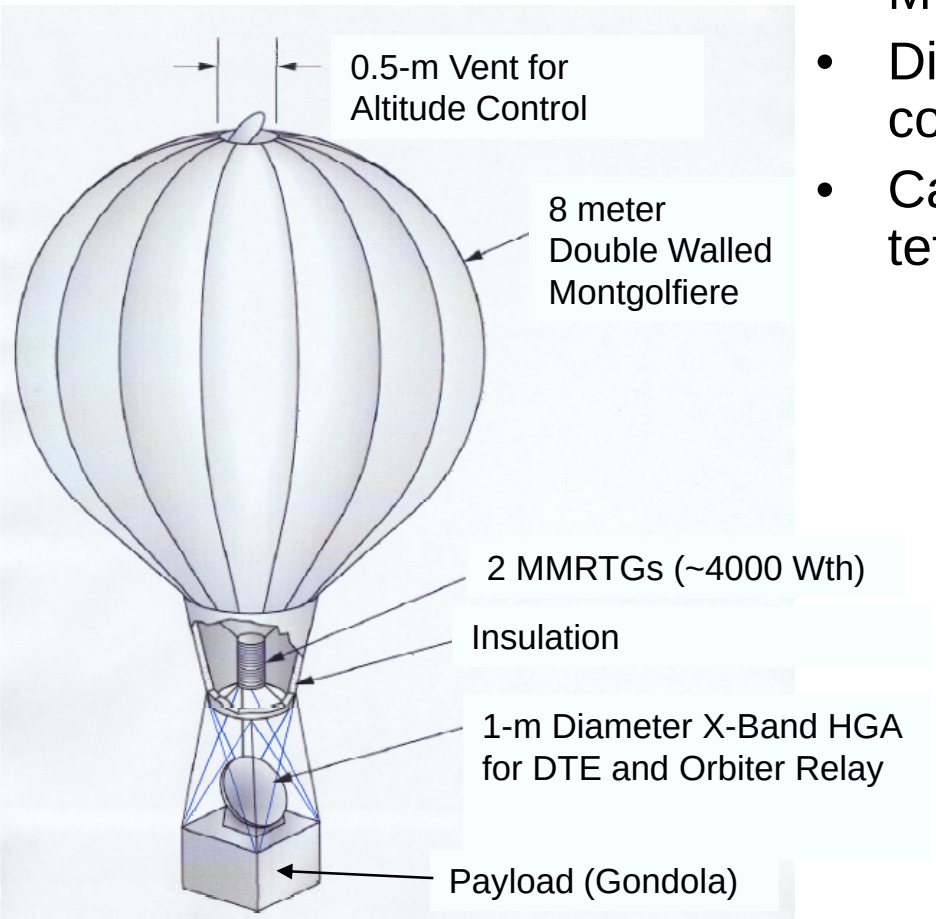


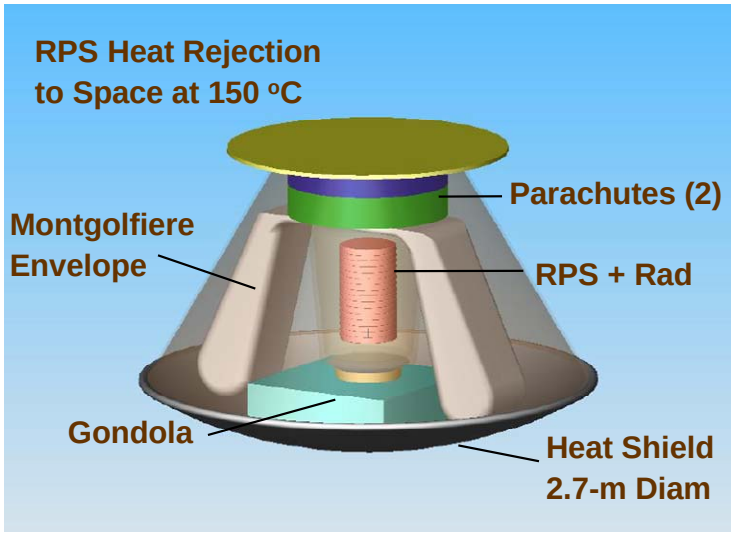


Another harpoon device is a simple gravity-dropped probe that traps samples in a sharp, hollow point. The harpoon tip is designed with small wires (not shown) that trap small particulates from falling out the end of the tube when lifted. There is also a liquid trap in the top of the harpoon for retaining liquids if the harpoon lands in a liquid hydrocarbon lake. Ten harpoons are planned, but these could be re-dropped numerous times.

TiPEx Concept (2006)

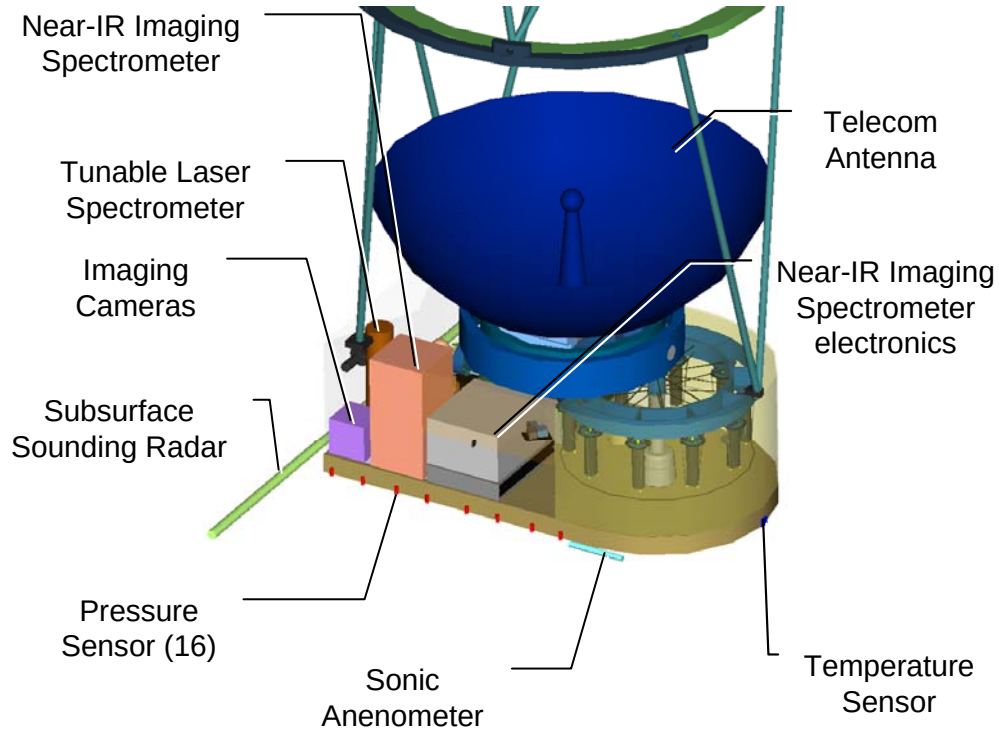
- 8m diameter Montgolfiere using two MMRTGs
- Direct-to-Earth and relay communications
- Capable of surface sampling using tether system



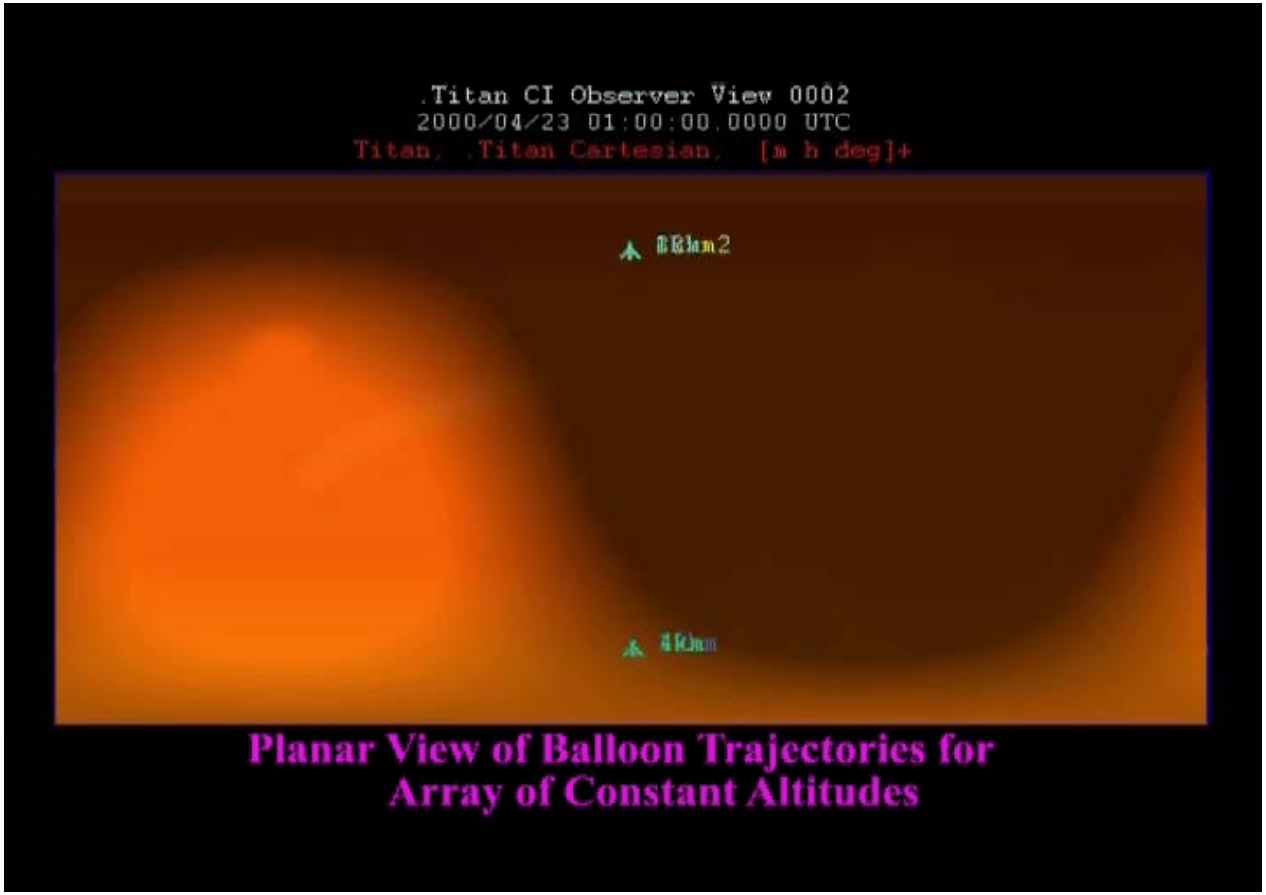


TiPEx Instruments

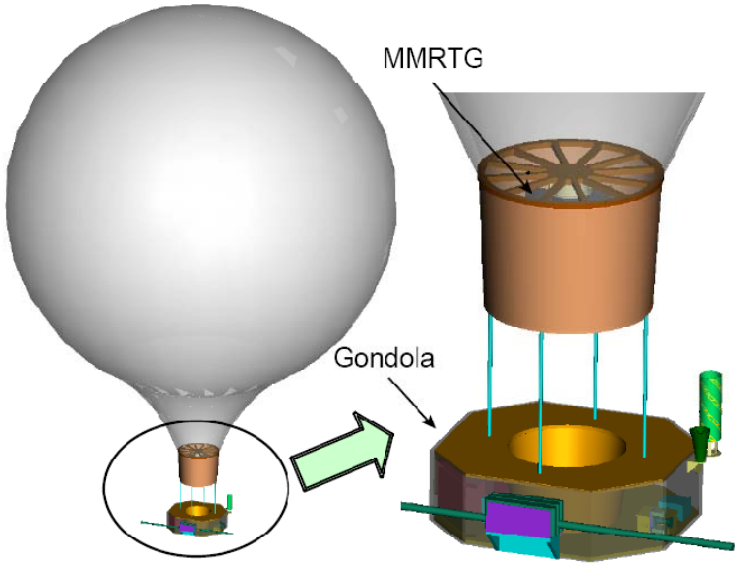
- Gondola
  - Subsurface sounder
  - Near-IR spectrometer
  - Tunable laser
  - Sonic anemometer
  - Imaging camera(s)
  - P-T sensor
  - Gas Chromatograph and Mass Spectrometer
  - Surface Sample Analysis
    - Sample acquisition mechanism
    - GCMS with chiral support
    - Age dating
    - Surface hardness
    - Sample context imager
    - Sample microscope imager
    - Elemental Analysis



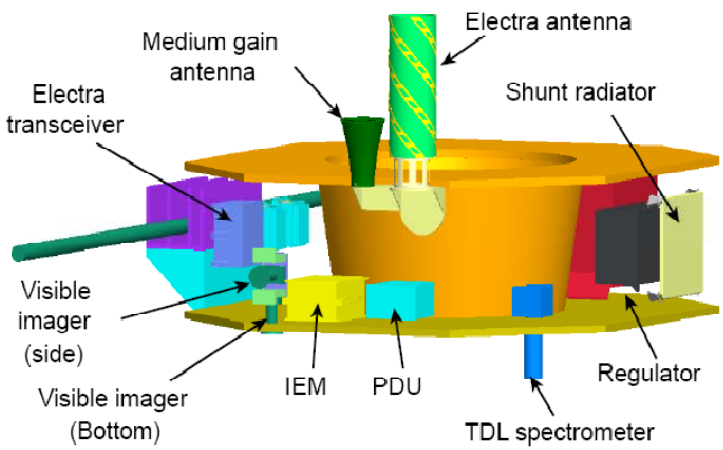
Balloon Trajectory Simulation

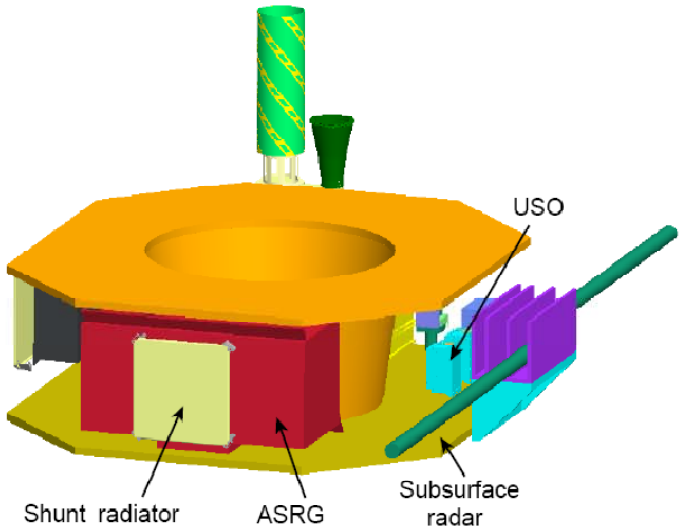


Titan Explorer 2007 Balloon



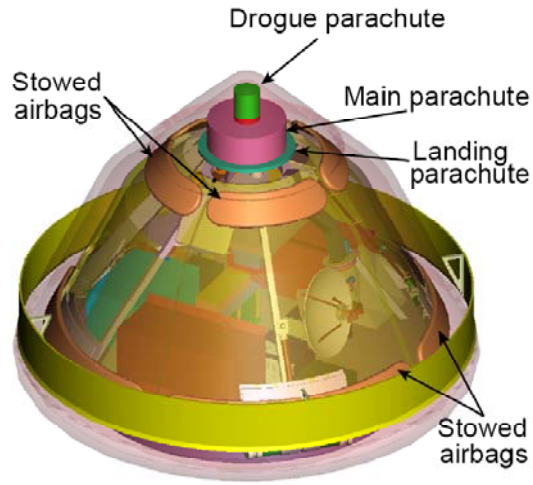
- 12m diameter Montgolfiere
- Single RTG would be used for thermal only
  - ASRG would be included on gondola for power
- Relay communications only
- Designed to fly at constant altitude
  - No surface sampling



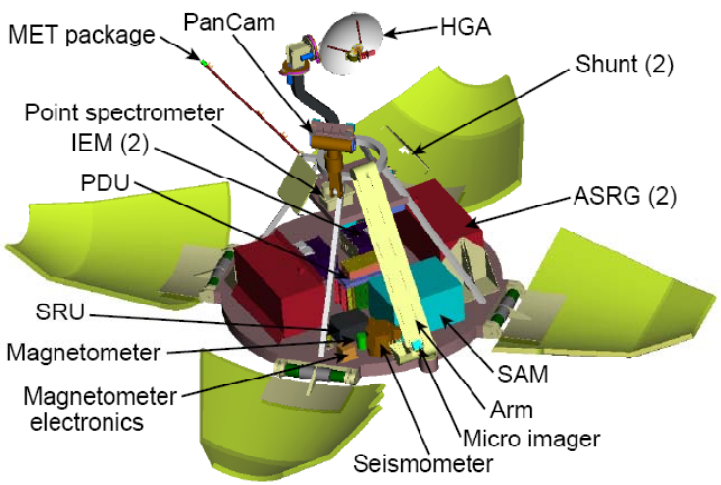


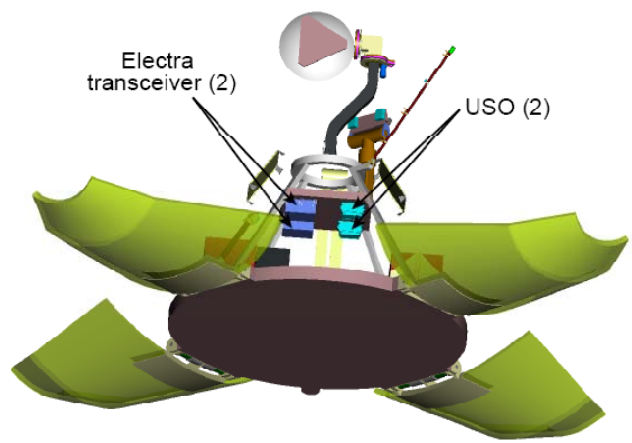
Baseline Titan Explorer 2007 Lander

Lander design provides access and fields of view for all instruments meeting Lander science requirements.



Lander and entry, descent and landing system package with adequate volume inside entry aeroshell.





Lander provides efficient structural and thermal design and meets all instrument accommodation requirements.

Summary

- Balloon technology for Titan is well understood given the long terrestrial experience and recent Titan-specific advances
- A 2-3 year plan has been developed to finish the balloon technology development and be ready for flight development
- The RTG-Montgolfiere balloon is a low-risk option that could provide substantial exploration capability at Titan
- There are options for enhancing the Montgolfiere balloon or switching to self-propelled blimp architectures
  - These options could provide enhanced exploration capability (e.g., self-propelled site targeting, surface sample acquisition, station-keeping, direct-to-Earth telecom)
  - There is additional development risk for these options that will be better understood and quantified with planned JPL R&D activities in the near future