Experimental Results for Titan Aerobot Thermo-Mechanical Subsystem Development

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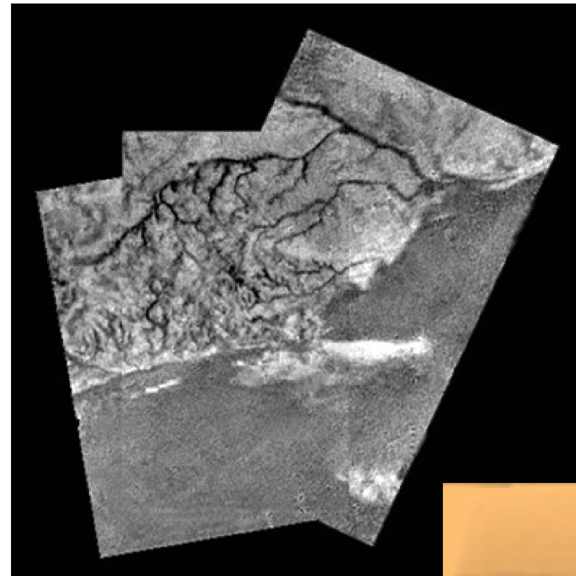
Introduction

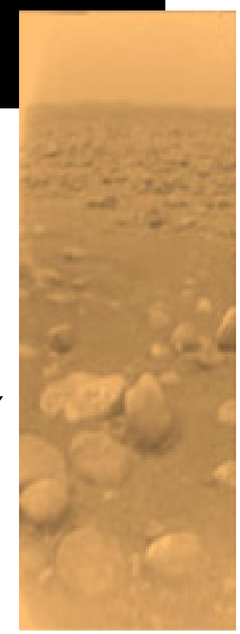
- This paper presents experimental results on a set of 4 thermo-mechanical research tasks aimed at Titan and Venus aerobots:
  1. A cryogenic balloon materials development program culminating in the fabrication and testing of a 4.6 m long blimp prototype at 93K.
  2. A combined computational and experimental thermal analysis of the effect of radioisotope power system (RPS) waste heat on the behavior of a helium filled blimp hull.
  3. Aerial deployment and inflation testing using a blimp
  4. A proof of concept experiment with an aerobot-mounted steerable high gain antenna
- These tasks were supported with JPL internal R&D funds and executed by JPL engineers with substantial industry collaboration for Task #1, the cryogenic balloon materials

Why Titan?

- Titan combines two powerful motivations for future exploration:
- Scientific
  - The Decadal Survey (2003) noted, “. . .the most compelling motivation is to understand the origin and destiny of life. . . . Titan provides a natural laboratory for the study of organic chemistry over temporal and spatial scales unattainable in terrestrial laboratories. Perhaps teeming with life or perhaps sterile today, (this) world do(es) contain the basic ingredients for life.”
- Public Excitement
  - The Cassini-Huygens mission has dramatically publicized Titan and shown it to be a fascinating world with a complex, if frozen, surface with channels (drainage basins) formed by a “methane cycle” and indications of (perhaps dry) lake beds and cryo-volcanism



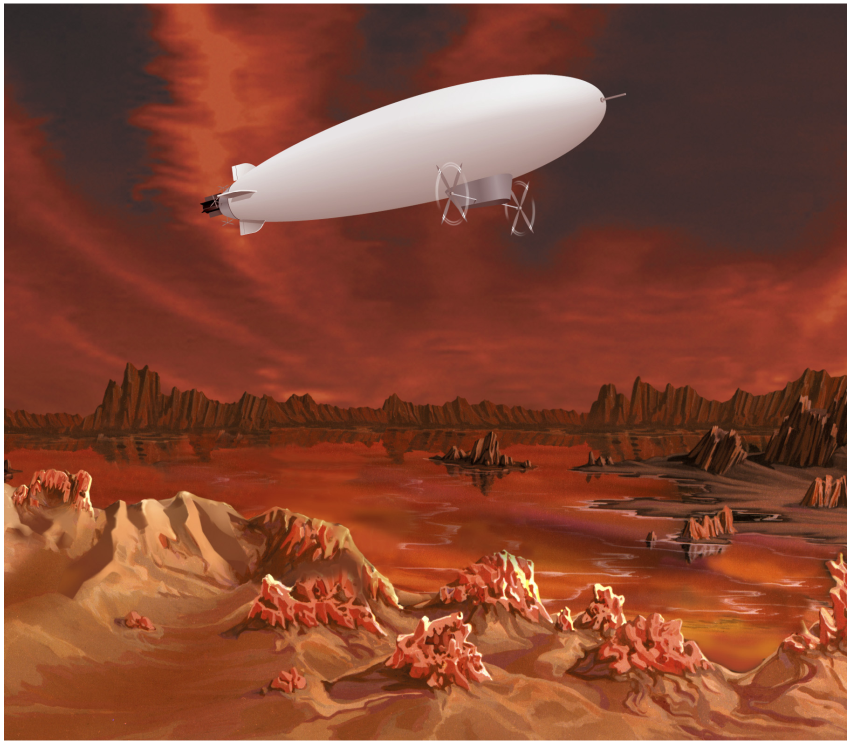
Titan surface from ~ 15 km altitude



Titan surface at Huygens landing site

The Case For "Proposed" Post-Huygens Titan Aerial Exploration

- Results from Cassini-Huygens strengthen the case for a follow-on mission with aerial mobility:
  - ***Huygens descent images*** show surface relief clearly from 15 km and below
  - ***Cassini fly by images,*** which view the surface through the entire atmosphere, are degraded by haze of greater optical depth than expected.
  - ***Huygens images*** reveal a complex landscape shaped by erosional processes (methane cycle) warranting much more detailed investigation.

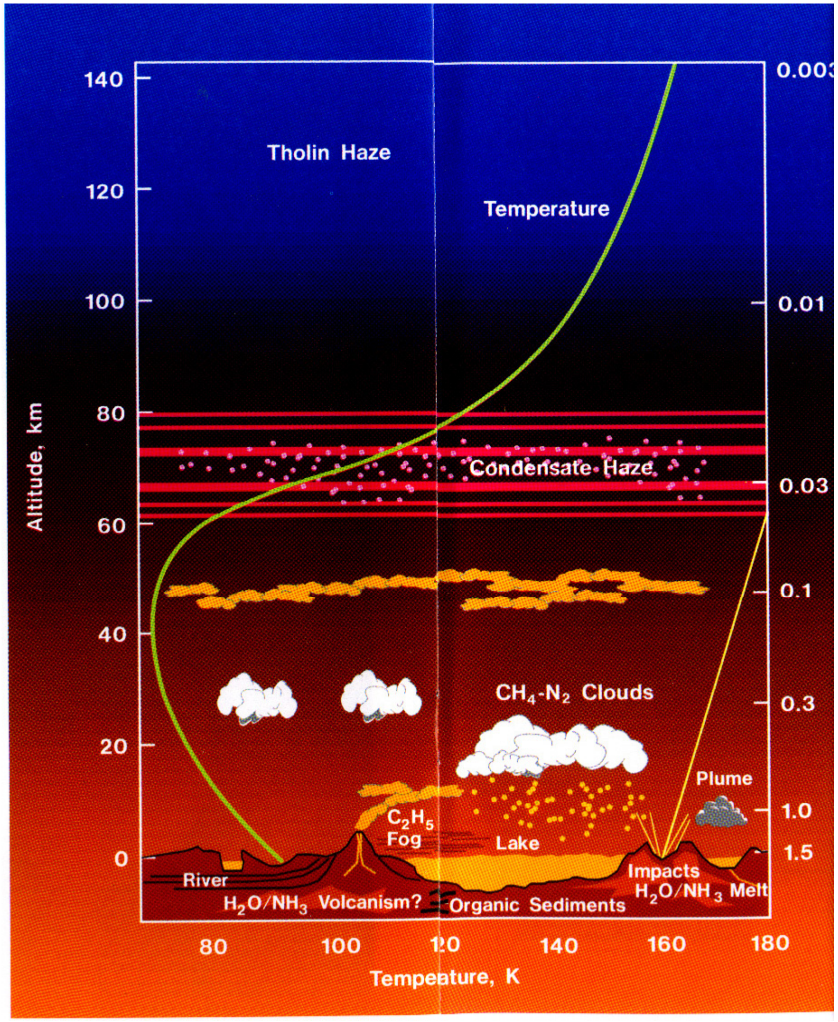


A pre-Huygens artist conception of aerobot at Titan

  - ***Indications of cryo-volcanism:*** highly localized places for investigation. Indicates the desirability for a vehicle with a "go to" capability.
  - ***Very low (<1.5 m/s) winds*** in the lower atmosphere (< 15 km) enable self-propelled aerobot concepts with modest power (100-200 W)

Titan Environment

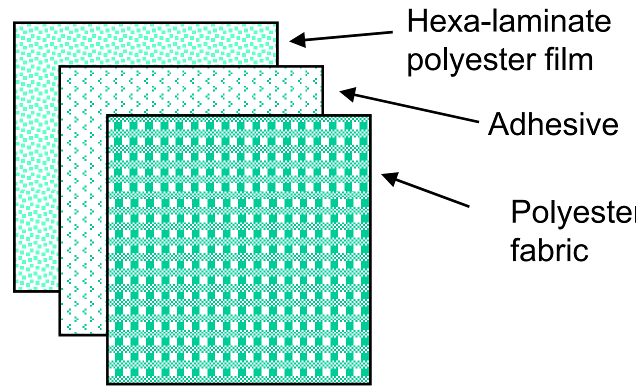
- Titan has a very thick, very cold atmosphere consisting of mostly N_2
  - Near surface temperatures are ~ 93 K (-180 °C)
  - Near surface pressure of 1.5 atm
  - Near surface density of 5.4 kg/m^3
- The river channels in the Huygens pictures were presumably carved by methane rain
  - Although the “lakes” appeared dry
- On large scales, the topography is relatively flat
  - Locally, the Huygens landing site shows ice “rocks”



Pre-Huygens description of Titan

Cryogenic Balloon Materials

- The key enabling technology for all Titan aerobot concepts is cryogenic balloon material for 90 K operation
- Previously reported work described our first generation polyester laminate that showed excellent cryogenic performance at coupon-level testing
- In the current work, taped joints were fabricated and tested for strength and flexibility at 90 K
- The best options were then used to fabricate cylinders which were also tested for strength and flexibility at cryogenic temperatures
- The strongest cylinders showed good performance at 100 K
  - Overlap seams worked best using a tape made from the same laminate as the balloon
  - However, only 77% of the expected cylinder burst pressure was seen compared to thin shell model estimates (we don't have an explanation)

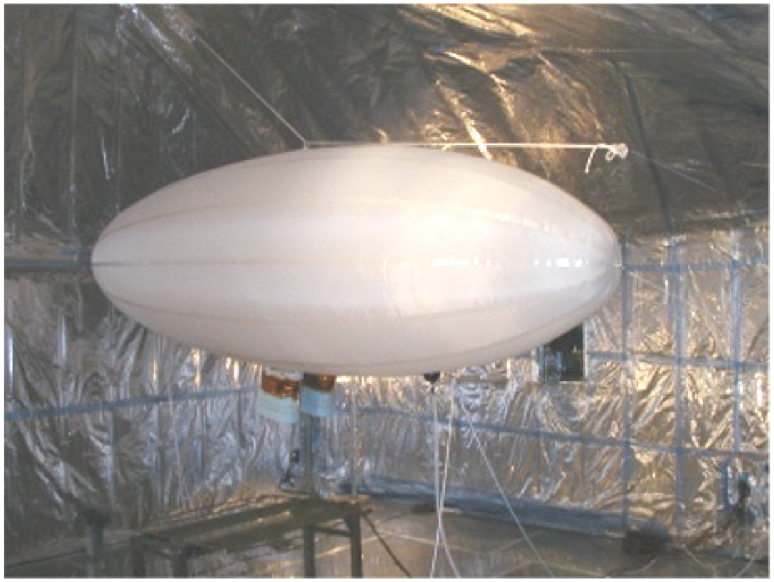


1st gen material is 94 g/m^2 with a 16400 N/m pull strength at 90K

Sample cylinder prior to cryogenic pressure test

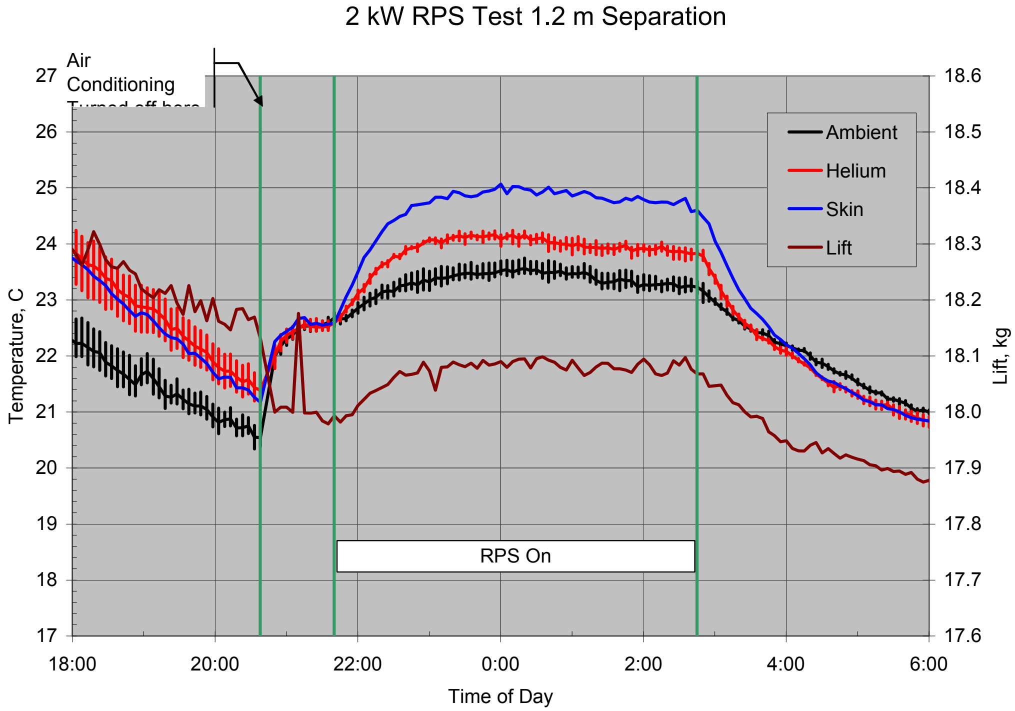
Sub-scale Aerobot Hull Prototype

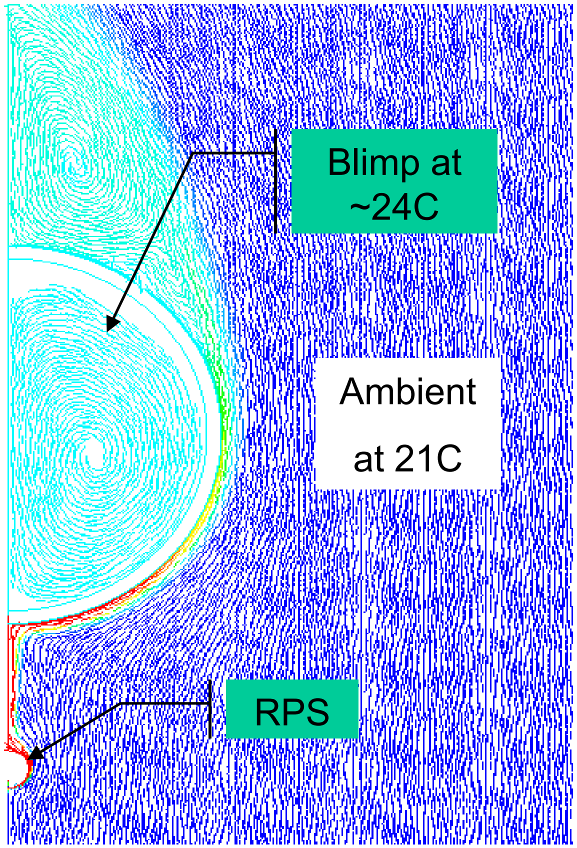
- A 4.6 m long aerobot hull was fabricated from the first generation material (~30% of full size Titan aerobot)
- This hull was inflated in a test chamber at Wyle labs and cooled to 93 K
  - Additional gas added during cooldown to keep hull nearly full
  - Small insulated and heated gondola had rotating propellers at this temp.
- No leaks detected during or after test on time scales of a few hours
- This demonstrates that the key materials and fabrication problems have been solved to first order
- A full scale hull with second generation material will be fabricated as part of the Lamart Phase II SBIR



RPS Testing and Modeling

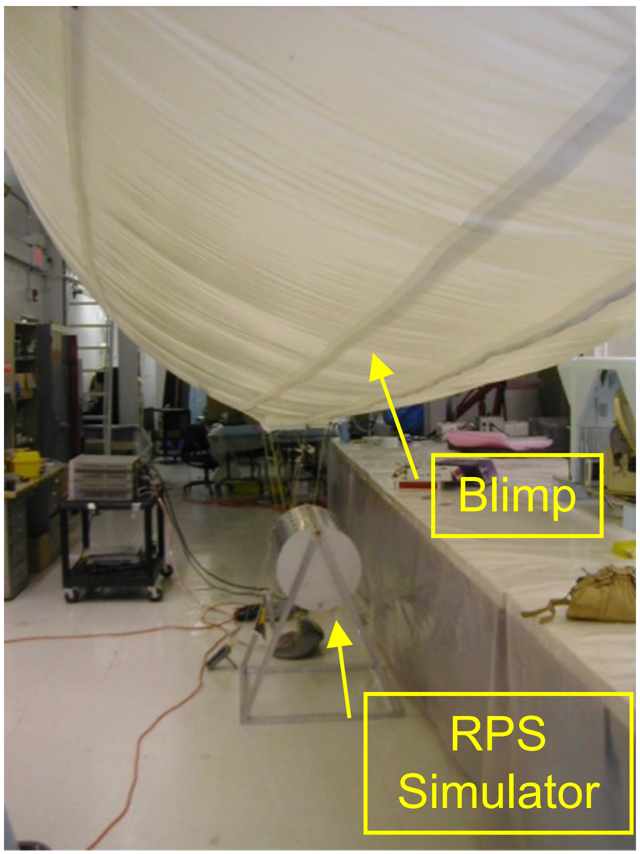
- Lab testing was performed with RPS simulator at two separation distances: 0.6 and 1.2 m.
- RPS was powered at 2 kW.
- CFD analysis of earth ambient test was performed to validate CFD model for Titan environment.



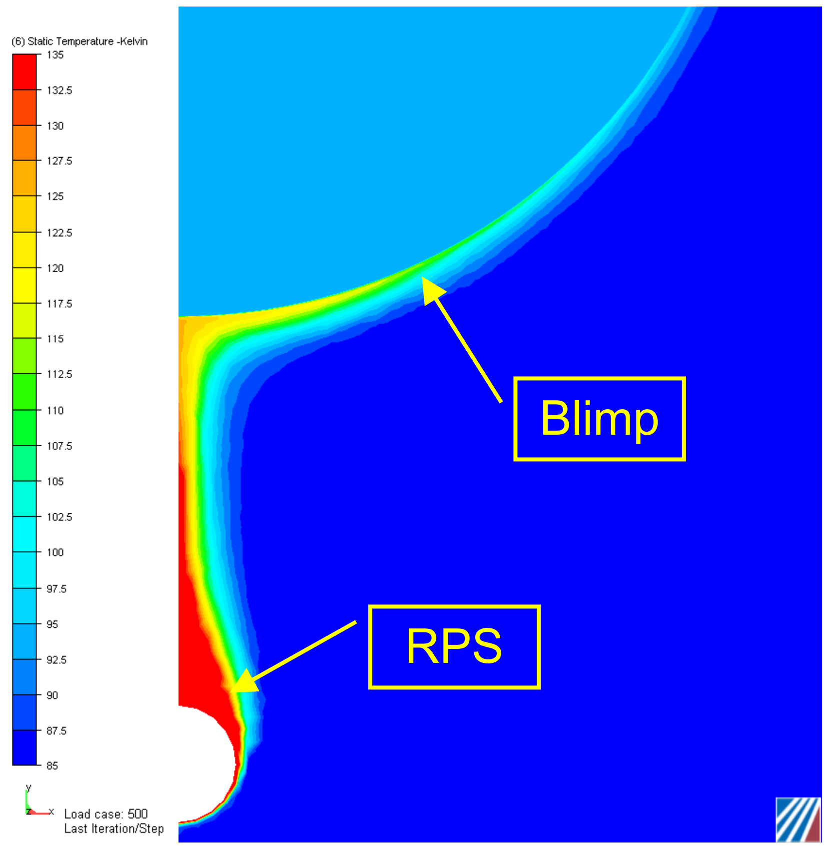


RPS Waste Heat Effect

- We did analyses and tests to evaluate the effect of 2000+ W of RPS waste heat on the buoyancy of the aerobot. Less than 20% of the RPS waste heat into the blimp.
- We discovered that placement of the RPS 1+ m below the hull was sufficient to minimize the buoyancy change to an easily tolerable amount (less than 2% change)

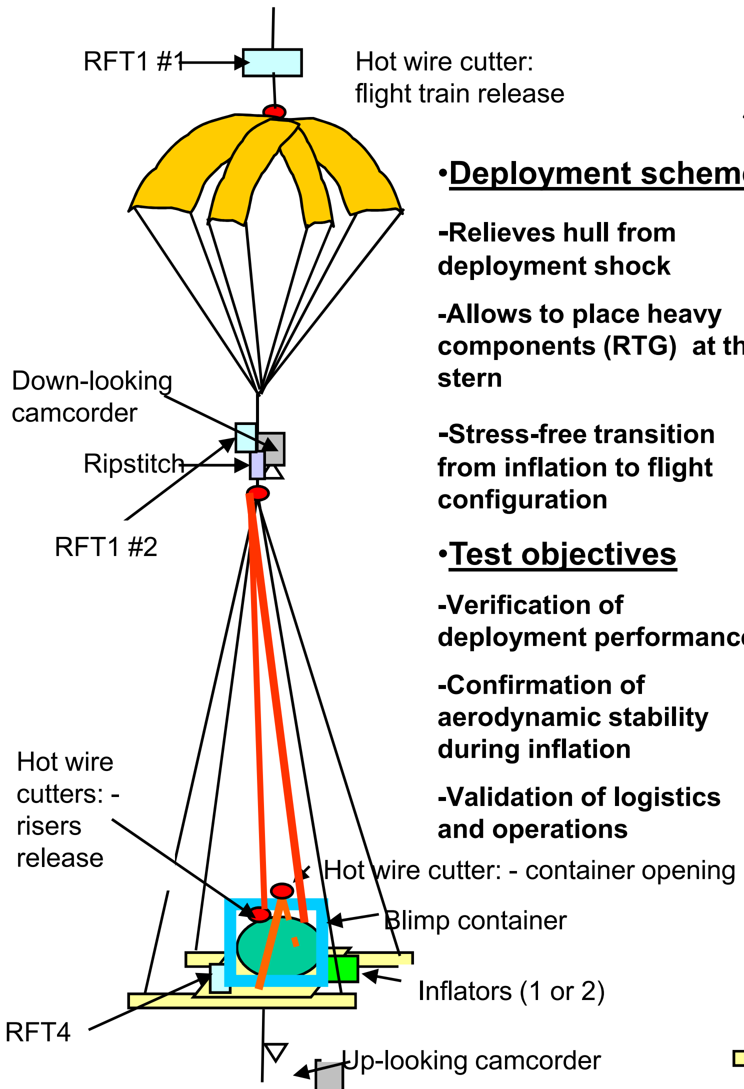


Ambient Test



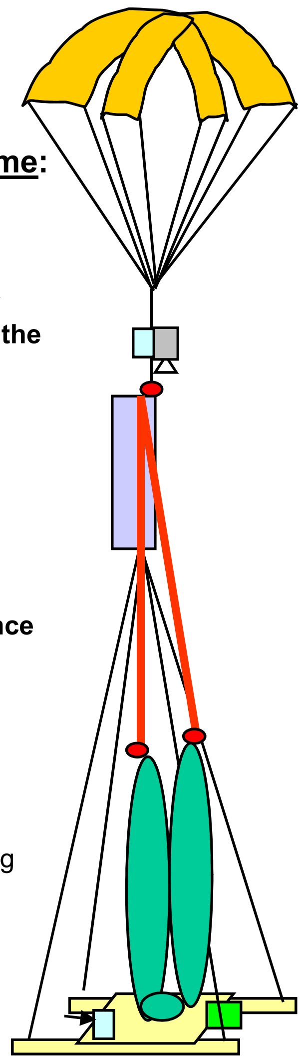
Model @ Titan

Deployment and Inflation Flight Test



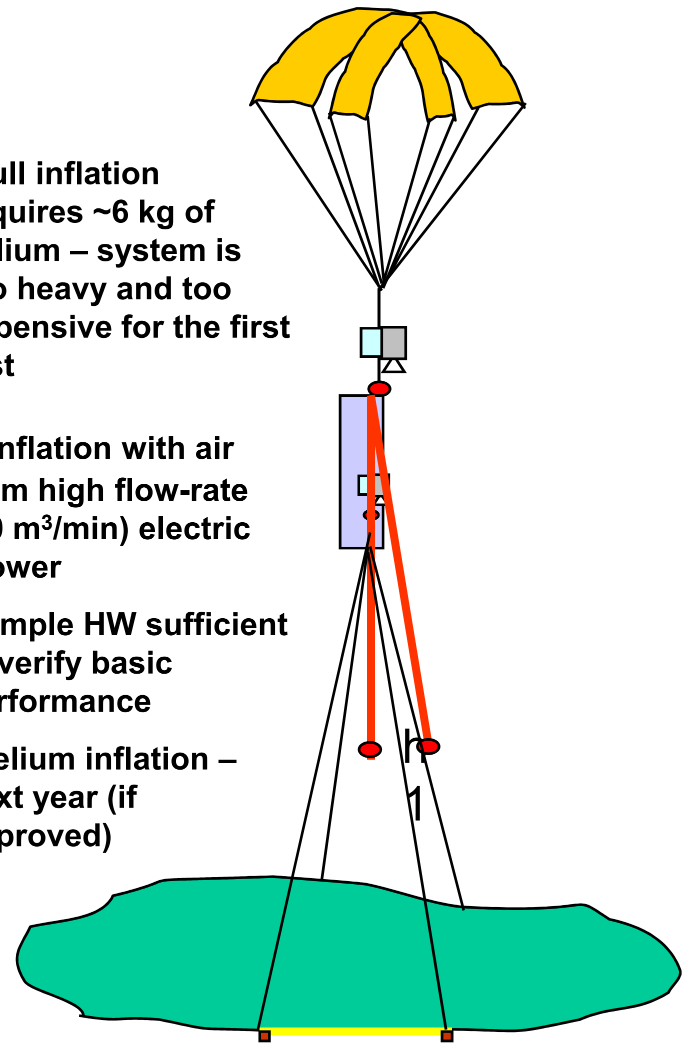
Flight train configuration

- **Deployment scheme**:
  - **-Relieves hull from deployment shock**
  - **-Allows to place heavy components (RTG) at the stern**
  - **-Stress-free transition from inflation to flight configuration**
- **Test objectives**
  - **-Verification of deployment performance**
  - **-Confirmation of aerodynamic stability during inflation**
  - **-Validation of logistics and operations**



Blimp deployment

- **Full inflation requires ~6 kg of helium – system is too heavy and too expensive for the first test**
- **Inflation with air from high flow-rate (10 m^3/min) electric blower**
- **Simple HW sufficient to verify basic performance**
- **Helium inflation – next year (if approved)**



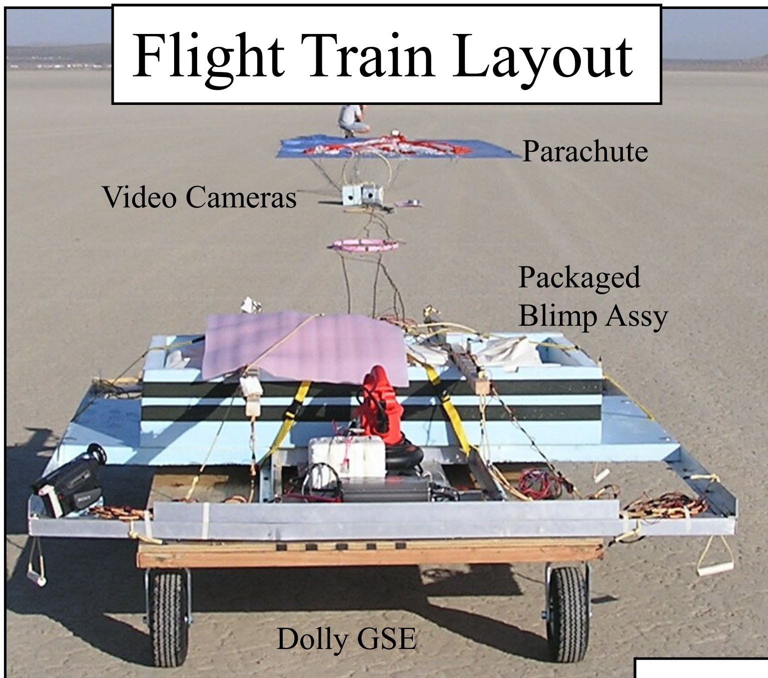
Blimp Inflation

Aerial Deployment Test

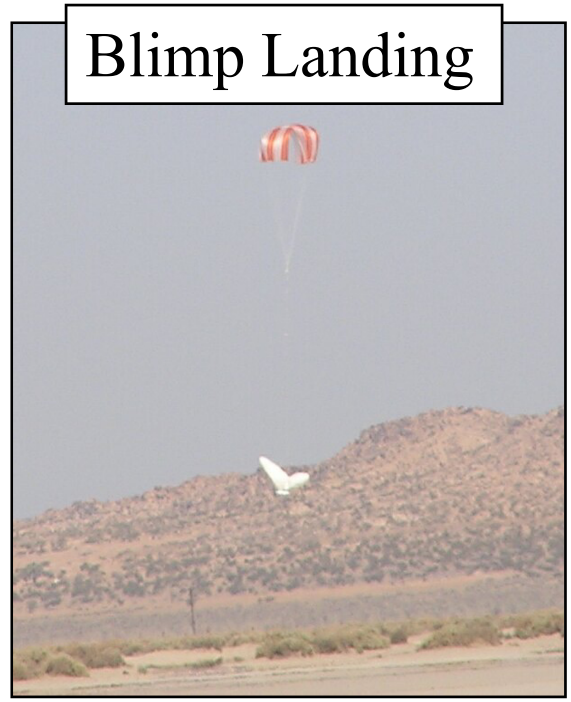
- Helicopter lifted flight train to 5000 ft above ground level
- Flight train was remotely cut from helicopter tow line at designated altitude and location
- Pre-deployed 46 foot diameter cross parachute inflated and provided 5 minutes of descent time
- Blimp was remotely deployed from packaged configuration, 5 m free fall under parachute
- Electric "leaf blower" inflated blimp with ambient air using remote command
  - Powered by sealed gel type automobile battery and 1500 watt power converter
- Blower turned off before landing
- Blimp and parachute recovered from dry lake bed in reusable condition

Aerial Deployment Test

Flight Train Layout



Blimp Landing



Blimp Recovery

Steerable Antenna Proof of Concept Test

- Direct to Earth telecom capability from the Titan aerobot would be very helpful
- We conducted a proof-of-concept test using a commercially available mechanically steerable antenna
  - This device requires ~ 1 deg pointing to obtain DirecTV signals, comparable to the ~ 0.5 deg pointing needed at Titan
- The antenna was suspended below a blimp and moved around by hand to simulate powered flight
- The antenna kept lock on the signal throughout the testing
- We conclude that this approach is viable for Titan aerobots

Conclusions

- This paper presented experimental results on a set of 4 thermo-mechanical research tasks aimed primarily at Titan aerobots, similar technologies with different materials may be used at Venus
  1. Cryogenic balloon materials were developed and rigorously tested for toughness, leakage and fatigue at Titan atmospheric temperatures.
  2. A 4.6 m long blimp prototype was fabricated and "flown" in a large environmental chamber at 93K demostrating operation of motors and survivability of blimp envelop under Titan-like conditions. No helium leakage was observed.
  3. A computational thermal/fluid analysis of the effect of radioisotope power system (RPS) waste heat on the behavior of a helium filled blimp hull was conducted. The model was validated with an ambient test which was compared to the ambient CFD model.

Conclusions Cont.

4. An aerial blimp deployment method simulating atmospheric entry deployment scheme suitable for Titan or Venus was developed and successfully demostrated through field testing.
5. A proof of concept experiment with an aerobot-mounted steerable high gain antenna was successfully demonstrated simulating DTE communication for a blimp aerobot platform.

- Future work will focus on developing autonomous navigation techniques and technologies for the aerobot platform