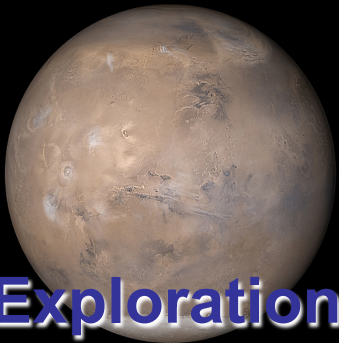
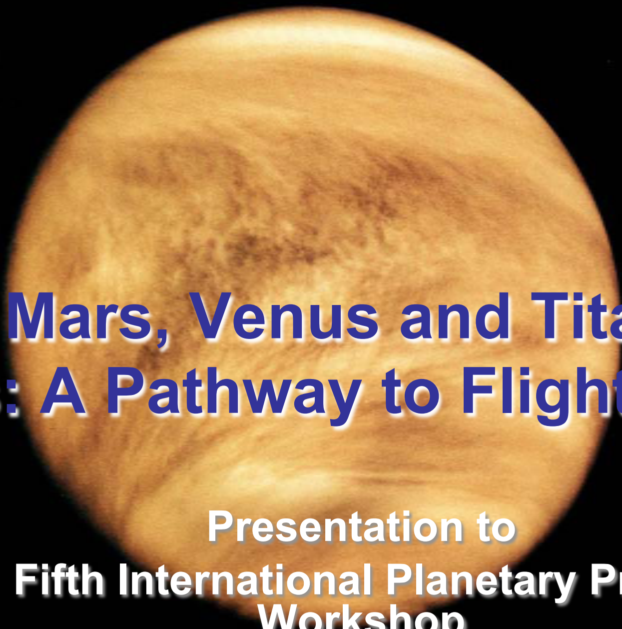
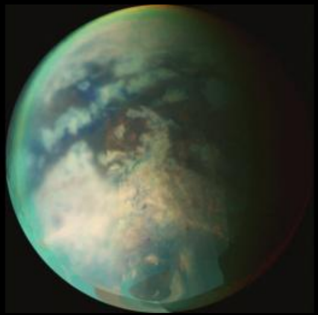




Exploration of Mars, Venus and Titan with Planetary Aerobots: A Pathway to Flight Readiness



Presentation to
Fifth International Planetary Probe Workshop
Bordeaux, France

James A Cutts
Jeffery L Hall
Elizabeth Kolawa

Jet Propulsion Laboratory
California Institute of Technology

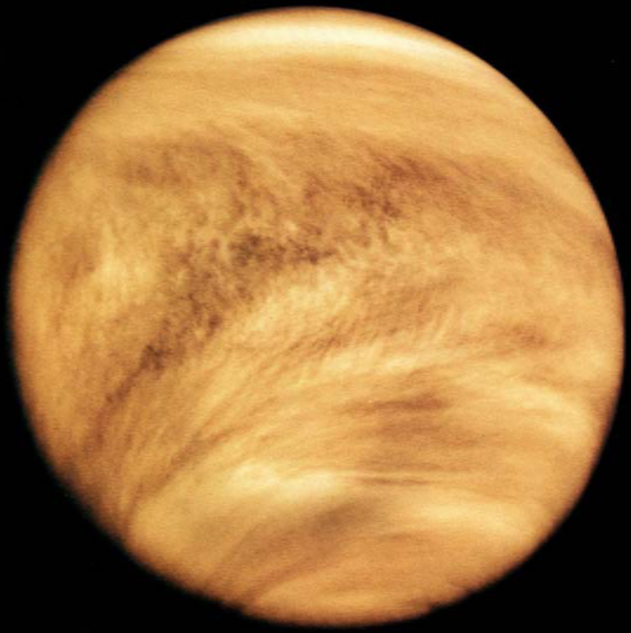
June 25, 2007

Topics

- Worlds with atmospheres and solid or liquid surfaces.
- Types of platform for solar system exploration
- In Situ Exploration with lighter-than-air vehicles
- Lighter than air vehicles for exploring
  - Mars
  - Venus
  - Titan
- Major Challenges
- Conclusions

Venus and Earth

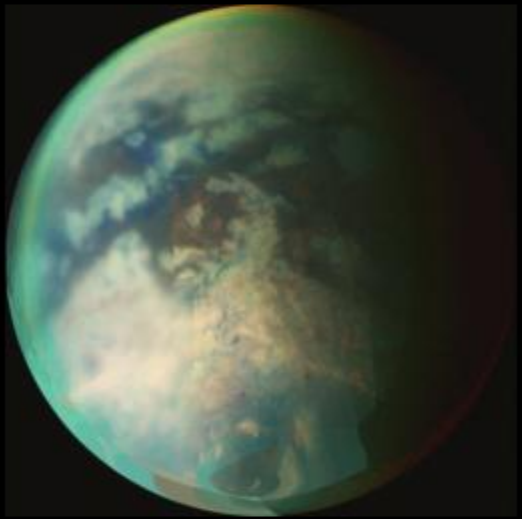
Worlds with atmospheres and solid or liquid surfaces

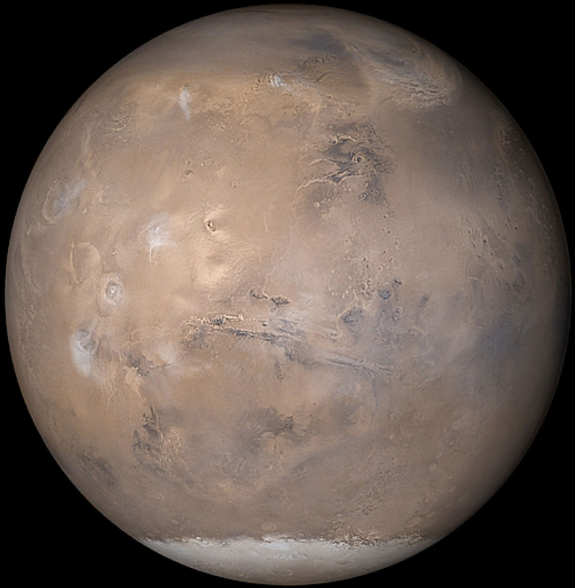


Venus Visible Image
Mariner 10

Venus Radar Image
Mariner 10

Earth, Titan and Mars: Worlds with atmospheres and solid or liquid surfaces





Atmospheric Environments of Venus, Titan and Mars?

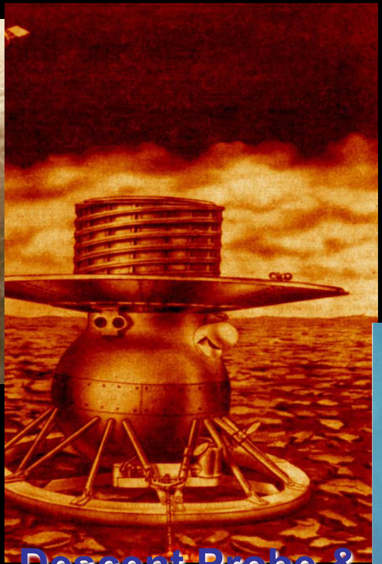
Parameter	Units	Earth	Venus	Titan	Mars
Temperature	K	290	750	90	155 - 300
Pressure	Bars	1	90	1.5	0.006
Density	kg/m^3	1.23	65	5.5	0.010

Planetary Exploration – Types of Exploration Platform

Flyby Missions
1962 – Present

Orbiter Missions
1971 – Present

Spacecraft
Platforms



Descent Probe &
Lander Missions
1972 – Present

Fixed
Site

Aerial
Mobile

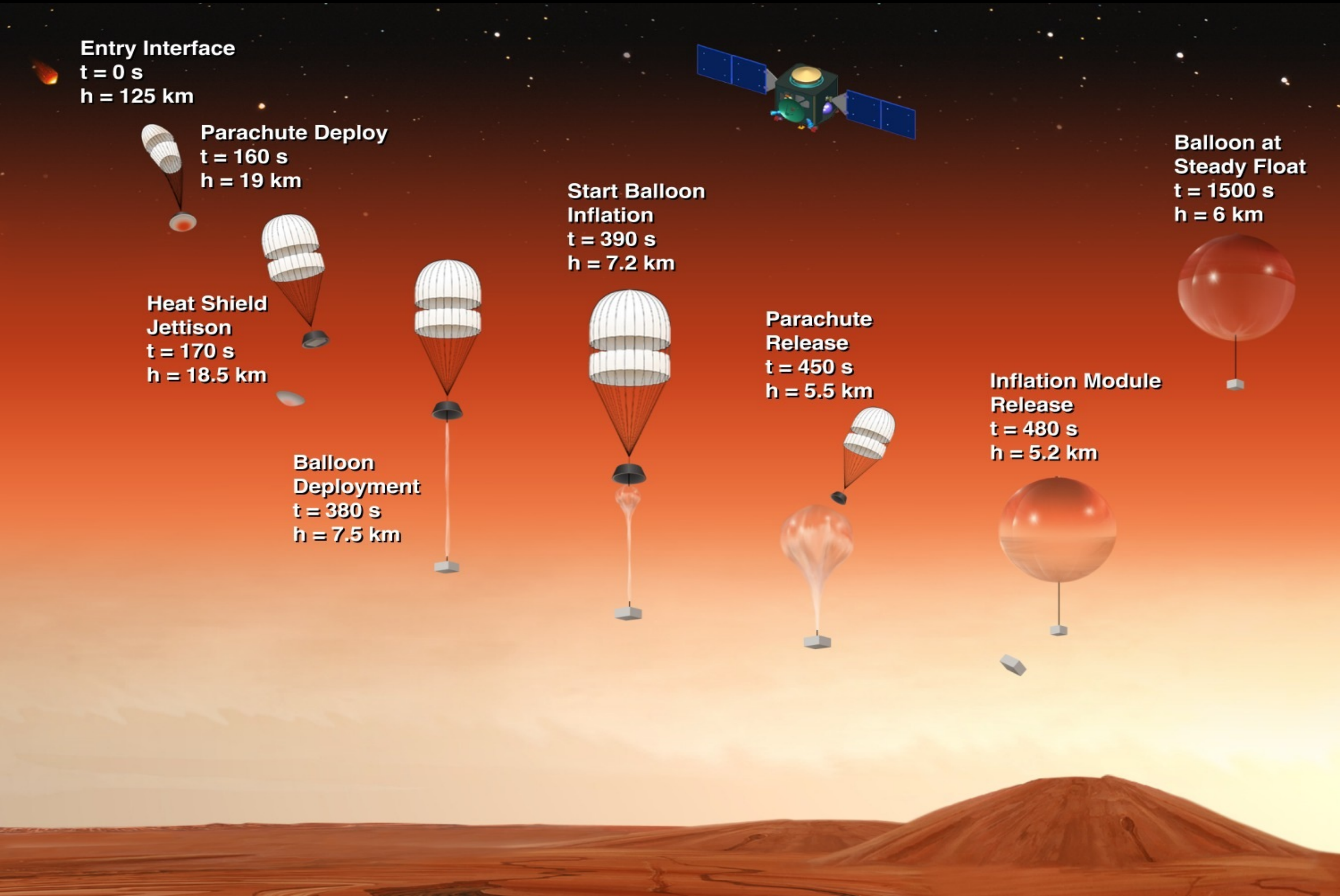
In Situ Exploration
Platforms

Surface
Mobile

Rover Missions
2004 – Present

Concept for Mars Superpressure Balloon - 1998

Aerial Inflation of a Mars Balloon



Mars Superpressure Balloons: Technology Alternatives

Pumpkin Balloon

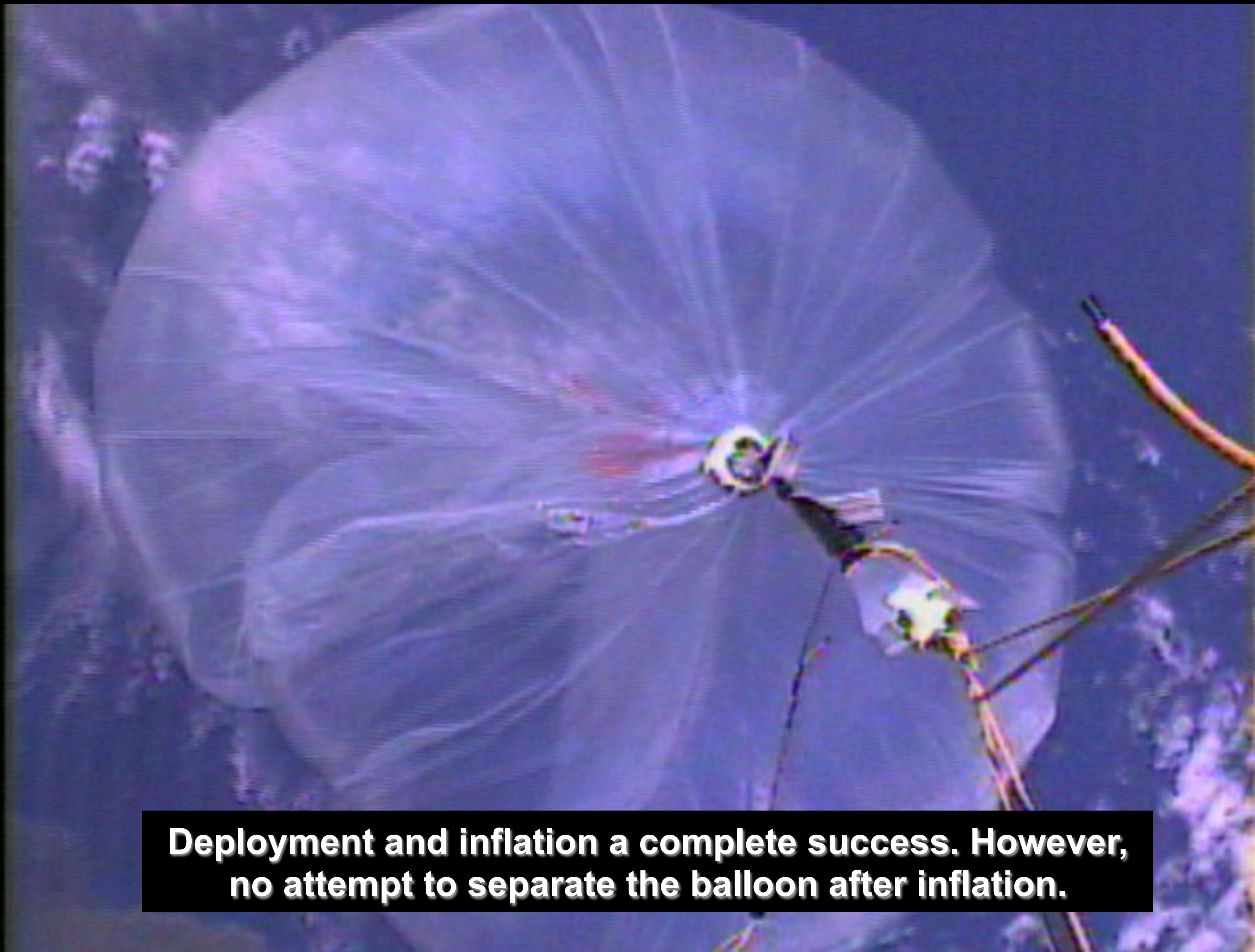
- Polyethylene film and PBO tendons
- Tendon reinforcement along each gore
- Tendons carry most of the superpressure load allowing for thinner balloon films
- Tendons carry most of the deployment shock loads

Spherical Balloon

- Mylar film with taped seams
- Extra thick end caps and
- No other reinforcement

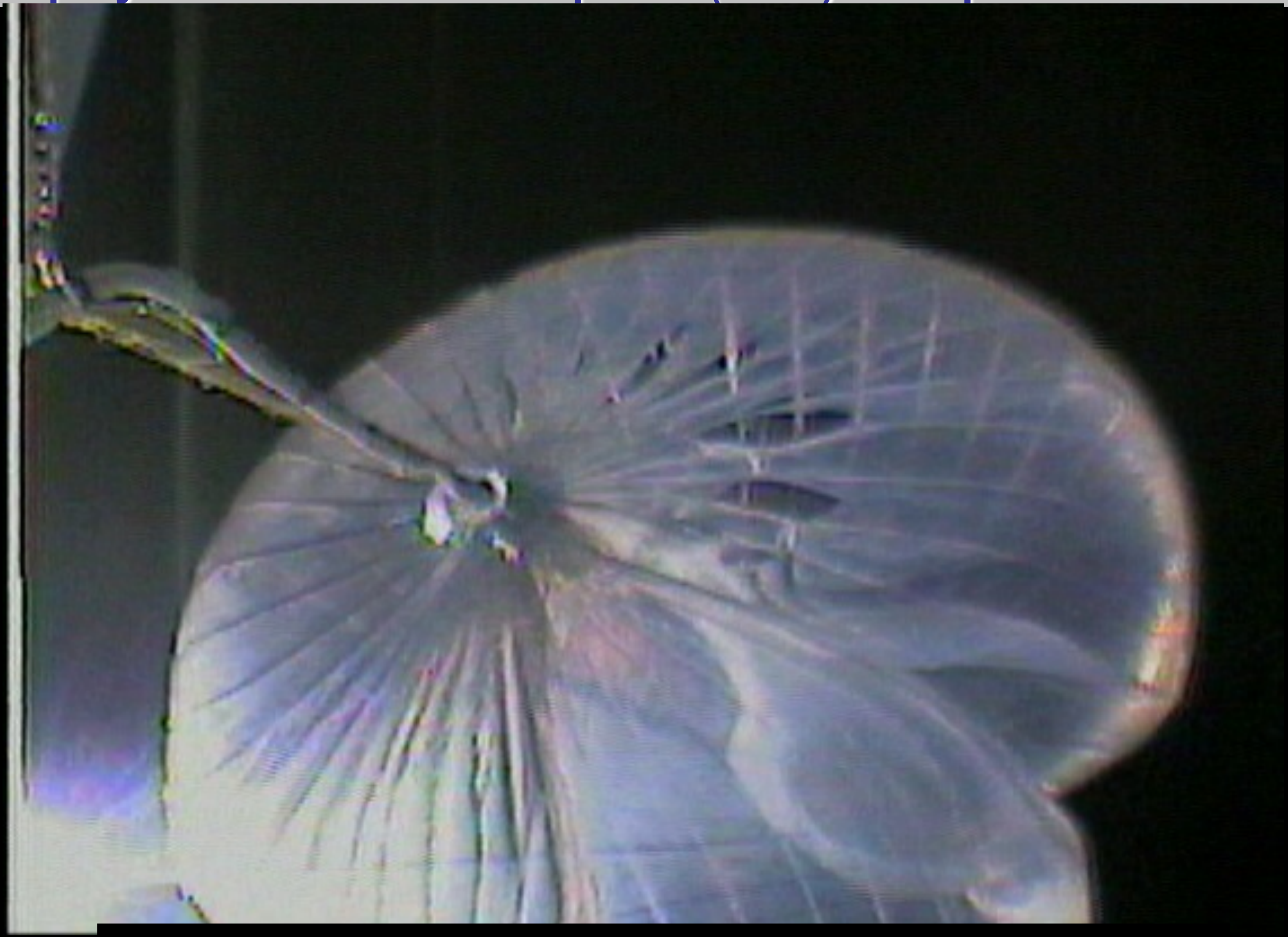
Supported by NASA's Mars Technology Program

Prototype Mars Superpressure Balloon Deployment Test in Stratosphere (2006)- Spherical Balloon



Deployment and inflation a complete success. However, no attempt to separate the balloon after inflation.

Prototype Mars Superpressure Balloon Deployment Test in Stratosphere (2006)- Pumpkin Balloon



Parachute failed to fully deploy causing dynamic pressure on the balloon during inflation to be more than double the planned value (12 Pa vs 6.5 Pa).

Mars Superpressure Balloon: Pathway to Flight Readiness

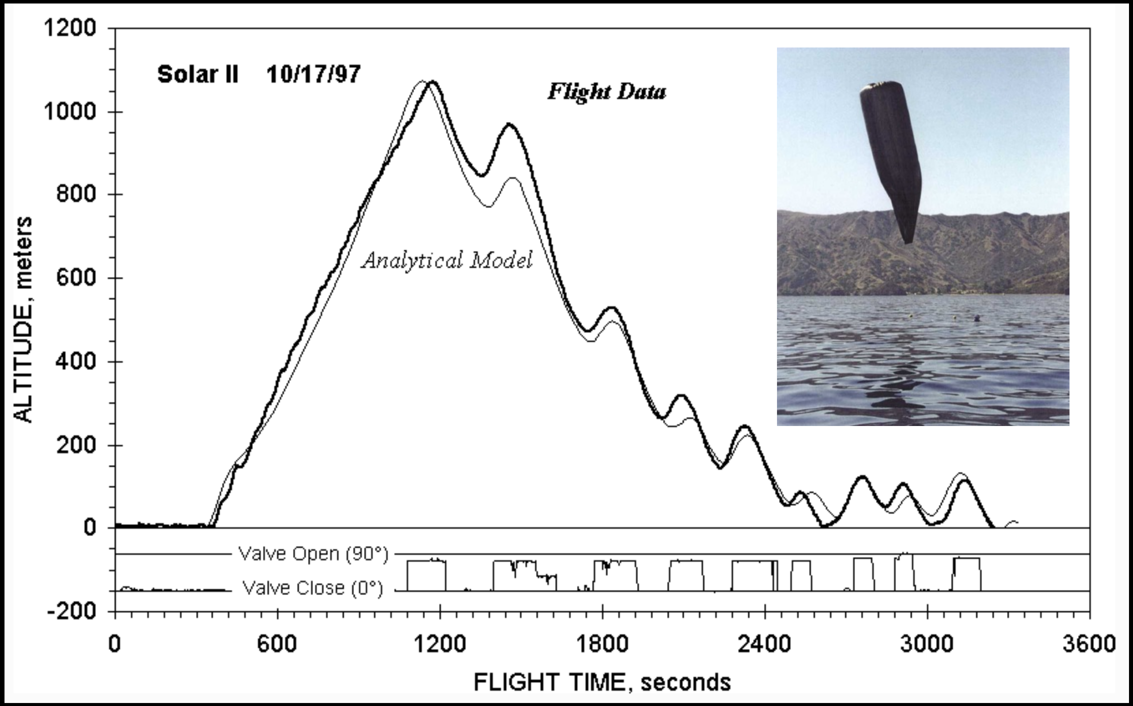
- An end-to-end demonstration of deployment, inflation and float in the stratosphere is still needed.

- Two more flight tests of the superpressure balloon are planned for June 27 and June 29 2007
  - A 12 m diameter sphere (900 m^3, 70% larger volume than 2006) – providing 5kg payload capability at Mars.
  - A 660 m^3 pumpkin (15% larger volume than 2006)
  - Both tests will include parachute and inflation system separation and subsequent balloon float

- No further superpressure balloon tests are currently funded

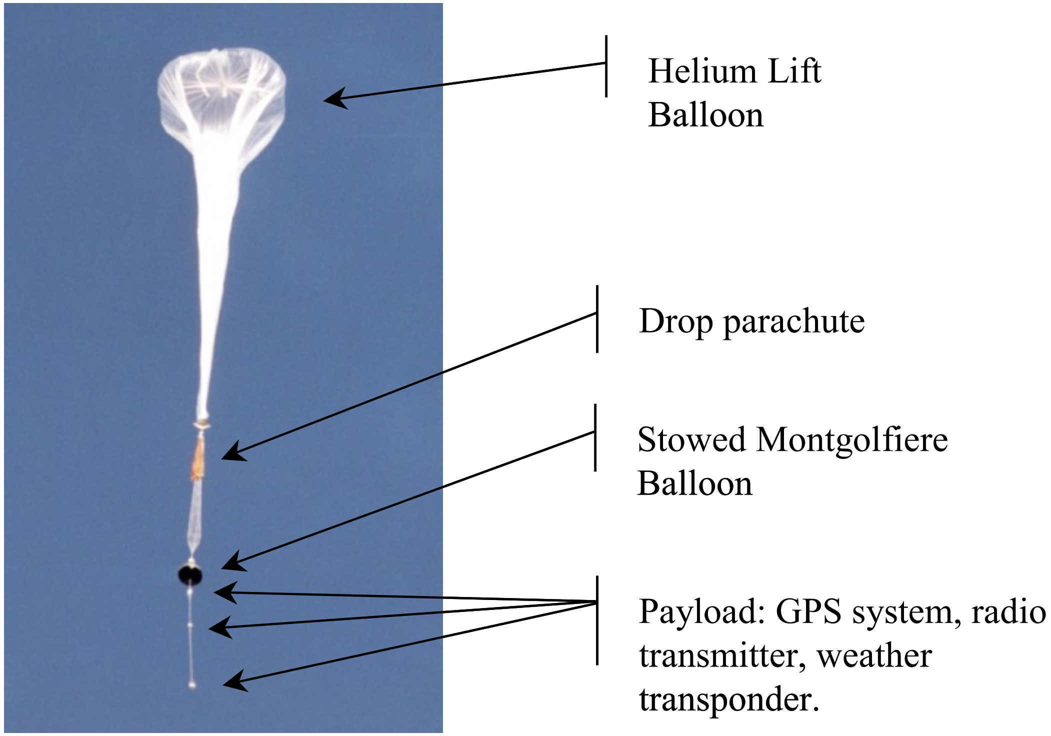
If successful, the June stratospheric deployment tests will retire most of the risks associated with sustained flight of payloads of a few kgs for focused science objectives on Mars

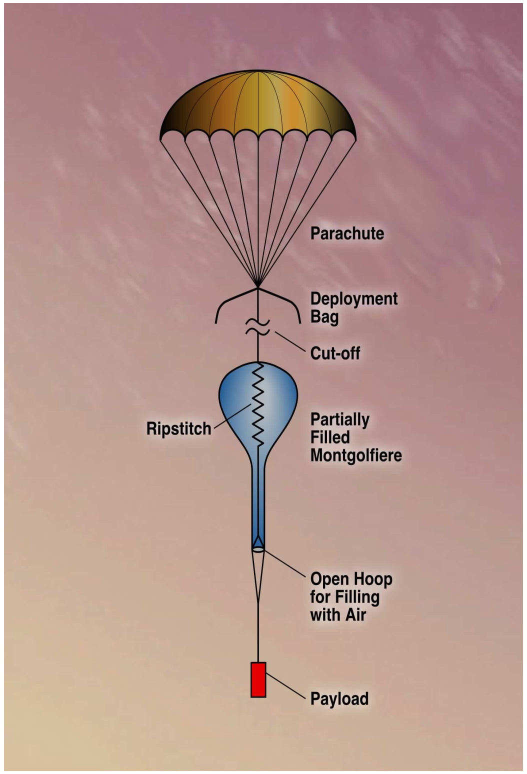
Mars Solar Montgolfiere Balloon: Tropospheric Tests



These tropospheric tests have established the principle of altitude control with a vent at the top of the balloon.

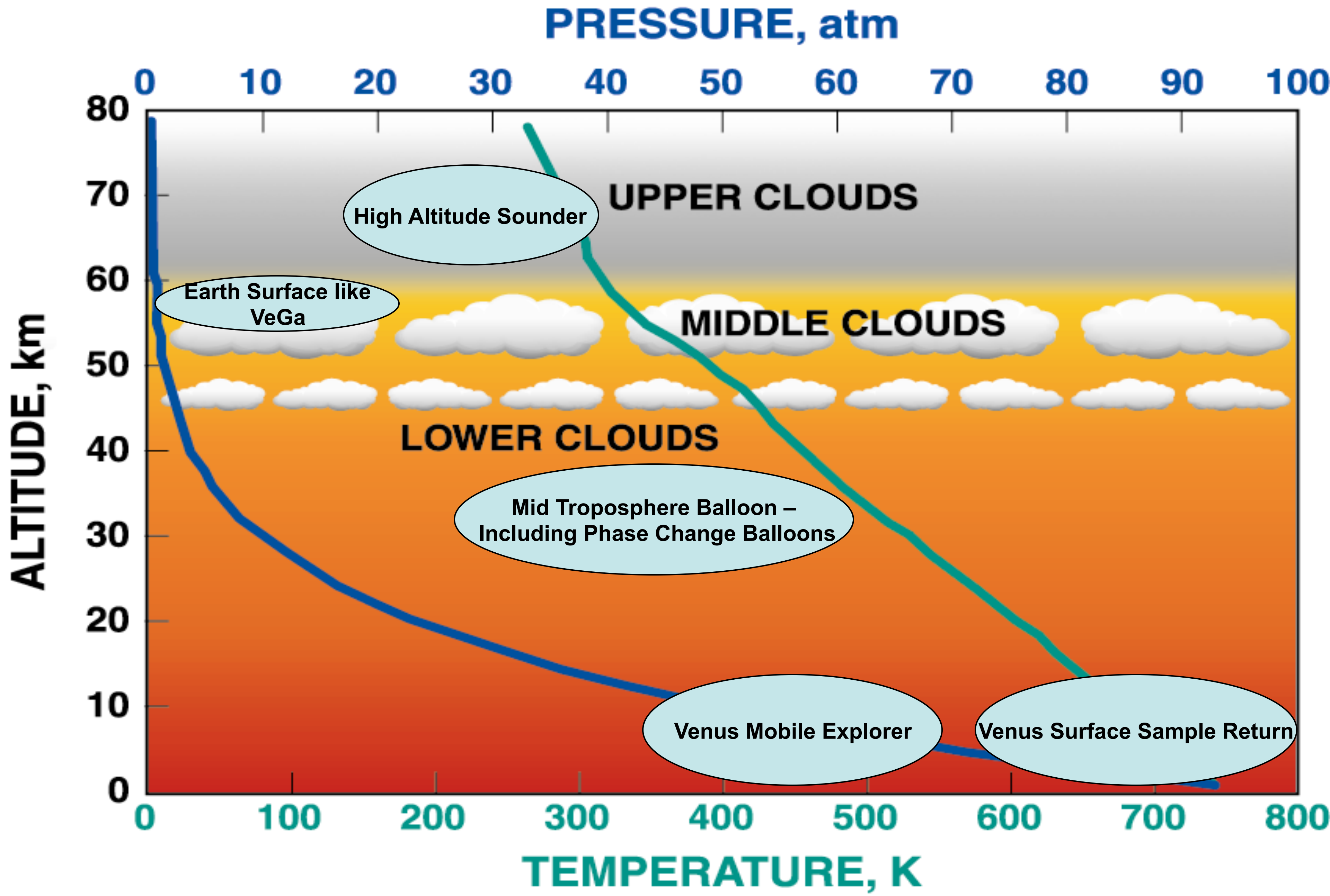
Mars Solar Montgolfiere Balloon: Stratospheric Tests





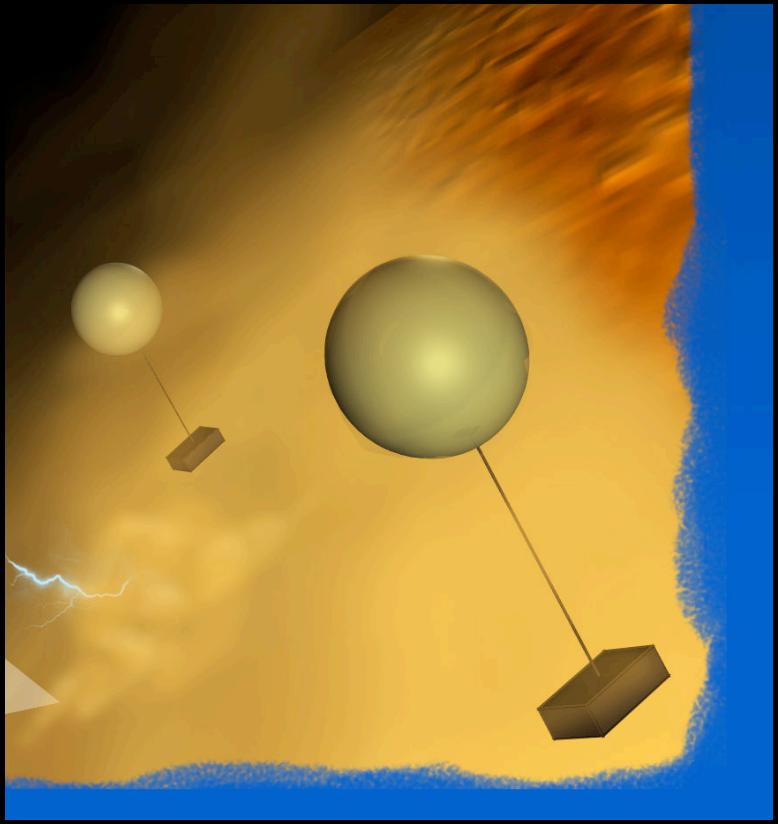
- Several Earth stratospheric deployments have been conducted.
- Several tests with a 15-m diameter balloon have been successful
- **A 30-m test is pending in July, 2007**.

Venus Environment



Venus High Altitude Balloons
VEGA Mission, 1985 – Earth Test Flight

Recent Venus Superpressure Balloon Development

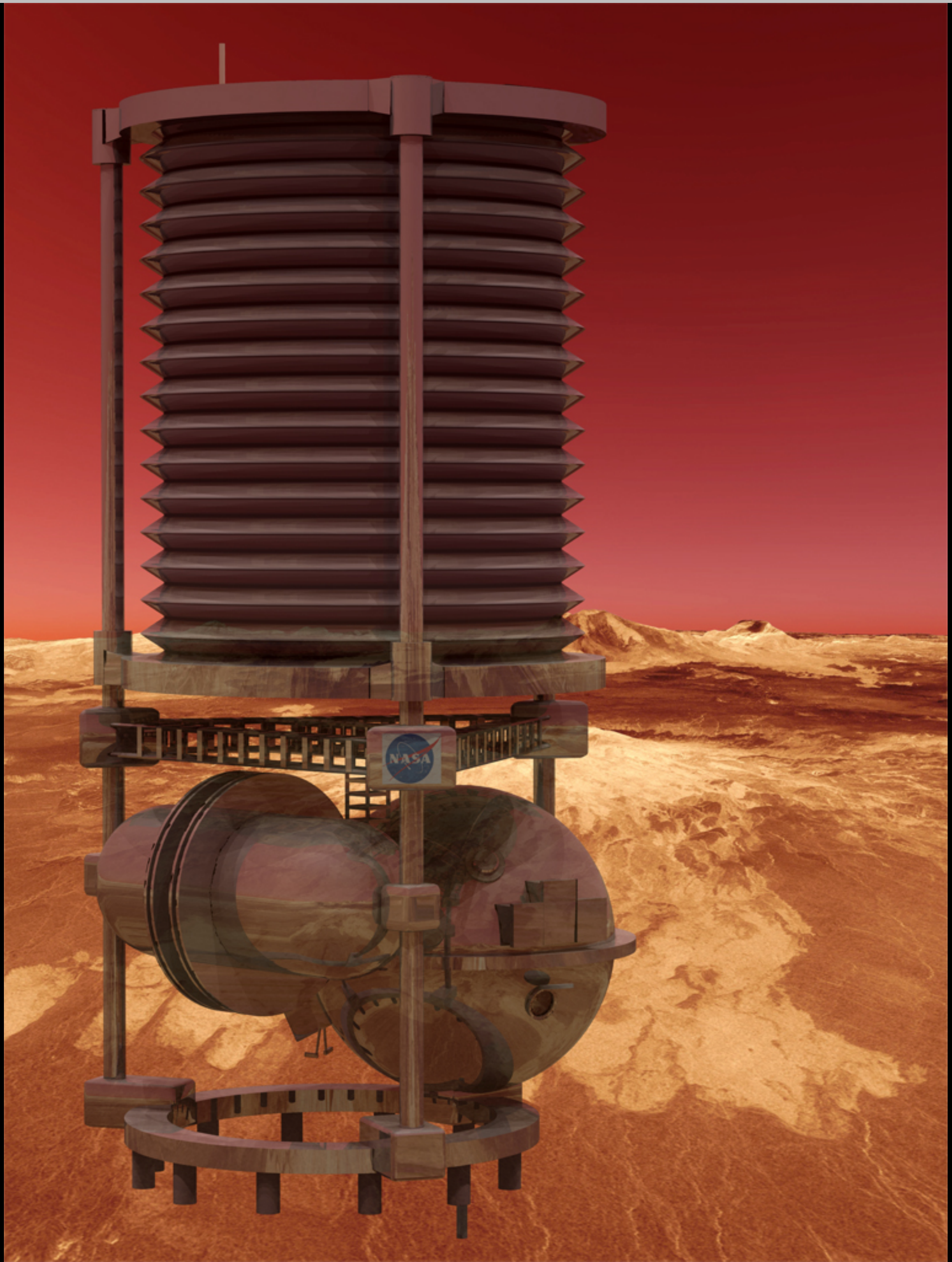


Venus High Altitude Balloon - Finite Element Modeling

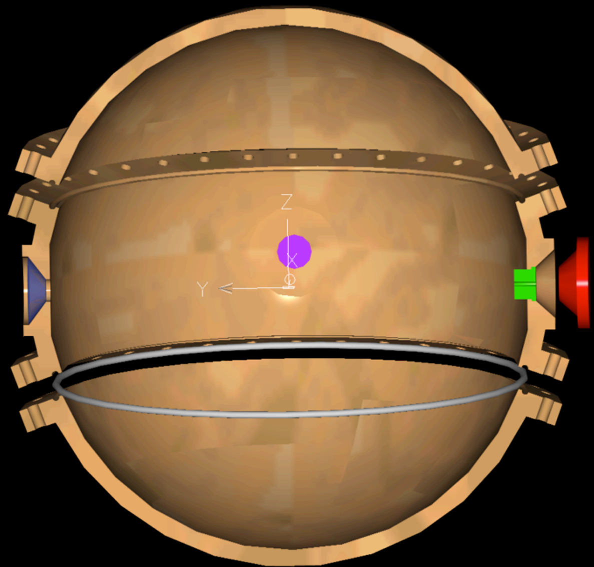
Venus Mid Troposphere Balloon

- Target altitude is ~20km where temperature is ~250C, pressure 15 bars.
  - Measurements there may be key to unraveling the mystery of Venus superrotation.
- High temperature electronics for <300C is available
  - CMOS compatible Silicon on Insulator (SOI) MESFETS (see paper by **Ervin et al, IPPW4**)
- Balloon materials demonstrated at 300K with adequate strength for superpressure balloon **Yavrouian et al, 1999**
  - Kapton FN – coextruded combination of Kapton and Teflon
  - Polybenzoxazole film is an alternative
- Proof of principle of **phase change balloons** demonstrated at JPL in the ALICE program in 1990s with refrigerants. Need to validate with water or ammonia balloons at Venus temperatures

Venus Mobile Explorer – Exploring the Surface of Venus

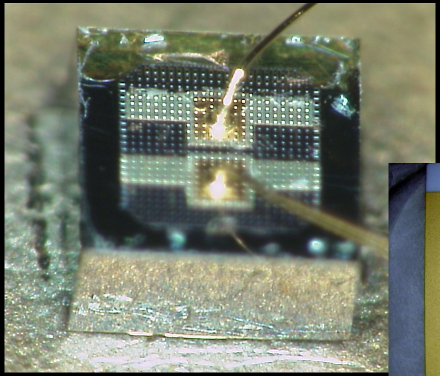


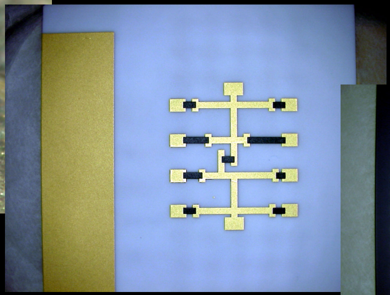
Technology for near surface operations on Venus

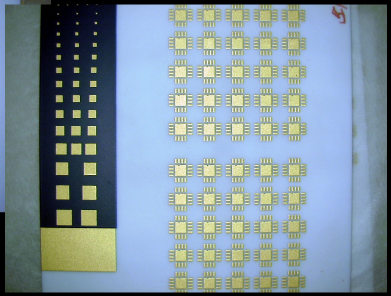


Pressure vessel & insulation

Metal bellows buoyancy device

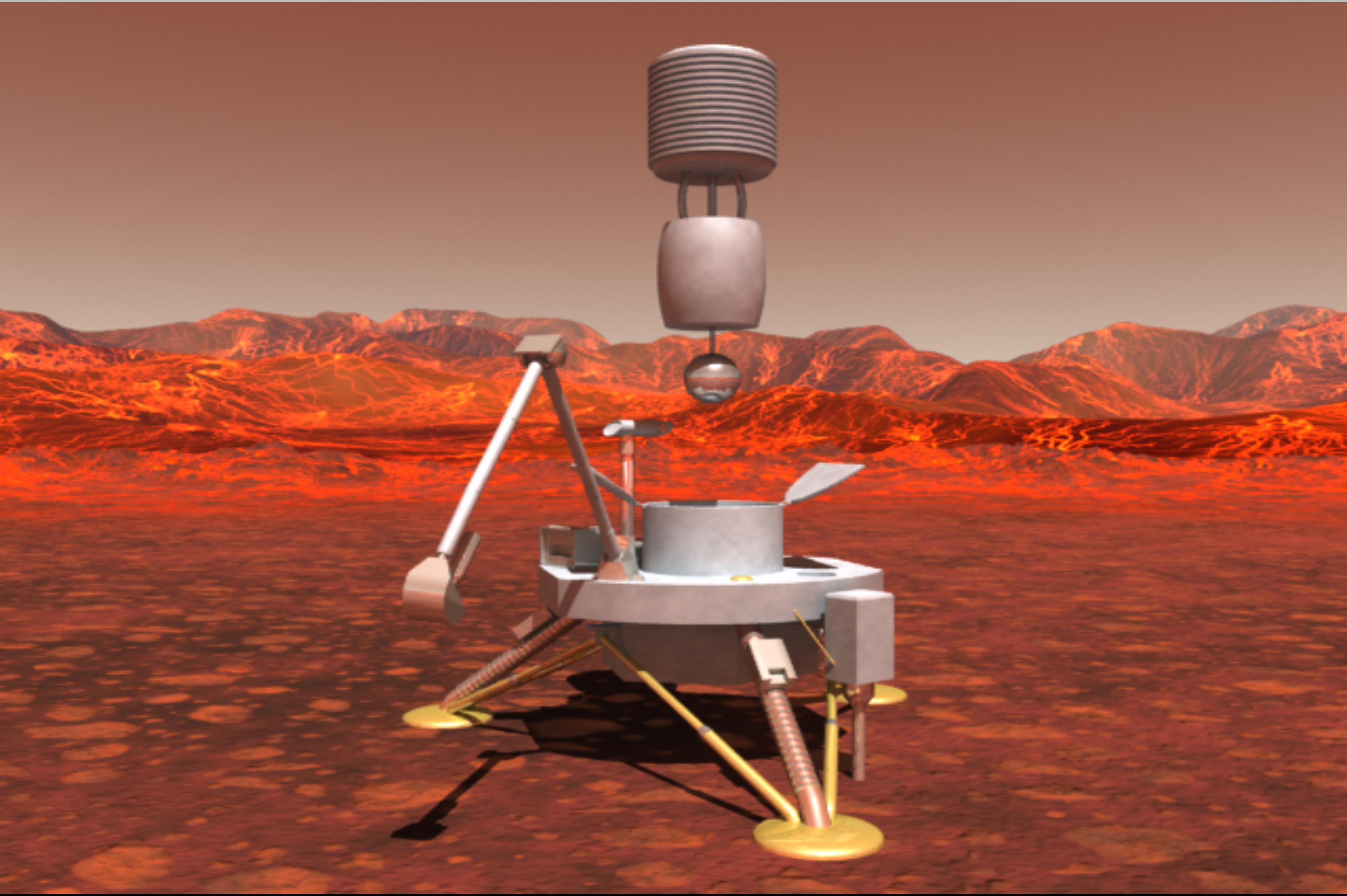






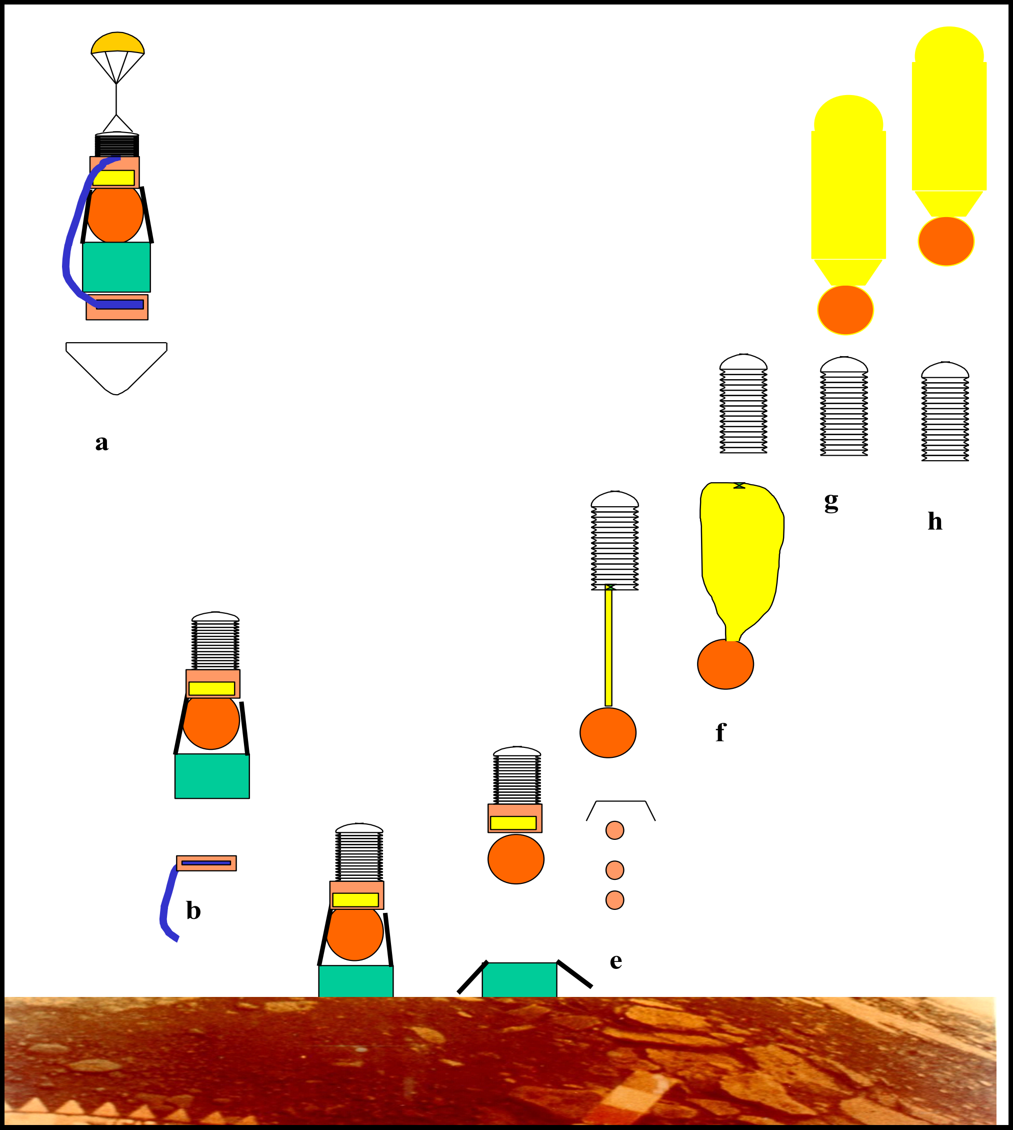
High temperature electronics

Venus Surface Sample Return
Bringing a sample from the Venus Surface back to Earth



Venus Surface Sample Return

Dual Balloon Concept



Venus Dual Balloon concept, Kerzhanovich et al IPPW4

Venus Aerobots: Path to Flight Readiness

- **Next step** is a superpressure balloon flying in the same regime as the VeGa balloons
  - Large and more sophisticated payload than VEGA
  - Longer duration flight with multiple circumnavigation
  - Technology is ready

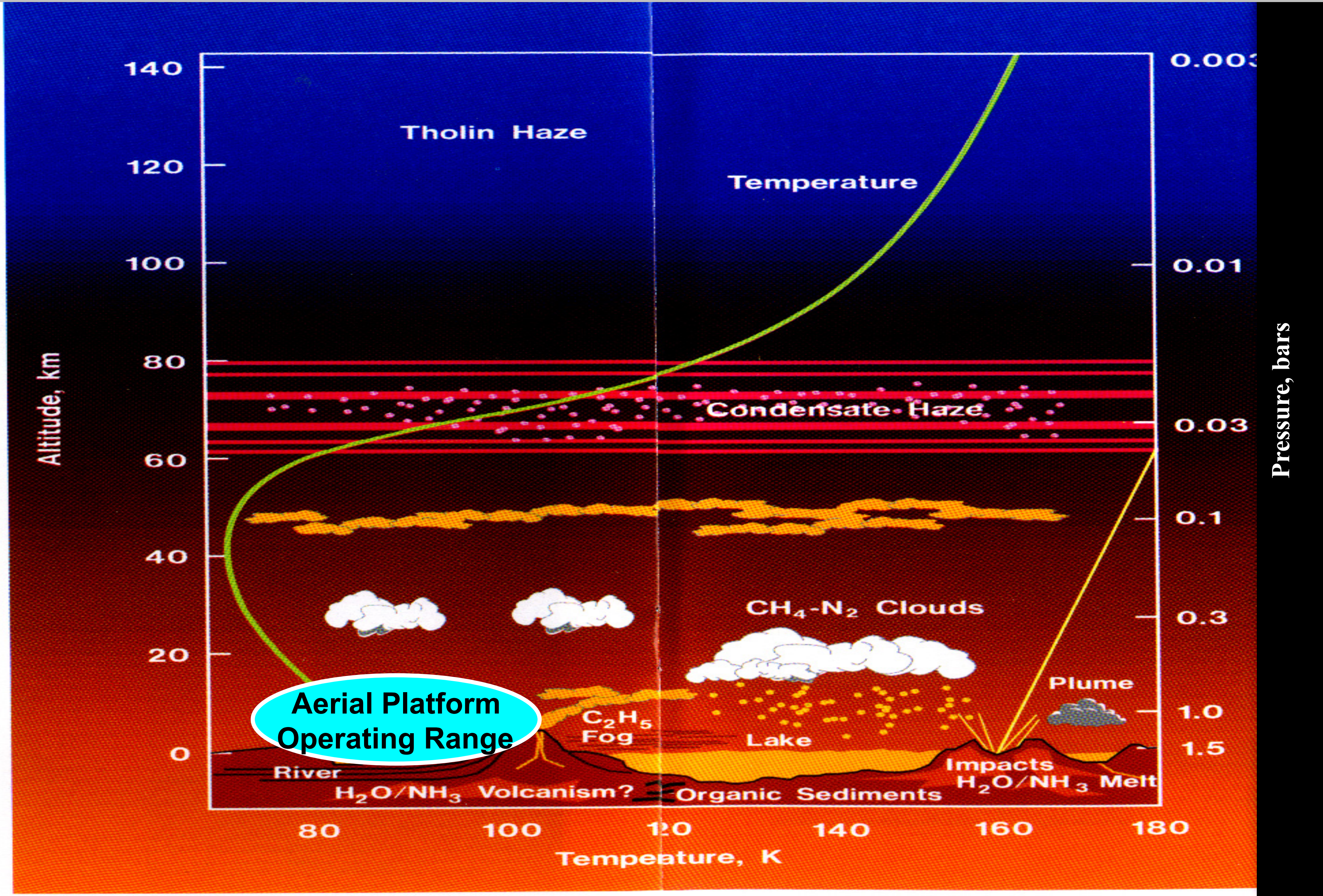
- Technologies for the extreme environments of Venus – discussed at IPPW4 – are critical to all further scenarios and there are many interrelationships and **feed forward opportunities**.

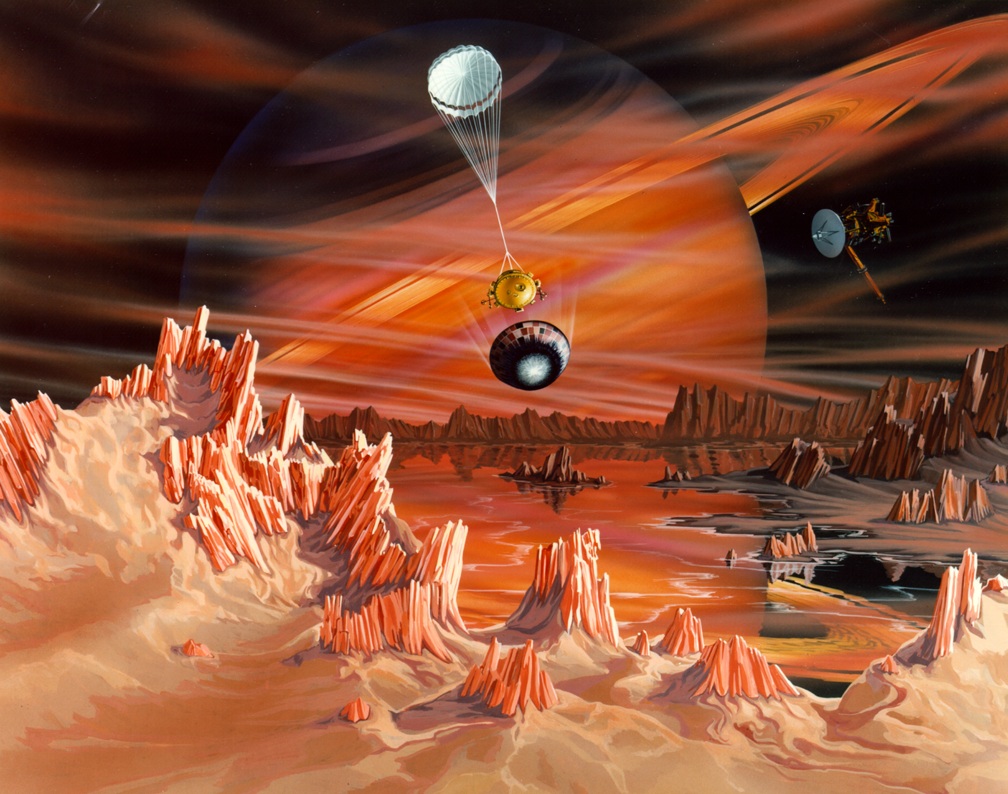
- Next step will depend on not only technology readiness but the value of the science that the mission can yield.

- Venus Mobile Explorer which can open up the surface of Venus to detailed in situ exploration may be a major driver for future development.

- Venus Surface Sample Return is impossible without a balloon capability that can provide transit from the surface to ~65km

Titan Environments

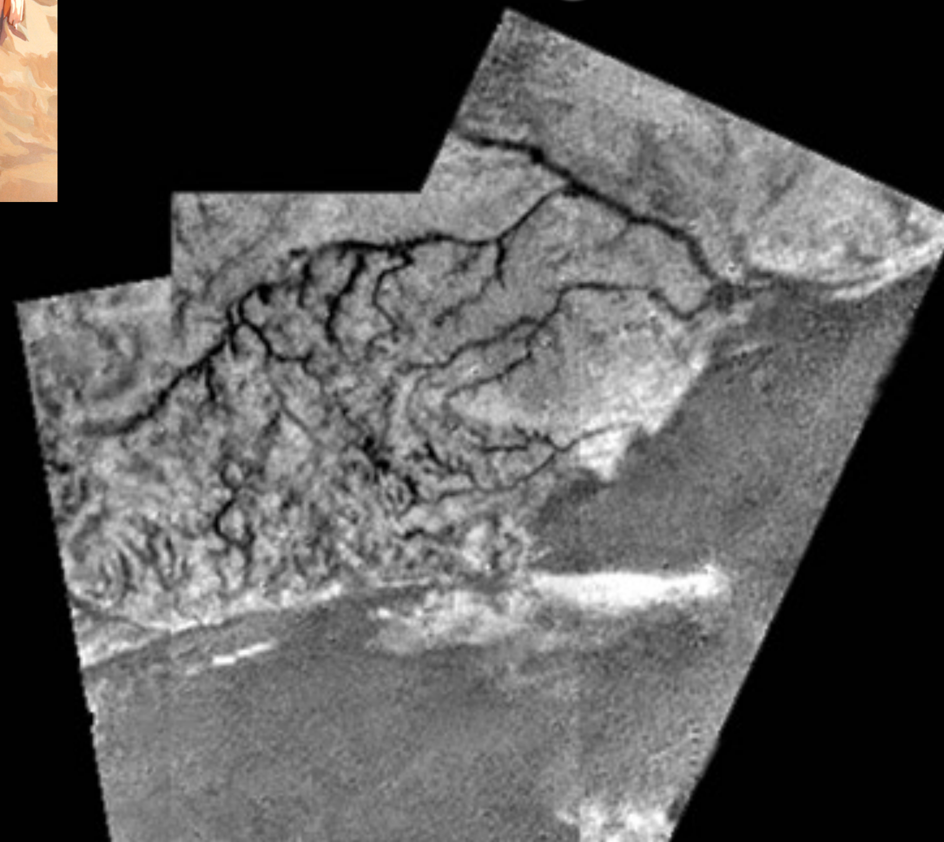




Aerial imaging from descending Huygens probe reveals that in the lower atmosphere:

- **It is cloud free**
- **Winds are light**

Spectacular landforms are seen from the descending probe



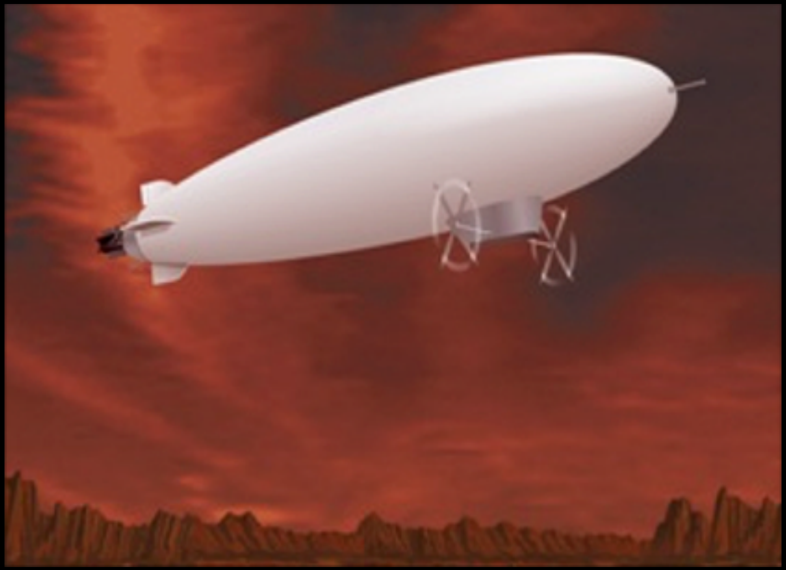
Titan Aerobot Architectures

Montgolfiere (Hot air) Balloon

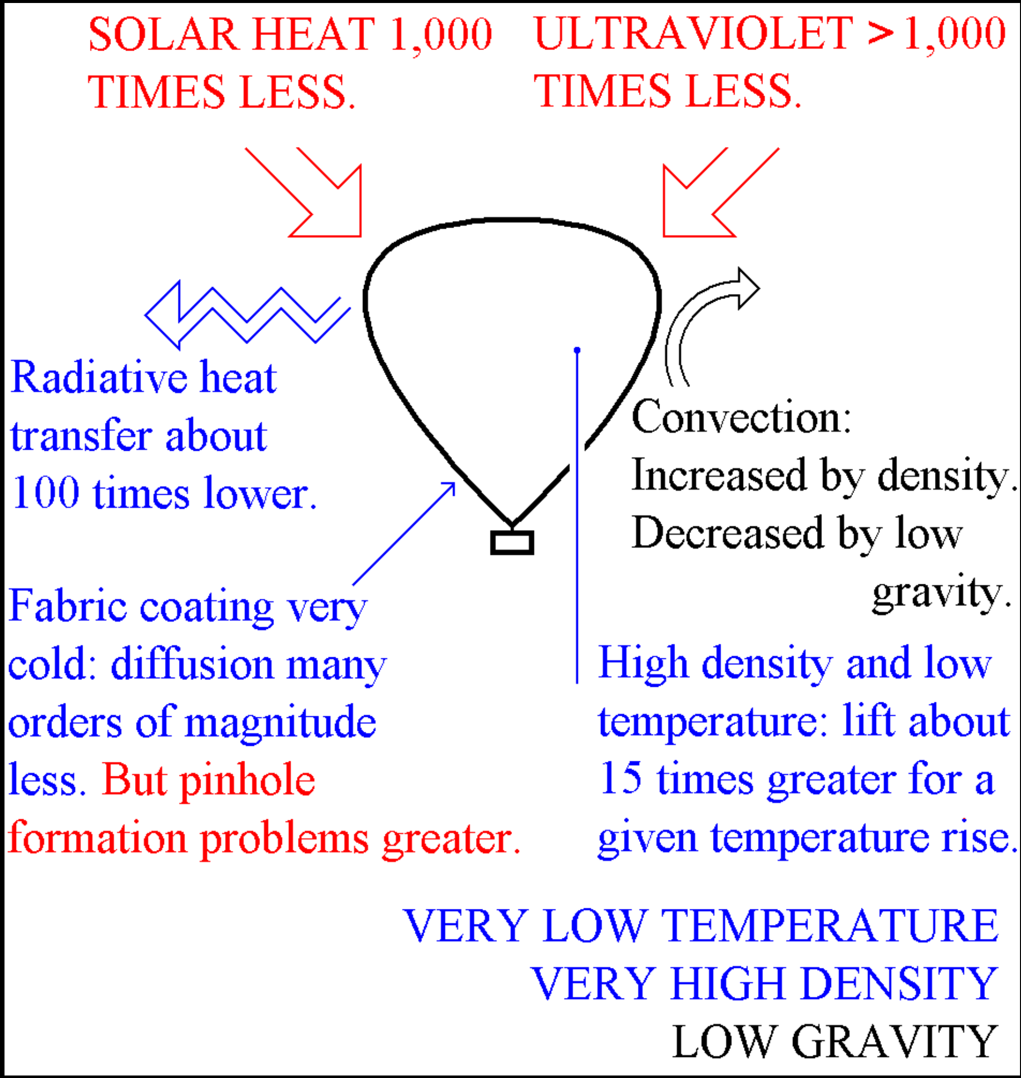
Wind-driven

Self-propelled

Self-propelled Blimp



Titan – The Ideal Environment for Lighter than air flight



Julian Nott, Titan the Ultimate Destination for Aerobots, IPPW4 Proceedings, 2006

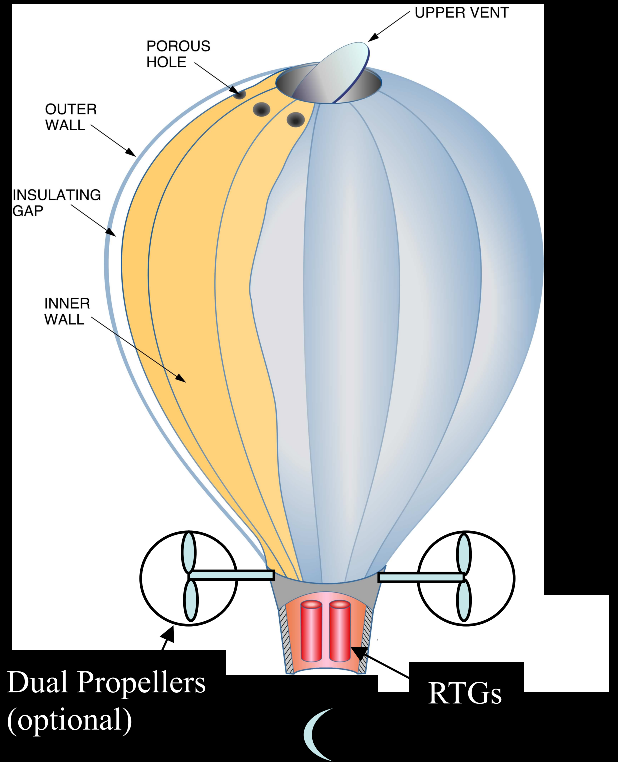
Envelope Material Development

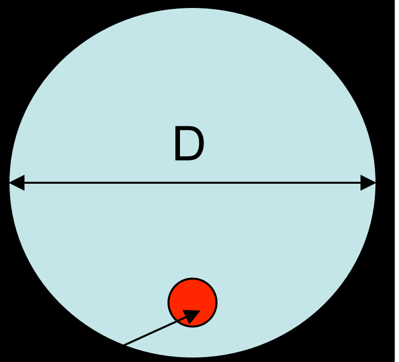
Gelbo Flex Test of
Polyester composite film
2000 cycles at 90K

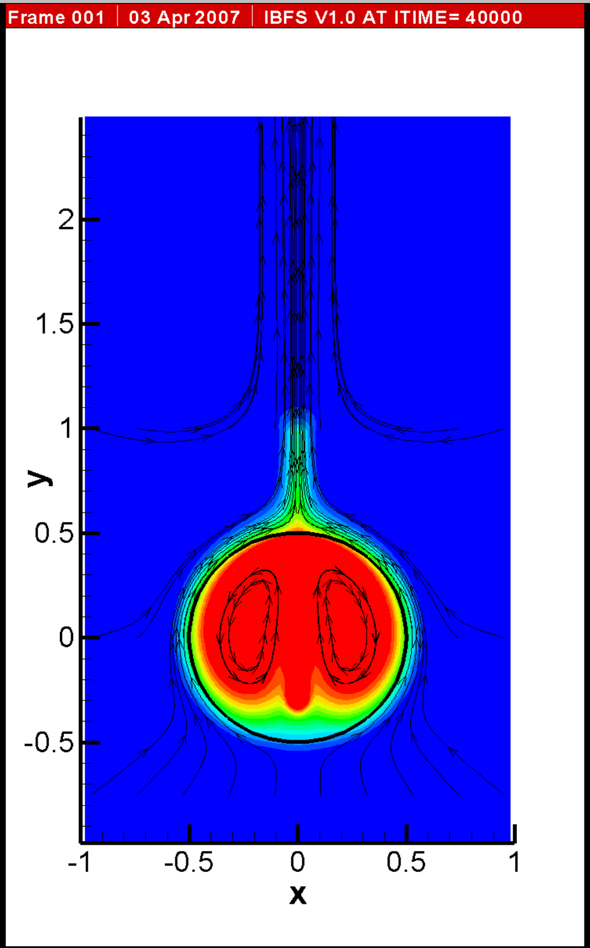
Blimp Hull at Cryogenic Temperatures.

Hall et al, Proceedings of COSPAR, 2004

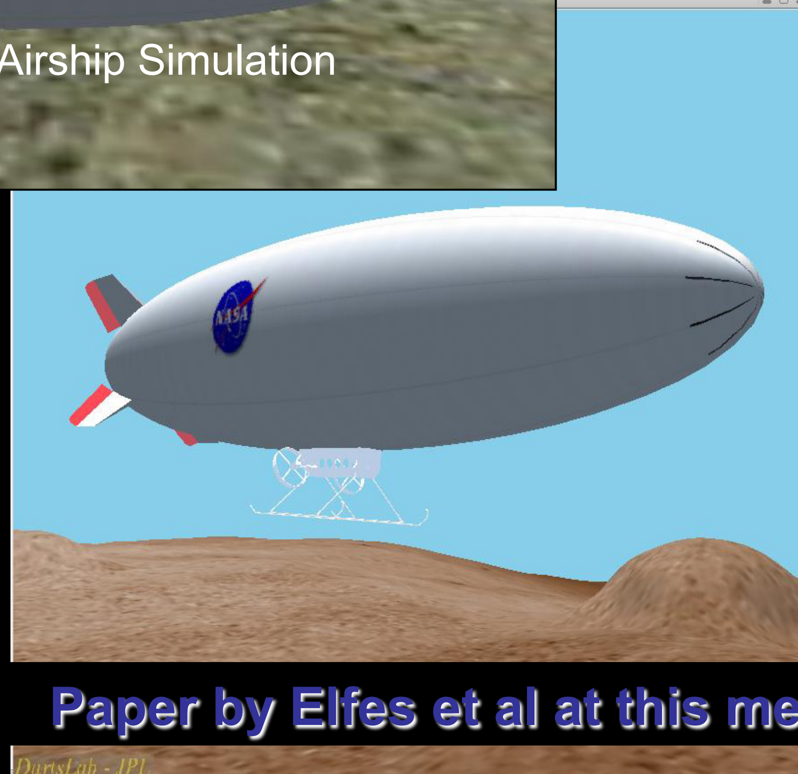
Titan Montgolfiere aerobot - thermal modeling

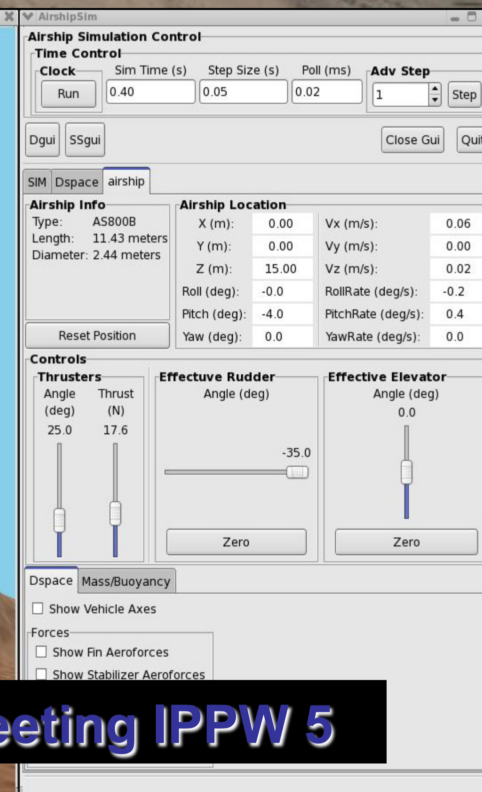






Aerobot Aerodynamic Model/Simulator





Paper by Elfes et al at this meeting IPPW 5

Aerial Platforms at Titan

- Titan is in many respects the ideal environment for surface exploration with a lighter-than-air vehicle
  - Dense and cold high molecular weight atmosphere
  - Little diurnal temperature variation and almost no UV radiation
  - Clear skies beneath the clouds and light winds at the surface

- A Titan aerobot can acquire:
  - Imaging and remote sensing surveys over a global traverse at resolutions ranging from meters to centimeters.
  - In situ sampling from a great diversity of terrains ranging from organic dunes, to cryovolcanic features to methane lakes.

- Although the principles of Titan aerobot operation are established, the practice is a long way from validation:
  - Significant investment in the aerial vehicle technology, instruments and cryo sampling methods
  - End-to-end simulations of aerobot deployment & operation & where feasible actual validation in cryogenic environments.

Summary

- Mars
  - Scientifically, aerobots occupy a ***niche role*** complementing the science that can be done with orbiters and surface rovers.
  - Superpressure balloons technology, capable of carrying payloads of a ~5 kg for mission durations of months is now within reach.
  - Solar Montgolfiere balloons with larger payloads but capable of long duration flight only in the summer polar regions may soon be demonstrated.

- Venus .
  - Scientifically, lighter-than-air technology must play a ***central role*** in the future in situ exploration and surface sample return from Venus.
  - Superpressure balloon technology for payloads of tens of kgs. over flight times of weeks to months at altitudes of 54-56 km is at hand.
  - Metallic bellows balloon technology can enable long duration mobile exploration of the Venus surface and ultimately Venus surface sample return.

- Titan:
  - Scientifically, a Titan aerobot provides the ability to carry out both ***remote sensing*** from beneath the Titan clouds and haze and ***mobile in situ sampling*** for a diverse range of terrains from organic dunes to methane lakes.
  - **Radioisotope Montgolfiere technology** offers the potential for long duration (years) operations for altitudes from 0 to 10 km with controlled surface sampling.
  - While the principles of Titan aerobot operation are established, the technology validation **sufficient for commitment to a Flagship mission** is still needed.

Acknowledgements

- ILC Dover – Venus mid altitude balloon
- Lamart Corporation – cryogenic balloon material for Titan
- Lyntech Corporation - Hydrogen Recovery System
- Winzen - Titan Montgolfiere design
- LSTC – Venus Balloon Finite Elements modeling
- GSFC/Wallops - Balloon design, lab testing and fabrication oversight
- Near Space – Titan balloons, Mars balloons, stratospheric test
- Tensys Corporation – Titan airship design
- Old Dominion College of Engineering & Technology – modeling simulation and visualization
- Johns Hopkins Applied Physics Lab – Titan Flagship Mission Study
- Jet Propulsion Laboratory – Viktor Kerzhanovich, Jack Jones, Kim Reh, Tibor Balint and others for help with this presentation.

Special Thanks: To Jacques Blamont whose vision of balloon exploration of the solar system played a key role in the establishment of the planetary aerobot initiative at JPL.