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Titan Altitude Cycling Balloon

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Image courtesy NASA/JPL-Caltech/Space Science Institute

Data analysis and modelling in the wake of Cassini-Huygens increasingly emphasizes Titan as a high-science value destination: Complex organic chemistry is shown to be possible at Titan's surface

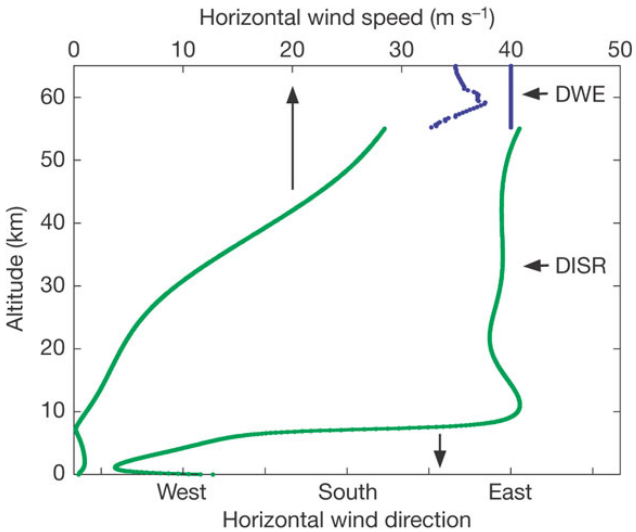
WHY A BALLOON PLATFORM?

- Even at 8km altitude, 1 cubic meter of lift gas can float ~4 kg of payload.
  Titan presents exceptional buoyancy due to it's high atmospheric density.
  (5.4 kg/m^3 near the surface vs Earth's 1.2 kg/m^3)
- Helium diffusion through candidate balloon membranes is essentially zero
  at Titan's cryogenic temperatures (Pauken & Hall, 2014)
- Persistent global-regional observational mobility
  Titan is cloud-covered, precluding detailed survey from an orbiter.
  Titan's surface and limited characterisation fidelity severely limits surface mobility:
  - Evidence of complex pool/lake/ocean liquid network
  - Spring-fed flows and precipitation drainage channels
  - Variable firmness of solid ground
  - Cryo-vulcanism
  - Rough, steep terrain
  - Extensive fields of sand dunes

THE CASE FOR SUPER-PRESSURE

ROBUSTNESS…

Thin Red Line Aerospace super-pressure altitude control balloon prototype



Horizontal wind speed and direction (counter-clockwise from east) as a function of altitude.*

… ***<u>in the face of potentially inclement meteorology</u>***:

- Strong and variable winds, convective turbulence
- Rain and drizzle, "Huygens measured a damp surface (Niemann et al. 2005), which, given the relatively dry atmosphere (45% humidity), poses the question of whether there was recent rainfall." (Griffith, 2009)
- Titan's upper cloud layer consists of solid particles, mainly CH_4, and most resembles a terrestrial cirrostratus. The lower cloud consists of a liquid binary CH_4-N_2 mixture and resembles a terrestrial stratus. Either cloud may or may not contain small amounts of C_2H_6 ice as condensation nuclei. (Tokano et al. 2006)

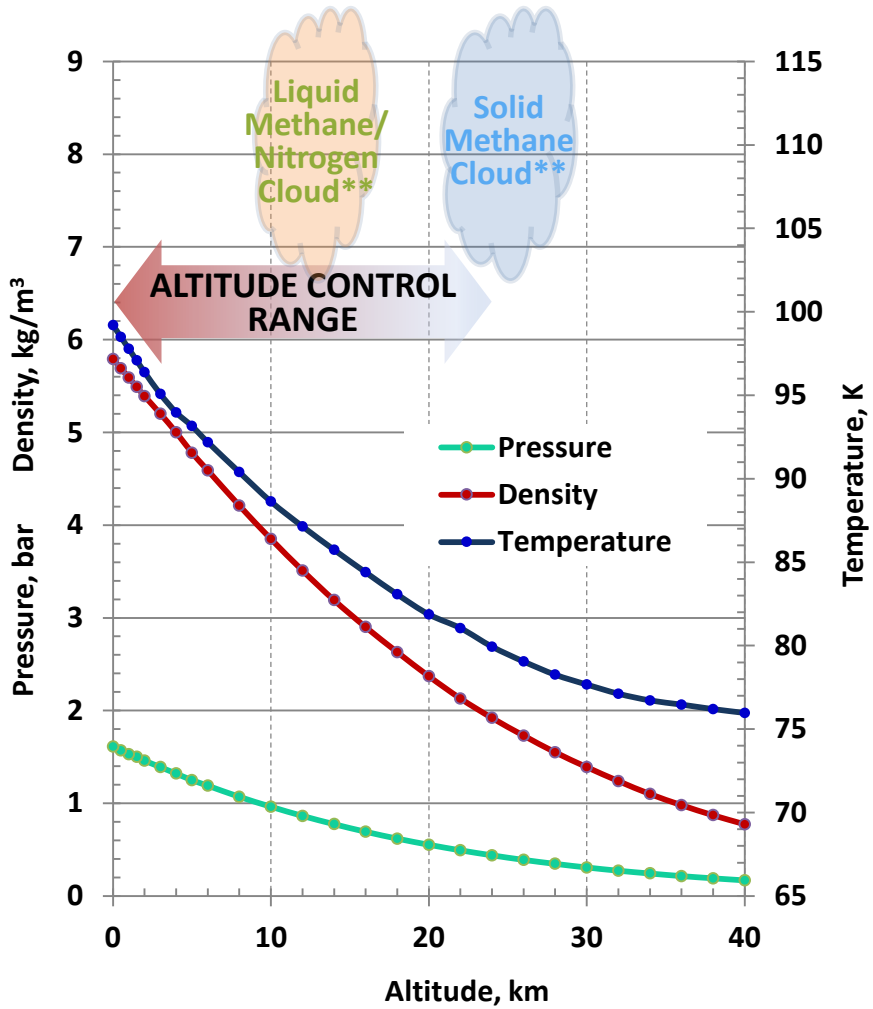
*Credit: Tomasko, M. G., et al. "Rain, winds and haze during the Huygens probe's descent to Titan's surface." Nature 438.7069 (2005): 765-778.

WHY ALTITUDE CONTROL?

- **UNSURPASSED MOBILITY**
  Measurements of atmospheric properties over a range of altitudes.
- **SURFACE SAMPLING**
- **TRAJECTORY CONTROL**
  Wind direction and speed vary with altitude allowing for more pro-active mission planning.

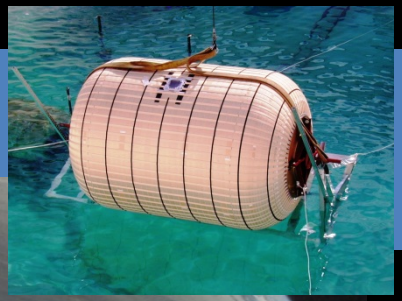
POWER

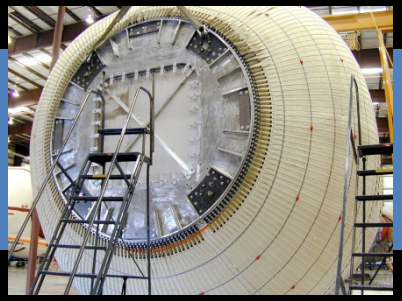
"Solar flux at Titan's surface ≈1 W/m^2, inadequate for solar-powered vehicles. Nuclear power provided by radioisotope decay is the only electric power source in the foreseeable future, with a likely output on the order of 100 W for a reasonably sized vehicle. This very limited available power strongly motivates the use of a buoyant vehicle" (Hall et al, 2006).



TITAN's LOWER ATMOSPHERE

*Data from Yelle, R. V., Strobel, D. F., Lellouch, E., & Gautier, D. (1997). Engineering models for Titan's atmosphere. *Huygens: Science, Payload and Mission*, 243-256.
**Data from Tokano, T., McKay, C. P., Neubauer, F. M., Atreya, S. K., Ferri, F., Fulchignoni, M., & Niemann, H. B. (2006). Methane drizzle on Titan. *Nature*,*442*(7101), 432-435.

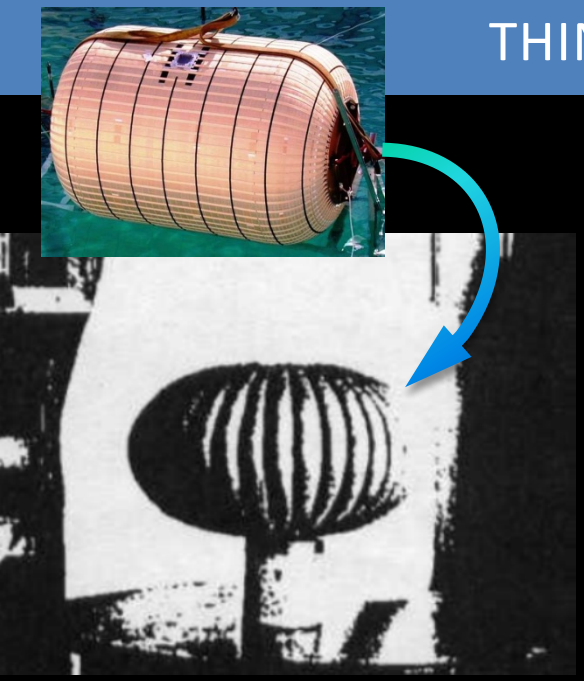




THIN RED LINE AEROSPACE

HABITATION
DECELERATORS
TPS, MMOD, MLI

THIN RED LINE's breakthrough UHPV* PRESSURE SHELL



1919 G.I.Taylor

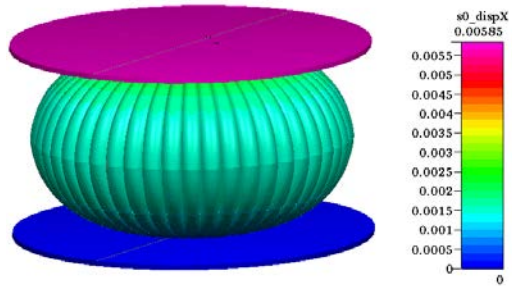
2011 Thin Red Line UHPV

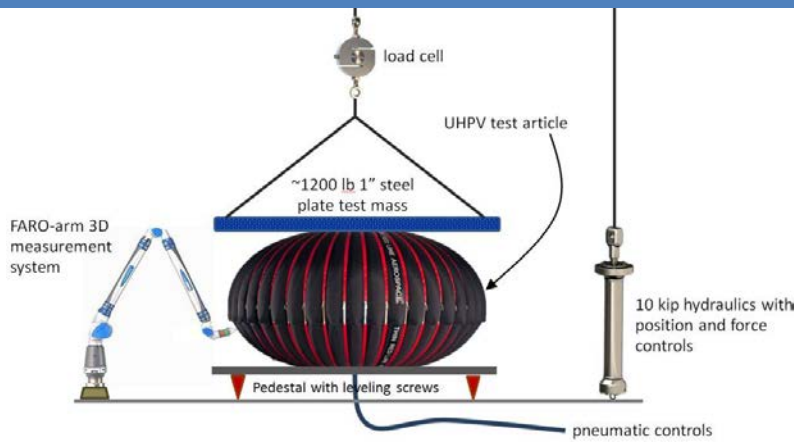
- The hoop structure of an axisymmetric inflatable constrains the internal pressure to give the inflatable its particular shape. Removing the hoop structure from any axisymmetric inflatable results in default, oblate spheroidal geometry shown at left.
- With no hoop structure, the global pressure load is borne exclusively in the meridional sense, i.e. by the tendon array connecting poles. Mass-optimized, scalable, structural determinism is achieved.
- Thin Red Line's UHPV is the structural singularity that permits the 3-D geometry to be constructed as a single, planar envelope. Problems associated with conventional, gore-based construction of 3-D fabric shells are eliminated.

- Incorporation of the most complex, fragile fabric options may now be considered.

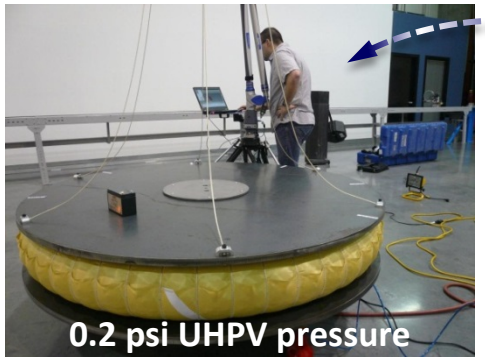
*Ultra High Performance Vessel

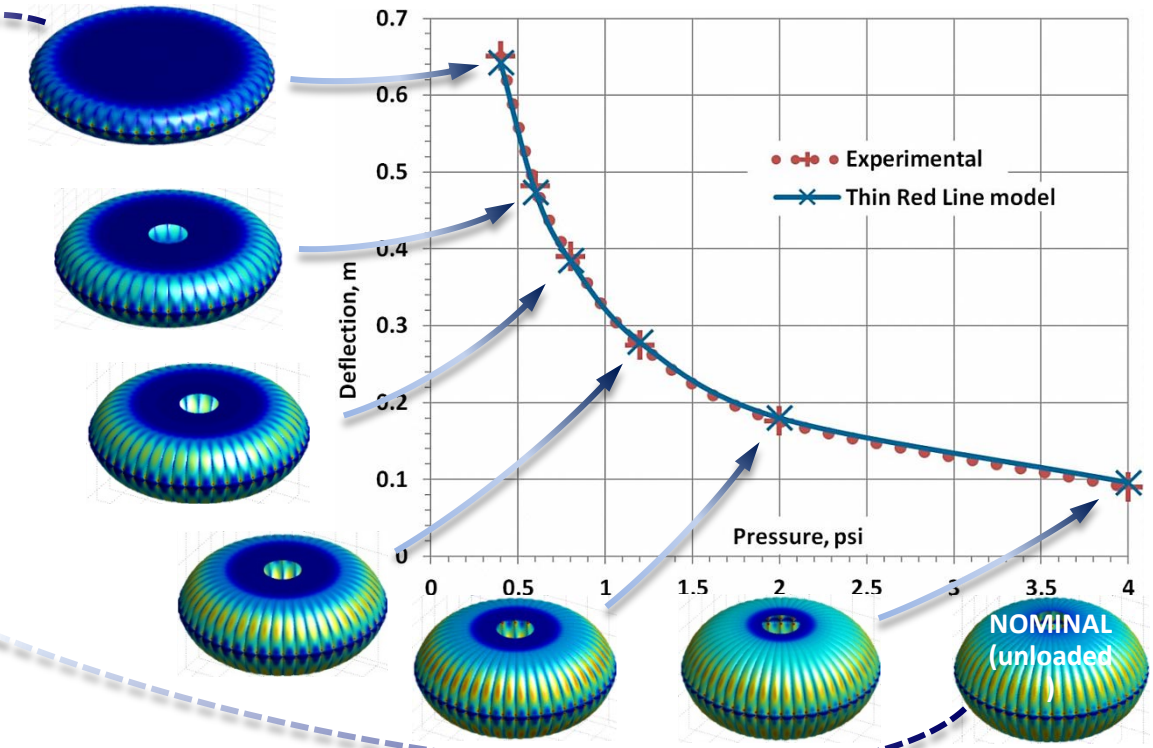
TEST & MODEL: DEFLECTION, VIBE, WIND TUNNEL, BURST…





1200 lb mass applied for large amplitude test article deflection and model correlation test*





***Animations courtesy of CFD Research Corp.**

MATERIALS FOR A CRYO ENVIRONMENT

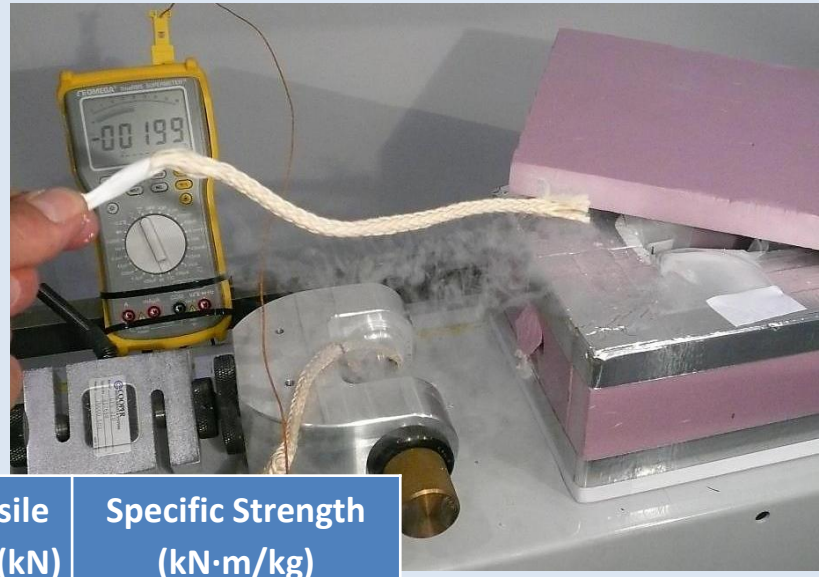
*JPL Titan Super-Pressure Balloon Cryogenic Leak Testing**

- At Titan helium loss in a super pressure balloon via diffusion is very low. Gas diffusion theory through a membrane predicts helium permeability is 4 orders of magnitude lower at 90 K than at 300 K
- Cryogenic testing of the balloon under super pressure (at 2-3 times the flight requirements) showed the balloon maintained constant density at Titan-like temperatures for several days.

*Pauken, M. T., & Hall, J. L. (2014). Development and Testing of a Titan Superpressure Balloon Prototype. *LPI Contributions*, *1795*, 8006.

Thin Red Line Cryo Testing of Balloon Tendons

- Testing involved Spectra™, Dyneema™, Vectran™, Technora™
- Significant increases in Specific Strength were observed, especially for Spectra™/ Dyneema™ polymers



Fiber	Construction	Test Temperature (K)	Lin. Density (g/m)	Ave. Tensile Strength (kN)	Specific Strength (kN·m/kg)
Spectra®	16-carrier braided cordage	298	6.56	11.09	1691
		77		17.82	2716 **(+60.6%)**

ALTITUDE CONTROL MECHANISMS

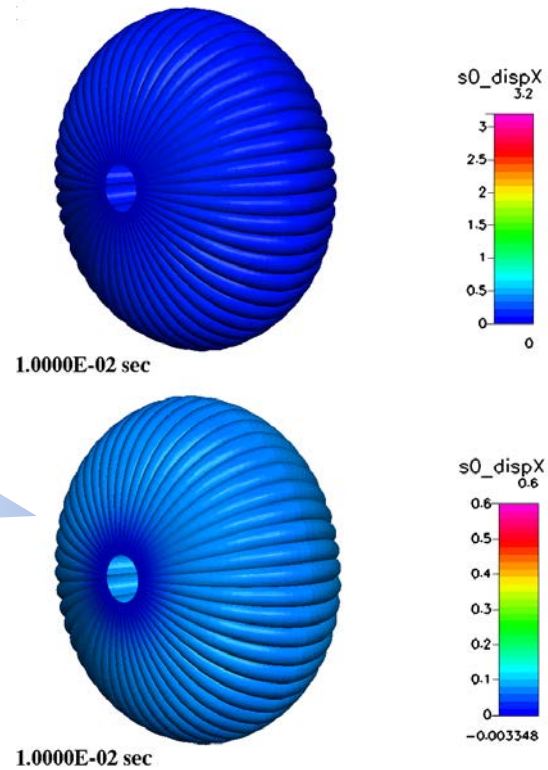
Without expending ballast or lifting gas, buoyancy can be controlled by altering the vehicle's density:

1. Pumped Compression (PC)
2. Mechanical Compression (MC)
3. Thermal Regulation (Montgolfière)
4. Phase change fluid (PCF) "reversible fluid"

Pumped Compression and Mechanical Compression are identified as primary candidates for persistent flight, precise control, and great altitude range.

***Mechanical Compression Advantages**:*

- *Super-pressure robustness**
- *High energy efficiency: 40% ROM higher than pumped*
- *Motors tolerate immense temperature range (20–570K)*



MECHANICAL COMPRESSION

- Compression of a buoyant balloon's volume increases its density—leading to the vehicle's descent.
- Descent continues if **constant**, compressive load of sufficient amplitude is maintained.
- As the balloon descends into higher densities of the lower atmosphere its volume diminishes accordingly— **but not because of increasing compression energy requirement**.

***Animations courtesy of CFD Research Corp.**

THE ALTITUDE CONTROL PLATFORM

CHALLENGE

Balloon volume varies with atmospheric pressure and temperature:

Full lower atmosphere mobility—between Titan's surface and 15-20km altitude—requires up to 4:1 range of balloon volume variation.

SOLUTION

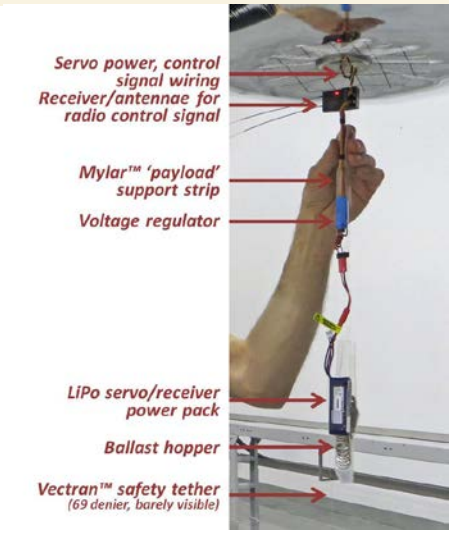
- *The mechanical compression altitude control balloon comprises a modular 'stack' of identical UHPV balloon segments connected to one-another at respective poles.*
- *A tension cable connecting 'North' and 'South' poles facilitates compression of the UHPV stack.*
- *A motor installed at the bottom apex of the balloon controls tension cable length to adjust buoyancy.*

Concept is ideal for controlled descents to the surface of Titan for sampling and rapid ascents to avoid hazards.

BUOYANCY CONTROL FREE-FLYER TEST

KEY OBSERVATIONS—*in simplified terms*

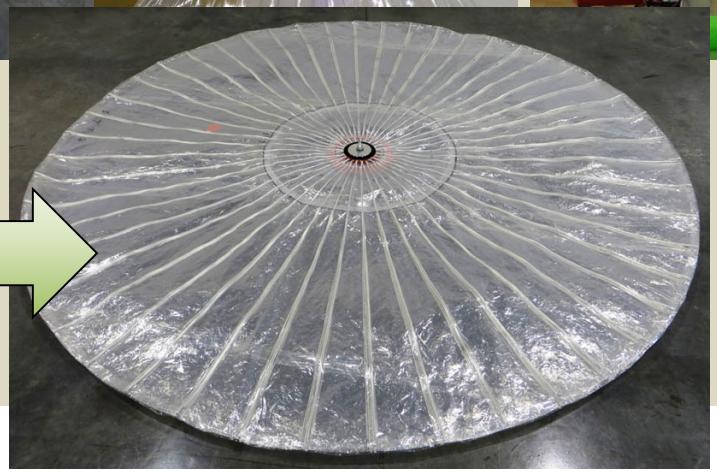
- To make the balloon descend from float altitude, the mechanical compression system needs only to overcome the float super-pressure with enough margin to maintain desired descent velocity.
- To maintain descent the motor is only required to maintain constant tension on the compression tendon
- As the balloon descends into higher densities of the lower atmosphere its volume diminishes accordingly—but not because of increasing compression energy requirement.



MECHANICAL COMPRESSION PROTOTYPE

PLANAR SUPER-PRESSURE CONSTRUCTION

Ease of packaging by collapsing the UHPV segments which minimizes the chance of leaks resulting from pinholes from balloon folding.



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Technical POC is Dr. Michael Pauken, NASA-JPL.