BALLOON FOR LONG-DURATION STUDIES OF THE ATMOSPHERE OF VENUS

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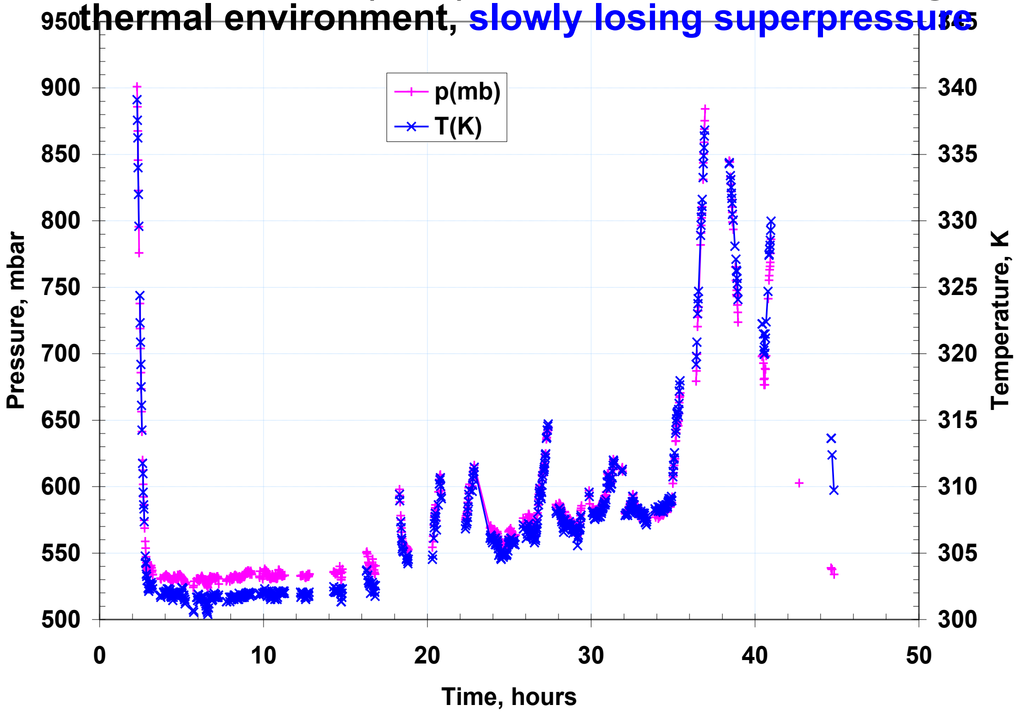
Why Balloons on Venus?

- Key questions can be addressed
  - Origin and evolution
    - measurements of noble gases distribution/isotopes
  - Global circulation
    - balloon tracking, on-board meteo
  - Volatiles and organics
    - sulfur cycle and active gases measurements
  - Middle cloud meteorology
    - on-board meteo/nephelometer, tracking
  - Surface-atmosphere interaction
    - spatial and temporal variability of SO_2 and other gases
- Long-duration (potentially many days) when flying above extremes of deep atmosphere
- Global coverage: circumnavigate in several days with superrotation + meridional circulation
- Carrier for deep atmosphere/ surface drop-sondes
- Less expensive, no landing and extreme environment risks

Twin VEGA Balloons – The Only Planetary Aerial Vehicles So Far

- 3.5 m diameter spherical superpressure balloons. Barebones science package
- Material – sulfuric acid resistant fluoropolymer fabric coated with fluoropolymer, 300 g/m^2
- 12 kg balloon, 2 kg helium, 6.9 kg gondola. Payload mass fraction = 0.33
- In 46 hours traversed ~1/3 of Venus circumference in equatorial zone (+/-7^o) at ~54 km altitude in benign thermal environment, slowly losing superpressure



Need for Advanced Balloons

- **Why not re-fly VEGA balloons?**
  - **Material is too heavy – inefficient for more capable payloads**
  - **Highly permeable – not long lasting**
  - **Poor optical properties - high temperatures, superpressure and leak rate on day side**

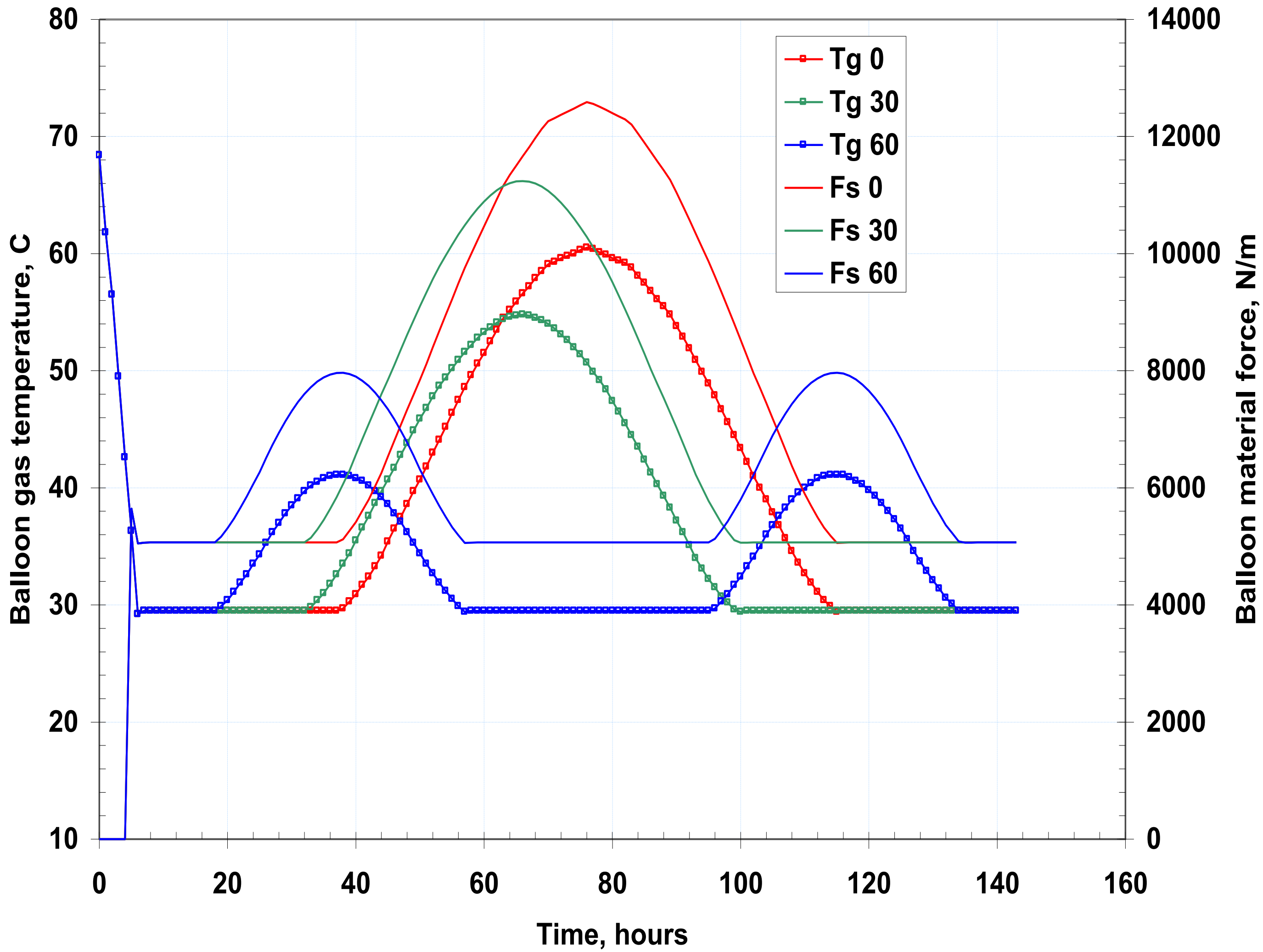
- **Balloons for advanced missions have to be robust and capable for**
  - **Heavy payloads: >40 kg**
  - **Long duration: > 6 days**
  - **Global flights: multiple day/night cycles and circumnavigation at any latitude**
  - **High payload mass fraction: >0.5**
  - **Tolerate Venus environment: clouds of 85% sulfuric acid, vertical winds up to +/-3 m/s**

Balloon Design Approach

- Benign thermal environment: altitude 54-56 km
- Capable for long duration: superpressure (constant volume) balloon
- Sphere: most mass efficient
- Robust: safety factor (ratio of burst load to actual load) >2.5 in the most adverse combination
- Low gas permeability: metallized film
- Minimum day/night temperature variations: minimum optical absorptivity/infrared emissivity ratio (α/ε)
- Tolerate sulfuric acid of Venus clouds: fluoropolymer outside layer

Balloon Flight Simulation

- •Full trajectory simulation after balloon inflation
- •5.5 m diameter balloon @55.5 km
- • a/e= 0.19 (25 μm silverized Teflon)
- •1.5 multiplier to radiation model for worst-case
- •Vertical winds up to 3 m/s (maximum encountered by VEGA balloons)



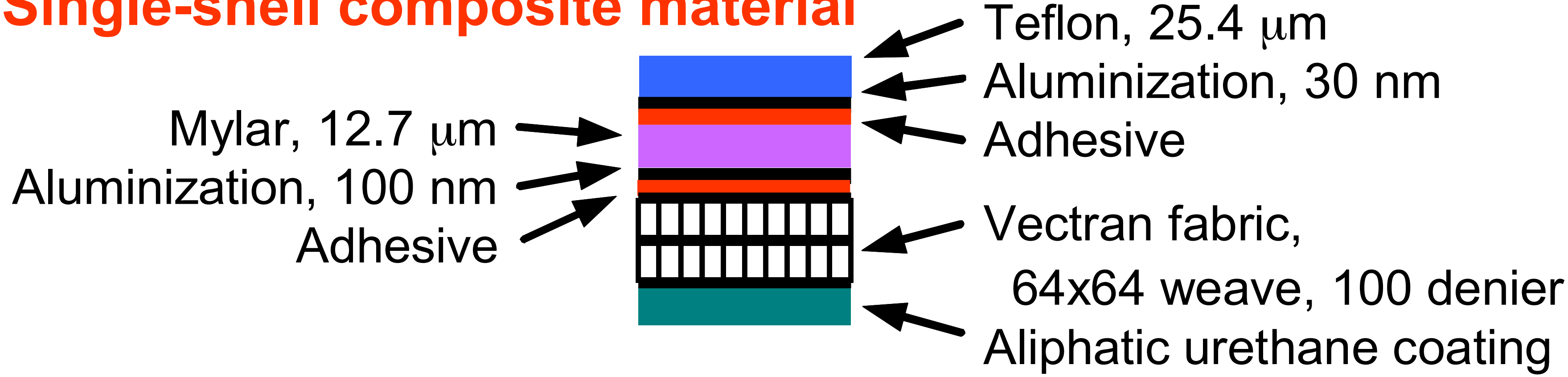
Flight Simulation Results

Latitude, deg	Vertical wind, m/s	Balloon tempera-ture, C	Maximum superpressure, Pa	Material load, N/m	Safety factor (prototype)
0	*0*	64	9350	12580	3.8
0	*3*	56	11780	16400	3.0
30	*0*	55	8070	11240	4.4
30	*3*	49	10810	15050	3.4
60	*0*	41	5720	7970	6.5
60	*3*	35	8420	11720	4.5

Full-Scale Prototype Balloon ("Alpha") Has Been Designed, Built and Tested by JPL/WFF/ ILC Dover Team

Balloon metric	Value
Diameter	5.5 m
Envelope areal density	176 g/m^2
Balloon mass	23.7 kg
Payload mass	44 kg
Helium mass	7.8 kg
Payload mass fraction	0.58

Single-shell composite material



ILC Dover proprietary sulfuric acid resistant adhesive for outer layer

Comprehensive Mechanical, Thermal and Sulfuric Acid Tests of Material Met Expectations

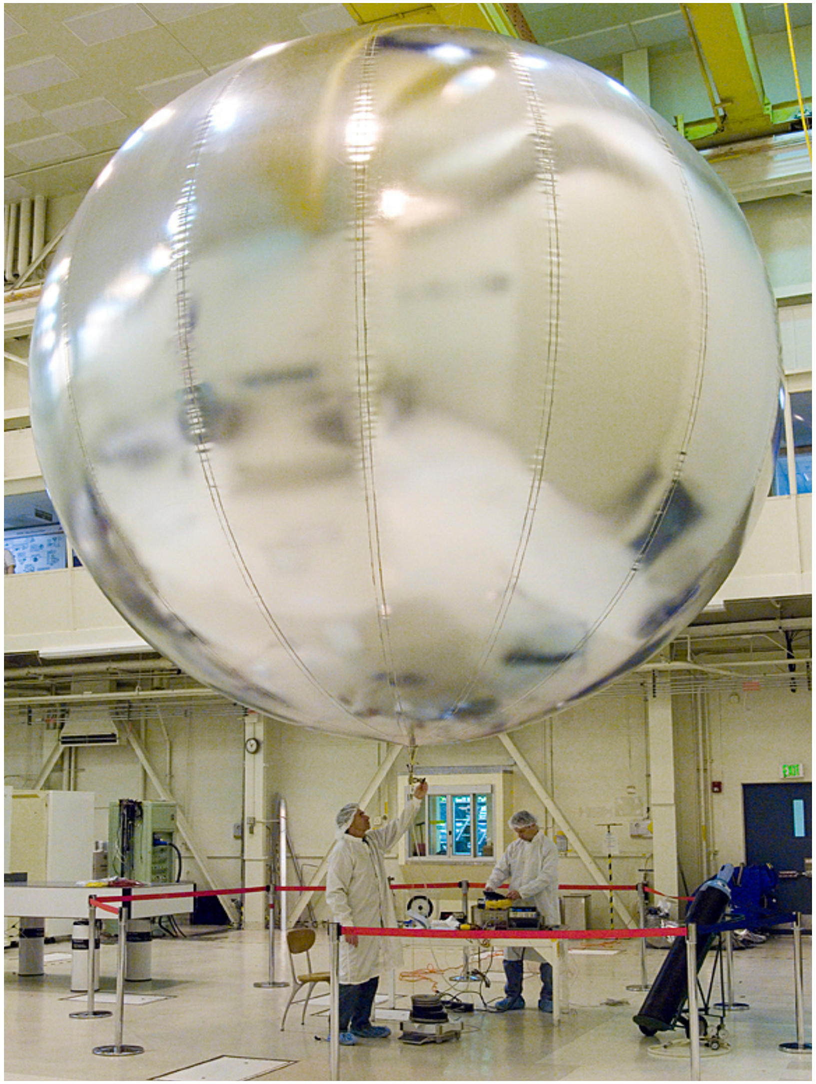
Parameter	Specification	Value
Areal density, g/m^2	ASTM D3776	176
Thickness, mm	ASTM 1777	0.17
Tensile strength @23 C (warp), kN/m	ASTM D5035	71
Tensile strength @23 C (fill), kN/m	ASTM D5035	57
Elongation at break (warp), %	ASTM D5035	5.3
Elongation at break (fill), %	ASTM D5035	7.0
Helium permeability, liters/m^2/day	ILC STP 029	~0
Seam tensile strength (warp), kN/m *	ASTM D5035	45
Seam tensile strength (fill), kN/m *	ASTM D5035	57
Tensile strength @75 C (warp), kN/m	ASTM D5035	60
Tensile strength @75 C (fill), kN/m	ASTM D5035	47

**Polyester fabric based seam tape, stronger Vectran fabric for the next prototype*

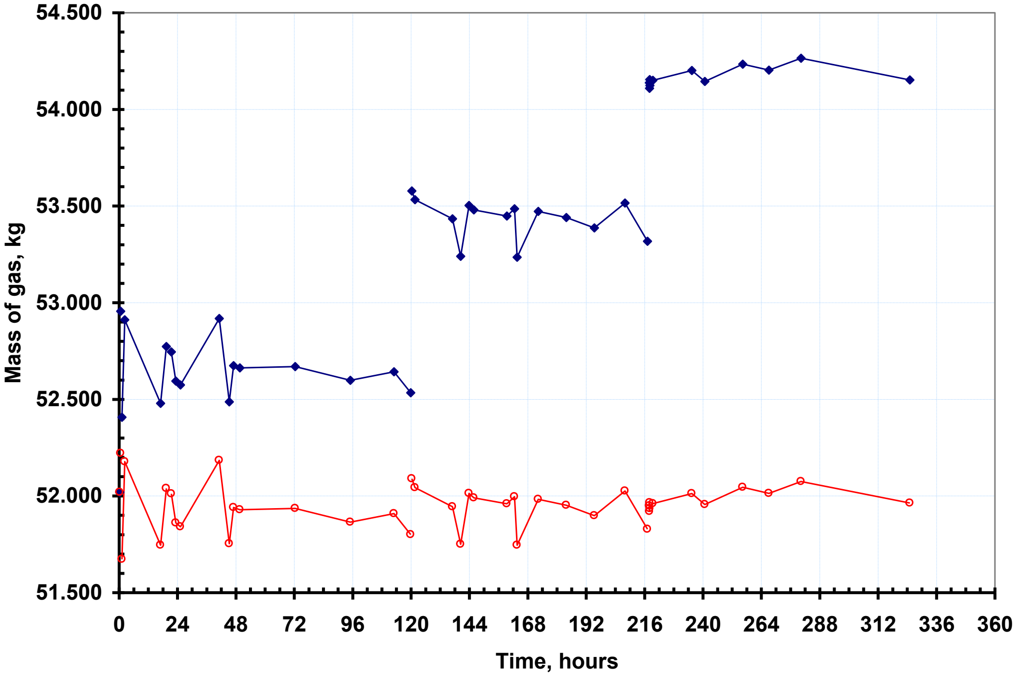
			Sulfuric Acid Concentration, %			
Component	Test temp, C	Test duration, day	75	85	92	96
Balloon material	25	7	Negligible effect	Negligible effect	Negligible effect	Negligible effect
Balloon material	70	7	Negligible effect	Negligible effect	Not tested	Not tested
Balloon material	70	2	Not tested	Not tested	Negligible effect	Negligible effect
Balloon material bi-fold	25	14	Negligible effect	Negligible effect	Negligible effect	Negligible effect
Balloon material bi-fold	70	2	Negligible effect	Negligible effect	Negligible effect	Negligible effect
Balloon seam	25	6	Not tested	External discoloration and/or wrinkling	External discoloration and/or wrinkling	External discoloration and/or wrinkling
Balloon seam	70	2	Not tested	External discoloration and/or wrinkling	External discoloration and/or wrinkling	External discoloration and/or wrinkling
Vectran fabric	25	2	Negligible effect	Negligible effect	Not tested	Not tested
Vectran fabric	70	7	Negligible effect	Negligible effect	Not tested	Not tested
Mylar film	25	14	Negligible effect	Negligible effect	Not tested	Not tested
Mylar film	70	2	Not tested	Negligible effect	Not tested	Not tested

Negligible effect	External discoloration and/or wrinkling but no evidence of acid penetration	Not tested

No Helium Leak In 2-week Test



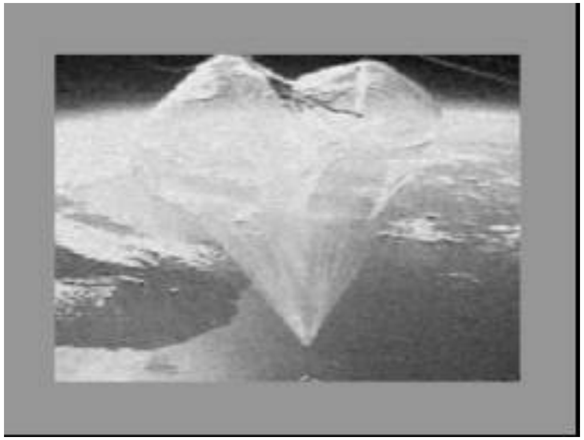
- Balloon inflated with ~50/50% helium-nitrogen in JPL SAF clean room
- Known amounts of nitrogen added two times to vary superpressure level
- Monitored buoyancy, superpressure, ambient pressure, temperature and humidity to calculate mass of gas
- No noticeable leak measured



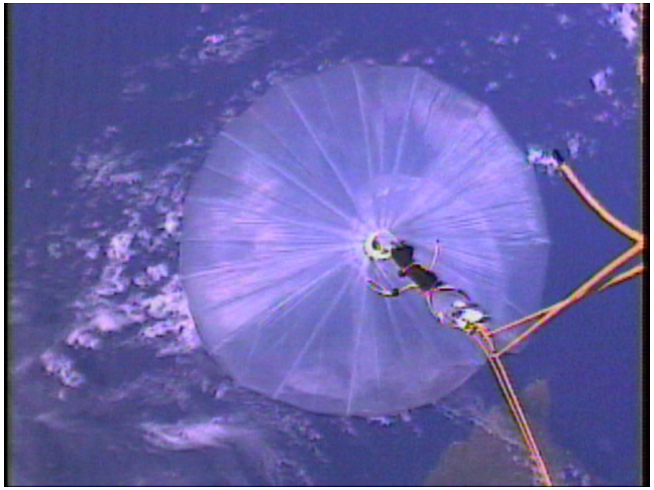
Aerial Deployment and Inflation Not Major Risk Anymore

- Progressively successful aerial deployment and inflation flight tests at much higher material stress levels
- No damages or pinholes in numerous hangar drop tests of much weaker 10-m 12 μm Mylar balloon

August 1998, H~1 km: 3-m spherical 12 μm Mylar balloon



June 2002, H~30 km: 11-m pumpkin 20 μm PE balloon



May 2006, H~30 km: 10-m spherical 12 μm Mylar balloon

June 2006, H~1 km: 11-m 50 μm polyester airship

Summary

- Balloons can be used as long-duration science platforms for global studies of atmosphere and surface of Venus
- Can carry significant payload mass and instruments to address key questions about origin, evolution and processes on Venus
- Also closes gaps and provides "ground truth" for orbiter data
- **Prototype of next generation sulfuric-acid tolerant balloon capable for long-duration global flight has been designed, built and tested successfully**

Pack in aeroshell and launch to Venus

Europeans are waiting in orbit!