



# Venus Aerial Platform Technology

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# Topics



- Mission Modes Requiring Aerial Platform Technology
- Sustained Aerial Platform
  - Superpressure(constant altitude) balloon
  - Variable altitude balloons
  - Solar Powered airplane
- Aerial Platforms and Dropsondes
  - Dropsondes for atmospheric research
  - Deep dropsondes for surface imaging
- Mobile Vehicles near surface
- Venus Surface Sample Return

# Mission Modes requiring Aerial Platform Technology



- **Sustained aerial platform (e.g. balloon)**
  - Operates at one or more vertical levels in the cloud layers
  - Conduct an *in situ* study of global atmospheric circulation
  - equipped to study the cloud region *in situ* to understand chemical processes, atmospheric structure and evolution, atmospheric stability, and to constrain biosignatures
- **Dropsondes**
  - Vehicles deployed from an aerial platform
  - Determine how atmospheric circulation patterns vary with altitude
  - Understand global atmospheric circulation at the surface
  - Deep dropsondes – surface imaging of targeted locations
- **Mobile platform on the surface or in the lower atmosphere**
  - mobility 10's to 100's km
  - equipped to analyze surface compositional variations on a regional scale

# Sustained Aerial Platforms

## VEGA Balloons



- The Soviet VEGA mission that flew two balloons at Venus in 1985.
  - These are the only balloons to have ever flown at another planet
- Two identical copies flew for 2 days each, carried as secondary payloads on the VEGA 1 and VEGA 2 landers.
- Metrics:
  - Type: helium-filled spherical superpressure
  - 3.5 m diameter
  - Teflon-like coated fabric material
  - 7 kg payload
    - Temperature, pressure, illumination, aerosol and wind measurements
  - 53-55 km altitude (in the clouds)



VEGA prototype test

- Ambient temperature  $\sim 30$  °C
- Aerially deployed and inflated
- Battery-powered
  - Balloons still flying when batteries died

## Sustained Aerial Platforms



# Venus Super-pressure Balloon Development

- JPL and its partners have designed, fabricated and tested two 5.5 m diameter balloons for operating at same altitude region as VEGA
  - Payload capacity is 45 kg at 55 km.
  - Lifetime is predicted to be in excess of 30 (Earth) days.
- Extensive testing of these balloons and other subscale engineering models performed to assess buoyancy, leakage, sulfuric acid resistance, aerial deployment and inflation and folding/packaging robustness.
- The technical progress is documented in a series of published papers



**First 5.5 m Venus prototype balloon in lab testing.**

### Papers on Venus Super-pressure Balloons

AIAA Paper 2013-1292, "Pinhole Effects on Venus Superpressure Balloon Lifetime."  
"Technology Development for a Long duration, Mid-Cloud Level Venus Balloon," *Advances in Space Research*, Vol. 48, No. 7, pp. 1238-1247, October, 2011.

"Second generation prototype design and testing for a high altitude Venus balloon", *Advances in Space Research*, Vol. 44, pp. 93-105

# Sustained Aerial Platform

## Aerial Development and Inflation



- Venus is a very friendly environment for the deployment and inflation of a balloon:
  - Balloons designed for the 55 km altitude range are robust
  - The atmosphere is dense allowing very slow parachute descent
- A key design characteristic is that the balloon finishes inflation at an altitude below the equilibrium float altitude and rises to that point after inflation.
  - VEGA did this to avoid over-pressurizing the envelope at excessively high altitudes.
  - It allows us to deploy at balloon at an “easy” 55 km and then ascend to 65-75 km if desired
- This Venus super-pressure balloon technology development is largely complete (TRL = 5-6).

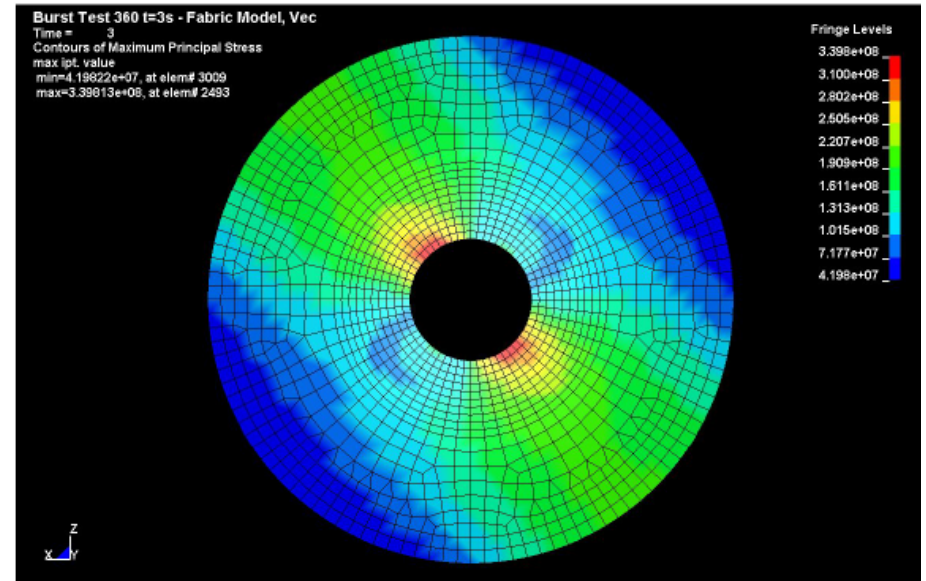


Second 5.5 m Venus prototype balloon during aerial deployment and inflation testing.



## Sustained Aerial Platform Super-pressure Balloon – Scalability

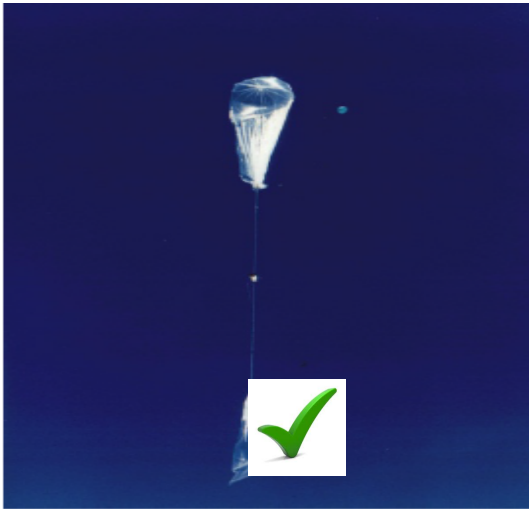
- Engineering efforts are ongoing to:
  - Increase the payload capability to 100 kg by increasing balloon diameter to 7 m diameter
  - Extend flight lifetime by improving the leakage performance of the balloon envelope material
- These are engineering developments and an incremental change of this kind does not require new technology



**Stress analysis of  
balloon end cap**



## Venus Aerial Platform Concepts Altitude Controlled Aerostats



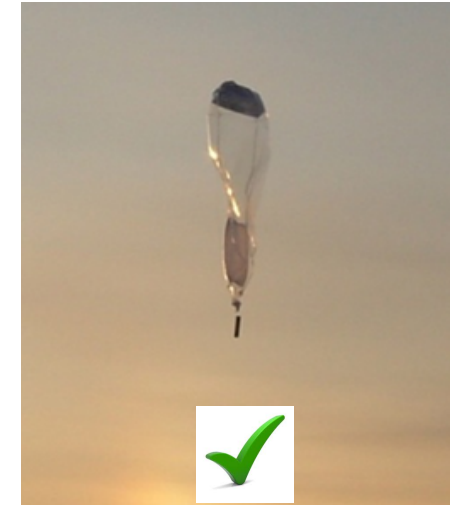
### Reversible Fluid

- Two balloons – one helium and one with a fluid that changes phase at different altitudes
- Fluid is gas at lower altitudes and changes state to a liquid as it rises slowing the ascent rate
- Depends on vapor pressure curve of fluid being steeper than lapse rate



### Thermal IR Montgolfier

- Balloon inflated with ambient atmosphere during descent
- Heated by solar radiation during the day and planetary IR radiation at night
- Long duration mission lasting more than one day depends on strong nighttime infrared radiation



### Pumped helium

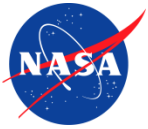
- Super pressure balloon inside a zero pressure balloon
- Helium pumped into the super pressure balloon to lose lift
- Helium released from the super pressure balloon to ascend
- Helium released from super pressure balloon to survive day night cycle

**Feasible below 55 km where lapse rate is 8C/km**

**Infeasible - insufficient night time IR radiation on Venus**

**Feasible – ample solar power above 55 km**

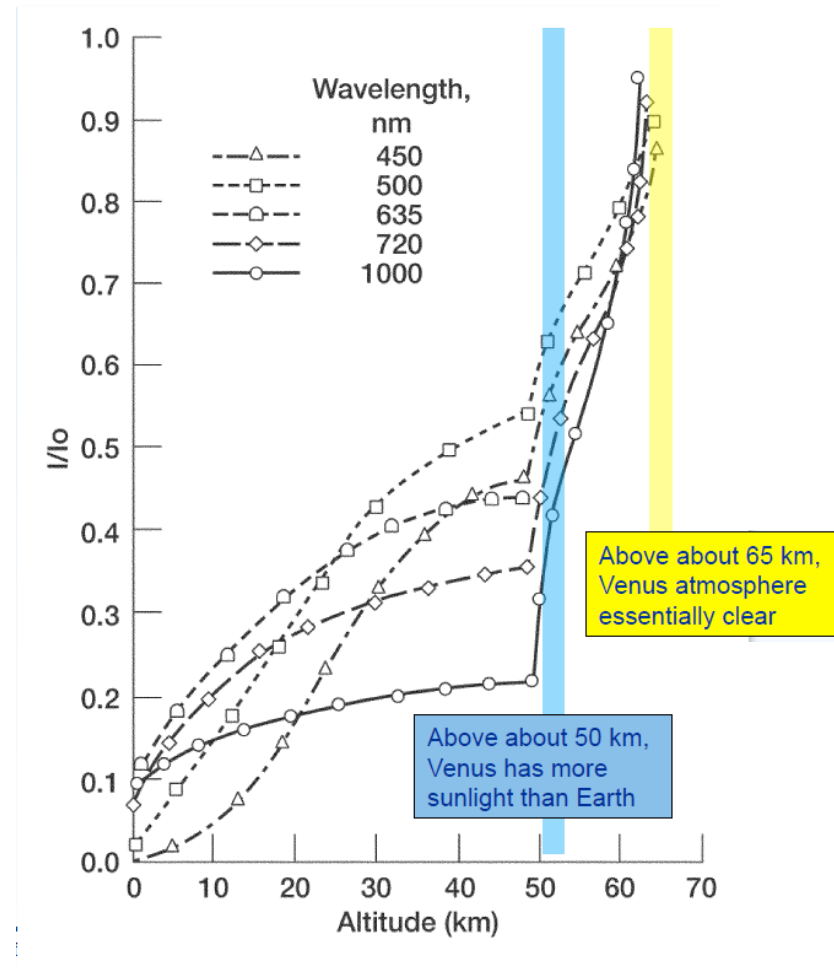




## Venus Aerial Platform Concepts Solar Powered Airplane

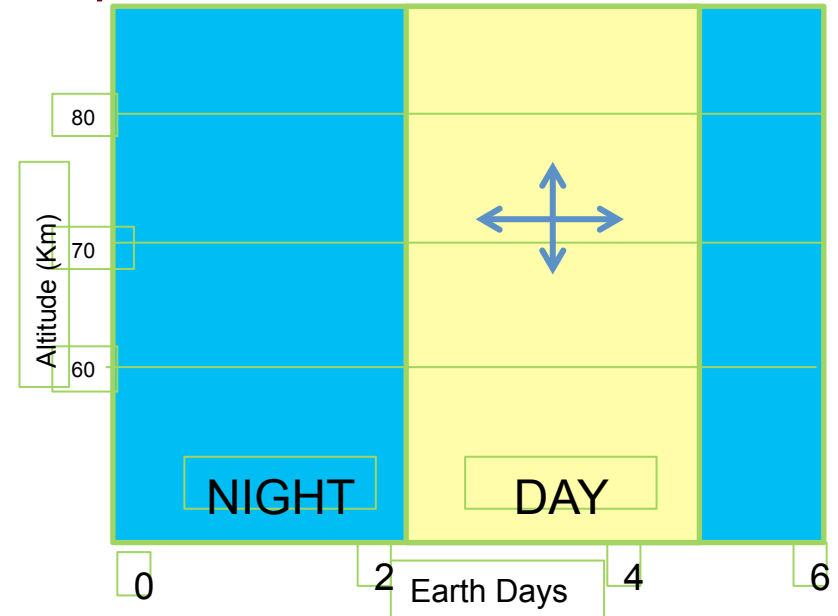
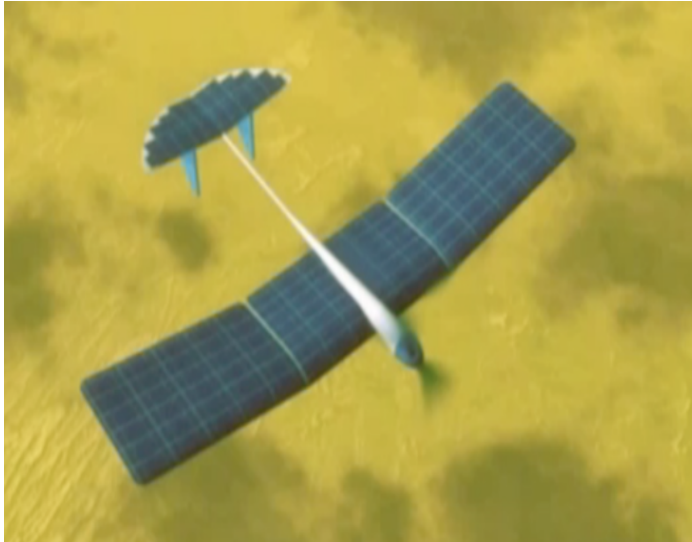
### Background

- Concept of solar airplane at Venus was proposed by Landis in 2001
- Concept takes advantage of the high solar radiation levels in the Venus atmosphere
- Studies of the concept were sponsored by the NASA Revolutionary Aerospace Systems Concepts (RASC) program in 200 and 2003





# Venus Aerial Platform Concepts Solar Powered Airplane



## Concept

- Solar powered long duration airplane that station keeps on the day side of the planet
- Altitude range limited by the availability of solar power and the power required to fly at wind speed.
- Can change latitude but cannot access higher latitudes

## Science Assessment

- Provides long duration operation and ability to ascend and descend through part of cloud
- Could fly through different air parcels to explore cloud heterogeneity

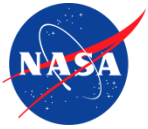
## Technical Readiness

- Power margins for station keeping at 130 m/sec need study<sub>10</sub>



## Dropsondes

- Dropsondes –
  - Understand global atmospheric circulation as a function of altitude
- Deep dropsondes –
  - Understand global atmospheric circulation at the surface
  - Surface imaging



# Dropsondes

## Sounding the Venus atmosphere

### Concept:

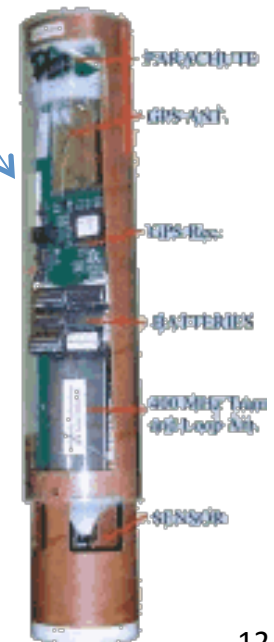
- Small instrumented probe that is dropped from an aerial platform.
- Multiple dropsondes can be carried on a single platform.

### Measurements

- Determine how atmospheric circulation patterns vary with altitude
- Each dropsonde measures atmospheric, temperature and pressure as it descends beneath a parachute
- Uses tracking and accelerometer data to measure horizontal and vertical winds

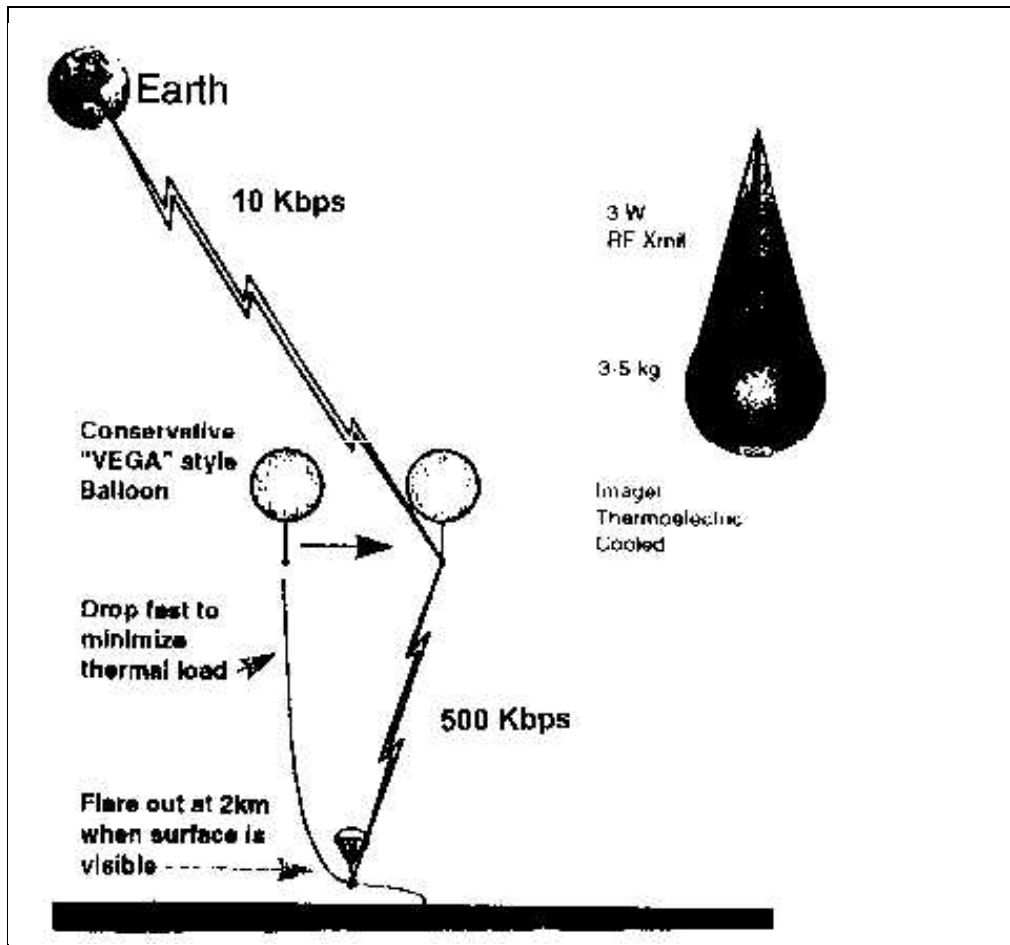


Dropsonde



# Dropsondes

## Deep Dropsonde for Surface Imaging at Venus

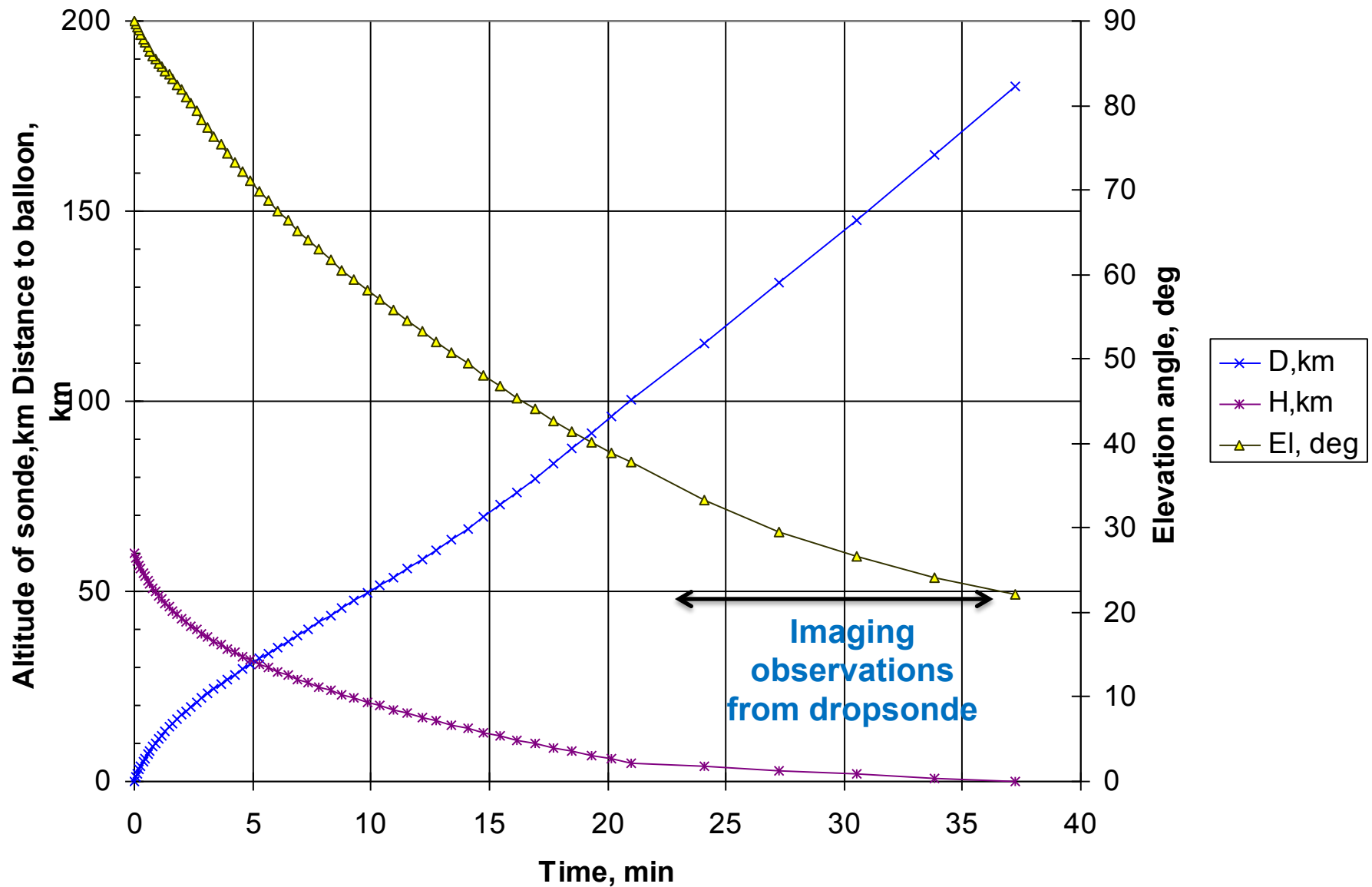


Miniature pressure vessel designed for Venus surface temperatures and pressures

Venus Aerobot Multisonde Mission: Atmospheric Relay for Imaging the Surface of Venus by Viktor Kerzhanovich et. al. AIAA 99-3857, 1999

# Dropsondes

## Deep Dropsonde – Mission Profile



## Dropsondes



# Deep Dropsonde vs Probe

Attribute	Probe	Deep Dropsonde
Concept	Deployed on separate trajectories during approach to Venus	Deployed from balloon after balloon has entered Venus and begun to “orbit” the planet
Heat shield	Separate heat shields for each probe	One heat shield only for the balloon platform.
Scalability	No hard restrictions	Bounded by payload capability of balloon platform
Geographic Dispersion	Broad. Limited by approach and entry conditions	Limited to narrow latitude bands defined by balloon ground track
Targeting	Approximately 200 km uncertainty from direct entry	Precise. <10 km uncertainty. Deployed from balloon
Data rate	~1 kbps to flyby spacecraft at range 2000 to 100,000 km	~1 Mbps to balloon at range 10 to 200 km



## Mobile Platform on Surface or Lower Atmosphere Near-Surface Venus Flotation Device

- Venus Exploration Roadmap calls for a mobile vehicle with surface or near surface mobility and range 100 km, lifetime 12 months
- There are two options for achieving surface or near surface mobility required for the
  - A wheeled or legged vehicle on the surface
  - An aerial vehicle using a flotation device capable of operating at 460C operating in the lower atmosphere
- A bellows-based flotation device has the ability to expand allowing the vehicle to rise to heights of 10 to 15 km if desired.
- The flotation device is currently considered to be at TRL 4



# Mobile Platform on Surface or Lower Atmosphere Near-Surface Venus Flotation Device

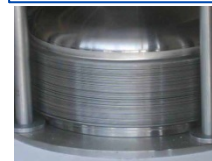


- Flotation devices are attractive solutions to mobility near the surface of Venus because of the dense atmosphere ( $70 \text{ kg/m}^3$ )
- A prototype was constructed and successfully tested at  $460^\circ \text{C}$ 
  - It was based on a stainless steel bellows design 20 cm in diameter.
  - The reusable (elastic deformation) length was 90 cm and the completely extended (plastic deformation) length was 2.2 m
  - Has capability of operating from the surface up to a maximum altitude of 15 km

Maximum  
Plastic  
Deformation  
(and  $460^\circ \text{C}$ )

Maximum  
Elastic  
Deformation

Before  
Inflation



**Prototype stainless steel bellows  
flotation device**

# Venus Surface Sample Return (VSSR) Approach



- Balloon technology has been an essential part of any scheme for Venus Surface Sample return since these missions were first studied in the 1970s
- Most concepts involve transferring a sample from the surface to an altitude from where the sample could be launched to orbit (>65Km)
- Balloon materials were investigated at JPL for these kinds of altitude excursions but no solution was found that was sufficient robust at low altitudes and sufficiently lightweight at high altitudes
- The two balloon concept, based on the metal bellows technology could address this particular technical challenge

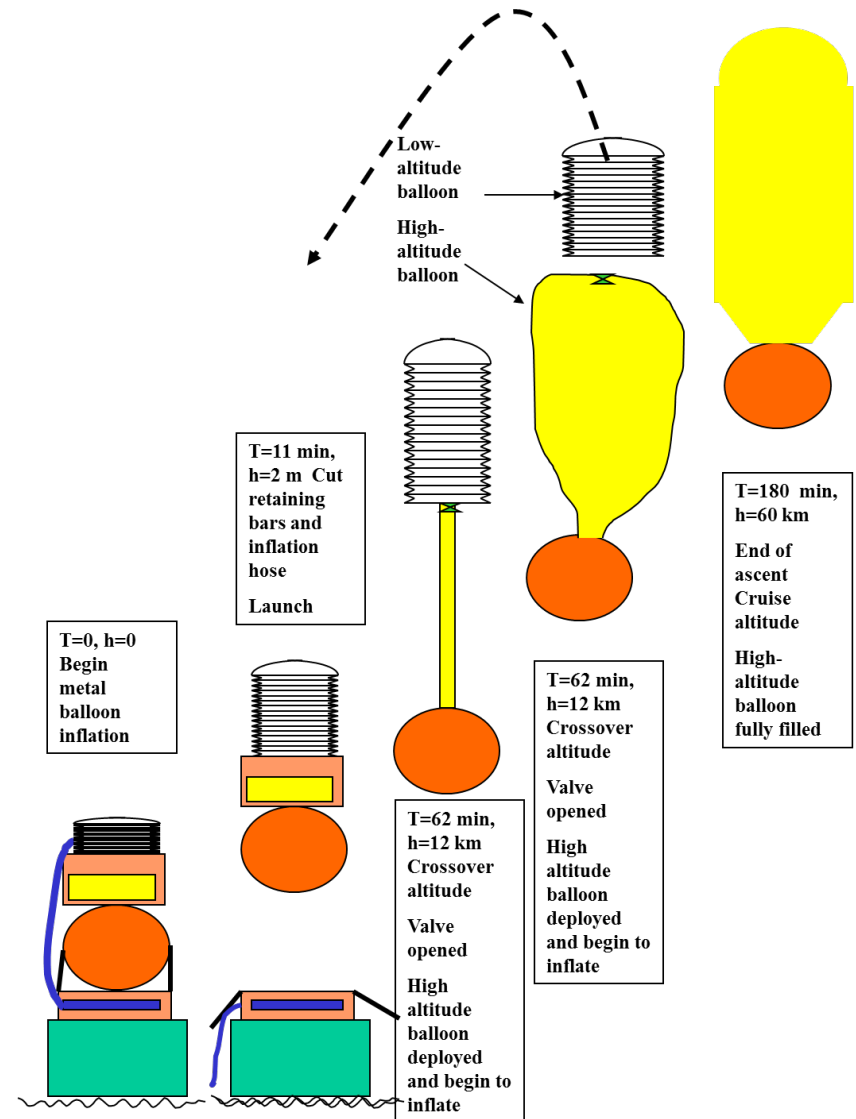
**Many other technical challenges remain to be solved  
to make VSSR feasible never mind affordable**

# Venus Surface Sample Return (VSSR)

## Two Balloon Systems



- A metal balloon can be used as part of a two-balloon system for a Venus surface sample return mission concept
- Use of a balloon is imperative to get the sample to a high altitude for rocket return to the Earth.
  - The Venusian atmosphere is too thick to do a surface rocket launch and get to the Earth.
- No one kind of balloon could traverse the entire 0 to 55 or 60 km altitude range using known technology.
- The idea of a two-balloon system was conceived to circumvent this problem:
  - Use a metal balloon to launch from the surface and get to 12-15 km altitude.
  - Deploy and inflate (transfer the helium in the metal balloon) a polyimide (Kapton FN) balloon at this altitude and use that to take the sample to the launch altitude of 55 km.
  - Published as “Two Balloon System to Lift Payloads for the Surface of Venus”, AIAA-2005-7322



# Summary

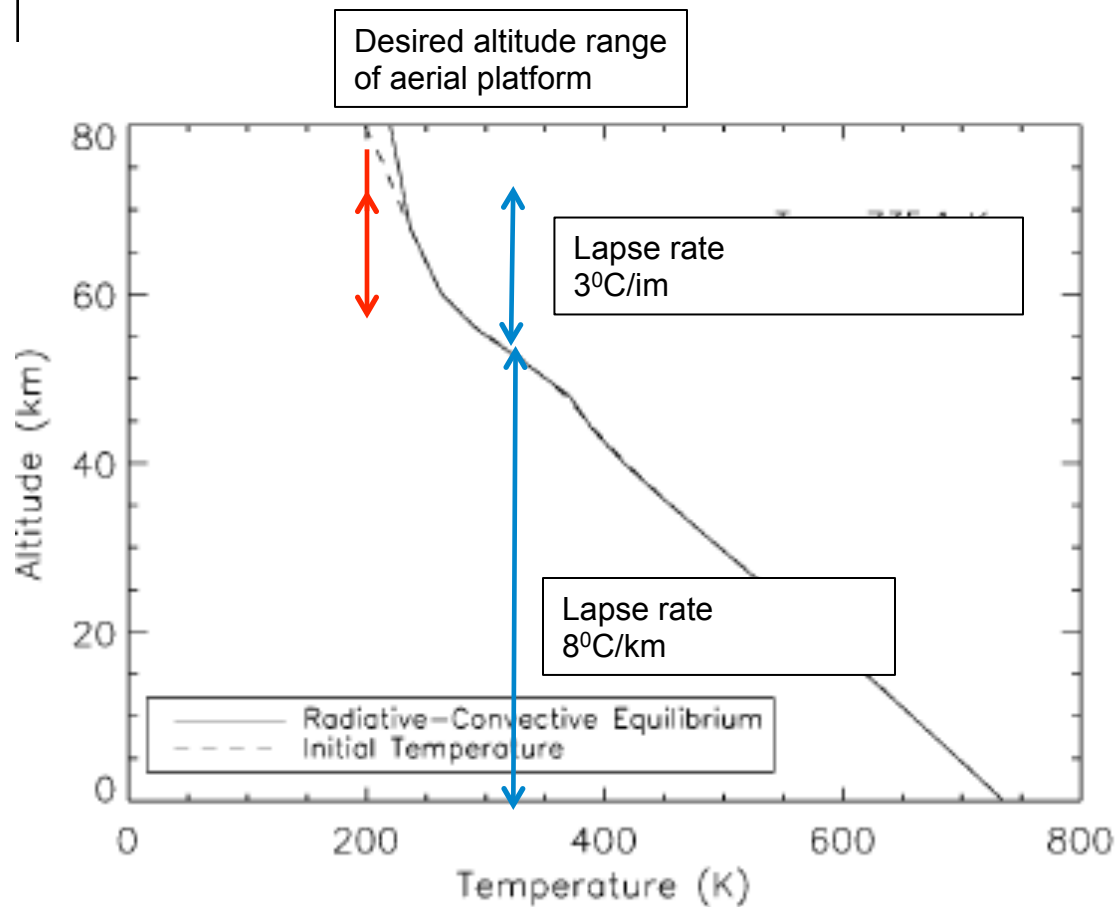


- Super-pressure balloons capable of lifetimes in excess of 30 days on Venus at a constant altitude of 55 km *are a mature technology at TRL 5 to 6*
  - Small balloons in the 3.5m class with 8 kg payload flew in the 1980s
  - Balloons in the 5.5 m class with a 45kg payload have been built and tested in relevant environments
  - Larger balloon in the 7m class with 100 kg payloads are an engineering development
- Balloons capable of altitude changes and solar powered airplanes have been proposed and are at various stages of development. *Investment is needed*
- Dropsondes for atmospheric sounding and deep sondes for surface imaging can provide a powerful complement to a superpressure balloon system. Sondes can be implemented with existing technology; *deep sondes require investment*
- Flotation devices for operation near the Venus surface have been demonstrated and could provide the mobility for the Roadmap's near surface mobility vehicle. They are currently at TRL4
- These same flotation device technology could be an element in a two stage flotation system for Venus Surface Sample Return (VSSR)



## **Backup / Alternate Charts**

# Atmospheric pressure and temperature lapse rate in the target altitude regime



- Atmospheric pressure ranges from 0.1 atm. to 0.02 atm.
- Atmospheric density ranges from 0.21 kg/m<sup>3</sup> to 0.028 kg/m<sup>3</sup>
- These conditions are compatible with airplanes and high altitude balloons
- The desired altitude regime is not in the convective zone
- Lapse rate is not suitable for certain balloon concepts

Temperature profile from Mark Bullock, The Stability of Climate on Venus PhD Thesis, University of Colorado, 1997

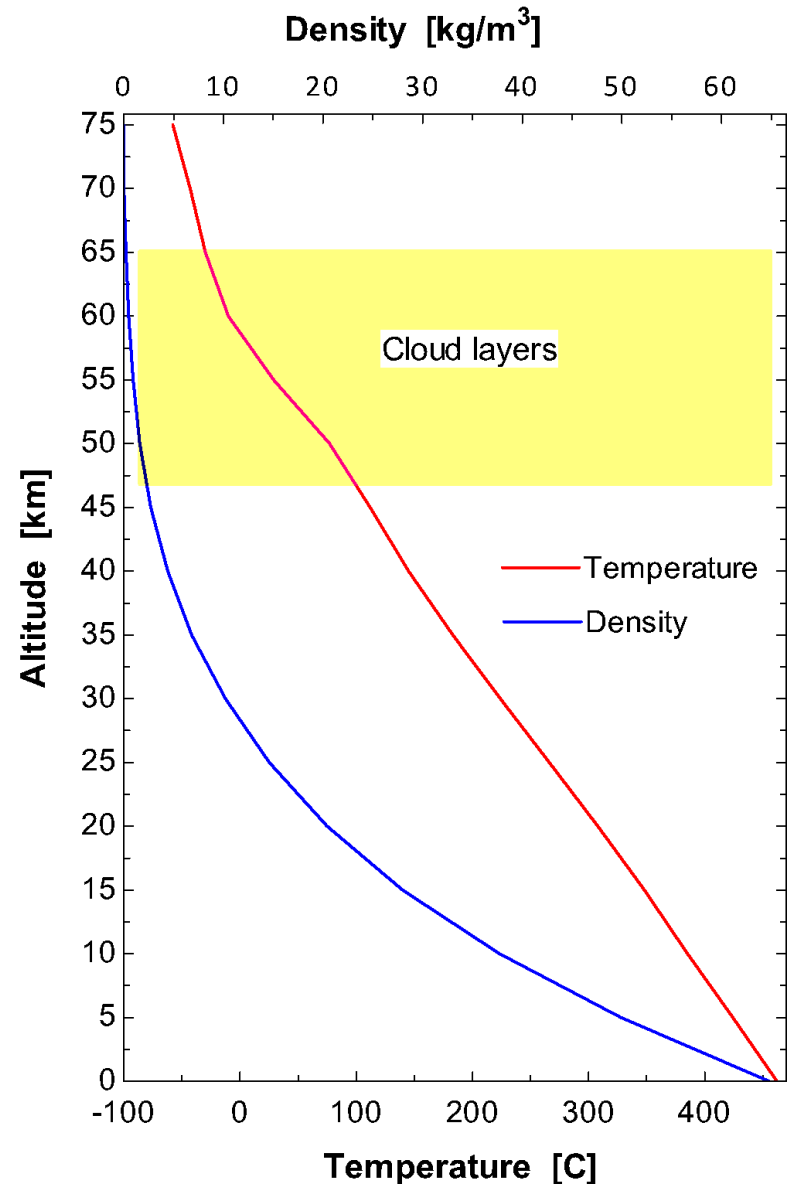
# Venus Ballooning at High Altitudes



- The challenge of ballooning at high altitude (60-75 km) at Venus is that the atmospheric density is low:

Altitude (km)	Density (kg/m <sup>3</sup> )
55	0.92
60	0.47
65	0.21
70	0.084
75	0.033

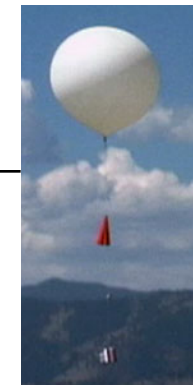
- Buoyancy scales with volume\*density
- $\rho (75 \text{ km}) / \rho (55 \text{ km}) = 0.036$ 
  - A factor of 28 less than the VEGA balloon altitude.
- Venus at 75 km has the same density as the Earth at 22 km (69,000 ft).



# Standard Terrestrial Balloon Types



Type	Description	Altitude Control
Superpressure	Sealed, constant volume balloon. Balloon changes pressure instead of volume. (e.g. VEGA)	Inherently stable in altitude until pressurization is lost.
Zero pressure	Vented balloon through long ducts. Most common scientific balloon used on Earth.	Requires active control. Typically achieved with gas venting and ballast drops.
Weather	Highly flexible rubber balloon, designed for one vertical profile only.	Unstable in altitude. Performs one ascent, then bursts upon reaching max altitude.
Hot air	Vented through hole at bottom of balloon. Heat source (chemical, sun, nuclear) provides buoyancy.	Requires active control of buoyancy through opening and closing of apex valve and/or burner variations for chemical heat sources.
Blimp	Sealed, streamlined, constant volume balloon. Internal compartment (ballonet) fills/unfills with ambient atmosphere to maintain internal pressure and hence shape.	Requires active control via onboard propulsion system and control surfaces (like an airplane).





# Aerial Deployment and Inflation



- All Venus balloons require an aerial deployment and inflation sequence upon arrival at Venus to transition from a folded, stored state to a flight condition.
- For VEGA, this occurred over a few minute period during a parachute-assisted descent through the clouds.
- This process includes injection of the buoyancy fluid or heating of the ingested atmosphere depending on which kind of balloon you have.
- The VEGA success is a proof-of-concept that Venus balloon aerial deployment and inflation is feasible.
  - But any specific new design will require a verification and validation process to prove viability.
  - This is not likely to be a major risk item: the Venus atmosphere is very dense providing lots of time to deploy and inflate, and the Venus balloons themselves tend to be robust.
- A key design characteristic is that the balloon finishes inflation at an altitude below the equilibrium float altitude and rises to that point after inflation.
  - VEGA did this to avoid overpressurizing the envelope at excessively high altitudes.
  - It allows us to deploy at balloon at an “easy” 55 km and then ascend to 65-75 km.

# Sustained Aerial Platform Aerial Deployment and Inflation Sequence

