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Aerial Platform Options For Venus

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Introduction

- This presentation summarizes the approach and results from the NASA Venus Aerial Vehicles Study (2017-2018)
  - Further details can be found in the final report expected to be finished and released in the near future.
- Study objectives:
  - Identify viable aerial platform technologies
  - Identify and prioritize what science could be obtained from the different platforms
  - Quantify resource needs (mass, power, volume)
  - Assess the technological maturity of different platforms
- Study characteristics:
  - The study consisted of two multi-day face-to-face workshops with intervening time for science and engineering analysis.
  - It involved a cross-disciplinary team of scientists, engineers and technologists drawn from NASA centers, industry and universities (~ 30 people altogether).

7 Types of Aerial Platforms Were Considered

(Terrestrial Examples Shown Below)

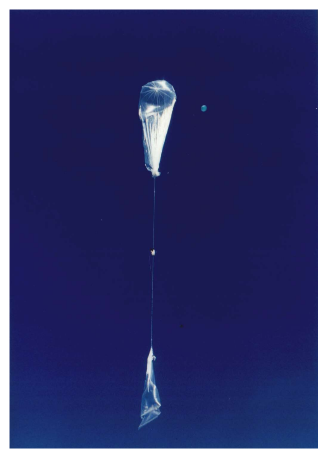
Balloons/Aerobots

Superpressure Balloon (JPL Venus prototype)

Mechanical Compression Balloon
(Thin Red Line Aerospace)

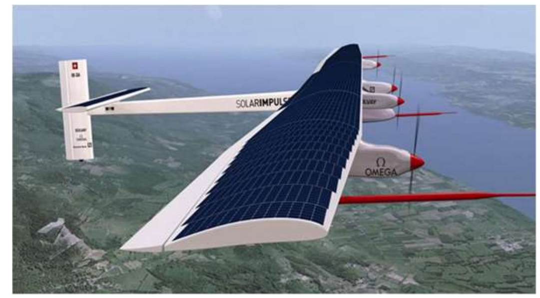
Pumped Helium Balloon (Paul Voss CMET)

Air Ballast Balloon (Google Loon)

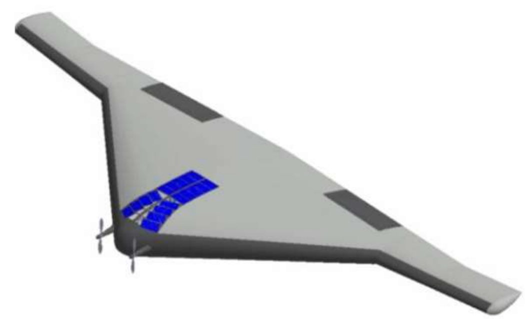


Phase Change Fluid Balloon (JPL)

Aircraft and Hybrid



Solar Aircraft (Solar Impulse 2)



Hybrid Airship (Northrup Grumman VAMP)

Platform Type Comparison

Platform Type	Main Buoyancy Method	Envelope Type	Altitude Change Method
Super-pressure Balloon	He or H_2	super-pressure	None
Pumped Helium (He)	He or H_2	zero-pressure	compress and store buoyancy gas
Mechanical compression balloon	He or H_2	super-pressure	compress envelope
Air ballast balloon	He or H_2	Zero- or super-pressure	compress and store ambient air
Phase change fluid (PCF) balloon	He augmented with a PCF (e.g., H_2O or NH_3)	zero-pressure	change of phase of PCF (e.g., H_2O or NH_3)
Solar airplane	propulsive-driven aerodynamic lift	N/A	lift modulation
VAMP	He or H_2 buoyancy augmented with aerodynamic lift	super-pressure	lift modulation

Analysis Methodology

- Quantitative comparisons of the different vehicle types focused on a Venus cloud-level flight scenario in the range of 50-60 km altitude.
  - Temperatures are between -10 °C and +76 °C and therefore generally survivable for avionics and instruments without extraordinary thermal control measures.
  - Daytime solar energy is sufficient for all vehicle requirements with the qualified exception of the solar airplane.
  - This altitude range enables a wide range of important atmospheric science investigations.
  - The final report will provide information on below 50 km opportunities and the vehicle options for meeting them.
- Venus-relevant designs are rudimentary for most vehicle types.
  - Quantitative estimates rely extensively on extrapolations from similar Earth vehicles and a variety of rules of thumb from various studies and mission proposals.
  - The study team performed cross-checks to try and ensure fair comparisons between the platforms.

Platform Mass Comparisons

- The table below shows the basic platform mass comparison for a cloud-level vehicle with a 10 kg science instrument payload.
  – The presumption is that all vehicles except VAMP require their own aeroshell to safely enter the Venusian atmosphere.
    - VAMP requires an ≤ 8 km/s entry speed achieved via propulsive orbit insertion combined with aerobraking.
  – System arrival mass in the table is all mass approaching Venus including the flying vehicle, deployment and inflation system, aeroshell, parachutes and propulsion system (if necessary) including fuel.

Science Instrument Payload:	10 kg			
Platform	Altitude Range (km)	Flying mass in Venus atmosphere (kg)	System arrival mass at Venus approach (kg)	Notes
Superpressure balloon	54	64	290	Basic pressurized balloon (VEGA was this type)
Pumped helium balloon	50-60	87	380	Balloon-within-a-balloon concept
Mechanical compression balloon	50-60	96	420	TRL stacked balloon concept
Air ballast balloon	50-60	86	380	Partitioned balloon concept (Google Loon is this type)
Phase change fluid balloon	50-60	140	400	Ammonia-water fluid design
Solar airplane	66-75	128	680	Can make brief descents below 66 km
VAMP (aerobraked)	50-60	450	1100	Enters from low orbit after aerobraking

Observations

1. The simplest concept of superpressure balloon has the lowest arrival system mass of all the lighter-than-atmosphere concepts. More capability (changing altitude and/or lateral control) requires more, and sometimes significantly more, mass.
2. The set of four variable-altitude balloons (pumped helium, air ballast, mechanical compression and phase change fluid) are of comparable overall system arrival mass in this analysis and approximately 1/3 more than the superpressure balloon.
3. Phase change balloons are extremely energy efficient since they can change altitude passively and use zero pressure balloon materials that are less challenging in the harsh Venus atmosphere.
4. Although not distinguished on mass, mechanical compression balloons are believed to be capable of changing altitude more quickly and with greater energy efficiency than pumped helium or air ballast balloons.
   - Set against this advantage is an as-yet unknown effect of possible flight-time limiting pinhole generation in the highly stressed balloon material during repeated compression cycles.

Observations (cont.)

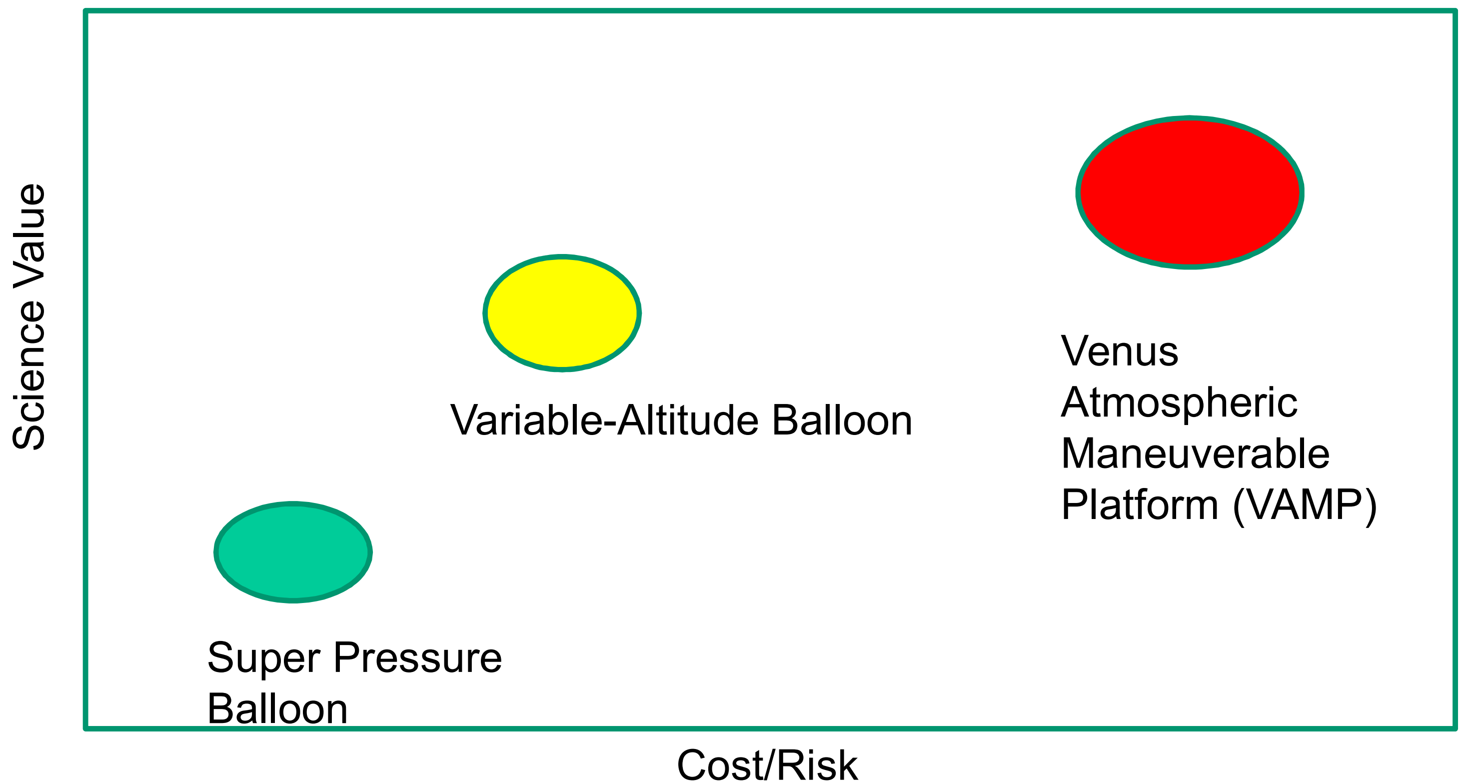
5. The solar airplane requires ~70% more mass than a variable altitude balloon for the 10 kg science instrument case.
   - Also note the restriction to sustained all-daytime, near sub-solar flight above 66 km to get sufficient sunlight.
   - Temporary excursions below 66 km are possible with duration and minimum altitude dependent on energy storage capability.
6. Vehicle operation below 50 km may be more limited by instrumentation temperature limitations than balloon platform limitations.
   - Temporary excursions with insulated payloads are possible, with heat rejection (payload cooling) performed upon return to higher altitudes.
   - The phase change fluid balloon is particularly designed for this kind of altitude cycling and can do it without pumps or winches.

Observations (cont.)

7. VAMP requires by far the most arrival mass at Venus, more than double any of the balloon options.
   – This is driven by both the size of the basic vehicle and the need to carry a propulsion system to get into a large elliptical orbit. It assumes aerobraking to transition to a low, near circular orbit such that the maximum entry speed becomes ≤ 8 km/s as required for the vehicle thermal design.
   – While aerobraking saves ~ 1200 kg of mass compared to direct all-propulsive low orbit insertion, it delays entry by many months which must be accommodated in the overall mission design.
   – VAMP can uniquely provide scientific data in the region between 70 and ~90 km due to its very high altitude deceleration and controlled flight after atmospheric entry.

Venus Aerial Platforms - Cost-Benefit Trends

- Another key result from the study is that variable-altitude balloons represent a “sweet spot” in the option space between science value and cost/risk.
  - Even then, the increased value for fully 3D controlled vehicles (e.g., VAMP) is only achieved if the vehicle can broadly target surface locations and measure them from below the clouds. If that capability is not provided then science return is maximized with simpler altitude-controlled balloons.



Technology Status

- All vehicle types require Venus-design specific analysis, design, prototyping and testing before achieving sufficient technological readiness for flight.
  - Superpressure balloons are the most mature due to the VEGA balloon experience and subsequent JPL/ILC Dover/WFF Venus prototyping.
  - VAMP is the least mature and requires substantial development and Earth orbit flight testing to demonstrate the viability of its atmospheric entry followed by long duration atmospheric flight approach.
    - The development approach of the Hypersonic Inflatable Aerodynamic Decelerator (HIAD) project can serve as a model with its multi-prototype, multi-test flight campaign that deliberately scales up to full size in digestible pieces.

Conclusions

- The Venus Aerial Vehicles Study (2017-2018) provided a comprehensive assessment of achievable science, possible vehicle approaches and approximate resource needs.
- Variable altitude measurements were found to provide a significant increase in science value as compared to constant altitude superpressure balloons.
  - Recent terrestrial progress in variable altitude balloons suggest that similar balloons for Venus can be developed with modest investments.
- VAMP would provide additional science over variable altitude balloons, but requires a large, sustained development program to prove feasibility and quantify mass, power and volume metrics.

Backup Charts

Required Developments and Tests

	Superpressure balloon	Pumped Helium Balloon	Mech Compressio n Balloon	Air Ballast Balloon	Phase Change Fluid Balloon	Solar Airplance	Hybrid Airship
	SP	PHB	MCB	ABB	PCB	Airplane	VAMP
Survive and operate over design range*							
Design a full Scale prototype	X	X	X	X	X	X	X
Verify design with flight testing	X	X	X	X	Impractical	X	Partial
Perform piecewise experimental validation	X	X	X	X	X	X	X
Verify design with model based Validation	X	X	X	X	X	X	X
Deployment and Inflation							
Design packaging deployment and inflaction system	DONE	X	X	X	X	X	X
Validate with earth atmosphere flight tests	DONE	X	X	X	Impractical	X	Not Applic
Conduct Piecewise experimental validation					X		X
End to end entry, deployment and inflation							
Earth orbital flight test	NR	NR	NR	NR	NR	NR	X
X - still to be done							
NR - Not required							
* This will include diurnal cycling and altitude cycling							