Venus Variable Altitude Aerobots

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Background

The clouds of Venus offer a unique environment: ample sunlight, Earth-like temperatures and pressures, and strong zonal winds that can carry an aerial platform around the planet in just a few Earth days. This cloud layer is key to moderating the solar radiative balance of the planet, the transport of materials between the atmosphere and the ground, and the interactions (physical, chemical, and possibly biological) between atmospheric constituents. The two 1985 VeGa balloon flights [1], launched by the Soviet Union, successfully flew in these Venus clouds using superpressure balloons, which nominally have a fixed buoyancy and access only a single altitude.

JPL, Near Space Corporation, and Wash. U. are taking the next step in planetary balloon exploration capability by developing controllable variable-buoyancy balloons [2,3] that provide access to a large range of altitudes over the course of the flight with accordingly increased science return [4]. The "aerobot", an aerial robotic buoyant vehicle consisting of both a balloon and its payload, is expected to sample aerosols, measure remnant magnetism & atmospheric processes, and listen for surface seismic activity. Our variable-altitude aerobot was a primary mission asset for the Venus Flagship Mission study [5] for the 2023-2032 Planetary Science Decadal Survey. Standalone aerobot missions, or combined aerobot & orbiter missions, are further enumerated in our IEEE papers [6-7].

Architecture

The architecture consists of two balloons: an outer, metallized Teflon-coated unpressurized balloon (which protects against sulfuric acid aerosols and sunlight), and an inner Vectran-reinforced pressurized balloon which acts as a helium reservoir. Transferring helium between the chambers modulates the buoyancy and altitude. An aerobot of 12–15 m diameter [7] is desired for a carrying capacity of 100–200 kg, consistent with a major scientific investigation of and from the cloud layer, with altitude-control capability of 52 km to 62 km.

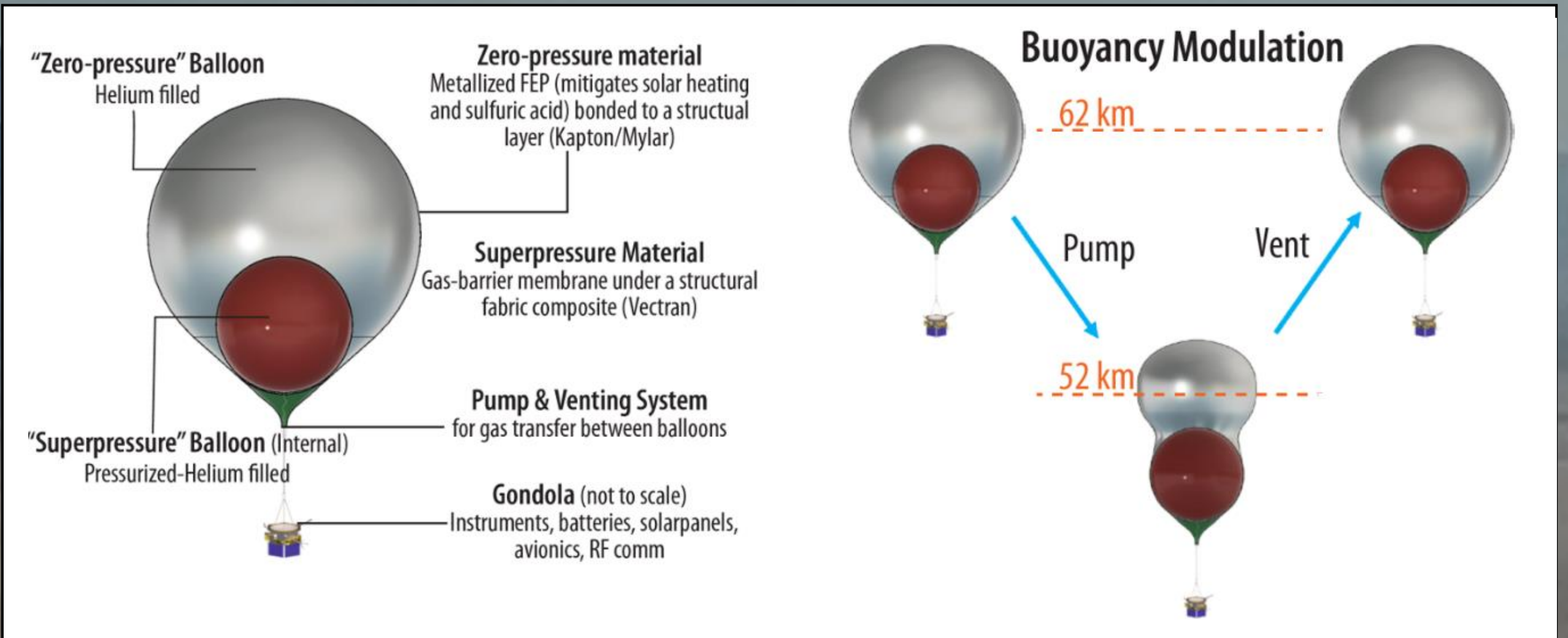

Figure 1: (Left) Venus Aerobot system architecture. (Right) Buoyancy modulation by pumping helium gas. Reproduced with permission from [6]

Approach & Results

Fabrication: Two subscale prototypes have been built so far [7,8] at approximately 1:3 scale to the Venus design points, with a third prototype in progress (Figure 2). These prototypes are of increasingly higher fidelity, with balloon envelopes and seams capable of withstanding the high-temperature (~100°C), high-pressure loads (~30 kPa), sulfuric-acid environment (94% concentration), and solar radiative heating (2300 W/m2) needed for flight in the Venus cloud layer.

Simulation: Simulation work focuses on understanding the flight dynamics of the aerobot, validated against static testing and indoor flights (Figure 3). The FLOATS model (built on the JPL DARTS toolkit) acts as our primary method of ensuring that the aerobot can perform the Venus mission desired by our science collaborators.

Pressure/Acid Testing: Environmental testing is separate for each balloon envelope - including load-to-failure burst testing of inner reservoir, and elevated-temperature acid immersion testing of external seams (Figure 4).

Inflation Testing: The aerobot must be inflated on Venus while hanging from a parachute in approximately 10 minutes, with the outer balloon filled at a slight head-start to the inner balloon – a process demonstrated within timeline constraints on our subscale prototypes.

Flight Test: The highlight of the task was JPL's first outdoor flight demonstration of a Venus prototype aerobot (Figure 5) in July 2022. Our subscale aerobot flew two flights at altitudes of the same atmospheric density as 54-55km on Venus (middle of the desired range), demonstrating altitude control by exchanging reservoir gas, and was recovered in good condition after both flights. The payload recorded both the dynamics & thermodynamics of the aerobot through an array of pressure, temperature, wind, inertial, and radiative flux sensors. Video and media release on the flight can be found here:

https://www.jpl.nasa.gov/news/jpls-venus-aerial-robotic-balloon-prototype-aces-test-flights

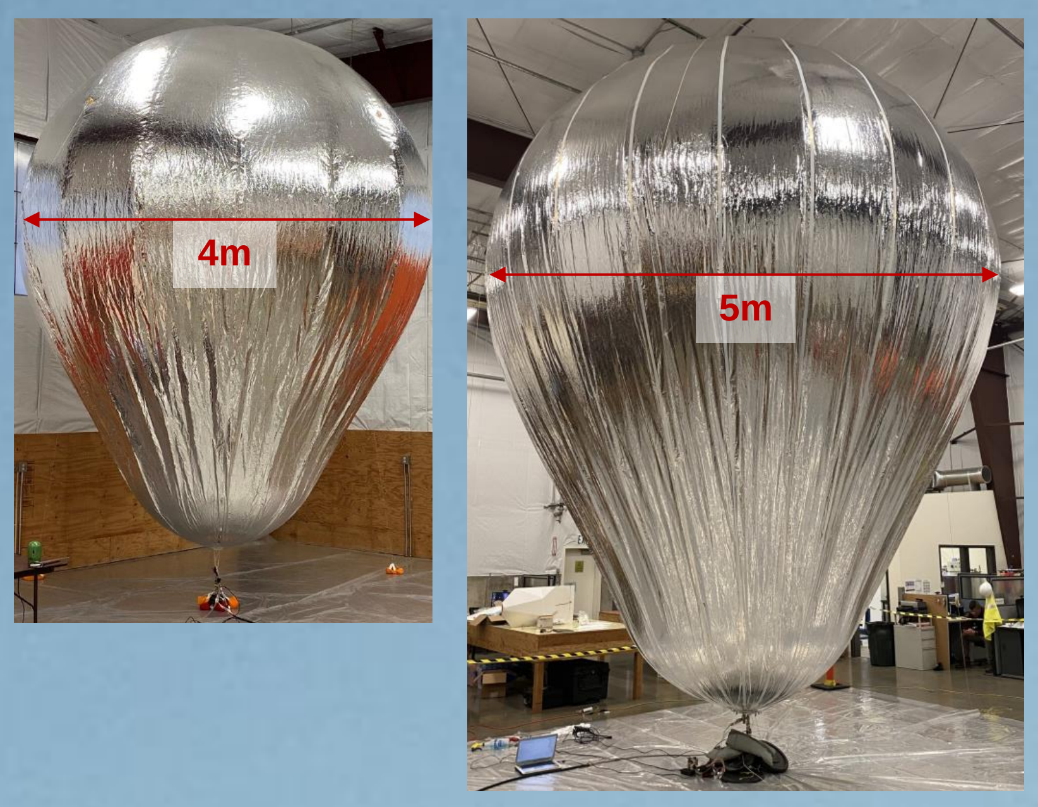

Figure 2: Two subscale aerobot prototypes fabricated from Venus-compatible materials

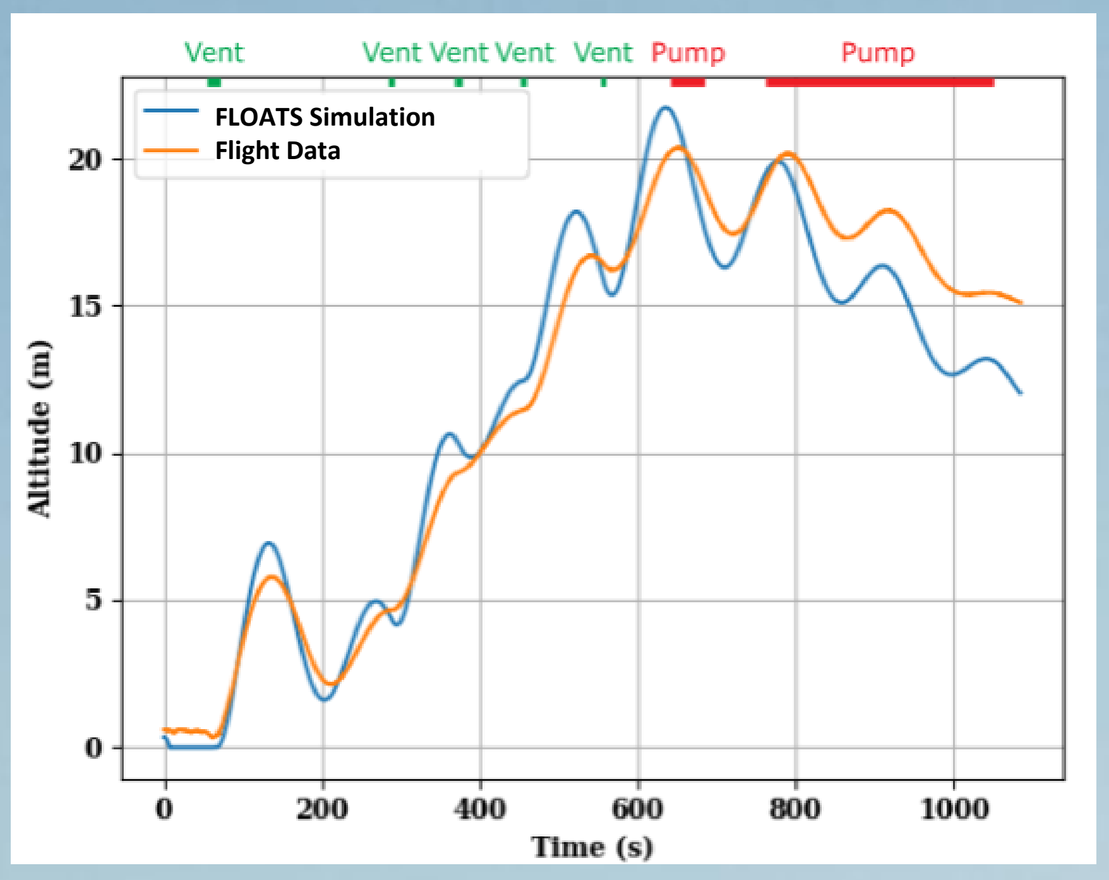

Figure 3: Comparison of simulation model against flight dynamics in an indoor hangar test.

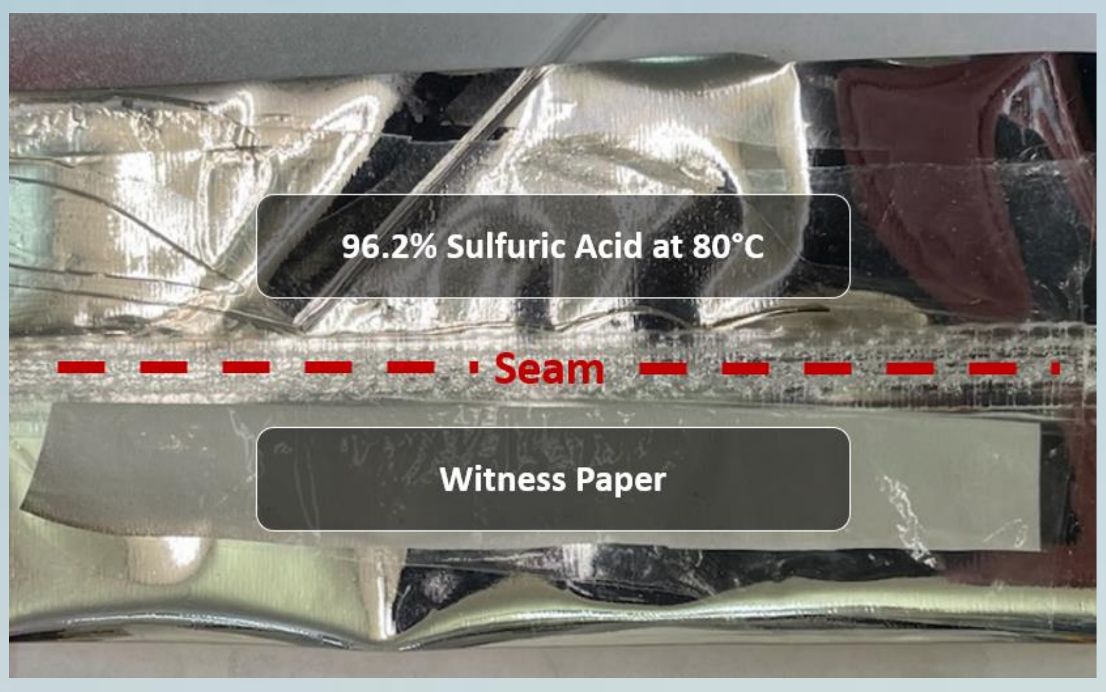

Figure 4: Elevated-temperature sulfuric acid test of exterior heat-sealed seam.

Figure 5 (Background): Subscale prototype in flight over the Blackrock desert, Nevada.

Significance of Results

The fabrication and environmental testing of Venus aerobot prototypes, as well as developing the modeling tools to predict their performance, are critical for improving the technical maturity of these plaforms for an eventual NASA mission call. The Venus balloon designs informed by this effort are scalable (we have design points from 100-230kg gondola mass), and can accordingly support payloads ranging from New Frontiers to Flagship. Development is currently on schedule for an independent **TRL5** evaluation in Fall 2023.

Publications/References

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