National Aeronautics and Space Administration

Venus Variable Altitude Aerobots

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Program: FY23 R&TD Strategic Initiative
Strategic Focus Area: Venus Science and Technology Initiative - Initiative Leader: Jeffery L Hall

Objectives

The overall task objective is to develop a Venus variable altitude "aerobot" (aerial robotic balloon) that can traverse an altitude range of 52 to 62 km and fly for a minimum of 1 month (and stretch goal of 100 Earth-days) in the Venus cloudlayer.

Our specific FY23 objectives were:
Obj. 1 (Environmental): Perform relevant environment testing of aerobot materials.
Obj. 2 (Packing/Inflation): Select a packing & extraction architecture for cruise.
Obj. 3 (Leak Testing): Perform assembly-level leak testing of the aerobot to demonstrate mission life
Obj. 4 (Sim. Development): Validate our simulation tools against data from Obj 1-3
Obj. 5 (Venus Application): Complete end-to-end mission lifetime simulations in support of Venus mission infusion efforts.

Background

While past JPL Venus balloon work has focused on fixed-altitude aerobots, a now desired capability of a long-lived aerobot is to change its float altitude through the modulation of its buoyancy gas. Our variable-altitude architecture consists of two balloons – an outer ZP balloon which provides most of the buoyancy (and protects against sulfuric acid aerosols), and an inner SP balloon which acts as a helium reservoir and provides the remaining buoyancy. Exchanging gas between chambers adjusts the altitude.

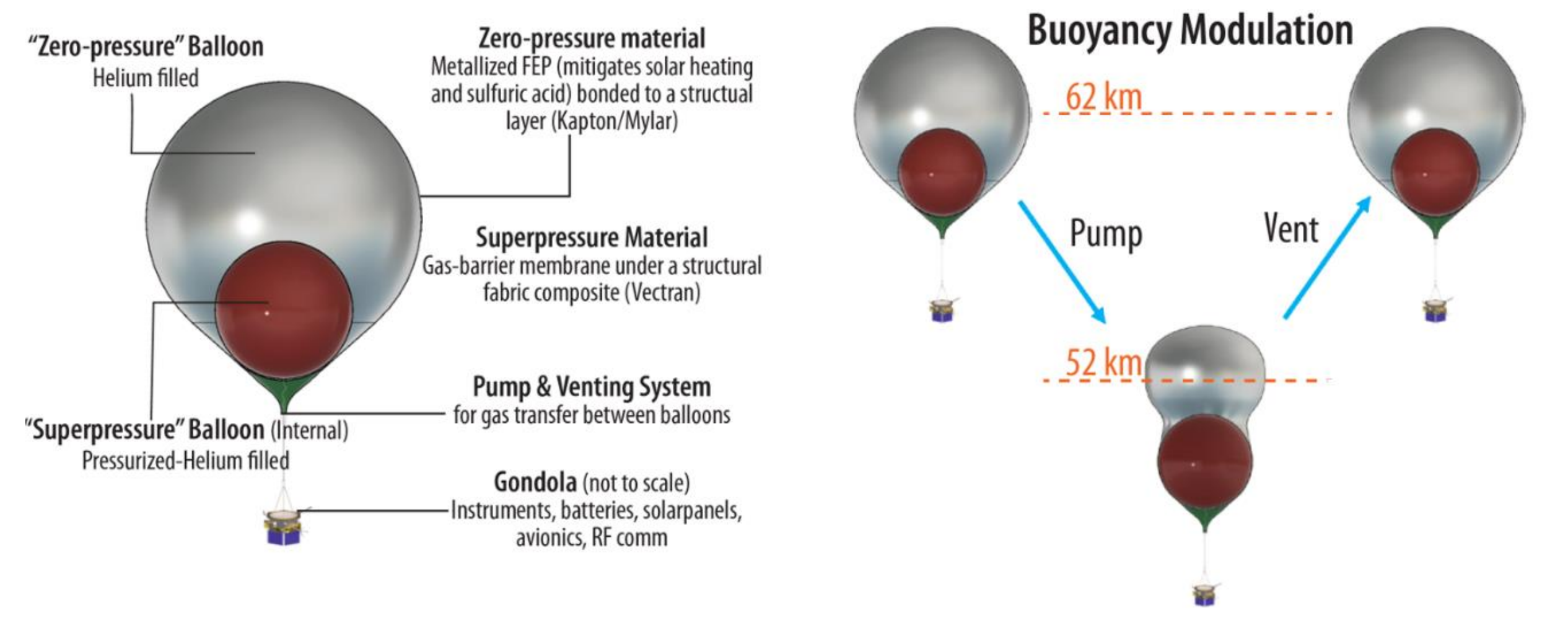

Figure 1: (Left) Venus Aerobot system architecture. (Right) Buoyancy modulation by pumping helium lifting gas.

Approach & Results

Environmental: Environmental testing is separate for each balloon envelope. The outer ZP envelope must be acid-resistant; while the inner SP envelope is protected from the acid but must withstand high pressures. We passed combined temperature-acid-load test of the ZP seams (Figure 2), meeting TRL5 requirement. We also performed our third burst test of a SP reservoir (Figure 3), achieving the highest load to date (+43%), was the first time that the rip initiation was captured on-camera, and led to follow-on seam optimizations.

Packing/Inflation: Before beginning its helium inflation on Venus, the aerobot must survive vacuum exposure during cruise and extraction from the aeroshell. Our partners at NSC demonstrated a zig-zig folded cruise-packing as part of their Phase II SBIR. We subsequently demonstrated multiple extractions of a similarly packed balloon, illustrating robustness to lateral wind.

Leak Testing: Helium retention of the envelope is the primary driver of mission duration on Venus. We accordingly inflated our aerobot prototype for week-long helium leak test to evaluate handling damage. Our instrumentation quantified and located the leaks – and while helium retention was sufficient for Venus science duration, lessons learned informed a more robust apex geometry for next prototype.

Simulation: We comprehensively validated our FLOATS simulation (DARTS toolkit) against the data collected during our FY22 outdoor test flights. Figure 4 compares the altitude profile of the flight against the simulation, capturing the control effort from the pump, vent, and termination systems. We subsequently used FLOATS to simulate a three-circumnavigation flight on Venus, employing a global climate circulation model for the atmospheric motion.

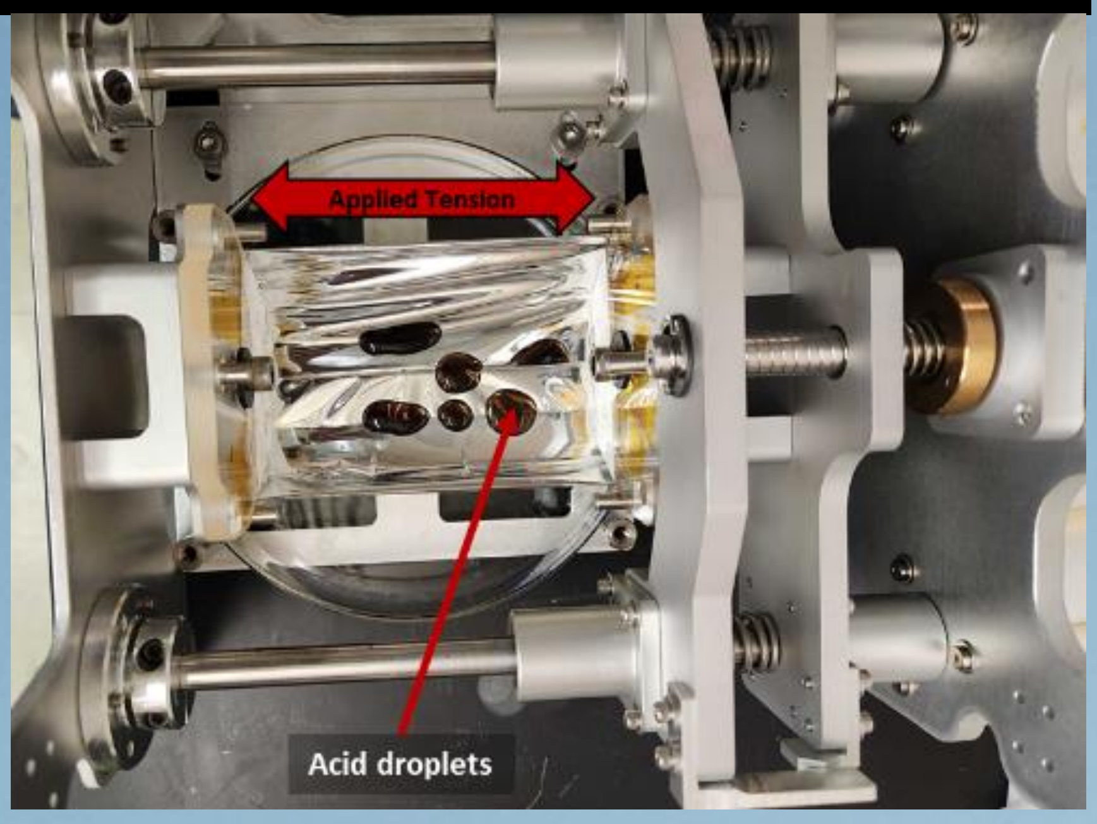

Figure 2: ZP material & seam after exposure to 96.2% sulfuric acid at 100C under 63N of tension

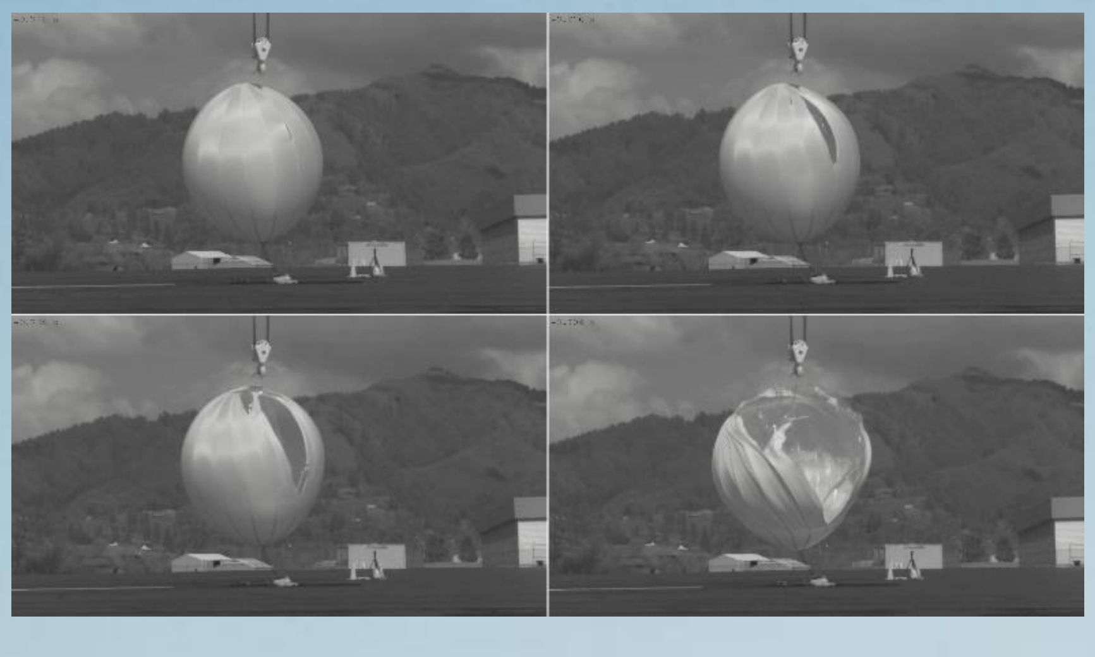

Figure 3: Stills from high-speed camera filming a pressure-to-burst test of SP balloon.

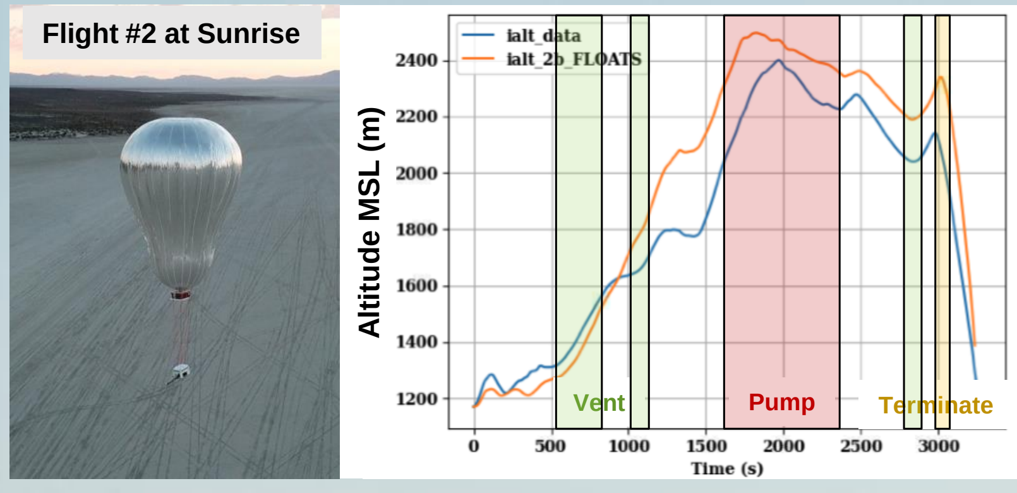

Figure 4: Validation of FLOATS simulation model against flight data collected in FY22 flight test.

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

Significance/Benefits to JPL and NASA:

The building and testing of Venus aerobot prototypes, as well as developing the modeling tools to predict their performance, are critical for improving the technical maturity of Venus variable-altitude aerobots for an eventual NASA mission call. Cloud-level aerobots are well suited for scientific investigations of the Venus atmosphere, radiative balance of the planet, and habitability studies of the cloudlayer – and have strong support in the 2023-2032 Decadal Survey. The Venus balloon designs informed by this task are scalable (we have design points from 25-230kg gondola mass), and can accordingly support payloads ranging from SIMPLEx to Flagship.

Additionally, we have made an extensive attempt to socialize JPL's Venus balloon progress with the wider NASA community. Over the course of this year, we presented at six conferences: VEXAG 2022, AGU 2022, LPSC 2023, JPGU 2023, LPI Clouds & Atmosphere 2023, and IPPW 2023. Over the three years of the task, we also published written manuscripts at AIAA Aviation Forum 2021 [A] and IEEE Aerospace 2022 [B] on the indoor flights, submitted an Acta Astronautica journal paper on the FY22 inflation [C], and have an AIAA journal paper in work on the Blackrock flight test.

Publications

[A] Hall, Jeffery L., et al. "Prototype Development of a Variable Altitude Venus Aerobot" AIAA Aviation 2021 Forum. 2021.
[B] Izraelevitz, Jacob, et al. "Subscale Prototype and Hangar Test Flight of a Venus Variable-Altitude Aerobot." 2022 IEEE Aerospace Conference. IEEE, 2022.
[C] Lo Gatto, Valentina, et al. "Inflation Sequence Tradeoffs and Laboratory Demonstration of a Prototype Variable-Altitude Venus Aerobot." Submitted. 2023 Acta Astronautica.

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