National Aeronautics and Space Administration

Venus Variable Altitude Aerobots

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Program: FY24 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 FY24 objectives were:

Obj. 1 (Relevant Env. Testing): Complete remaining relevant environment tensile testing of envelope materials (SP seams at ambient, ZP at 100C)

Obj. 2 (Fabrication): Complete 6.5m diameter aerobot with 3.5m diameter SP internal reservoir as our TRL5 test article

Obj. 3 (TRL Reporting): Complete TRA reviews to certify TRL5 for the aerobot & flight dynamics and TRL4 for cruise/deployment/inflation

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.

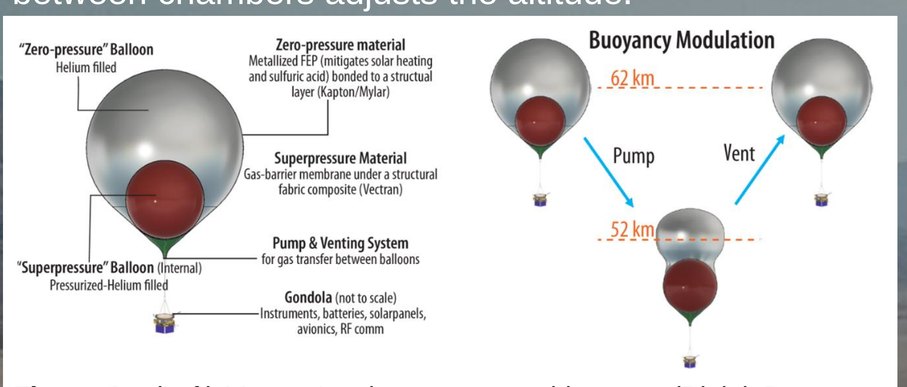

Figure 1: (Left) Venus Aerobot system architecture. (Right) Buoyancy modulation by pumping helium lifting gas.

Approach & Results

(Environment) 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. The sealing apparatus used for our ZP envelope changed and we successfully re-tested combined temperature-acid-load testing of the seals made with the new device. We additionally evaluated the uniaxial tension strength of the ZP parent material and seals under 100C conditions to quantify strength reductions compared to ambient testing (Figure 2). We examined the past SP seam design details and performed optimization-focused testing to improve the uniaxial strength of the seams. The improved seam design showed substantial improvement (+80%) over the design used in the previous burst (Figure 3). A similar seam with a more conservative change to the design (+30% improvement) that still achieves the 80 N/mm goal was used in the construction of the new 3.5m SP balloon due to manufacturability tradeoffs.

(Fabrication) Building Venus aerobot prototypes demonstrates the viability of the construction technologies and materials and shows the ability of the balloon-in-balloon architecture to scale with size. We completed the construction of a 6.4m diameter ZP envelope, the largest prototype produced so far. A 3.5m diameter SP balloon was built using improved seam designs based on the results of our optimization testing. The SP balloon was proof loaded to 1 psi to verify the shape and the strength of the seams (Figure 4). The two balloons were integrated together into a balloon-in-balloon aerobot and delivered to JPL.

(TRL Reporting) Improving our TRL for aerobot technologies brings the mission closer to being ready for inclusion in proposals. All systems within the Venus aerobot concept are currently TRL 4 or higher, with some systems having completed TRL 5 testing. Our review board accepted the aerobot deployment technology as TRL 4 based the work done in late FY23/early FY24 on small scale prototypes. The flight dynamics have demonstrated the necessary modeling behavior and were successfully tested but have not yet been put forward for formal TRL5 approval.

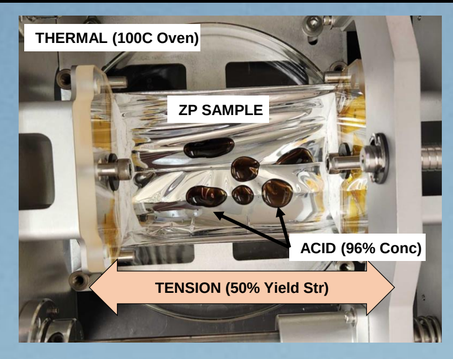

Figure 2: ZP material & seam after exposure to 96.2% sulfuric acid at 100C under 63N of tension.

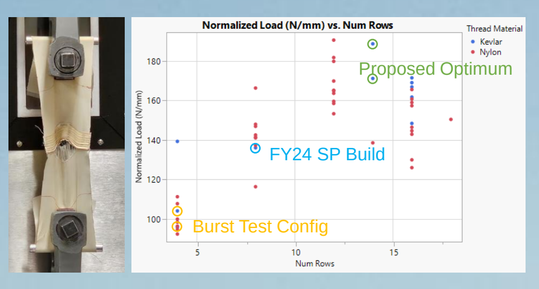

Figure 3: Normalized seam strengths achieved during design optimization campaign.

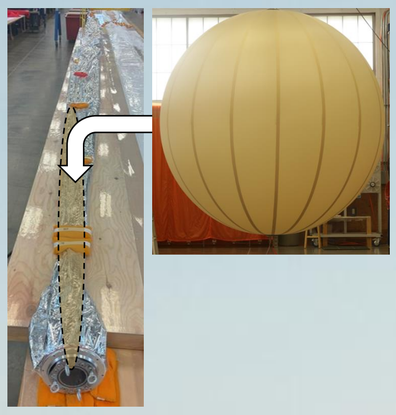

Figure 4: FY24 ZP envelope and temporarily inflated SP balloon prior to integration.

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 the technology at five conferences: VEXAG 2023 [A], LPSC 2023 [B], COSPAR 2024 [C], JPGU 2024 [D], IPPW 2024 [E], and a seminar at the Nationwide Eclipse Ballooning Program [F]. Over the four years of the task, we also published written manuscripts at AIAA Aviation Forum 2021 [G] and IEEE Aerospace 2022 [H] on the indoor flights, an Acta Astronautica journal paper on the FY22 inflation [I], and have an AIAA journal paper in work on the 2022 Blackrock Nevada flight test [J].

Publications

[A] Izraelevitz, Jacob, et al. " Test Flights and Altitude Control Demonstration of a Prototype Venus Aerobot." 20th Meeting of the Venus Exploration and Analysis Group (VEXAG). Vol. 19. 2022.
[B] Cutts, James et al. "Detection of Active Volcanism from the Clouds." 55th Lunar and Planetary Science Conference 2024.
[C] Cutts, James et al. “Exploring the Clouds of Venus with a Variable Altitude Aerobot Missions” COSPAR 2024.
[D] Byrne, Paul et al. " Phantom: A New Frontiers-class Aerobot Mission to the Venus Skies. Japan Geoscience Union Meeting, May 2023
[E] Izraelevitz, Jacob, et al. "Deployment Testing and Fabrication of Prototype Venus Aerobots" 21st Interplanetary Probe Workshop, 2024.
[F] Izraelevitz, Jacob et al. “Balloon Investigations for the Clouds of Venus”. Nationwide Eclipse Ballooning Program, 2024.
[G] Hall, Jeffery L., et al. "Prototype Development of a Variable Altitude Venus Aerobot" AIAA Aviation 2021 Forum. 2021.
[H] Izraelevitz, Jacob, et al. "Subscale Prototype and Hangar Test Flight of a Venus Variable-Altitude Aerobot." 2022 IEEE Aerospace Conference. IEEE, 2022.
[I] Lo Gatto, Valentina, et al. "Inflation Sequence Tradeoffs and Laboratory Demonstration of a Prototype Variable-Altitude Venus Aerobot.". 2023 Acta Astronautica.
[J] Izraelevitz, Jacob et al. “Flight Demonstration and Model Validation of a Prototype Variable-Altitude Venus Aerobot”. AIAA Journal, to be submitted. 2024.

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