National Aeronautics and Space Administration

Venus Variable Altitude Aerobots

Principal Investigator: Jacob Izraelevitz (347); Co-Investigators: Michael Pauken (353), Carolina Aiazzi (347), Siddharth Krishnamoorthy (335), Ashish Goel (347), Kevin Baines (322), Gerald Walsh (333), Rebekah Lam (353), Tim Lachenmeier (Near Space Corporation), Caleb Turner (Near Space Corporation)

Program: FY22 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 FY22 objectives were:

1. Model validation of our FLOATS (FLight Operations and Aerobot Trajectory Simulator) simulation tool against indoor hangar flight data taken in FY21.
2. Environmental testing (pressure & acid) of balloon materials to validate seam designs
3. High flow-rate inflations of a subscale prototype in a hangar environment.
4. Outdoor flight demonstration of a subscale prototype, executing altitude control over an altitude band of similar atmospheric density as 54-55km on Venus

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 balloon which provides most of the buoyancy (and protects against sulfuric acid aerosols), and an inner pressurized balloon which acts as a helium reservoir and provides the remaining buoyancy. Exchanging gas between chambers adjusts the altitude.

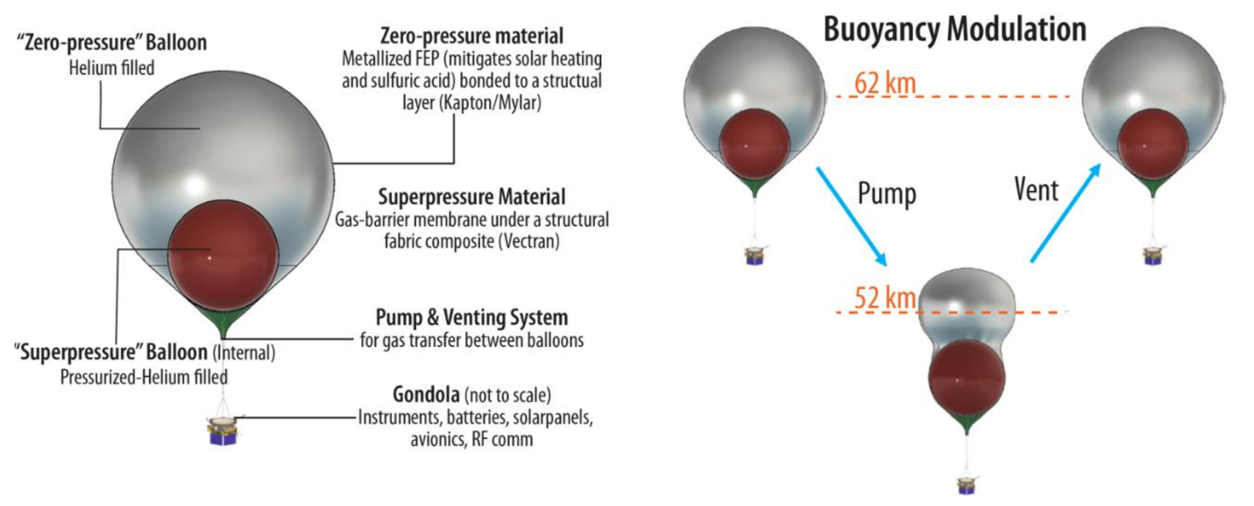

Figure 1: (Left) Venus Aerobot system architecture. (Right) Buoyancy modulation by pumping helium lifting gas.

Approach & Results

Simulation: Simulation work focused on understanding the flight dynamics of the aerobot, validated against static testing and indoor flights (Figure 2). 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. We plan a similar validation exercise using the recently completed outdoor field test.

Pressure/Acid Testing: Environmental testing is separate for each balloon envelope. We performed a load-to-failure burst test of a spare inner reservoir, which determined a known safe pressure and informed the Vectran purchase for our next prototype. We also passed elevated-temperature acid immersion testing of external seams (Figure 3) so have renewed confidence they will survive exposure to Venus cloud environment.

Inflation Testing: The aerobot must be inflated on Venus while hanging from a parachute. We simulated the required gas flow for this inflation into each balloon, and demonstrated it using a subscale prototype of similar shape. The process takes approximately 10 minutes, with the outer balloon filled at a slight head-start to the inner balloon.

Flight Test: The highlight of the task was JPL's first outdoor flight demonstration of a Venus prototype aerobot (Figure 4) in July 2022. Our approximately one-third scale 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. These will be the focus of an upcoming JPL media release.

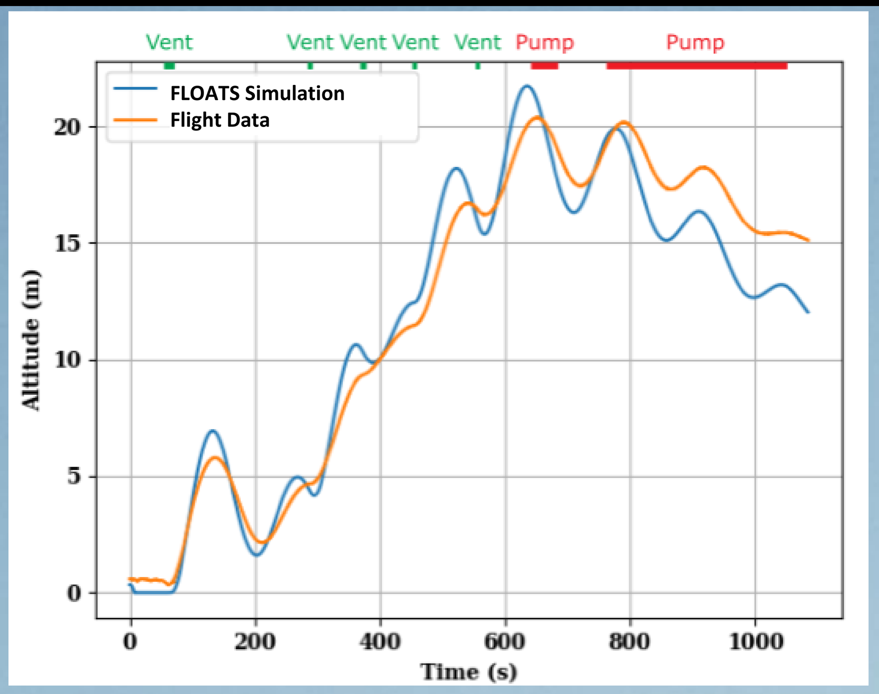

Figure 2: Comparison of simulation model against flight dynamics in an indoor hangar test.

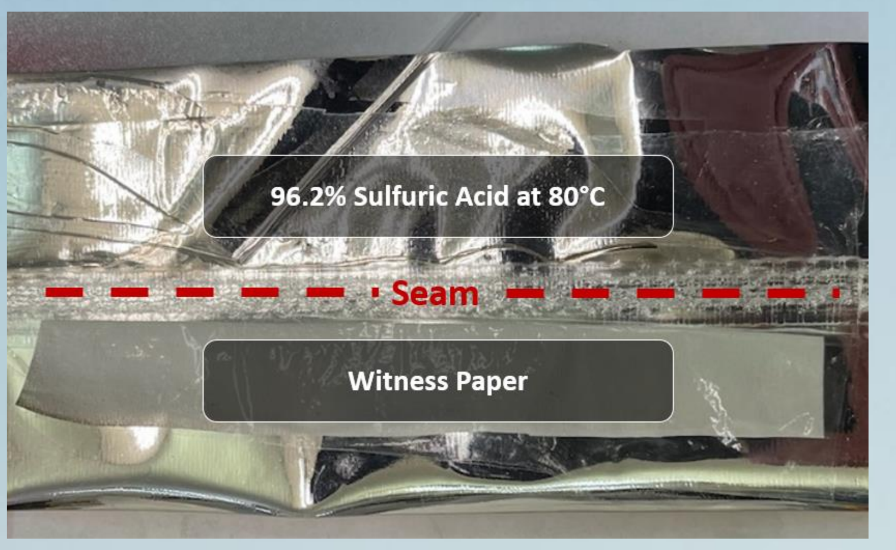

Figure 3: Elevated-temperature sulfuric acid test of exterior heat-sealed seam.

Figure 4 (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 atmosphere, radiative balance of the planet, and habitability studies of the cloudlayer. The Venus balloon designs informed by this task are scalable (we have design points from 100-230kg gondola mass), and can accordingly support payloads ranging from New Frontiers 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 the two years of the task, we reported progress at seven oral conference, including IPPW 2022 (where we were awarded best conference oral presentation) [A]. The data from the FY21 flights were presented at AIAA Aviation Forum 2021 [B] and IEEE Aerospace 2022 [C] and their conference proceedings, and a journal paper is planned based on the Blackrock flight testing.

Publications

[A] Izraelevitz, Jacob, et al. "Technology Developments in Dual Chamber Venus Variable Altitude Aerobots" *19th Interplanetary Probe Workshop*, 2022.
[B] Hall, Jeffery L., et al. "Prototype Development of a Variable Altitude Venus Aerobot" AIAA Aviation 2021 Forum. 2021.
[C] Izraelevitz, Jacob, et al. "Subscale Prototype and Hangar Test Flight of a Venus Variable-Altitude Aerobot." *2022 IEEE Aerospace Conference*. IEEE, 2022.

Acknowledgements

We would like to thank Jeff Hall, Jim Cutts, Paul Byrne, Len Dorsky, and Stacy Weinstein-Weiss for their exceptional guidance on the programmatic direction of this task. We would also like to thank Kevin Carlson and Carlos Quintana at Near Space Corporation for their supervision of the balloon construction and long days helping us with balloon inflations and flights. Finally, we would like to thank Kirk Barrow, Charlene Paloma, & Tino Faustino for making our field tests a reality, and the Blackrock Nevada BLM Office for the use of their property.

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
www.nasa.gov

PI/Task Mgr. Contact Information:
jacob.izraelevitz@jpl.nasa.gov

Pre-decisional, for planning & discussion purposes only.
Clearance Number: CL#
Poster Number: RPC-166