National Aeronautics and
Space Administration

Venus Variable Altitude Aerobots

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Venus Science and Technology 2**

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. We are targeting a 100 kg carry mass (~ 20 kg of science instruments) although we expect that this will be scalable up or down as needed for any particular mission concept. Due to the extremely strong and consistent zonal winds on Venus, this aerobot is expected to circumnavigate the planet passively every 5 to 7 Earth-days.

The specific FY21 objective was to prepare for an outdoor Earth flight test demonstration of a sub-scale (5 m diameter) prototype that would occur in the following year of the task. This preparation consisted of:

1. The design and fabrication of the sub-scale aerobot made from Venus-relevant materials
2. The maturation of our dynamics simulation tool, FLOATS (FLight Operations and Aerobot Trajectory Simulator), to simulate this test flights as well as specific Venus stress-cases on the baseline full-scale aerobot design

Background

The Venus cloud layer is a unique environment – there is ample solar power, relatively benign atmospheric pressures and temperatures, and the opportunity for in-situ access to the physical, chemical, and possible biological interactions of the Venus atmosphere. This task is currently pursuing the technologies required to design a buoyant aerobot, with a lifetime of months, to perform targeted science in this region.

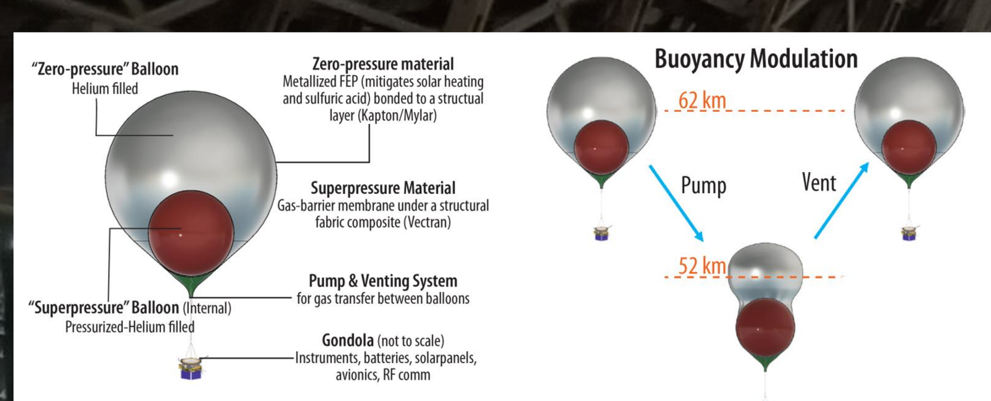

Figure 1: (Left) Venus Aerobot system architecture. (Right) Buoyancy modulation by pumpiing helium lifting gas.

While past JPL Venus balloon work has focused on fixed-altitude Venus aerobots [1,2], a now desired capability of a long-lived aerobot is to change its float altitude through the modulation of its buoyancy gas – allowing the aerobot to travel to different altitudes at different times, accordingly increasing the breadth of the science return [3]. Our variable-altitude architecture consists of two balloons [4] – an outer metallized Teflon balloon which provides most of the buoyancy (and protects against sulfuric acid aerosols), and an inner Vectran pressurized balloon which acts as a helium reservoir and provides the remaining buoyancy [5]. This type of variable-altitude aerobot (Figure 1) was recently baselined as a primary asset in the Venus Flagship Mission concept study [6], performed for the 2023-2032 Planetary Decadal Survey.

Approach and Results

The FY21 subscale prototype (Figure 2) is made of two balloon materials chosen early in the task: a metalized Teflon-Kapton laminate from Sheldahl corporation for the outer balloon, and a 200 denier Vectran fabric from Fabric Development Inc. for the inner helium reservoir. The geometric parameters, seam details, and structural loadpaths for the prototype were finalized during a March 2021 design review with Near Space Corporation. Additionally, as this prototype is to eventually fly outdoors, a top orifice was included to dump helium as an FAA requirement for terminating the flight.

Simultaneous with the balloon fabrication, we also designed and assembled a buoyancy control system to adjust the balloon altitude. This assembly includes the pump and vent for moving helium gas, but additionally logs the local altitude, reservoir pressure, atmospheric pressure, and four thermal node temperatures during flight. Figure 3 illustrates the first test of this buoyancy control system in JPL Building 248, prototyped using the leftover FY20 balloon, and the validation of the FLOATS model against the initial flight data.

The highlight of the task was a final indoor flight demonstration of the new balloon (main photo) in August 2021 in the Tillamook Airship Hangar. After the balloon passed acceptance testing (leak and structural) we integrated an updated buoyancy-control system and flew the assembly under a lightweight safety tether. This demonstration validated the control & telemetry systems needed for our outdoor test next fiscal year, and provided additional data to validate our FLOATS models.

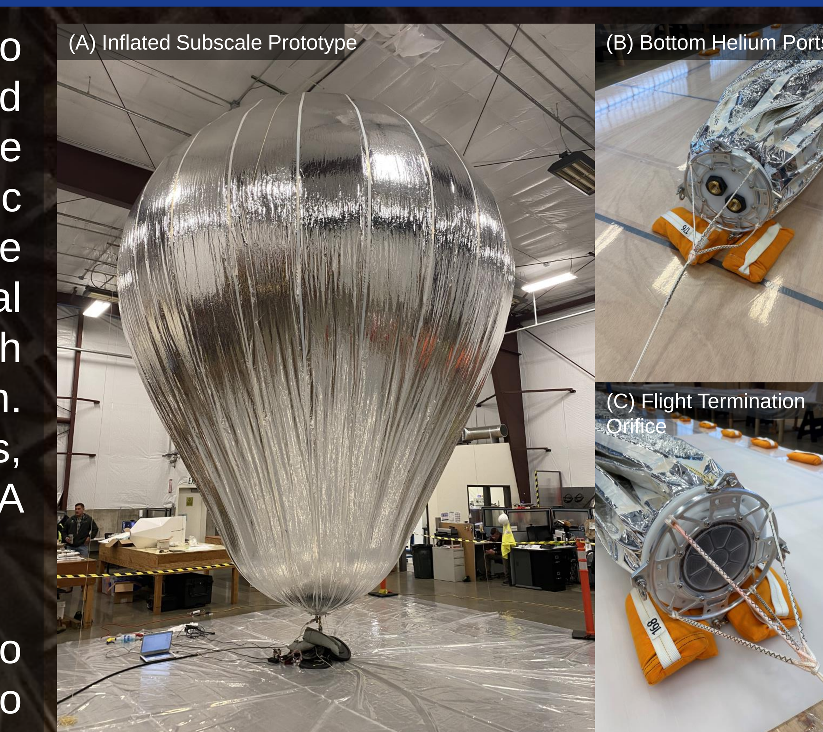

Figure 2: (A) Subscale (~5m diameter) variable-altitude Venus aerobot, made of a metalized Teflon-Kapton laminate with an internal Vectran buoyancy reservoir. (B) Helium access ports and (C) orifice for terminating the flight by dumping the helium.

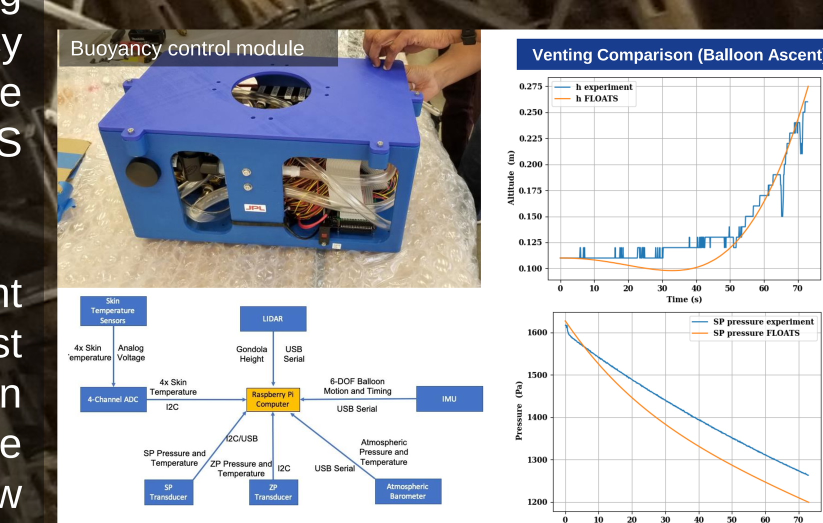

Figure 3: Left – buoyancy control module for adjusting balloon altitude, including pump/vent for transferring helium and logging capability of flight performance. Right – comparison of initial flight with FLOATS model simulations.

Significance of Results to NASA/JPL

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 [6]. The Venus balloon designs informed by this task are scalable (we have design points from 100-230kg gondola mass), and can accordingly support payloads 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 task, we reported progress at three oral conferences: AGU 2021 [A], COSPAR 2021 [B], and IPPW 2021 [C]. The data from the Quarter 3 initial flight was also presented at AIAA Aviation Forum 2021 [D] and its conference proceedings, and two more publications [E, F] are planned for next fiscal year based on the Tillamook hangar flight data.

Publications

[A] Izraelevitz, Jacob, et al. "Pumped-Helium Aerobots for Venus: Technology Progress and Mission Concepts." AGU Fall Meeting Abstracts. Vol. 2020.
[B] Hall, Jeffery, et al. "Venus Variable Altitude Aerobot Prototype Development." 43rd COSPAR Scientific Assembly. Held 28 January-4 February 43 (2021): 2318.
[C] Izraelevitz, Jacob, et al. "Pumped-Helium Venus Aerobots" 18th Interplanetary Probe Workshop, 2021.
[D] Hall, Jeffery L., et al. "Prototype Development of a Variable Altitude Venus Aerobot" AIAA Aviation 2021 Forum.
[E] (**IN PREP**) Izraelevitz, Jacob, et al. "Hangar Flight Testing of a Subscale Venus Variable-Altitude Aerobot." 19th Meeting of the Venus Exploration and Analysis Group (VEXAG). Vol. 19. 2021.
[F] (**IN PREP**) Izraelevitz, Jacob, et al. "Performance Predictions and Mission Applications for a Venus Variable-Altitude Aerobot." 2022 IEEE Aerospace Conference. IEEE, 2022.

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[4] Voss, Paul B., "Advances in Controlled Meteorological (CMET) Balloon Systems", AIAA Paper 2009-2810, May 2009.
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