Hangar Flight Testing of a Subscale Venus Variable-Altitude Aerobot

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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 in situ aerial platform around the planet in just a few Earth days. This cloud layer is key to 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 Vega balloon flights in 1985 [1], launched by the Soviet Union, successfully flew in the Venus clouds using superpressure balloons, which have a fixed buoyancy and nominally provide access to only a single altitude.

JPL and Near Space Corporation 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", a robotic buoyant vehicle consisting of both a balloon and its payload, is expected to sample aerosols, measure atmospheric conditions & processes, and listen for seismic activity from the surface. This type of variable-altitude aerobot was considered 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 upcoming IEEE Aerospace papers [6-7].

Objective and Prototype Design

The objective of this poster is to provide an overview of our 1/3 subscale variable-altitude Venus aerobot prototype, built over the last two years as a collaboration between JPL and Near Space Corporation. The prototype employs pumped-helium buoyancy modulation [2,3] and is made of fully Venus-relevant materials resistant to the acid aerosol environment, solar flux, and temperatures up to 100°C. The full-scale aerobot would be of roughly 12m diameter, target the 52km to 62km altitude band on Venus, and carry a hanging gondola mass of 100kg.

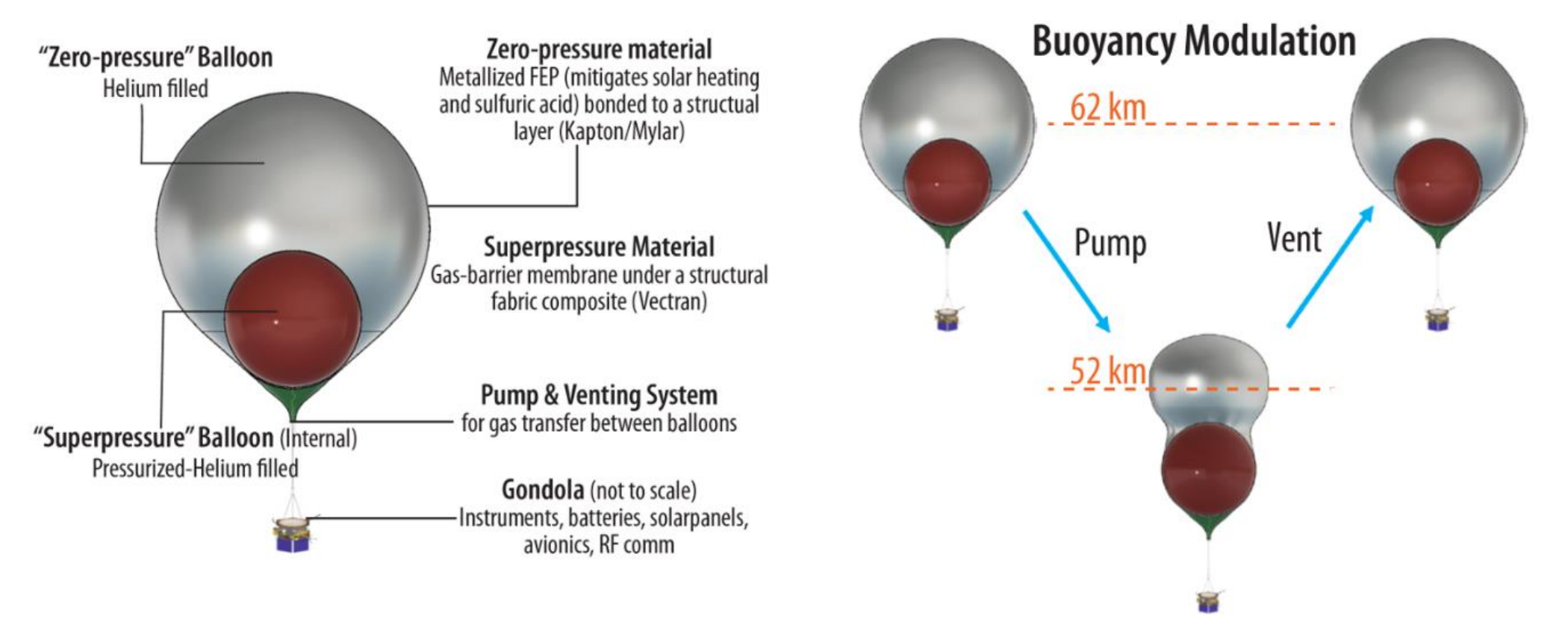
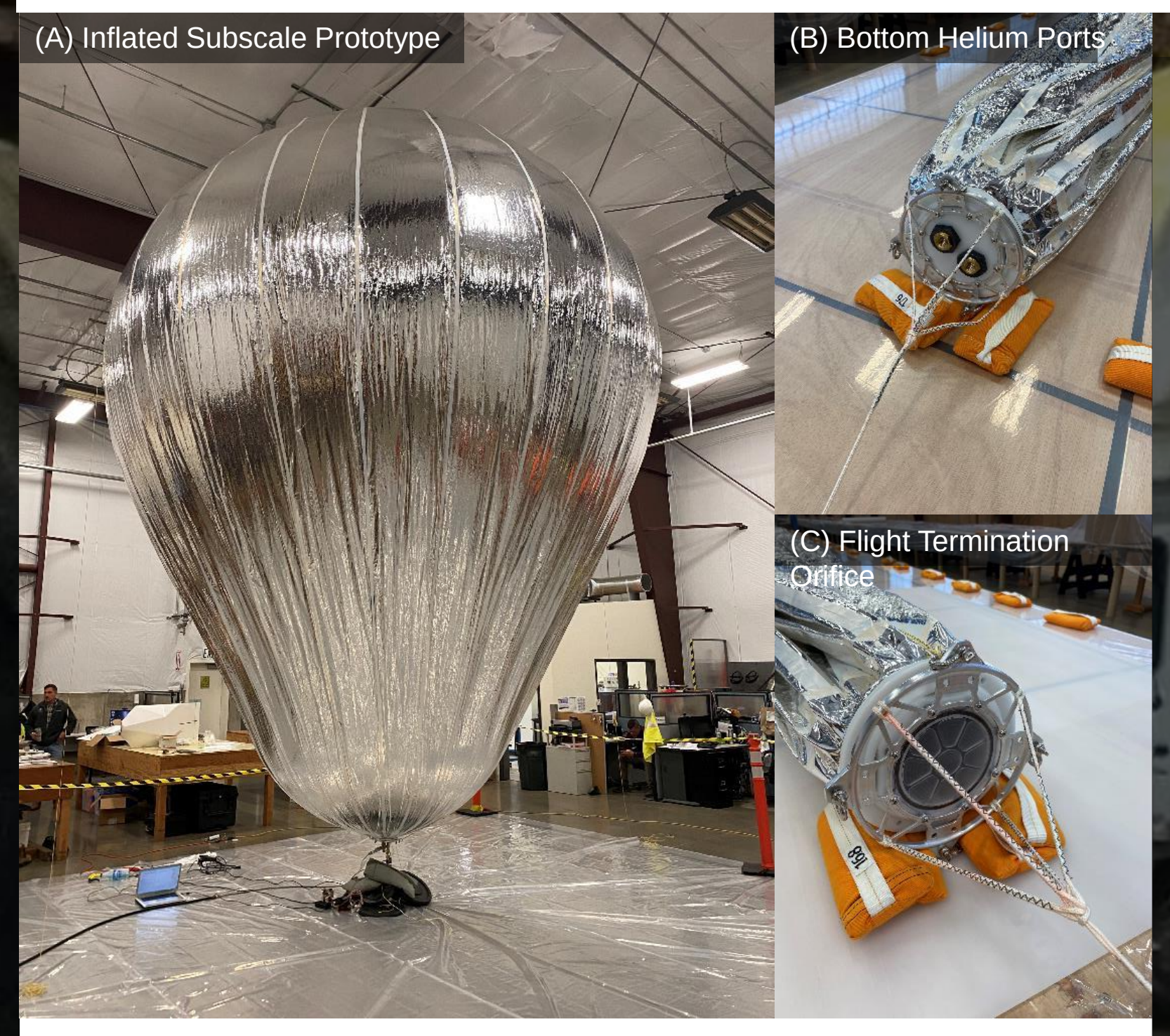


Figure 1: (Left) Venus Aerobot system architecture. (Right) Buoyancy modulation by pumping helium lifting gas. Reproduced with permission from [6]

The subscale prototype (Figure 2) is made of two balloon materials: a metallized Teflon-Kapton laminate for the outer balloon, and a 76x76 yarns/inch of 200 denier Vectran fabric for the inner helium reservoir. The metallization has the dual role of reflecting sunlight and mitigating helium diffusion. The reservoir also includes a heat-sealed urethane bladder for gas retention, and ports for gas access to both chambers. The subscale prototype has an outer balloon diameter of 5m, a reservoir diameter of 2.5m, and a sphere-cone geometry with a height of 6.25m when fully inflated.


(A) Inflated Subscale Prototype

(B) Bottom Helium Ports

(C) Flight Termination Orifice

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.

Approach and Results

The 2021 subscale aerobot prototype was flight-tested at Hangar B in Tillamook, Oregon over a period of five days (main photo). While on Venus the targeted altitude range is a band of 10km extent, the controlled environment of a hangar with little wind, known atmospheric properties, and ease of instrumentation allows calibration of our dynamics models during flights of 10's of meters prior to outdoor flights. During this test, the aerobot carried a buoyancy control module (Figure 3) for moving helium in/out of the reservoir and hosted a suite of instruments to characterize the aerobot's performance and atmospheric conditions, including:

- External barometer (atmospheric pressure)
- Downward-facing LIDAR (aerobot altitude)
- Internal pressure transducers (balloon temperature and gauge pressures)
- Skin temperature sensors (at four points)
- Atmospheric temperature loggers (hangar thermocline)
- INS for flight context to detect human interventions


Buoyancy control module

Figure 3: Buoyancy control module for adjusting balloon altitude, including pump/vent for transferring helium and logging capability of flight performance.

Simultaneously with the balloon development work, JPL has also developed the FLight Operations and Aerobot Trajectory Simulator (FLOATS) simulation tool to obtain accurate predictions of aerobot behavior for supporting missions. FLOATS models both the dynamics and the thermodynamics of the aerobot, and is built upon JPL's multimission DARTS/Dshell toolkit. Figure 4 illustrates one comparison between FLOATS and the hangar flight data over an intermittent ascent & descent of the aerobot employing the buoyancy control module. Improvements to the FLOATS tool is ongoing work and will be used for extending these simulations to predict performance of a full-scale aerobot on Venus.

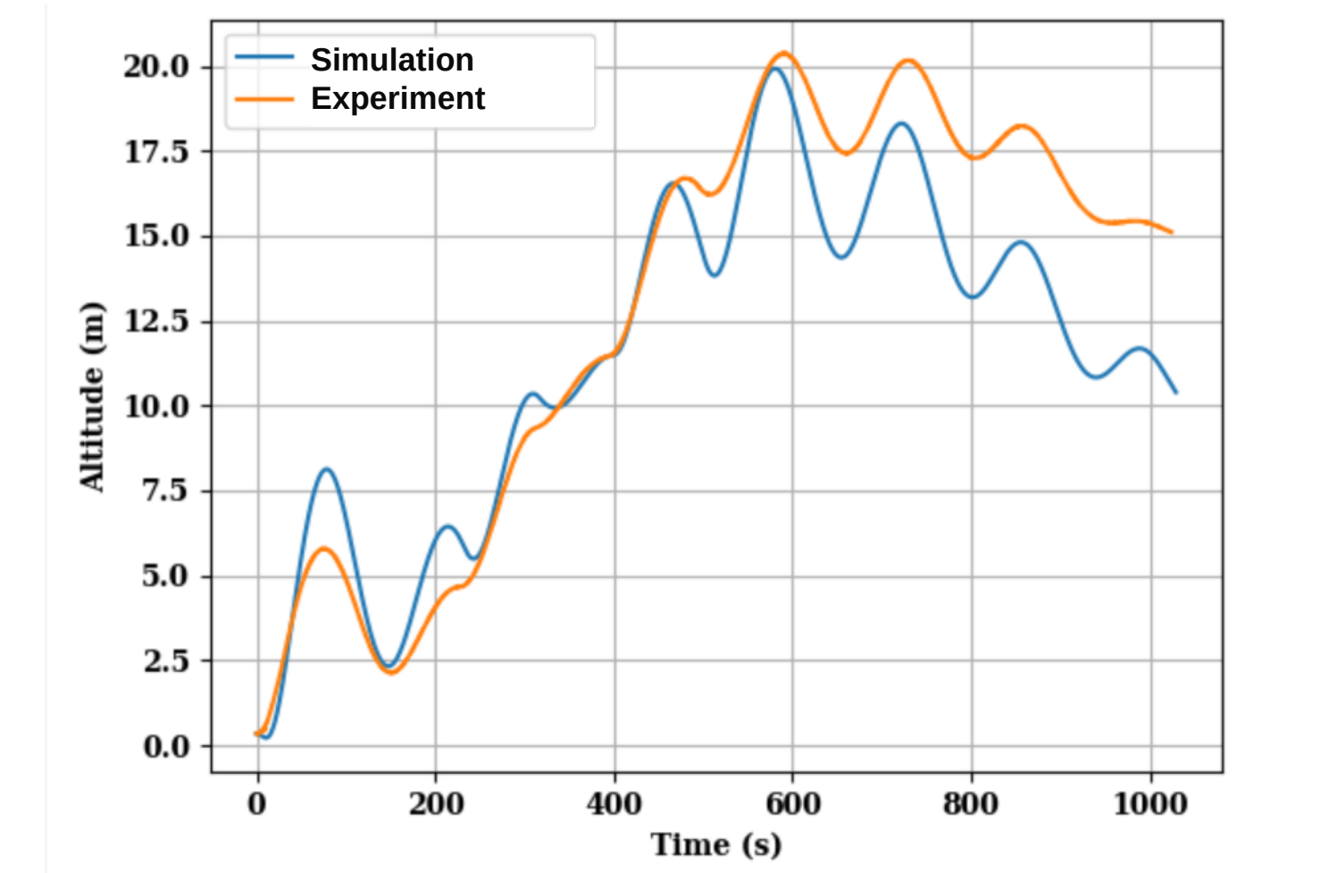


Figure 4: Comparison of FLOATS simulation against altitude data collected from the flight experiments

Significance of Results

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 [5]. The Venus balloon designs informed by this work are scalable (we have designs from 100-230kg gondola mass), and can accordingly support payloads from New Frontiers to Flagship [7].

References

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