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Development of an Aerodynamically Stable Tethered Payload for Imaging and Atmospheric Measurement Beneath the Cloud Layer of Venus

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Motivation

Aerobots are being actively studied as a proposed method of imaging and atmospheric sampling in the Venus atmosphere. Current aerobots can go no lower than an altitude of 52 kilometers, so a separate solution is needed to descend below the cloud layer and image Venus' surface.The TOBIAS Project (Tethered Observatory for Balloon-based Imaging and Atmospheric Sampling) focuses on testing the dynamics of a potential solution: a 'towbody' probe that can be raised and lowered from a balloon in the upper atmosphere.

Design Requirements

- Must be stable in winds of up to 10 m/s, using as few active stabilization methods as possible
- Internal payload pitch and roll rates must be within 0.01 rad/s, yaw rate within 0.38 rad/s

Tablet

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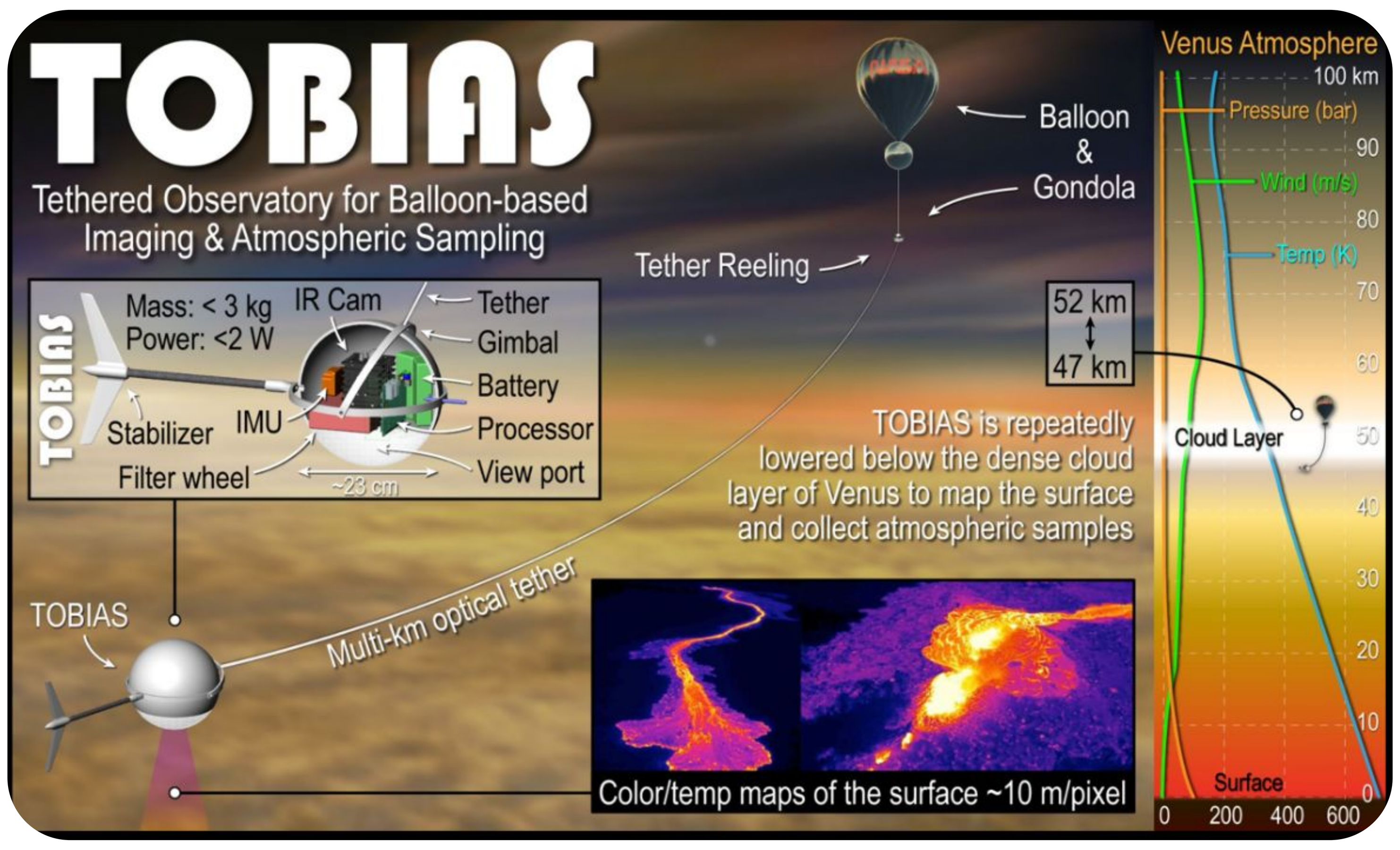
Concept Design



Design Methodology & Iterations

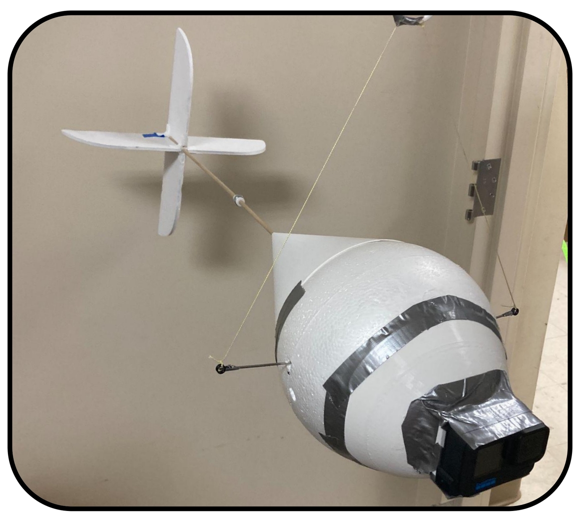
The towbody's general design comes from McGarey et al. We experimented with different variations of this design to determine the best features. We started with a spherical body section. To mitigate boundary layer separation associated with spheres in fluid flow, we included a 3D printed cone behind the body section, leading to our eventual 'teardrop shape'.

We eventually transitioned to a fully 3D printed hollow body, allowing us to easily swap out sections to test different features. With each prototype, the towbody's design was more rigid, but allowed for more degrees of freedom.

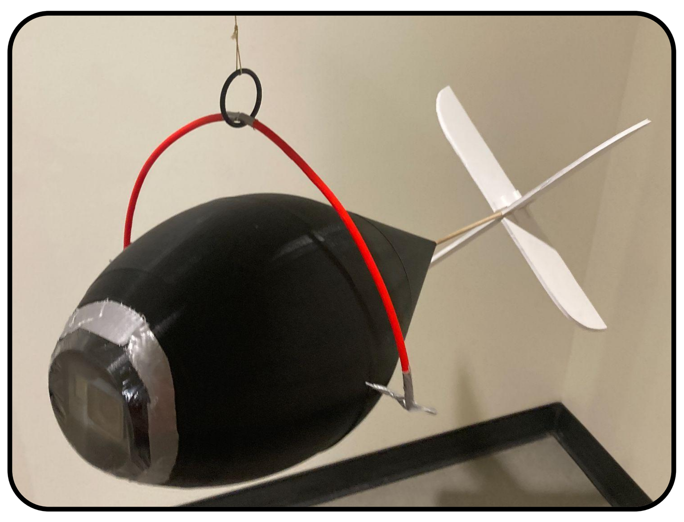
Initial TOBIAS concept	TOBIAS prototype 3
Spherical body section	Teardrop-shaped body section
Pivoting gimbal	Marionette gimbal
Tail section with vertical stabilizer	Tail section with vertical & horizontal stabilizers

TOBIAS Prototype Iterations

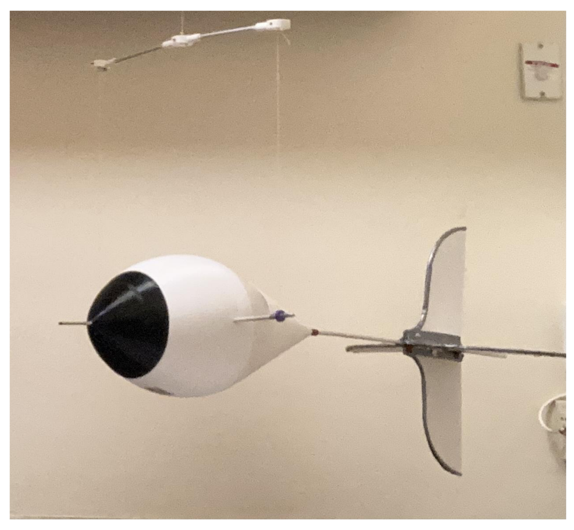
- Styrofoam sphere with 3D Printed sections on front and back of body
- Double attachment point on either side of body (slightly above center of gravity)
- Front-facing camera



- Hollow 3D Printed body
- Double attachment point with 'ring gimbal'
- Recessed forward and nadir facing cameras
- Electronics box to record roll rates



- 'Marionette' bifilar pendulum gimbal
- Increased-rigidity aluminum backbone
- Pitot tube in weighted nosecone
- Reworked tail section



Experimental Approach

Drone Testing

Test setup Towbody perspective

To test our design in a realistic setting, we connected our towbody to a drone with a 15-meter tether. We recorded the towbody dynamics with an IMU while flying the drone to evaluate the stability of each prototype.

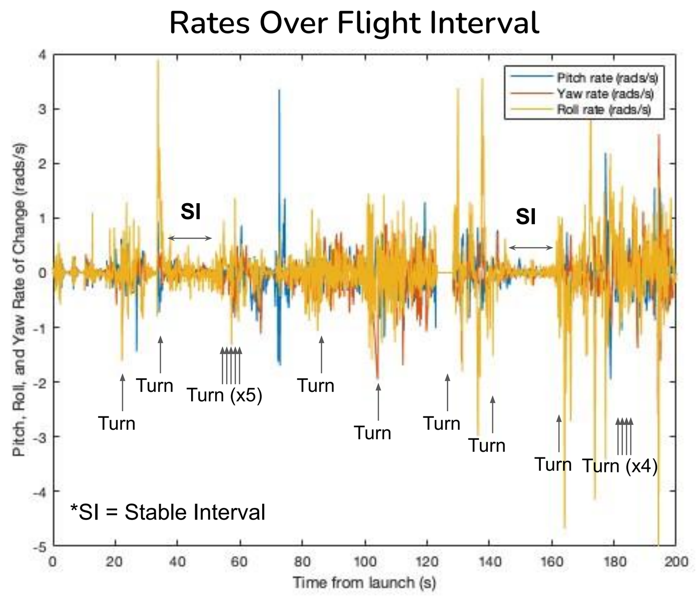
'Wind Cannon' Testing

To test our design in a controlled setting, we built a 'wind cannon': a device that outputs a laminar stream of air of roughly 5 m/s. This experiment replicates the towbody dynamics alone, without the effects of tether dynamics.

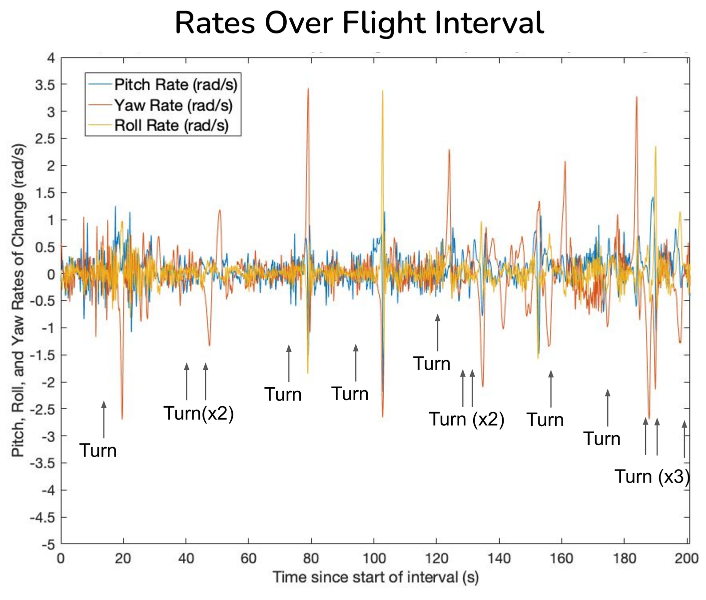
Results

Prototype 3, with a greater static margin and larger tail, marginally outperformed prototype 2 overall: pitch, roll, and yaw rates consistently returned to a baseline ~0.25-0.5 rad/s, punctuated by spikes that represent the towbody turning around to fly back over the lakebed. Prototype 2, however, had certain 'stable intervals' where the pitch, roll, and yaw rates were significantly lower (the second stable interval's rates were within ~0.1-0.2 rad/s for a period of 15 seconds). Prototype 3's large restorative torque was not necessarily a positive factor; it would have meant that the towbody was more sensitive to the wind. Turbulent winds above the lakebed could have prevented prototype 3 from achieving the same stable intervals.

Prototype 2: Pitch, Roll, and Yaw Rates Over Flight Interval



Prototype 3: Pitch, Roll, and Yaw Rates Over Flight Interval



Note: Sharp roll and yaw spikes represent the drone turning, rather than a stability decrease

Conclusion

Designing the towbody involves a wind sensitivity trade-off: A high restoring moment makes the towbody stable in laminar airflow, but makes it more susceptible to instability in turbulent conditions. Our tests provide an estimate of the dynamics of an aerodynamically stabilized towbody, and future iterative testing could determine the ideal tail sizing and location for maximum stability. Such iterative testing, paired with internal stabilization mechanisms, could prove this concept a viable technology for stable image capture and sampling.

Future Work

Further experimentation is needed to determine the ideal values for a few key variables: tail sizing, static margin, and tether attachment location. Further testing could also involve a testbed that more accurately reflects the Venusian atmosphere. Additional components like trailing drag bodies or a secondary gimbal could stabilize the payload further.

Acknowledgements

[1] McGarey et al. (2021) IPPW

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