TOBIAS

Tethered Observatory for Balloon-based Imaging & Atmospheric Sampling

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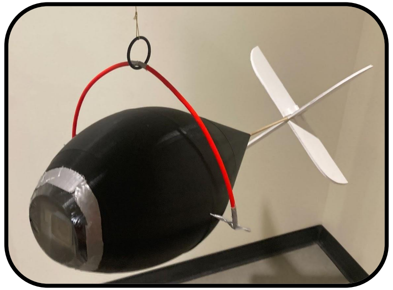
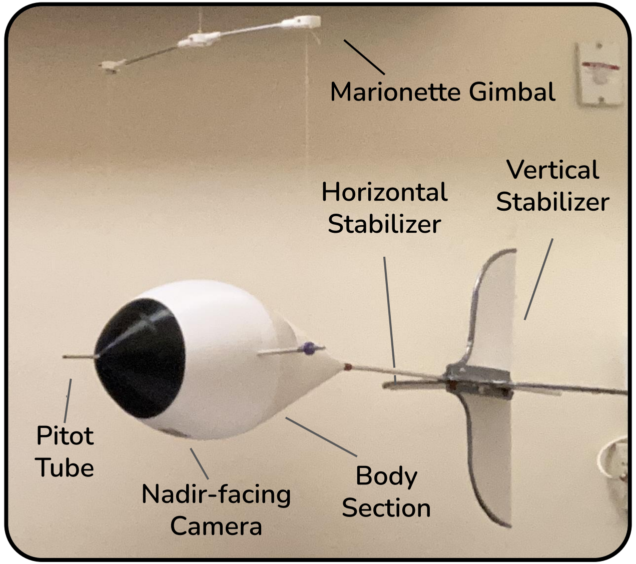
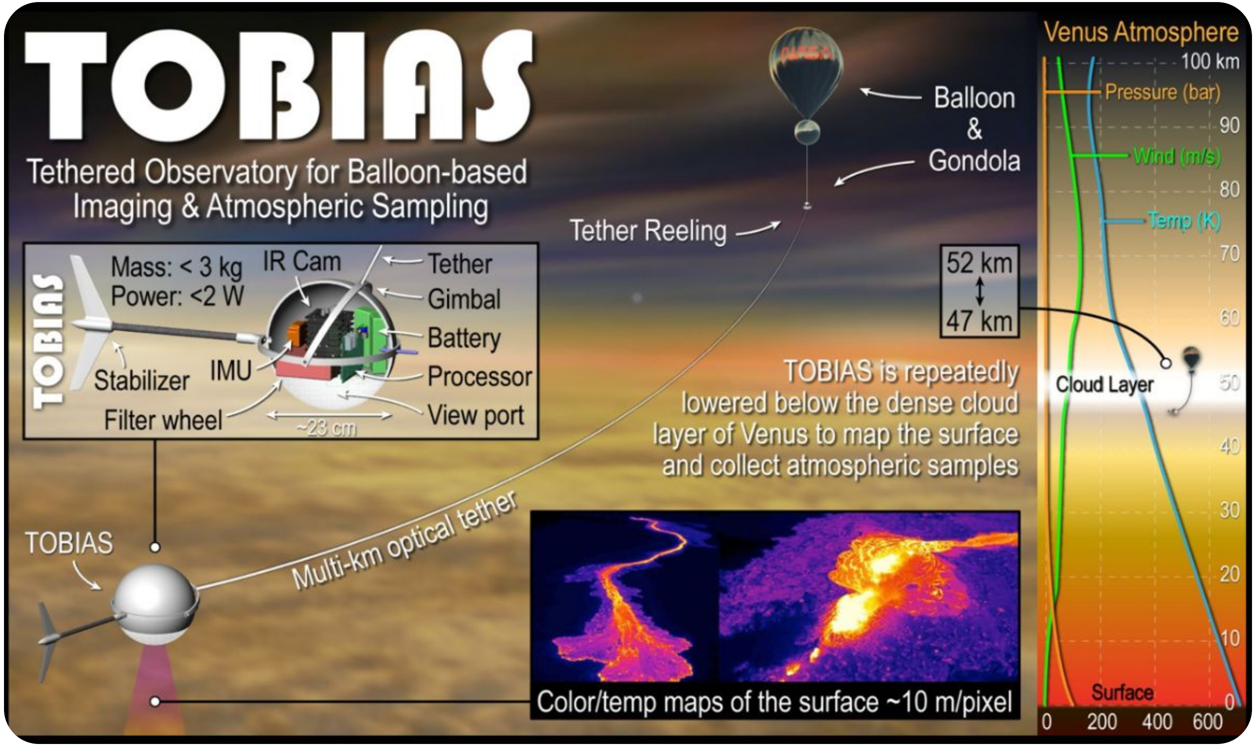
2. Jet Propulsion Laboratory, California Institute of Technology





Towbody Concept



- Stabilized towbody/probe trailing under balloon in Venus' upper atmosphere.
- Towbody is reeled under cloud layer to take high-resolution infrared images of surface.
- Once towbody reaches operating temperature limit, gondola reels it above clouds to cool

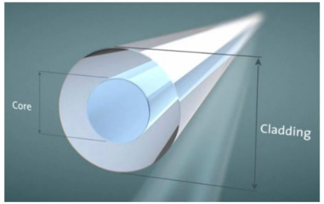
Optical Tether

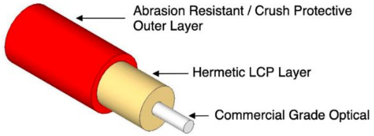
- Multi-kilometer (~10km) optical cable gondola to towbody & instruments
- Composite protective cladding around fiber optic core
- Experiences vast majority of drag in tether-towbody system

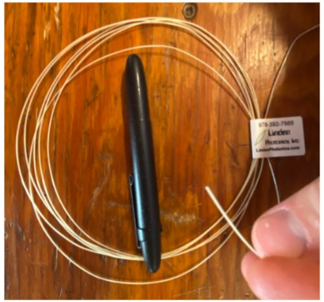
Tether Estimation

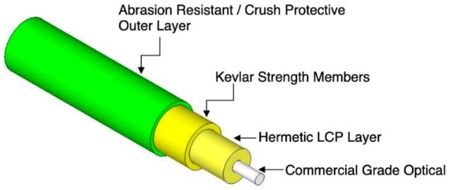
COTS Tethers for Comparison

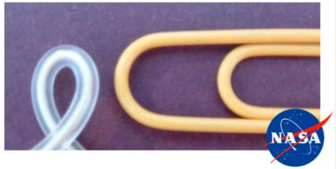
1. Corning SMF-28 (bare fiber)
    - Diameter: 0.15 mm
    - Tension: 20 N
    - Mass: 0.04 g/m
2. LINDEN-SPE-7273
    - Diameter: 0.48 mm
    - Tension: 178 N
    - Mass: 0.24 g/m
3. LINDEN-SPE-7092
    - Diameter: 0.90 mm
    - Tension: 222 N
    - Mass: 1.00 g/m
4. LINDEN-SPE-7282
    - Diameter: 1.90 mm
    - Tension: 1112 N
    - Mass: 3.60 g/m
5. LINDEN-SPE-7050
    - Diameter: 2.40 mm
    - Tension: 2002 N
    - Mass: 6.80 g/m









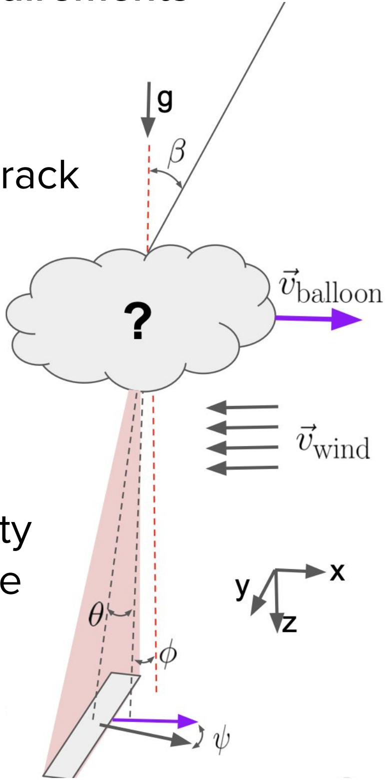


Design Requirements

Pointing Requirements

- Pitch: 10° of nadir
  Roll: 10° of nadir
  Yaw: 20° of ground-track alignment

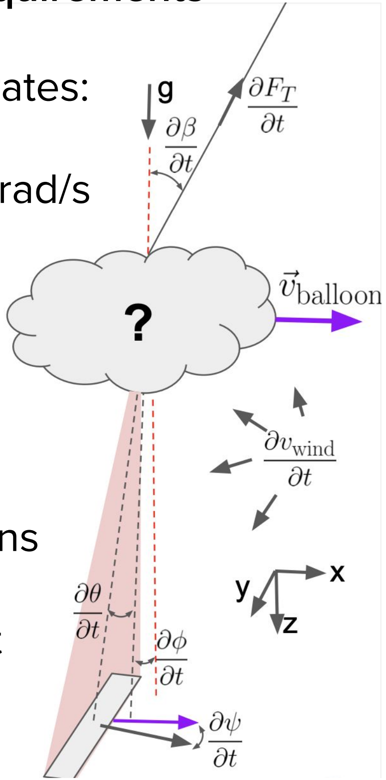
- Stabilize roll: gravity torque
  Stabilize pitch: gravity torque & wind torque
  Stabilize Yaw: wind torque



Stability Requirements

- Pitch and Roll rates: 0.01 rad/s
- Yaw rate: 0.38 rad/s

- Reduce natural frequencies
- Dampen vibrations
- mitigate ‘double pendulum’ effect

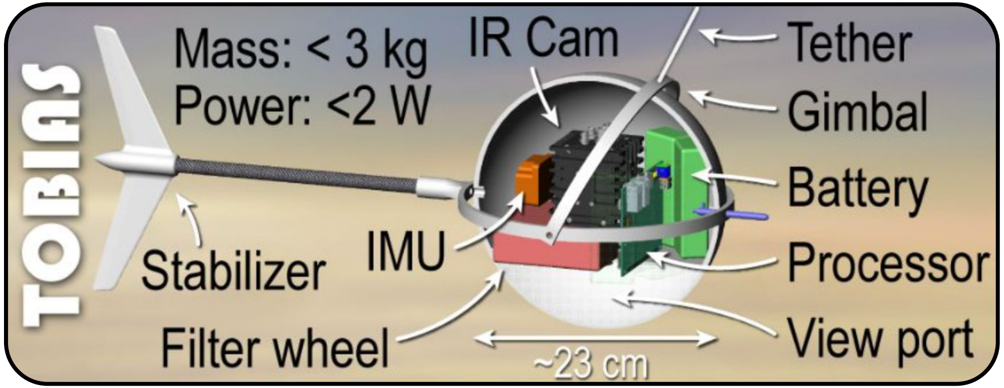


Environment Considerations

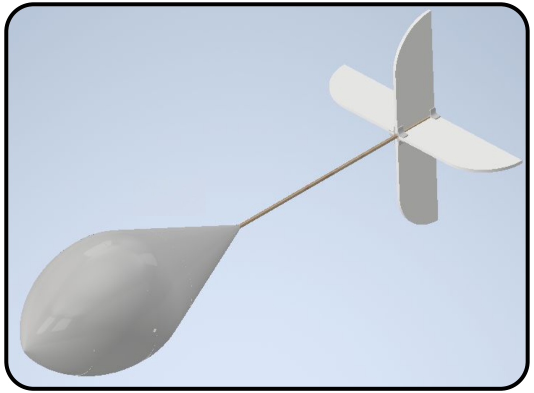
Category	Subcategory	Value
Gravity	Acceleration	8.87 m/s^2
Temperature	Min	-50 C (220 K) @ 65 km
	Max	125 C (400 K) @ 45 km
Pressure	Min	0.1 bar @ 65 km
	Max	2 bar @ 45 km
Altitude	Min	47 km (could be lower)
	Max	62 km (max float altitude)
Wind Shear	Max	3 m/s or 10 m/s
Chemical Content	Atmosphere, Clouds	CO_2, N_2, H_2O, H_2SO_4

- Meet static & dynamic stability in 10 m/s winds.
- Towbody must return to nadir-facing following perturbations & turbulence
- Dampen oscillations & vibrations in system

Iterative Prototyping



Concept Towbody Design

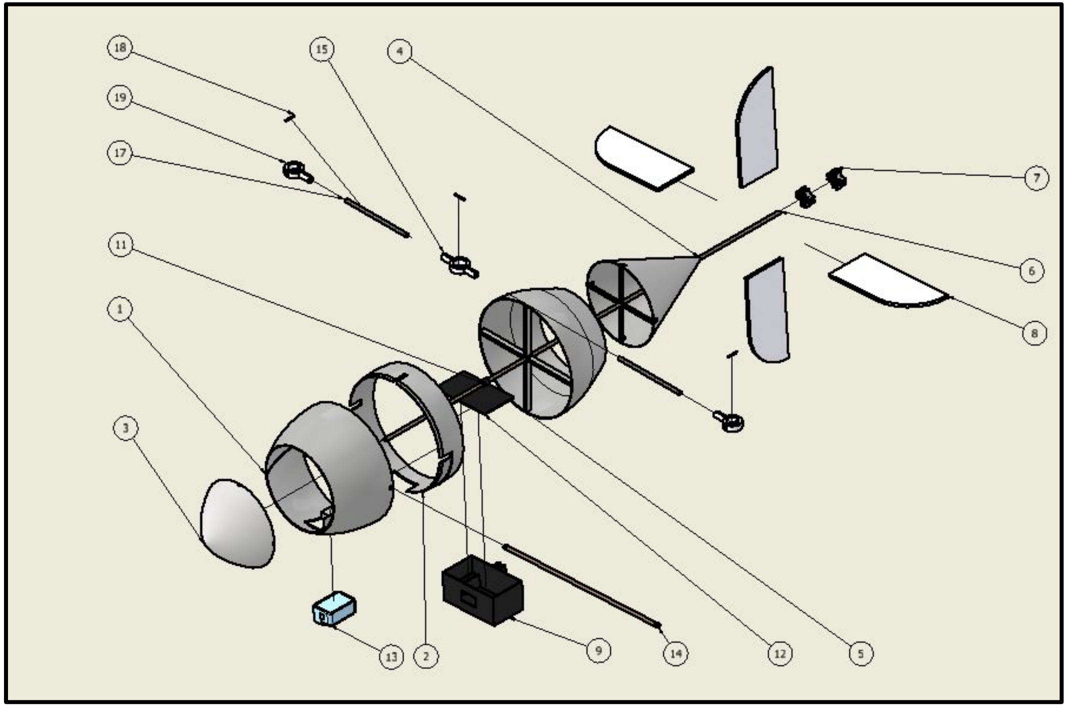


Prototype 3 Render

Design areas to improve upon with iterative testing:

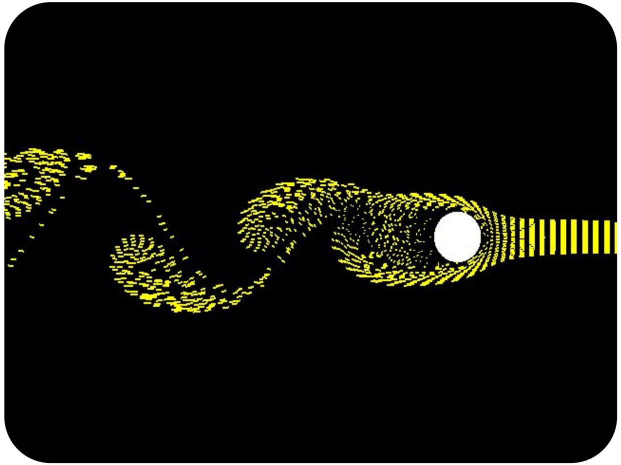
- ❖ Body section geometry
- ❖ Gimbal design
- ❖ Tether anchor point
- ❖ Tail section
- ❖ Towbody internals (payload housing, secondary stabilization)

Design Assembly

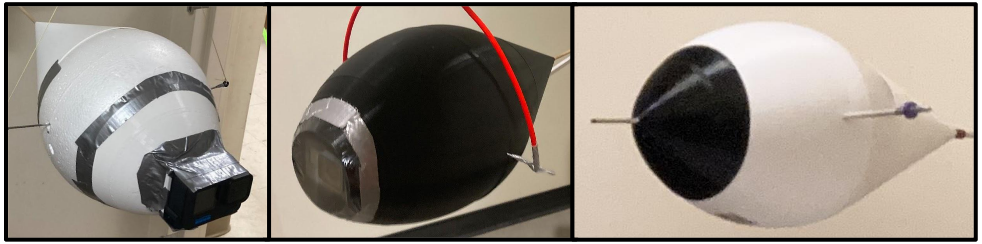


- 3D Printed body sections
- Electronics inside hollow body
- Built to be easily swappable

Body Section Prototyping

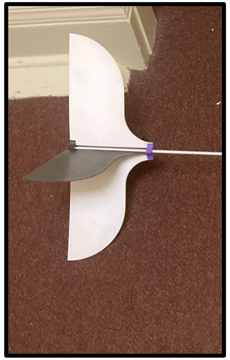
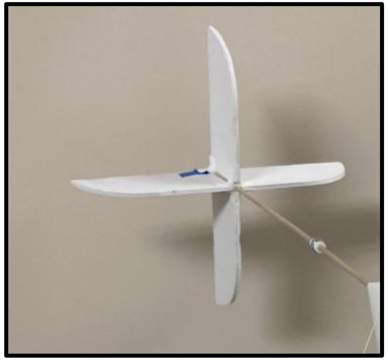
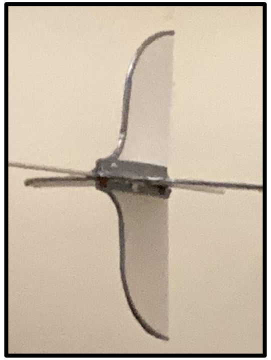
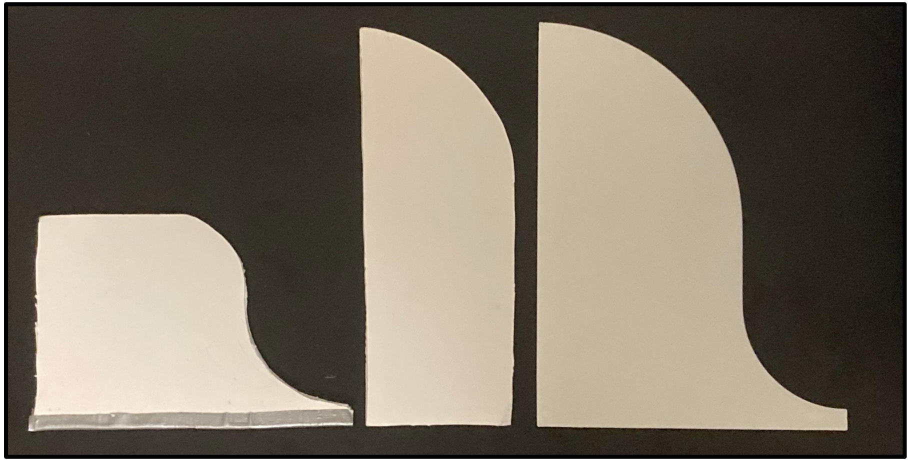


Credit: NASA Glenn Research Center



- ❖ First principles: A sphere in fluid flow results in boundary layer separation, creating a turbulent wake
- ❖ Added a 3D printed cone to prevent this effect.
- ❖ Final aerodynamic profile resembles a 'teardrop': symmetric aerofoil

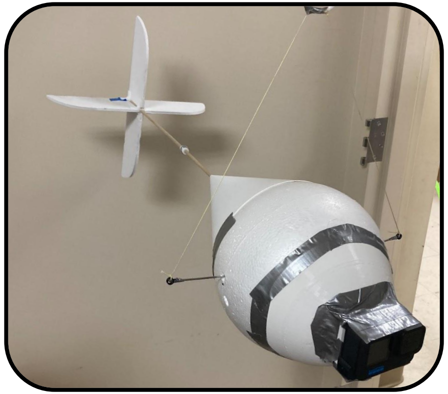
Tail Section Prototyping

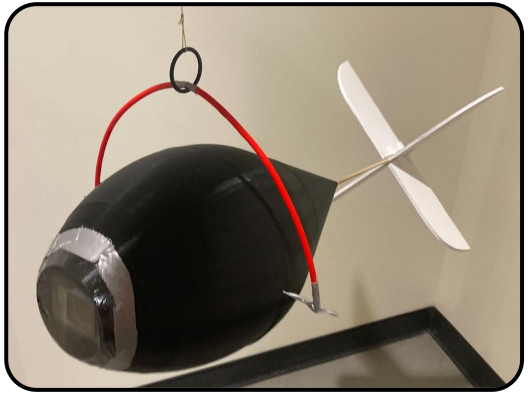
- Experimentation with different sizes
- Increasing restorative torque = **more sensitivity** to prevailing wind
- Tail size / Counterweight trade-off

Prototype Evolution

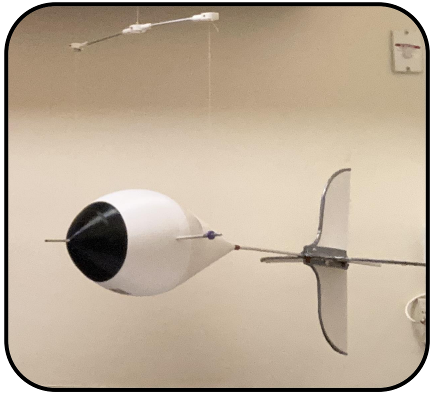
General Trends: **Increased rigidity** & **more degrees of freedom** with each iteration



Prototype 1

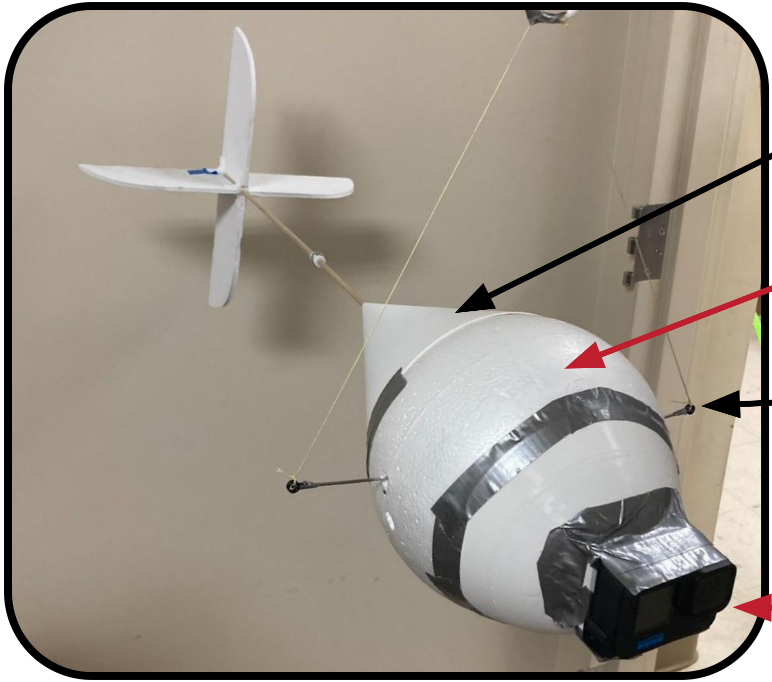


Prototype 2



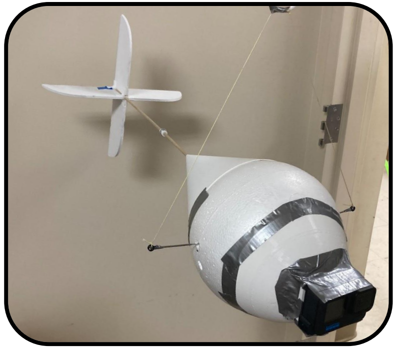
Prototype 3

Prototype 1



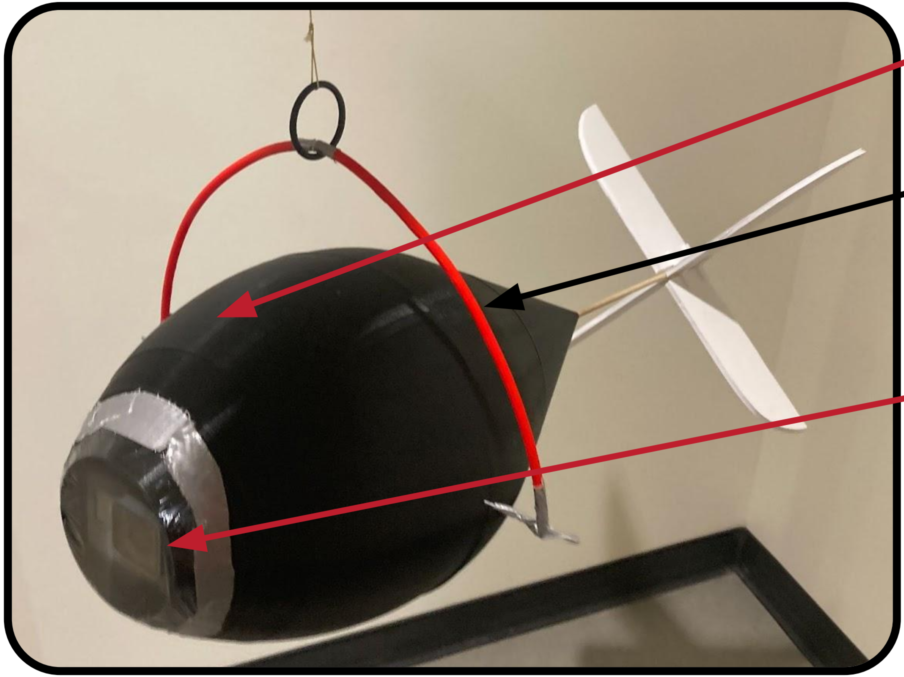
- 3D Printed components
- Styrofoam sphere
- Double attachment point on either side of body (above CG)
- Front-facing camera

Prototype 1



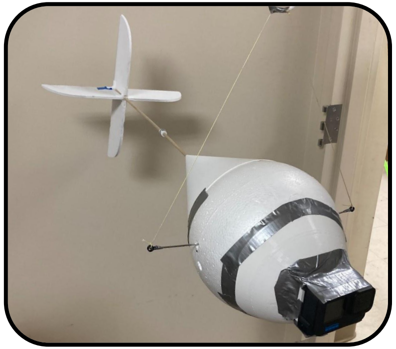
Pros	Cons
Adjustable weight distribution	Can pitch & yaw freely; not roll
Initial proof of concept (Statement of Issue)	Small high-frequency roll-axis vibrations
	No gyroscope/accelerometer

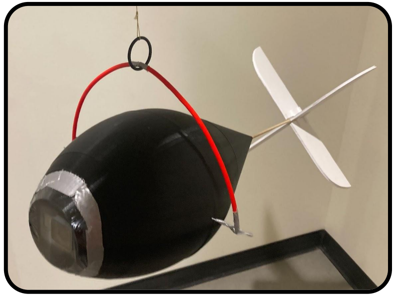
Prototype 2



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

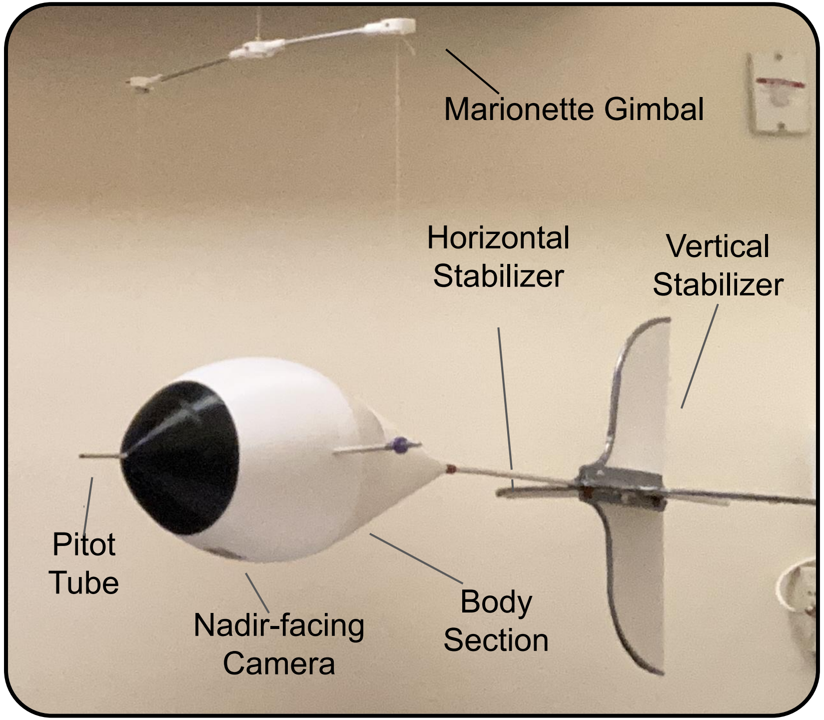
Prototype 2





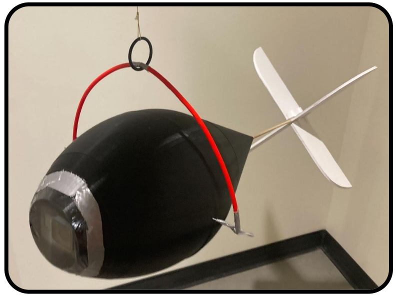
Pros	Cons
Increased range of motion	Unknown Air Speed
Improved Instrumentation	High-friction Ring Gimbal
Improved Aerodynamics	

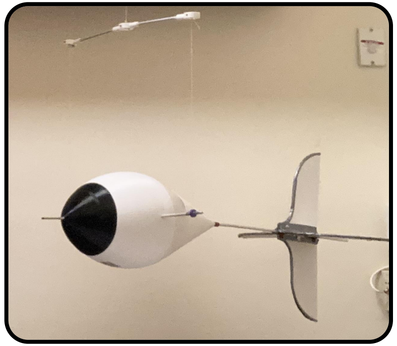
Prototype 3



- ‘Marionette’ bifilar pendulum gimbal
- Increased-rigidity aluminum backbone
- Pitot tube in weighted nose cone
- Reworked tail section

Prototype 3





Pros

Added Pitot Tube

Increased range of motion

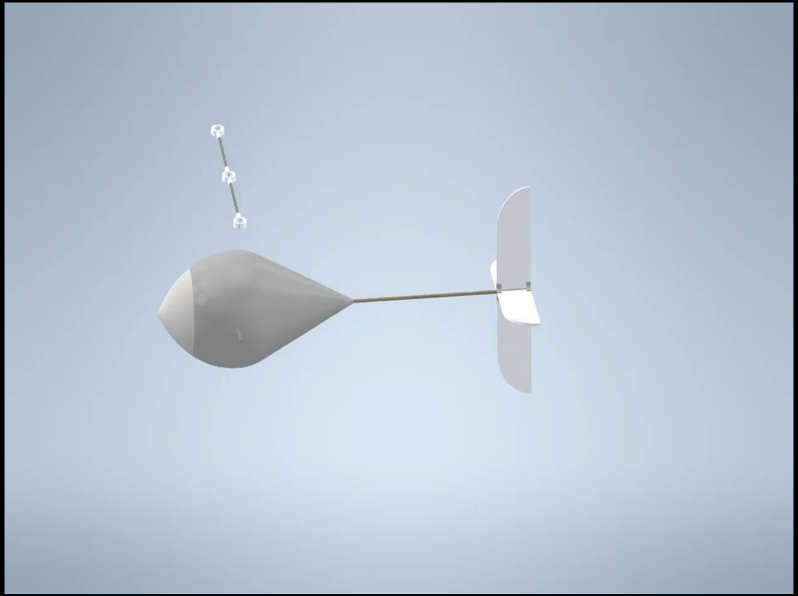
Increased rigidity

Improved consistent stability

Cons

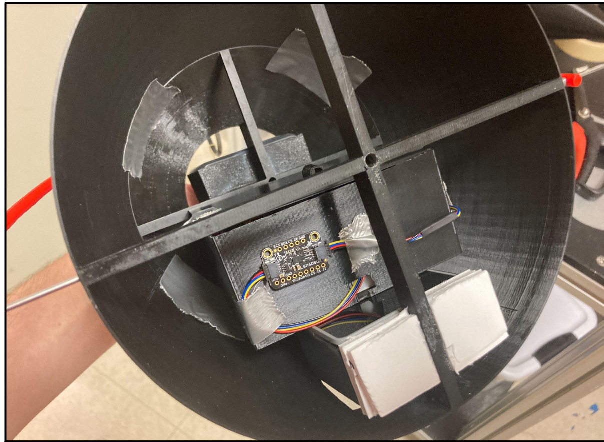
Dependence on local wind conditions

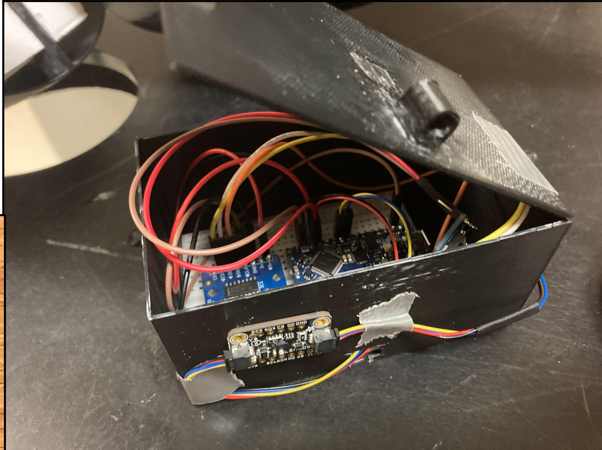
Design Assembly



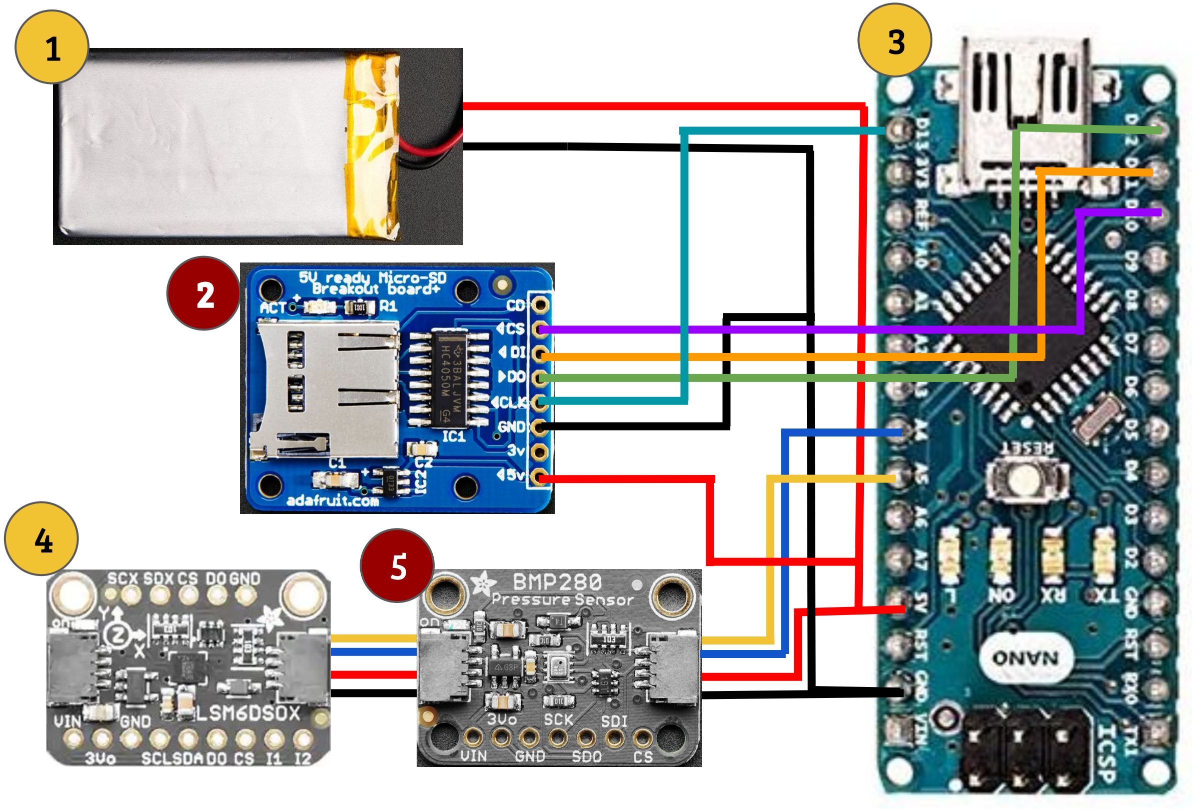
Instrumentation

- Arduino setup with Accelerometer, Gyroscope, Barometer & Thermometer, and Pitot tube
- Sensor values written to SD card onboard
- Data recovered and analyzed following test





Electronics



Color	Type
Red	Power (5v)
Black	Ground
Yellow	SCL
Blue	SDA
Purple	CS
Orange	DI
Green	DO
Cyan	CLK

‘Wind Cannon Testing’

- Controlled testing method: focus on **towbody dynamics**

- Industrial fan with a focusing section & laminarizing section

- Reaches top wind speeds of ~4 m/s

- During test: perturb body & observe damping effects

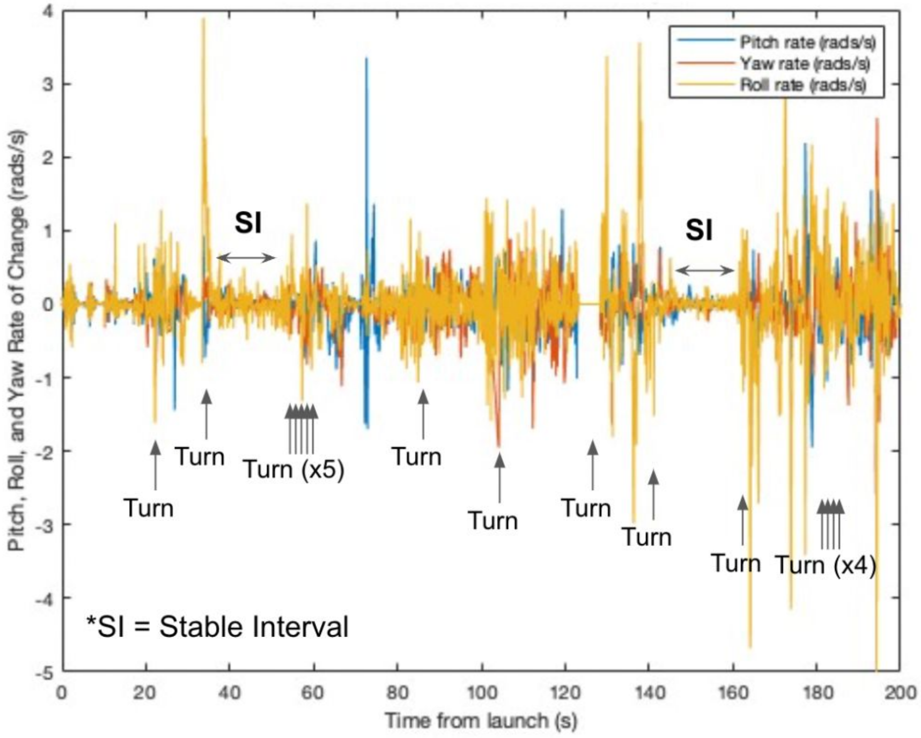
Drone Testing

- Prototypes tethered to drone flown over empty lakebed in ~15-second intervals
- Allows for observation of dynamics of tether-towbody system
- Changes in altitude or velocity equal torques about the CG

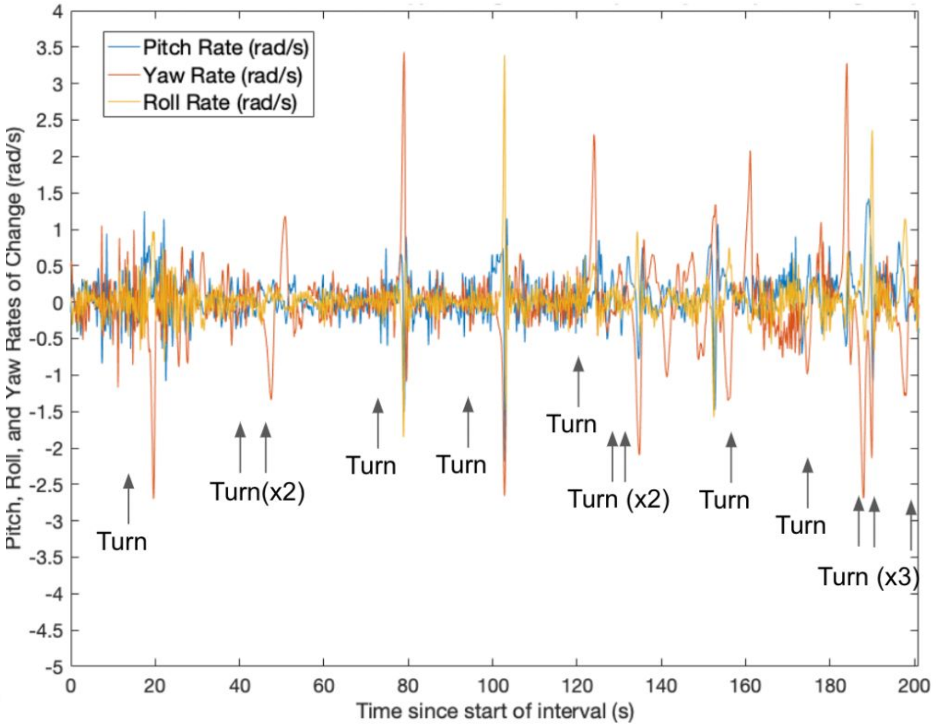
Drone Test Video

Testing Results

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

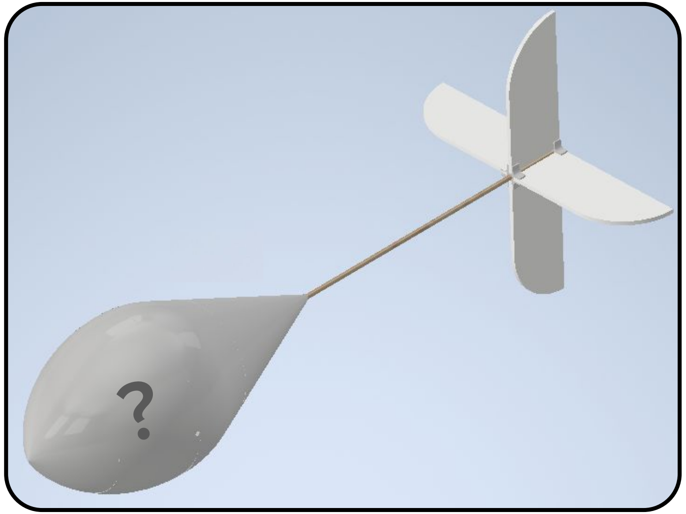


Prototype 3: Pitch, Roll, and Yaw Rates Over Flight Interval



Conclusion

- **Wind sensitivity trade-off** in design: Reached the upper restorative torque bound.
- **Tuned to low-turbulence** environments & **sensitive to turbulent winds**.
- Trade-offs present in design with further iterative testing informed by aerodynamic theory



Prototype Goals

Pointing Requirements

- Pitch: **10° of nadir**
  Roll: **10° of nadir**
  Yaw: **20° of ground-track alignment**

Stability Requirements

- Pitch and Roll rates: **0.01 rad/s**
- Yaw rate: **0.38 rad/s**

Initial Towbody 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

Future Work

- Iterative testing to find ideal:
  - Body shape
  - Tail sizing
  - Static margin
  - Anchor point
  - Secondary stabilization
- Prototyping additional components: docking port/winch
- Repeated drone and wind cannon tests for statistical significance.

Concept Future Towbody Design

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