HASP Student Payload Application for 2012

Payload Title: High Altitude Turbine Survey (HATS)

Payload Class: (check one)	Institution:	Submit Date:
☐ Small ☑ Large	Arizona State University	12/15/2012

Project Abstract

The High Altitude Turbine Survey (HATS) is an attitudinal wind velocity experiment aimed at understanding thrust and other performance characteristics of four varied micro-propellers along a vertical profile (35km). Onboard sensors including optical encoders, strain gauges, thermocouples, pressure gauges, an anemometer (wind V), and digital wind vane, will provide environmental data throughout accent and decent in order to create a velocity and thrust generation profile corresponding to altitude, pressure, and wind speed. The survey data will have a wide range of application towards further study including wind power generation from airborne turbines, propeller-driven airships, and micro-propeller performance characteristics at extended altitudes. The HATS team has progressed through PDR and CDR project phases and will continue with the build and test phase in early 2012.

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HATS	Arizona State University

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HIGH ALTITUDE TURBINE SURVEY // **H.A.T.S.**

Arizona State University
School of Earth & Space Exploration

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Submission for: H.A.S.P. Large Payload

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I. **Abstract**

The High Altitude Turbine Survey (HATS) is an attitudinal wind velocity experiment aimed at understanding thrust and other performance characteristics of four varied micro-propellers along a vertical profile (35km). Onboard sensors including optical encoders, strain gauges, thermocouples, pressure gauges, an anemometer (wind V), and digital wind vane, will provide environmental data throughout accent and decent in order to create a velocity and thrust generation profile corresponding to altitude, pressure, and wind speed. The survey data will have a wide range of application towards further study including wind power generation from airborne turbines, propeller-driven airships, and micro-propeller performance characteristics at extended altitudes. The HATS team has progressed through PDR and CDR project phases and will continue with the build and test phase in early 2012.

II. Payload Description

Mission Objectives

The primary mission objectives as described below are summarized here:

- Develop an apparatus for testing high altitude micro-turbines
- Characterize propeller RPM and thrust as a function of altitude
- Determine the extent of effects caused by environment conditions

Scientific and Payload Background

Renewable energy systems have become an increasingly popular field as the world looks to confront its ever-growing energy needs as well as reduce its reliance on fossil fuels. While wind energy has been used for many years to help offset energy demands and to provide access to energy in remote areas, it is often geographically limited and suffers from highly variable wind speeds [1]. Wind energy has often been plagued by extended periods of poor productivity due to surface wind lulls caused by daily to seasonal changes in wind conditions and weather. As power generation from wind turbines varies as a cubic function with wind speed, any small variation in velocity can have drastic effects on performance [1]. As such, in order for wind power to become a more serious contender in the renewable energy realm, identification of a global, reliable, high-speed wind source is paramount.

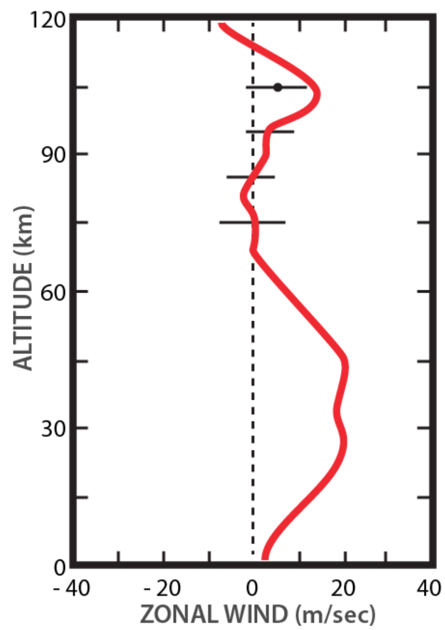


Figure 1. High Altitude Wind Speeds (Reproduced from [2])

Commercial aircraft utilize such a wind source every day. Several studies by the National Centers for Environmental Prediction and the Department of Energy have been conducted to analyze high altitude wind speeds. Figure 1 displays the averaged results of one such study [2].

In general, it can be seen that high altitude winds, which include winds higher than 500m, have greatly reduced variability and speeds an order of magnitude higher than surface winds [3]. Indeed, the available power density for high altitude winds exceeds 10kW/m^2, which is larger than many other renewable energy sources such as solar power, ocean currents, or geothermal [3]. Additionally, these high power densities can be found in variety of geographical locations enabling high altitude wind energy to be harvested in close proximity to its end users giving it a significant potential benefit over other renewable energies [4].

Although the potential benefit is great, the technology necessary to capture this energy is still in the early developmental stages. In general, there are four primary methods proposed for the successful conversion of this energy. These methods are described in Figure 2.

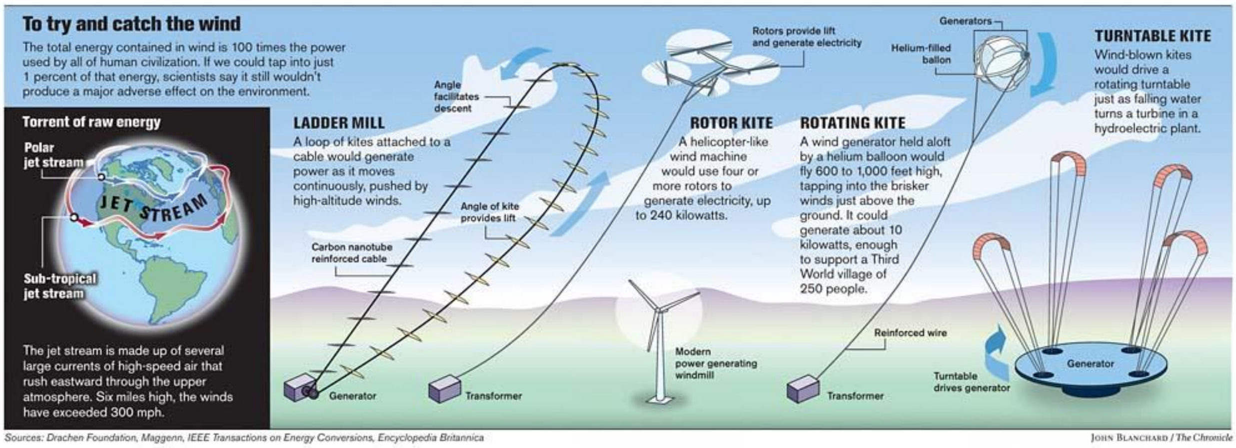


Figure 2. Alternatives for High Altitude Wind Harvesting (Reproduced from [5])

While each of these designs has its pros and cons, it can be seen that the greatest potential power generation stems from the development of tethered rotorcraft [3]. One of the primary concerns in developing these wind turbines is the ability to efficiently collect wind power at the lower atmospheric densities and to store or transmit the collected power to a station at the ground.

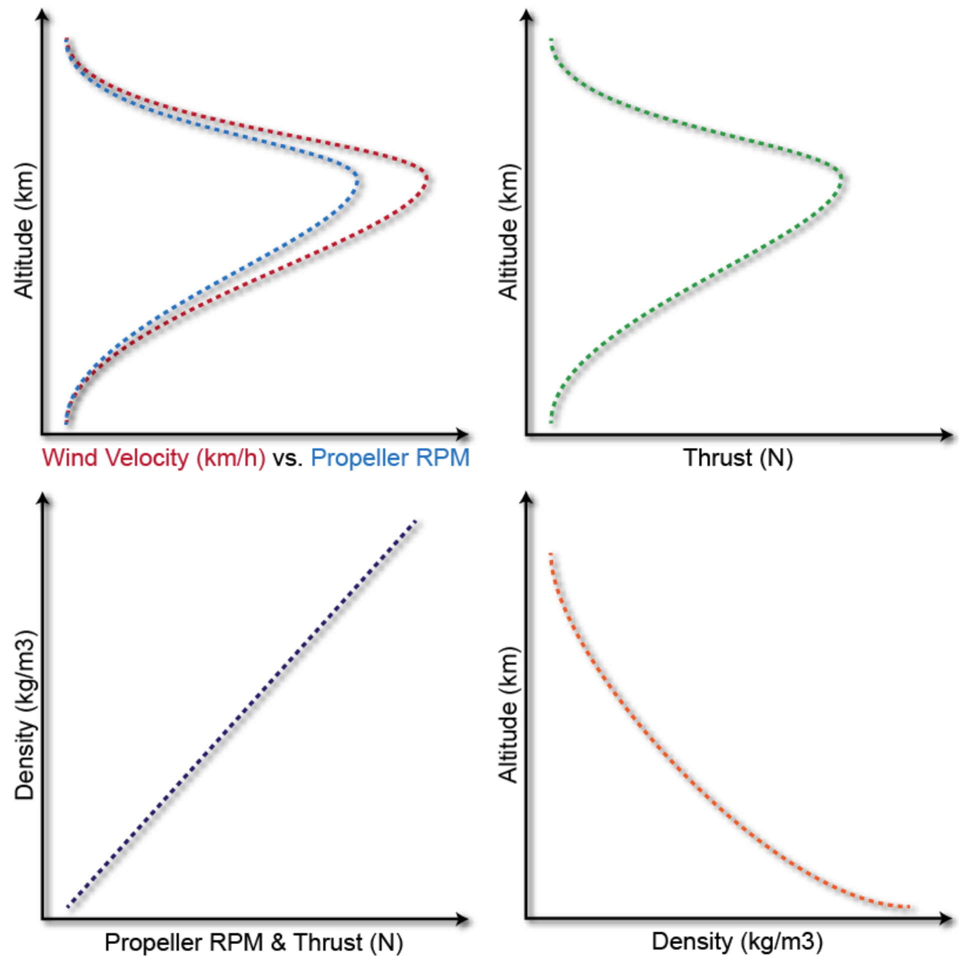
The Arizona State University High Altitude Turbine Survey (HATS) payload will focus on testing the performance of a few different propeller designs with regards to altitude and wind speeds. The test bed will include a wind speed sensor to compare the estimated ideal performance to the actual performance of the propellers as well as a variety of additional environmental sensors in order to characterize the impact of high altitude environments on propellers. The payload will be mounted to the large payload section of Louisiana State University's High Altitude Student Platform (HASP). In this way, propeller performance data can be acquired for a large range of altitudes. Particular emphasis, however, will be placed on the performance of the propellers during ascent and descent of the balloon.

In addition to data to be collected to facilitate the development of high altitude wind turbines, the propeller performance data can also be used in a variety of potential military and commercial applications Research surrounding the use of propeller-driven high altitude airships for surveillance, communication, and atmospheric research could greatly benefit from a systematic analysis of propeller response to altitudinal atmospheric conditions as provided by the HATS payload [6].

The HATS payload consists of four separate experimental micro-propellers situated in a propeller carriage and electronics box to be mounted to HASP. During HASP operation, the motor controlled propeller carriage will self-orient to wind direction using information obtained through its wind sensor package and routed to its primary motor. This wind sensor will consist of a wind vane and anemometer. Once aligned, all four propellers will rotate due to changes in the relative wind velocity to the platform and optical encoders will measure the rotational speed of the propellers. The propellers will also generate a small amount of thrust, which will be measured by the strain gauges mounted on each propeller shaft. The propeller data will be stored on the payload. The system will also collect and store data throughout the mission relating to temperature, pressure, wind direction, and wind speed. Upon return, the data will be analyzed to generate profiles of propeller performance with respect to altitude and environment.

For thermal management, the HATS payload will utilize an internal heater and insulation for its electronics box for protection against the low ascent and descent temperatures. At cruising altitude, where the temperatures will not be as severe, the heater, which will be connected to an internal temperature gauge, will be disabled automatically or manually, should the automatic system fail. The electronics box, which will be made out of aluminum, will then be able to radiate waste heat away from the electronics and maintain the internal temperature at an acceptable level.

The data gathered from HATS will provide data similar to those shown below:



References:

[1] Bolonkin, A. "Using of high altitude wind energy". *Smart Grid and Renewable Energy*, 2(2), 75-85, May 2011.

[2] A.E. Hedin, E.L. Fleming, A.H. Manson, F.J. Schmidlin, S.K. Avery, R.R. Clark, S.J. Franke, G.J. Fraser, T. Tsuda, F. Vial, R.A. Vincent, "Empirical wind model for the upper, middle and lower atmosphere", *Journal of Atmospheric and Terrestrial Physics*, 58(13), 1421-1447, September 1996.

[3] Roberts, B.W., Shepard, D.H., Caldeira, K., Cannon, M.E., Eccles, D.G., Grenier, A.J., Freidin, J.F., "Harnessing High-Altitude Wind Power," *Transactions on Energy Conversion, IEEE* , 22 (1), 136-144, March 2007.

[4] Archer C.L., Caldeira K., "Global Assessment of High-Altitude Wind Power", *Energies*, 2(2), 307-319, May 2009.

[5] Davidson, K., "Scientists look high in the sky for power", *The San Francisco Chronicle*, A-1, 7 May 2007.

[6] Makrinos, Stephen T., "High-Altitude Airships for Homeland Security Operations." *Sea Technology,* 46(8), 29 and 31-2, August 2005.

III. Project Management

The HATS payload has been conceptually designed and will be built during the continuation of the team's senior exploration design class at Arizona State University. As such, the organization of the team is shown in Figure 3.

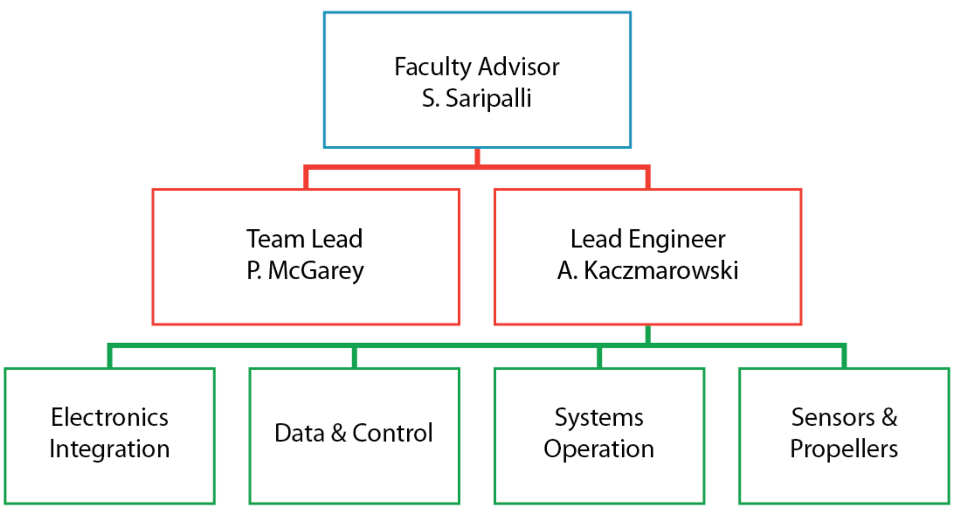


Figure 3. Team Structure

Subsystems

The HATS payload consists of 4 critical subsystems. Each subsystem will be tasked to a group member who will report directly to the team lead / systems engineer for the project.

- Electronics Integration - voltage regulation, wiring, circuit components, and the electrical integration of all sensors and controllers

- Data & Control - programming and integrating multiple Arduino controllers, sending and receiving data from all pertinent components, storing data
- System Operation - documentation and implementation of all test and flight materials, compliance between systems and with HASP
- Sensors & Propellers - coordination of all internal and external sensors, components, motors / design and analysis of micro-propellers. This subsystem will have one lead with several group members focusing on individual sensors (i.e.: pressure, temperature, wind sensor, propellers)

There will be a total of 7-9 team members working on the HATS payload. However, it is anticipated that only 2-3 of those members will participate in integration at CSBF and operations at Ft. Sumner.

Given the constraint of working within the senior design class schedule, the team fully expects to have a designed, built, and tested payload by no later than the end of April 2012. The team has established a schedule of benchmark achievements throughout the semester in order to stay on track and they are summarized below.

Schedule

January
- Software programming and test
- Design electronics and prototype
- Mechanical assembly

February
- Software integration with controllers and sensors
- Electronics final assembly
- Mechanical mounting components and motor assembly

March
- Software debugging and test
- Electronics testing and component integration
- Mechanical complete full assembly

April
- Full systems assembly and debugging
- Wind tunnel testing
- Documentation: Payload Integration, Flight Plan, etc.

Summer/Fall
- HASP Integration and Launch

IV. Payload Specifications

The HATS payload will be fully compatible with the HASP system. The HATS system requirements are outlined in Table 1.

Table 1. HATS System Requirements

Requirement	Quantity	HASP Compliance
Positions	1 Large Student Payload	
Mass	7.5 kg	
Dimensions	12.5" x 10.5" x 30" (*w* x *l* x *h*)	
Voltage	27 V	
Current	1.5 A	
Power Supply	Ascent, Cruise, and Descent	
Serial Downlink	Yes	
Serial Uplink	No	
Serial Interface	Yes	
Discrete Command	2 commands	
Shock Loads	10g Vertical 5g Horizontal	
CosmoCam	During Ascent and Descent every 10 min between altitudes 7 km – 20 km	

HATS will require power from HASP for ascent, cruise, and, by permission, descent. Should power not be available for the system during the descent phase, it will limit the performance data gathered to a single profile. While this would still produce a great deal of information for study, it would be less representative then having multiple samples. The HATS payload will rely on HASP for GPS data. The team understands that the maximum resolution for GPS data must be greater than 2 seconds. HATS will be mostly autonomous but will require the HASP system to send health data (internal temperature) and receive basic on/off discrete commands for the heater should the need arise. The downlink rate for the temperature data is accepted at 4800 baud for a large payload and available on the ground every 5 to 10 minutes. The HATS system will also make use of the HASP CosmoCam to ensure proper propeller cage alignment and propeller rotation during integral data collection phases namely between 7km and 16km altitude for both ascent and descent.

Mass Budget

The anticipated mass budget for the HATS system is given in Table 2. As can be seen, the mass for the HATS payload, 7.5 kg, is well below the requirements for the HASP system large payloads, 20 kg. This leaves plenty of room should some of the components exceed their expected masses.

Table 2. Mass Budget

Subsystem	Mass (kg)
Base Aluminum Frame	2.9
Propellers	0.028
Optical Encoders	0.012
Strain Gauges + Mounts	0.002
Electronics Box (Empty)	3.9
Pressure Sensors + Tubes	0.002
Temperature Sensors	0.001
Wind Sensor	0.050
Motor	0.5
Arduino(s)	0.096
Data Collection	0.006
Total Mass	7.5
Mass Under Requirement	12.5

Power Budget

Current Draw from HASP

- 50mA draw from HASP per i/o pin used
- 12 components x 50mA = 600mA
- 600mA → 0.6A
- Minimum 2 pins (power & data) per component = 24 pins
- 24 pins → 1.2A
- Max i/o use = 50 pins = 2.5A
- 26 free i/o pins

Voltage Requirements for Micro-controllers

- Each Arduino (3) requires a minimum of 7VDC
- Supplying 9V per Arduino reduces failure probability and ensures usage is below HASP minimum supply of 29VDC
- Total used: 27VDC
- Estimate Average of 2.25V (+/- up to 5VDC) per component
- 2.25V x 12 = 27V

Current Supply to Subsystems

- 40mA current supply per i/o from Arduino to subsystems, 20-50kΩ resistance per i/o pin
- 24 Pins → 960mA supplied, +/- dependent on component requirements

Post-Procurement Power Requirement Changes

- Possibly add batteries to compensate for unexpected power requirements

Footprint, Height, and Mounting

The HATS propeller carriage will be mounted on its electronics box, which will be directly mounted to the HASP mounting plate. The mounting plate is shown in Figure 4 below.

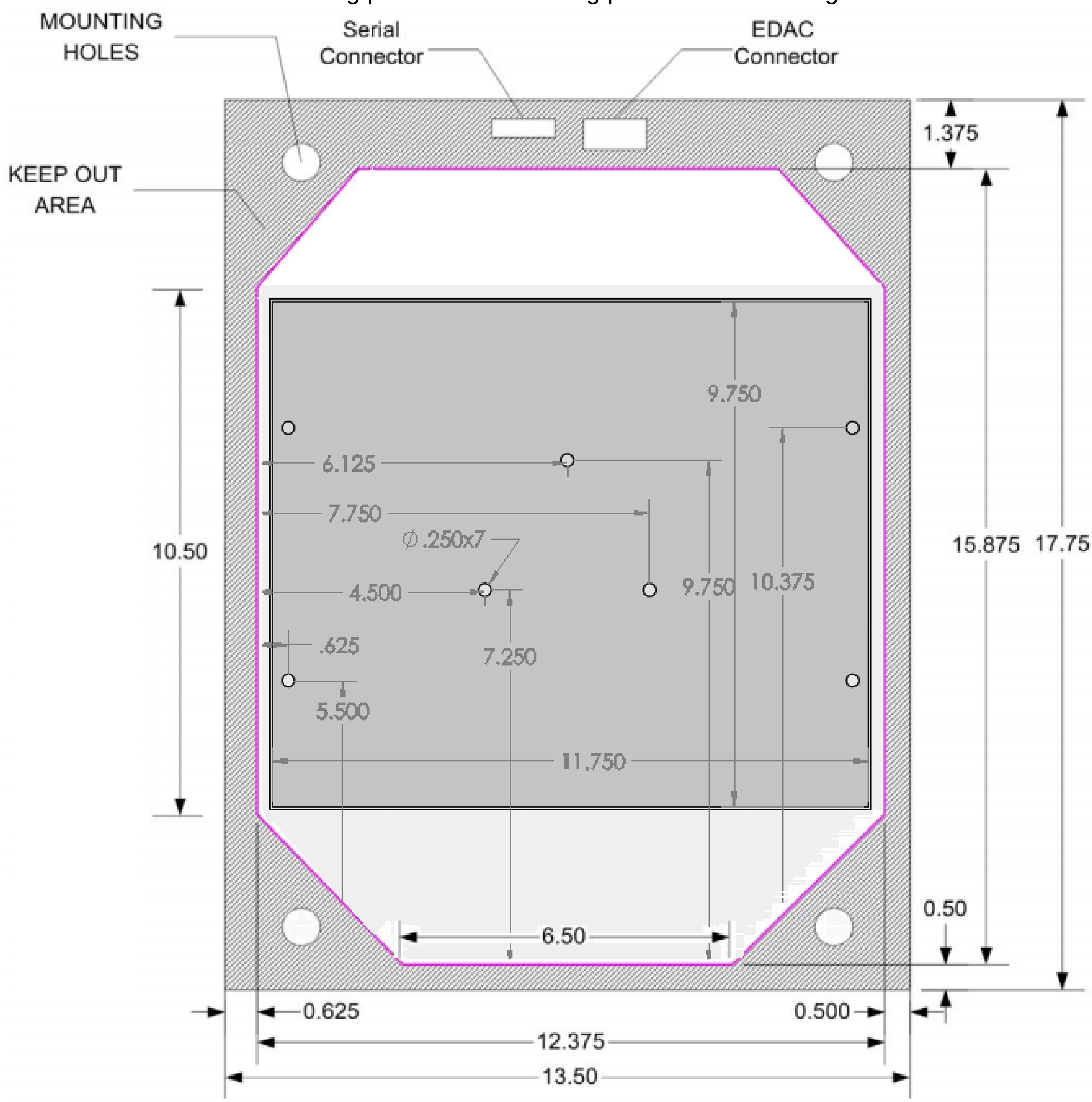


Figure 4. HATS Mounting Plate

Payload Orientation

HATS can be mounted in any of the four large payload locations. HATS will generate a small amount of thrust from its four micro-turbines. This will result in a small moment about the center of mass of HASP. Assuming the center of mass is approximately in the center of HASP Figure 5 shows the moment arms for a large payload mounting. The thrust generation will vary approximately ±45˚ as the propeller cage turns to align with wind direction. In order to reduce the spin induced by the propellers, HATS should be mounted as close to the center of mass as possible. It is anticipated that the thrust generated by the propellers will be quite small especially during cruise when the other payloads will be most active. Experimental and analytical testing of the propellers will be utilized in order to ensure that it is so. Additionally, should the moment generation for four propellers be deemed unacceptable, HATS can also be downsized to only two propellers.

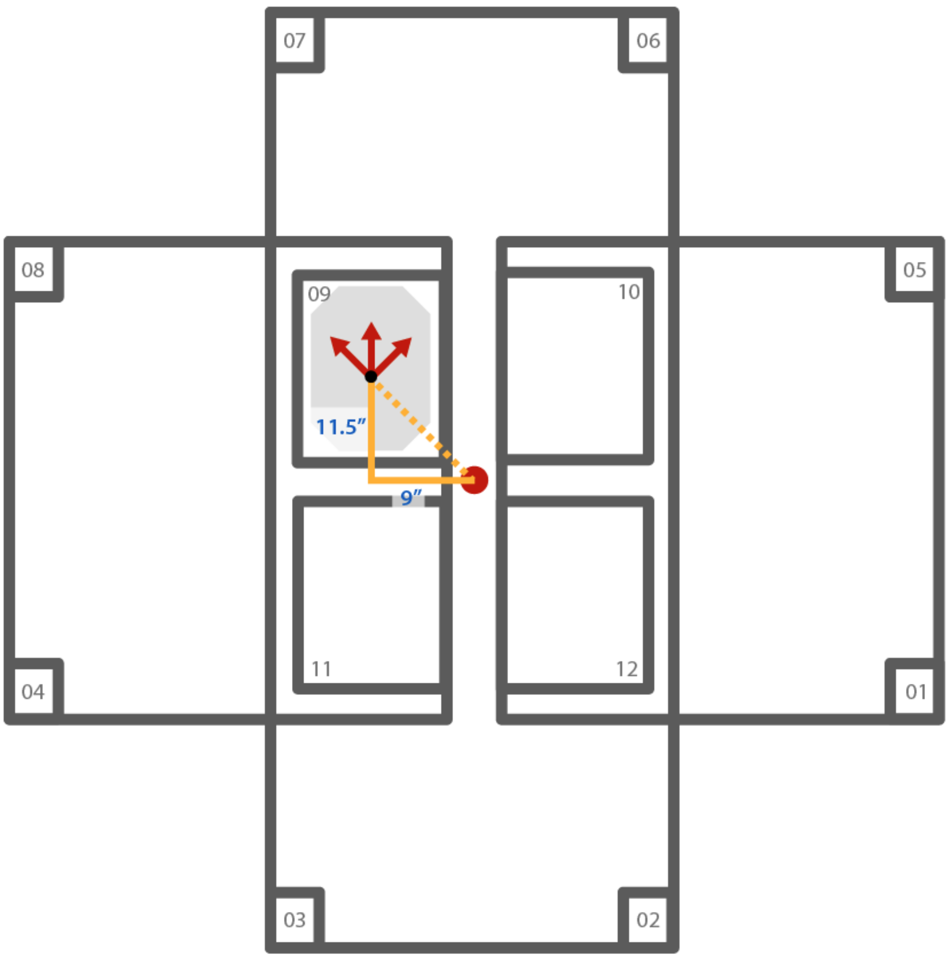


Figure 5. Moment Generation to HASP

Costs

The build cost is fully funded by *School of Earth & Space Exploration* Grant up to $5,000. However, the total budget for HATS is estimated to be much less than this. The budget is given in Table 4 below.

Table 4. Estimated Budget

Item Description	Purpose	Cost
3/8" Aluminum Plate	Side Walls	$58
1/4" Aluminum Plate	Electronics Box	$22
1/4" Aluminum Plate	Top and Bottom A	$29
1"x1"x0.125" Aluminum Angle	Attachments	$9
0.5" Square Aluminum Bar	Supports	$19
1/4"-20 S.S Pan Screw 3/4"	Fasteners	$12
1/4"-20 Steel Hex Nut	Fasteners	$3
1/4"-20 STL Flathead Screw 3/4"	Fasteners	$6
10-24 S.S. Pan Head Screw 3/4"	Fasteners	$7
Temperature gauge	Temperature Measurement	$98
Servo Motor	To turn propeller cage for wind alignment	$28
Micro-controller Board	Power/Data routing	$120
Barometric Pressure Sensor Breakout	pressure measurements	$75
Virtual Breadboard	Prototyping	$29
Voltage Regulator (9 V)	Maintain Divider Circuit	$1
SD Circuit Board	Holds the SD card for data logging	$102
Serial to USB Cable	HASP to Arduino I/O	$25
SD Data Card	Logging HATS data	$54
Usb to USB Cable	Arduino Master to Arduino Slaves	$20
Voltage Regulator (3.3 V)	Voltage regulation on Sc card circuit board	$6
Optical Encoders	RPM Measurement	$200
Wind Sensor	Wind Speed and Direction	$400
Strain Gauges	Thrust Measurement	$150
Propellers	Propellers	$80
Iglide T500 Form F (inch) 1/8" Shaft Diameter Flange Bearing	Plastic Bearings for propellers	$26
	Total Cost	**$1,577**

*** Team Travel Arrangements are also funded by Arizona State University NASA Space Grant.

Flight Integration Plan

Integration with HASP

- Confirm stand alone system operability
- Mount payload on HASP and confirm structural stability
- Interface with HASP power/data EDAC and confirm optimal system performance
- Run pre-flight data collection test
- Repeat tests prior to launch

Flight Plan

Ascent & Descent

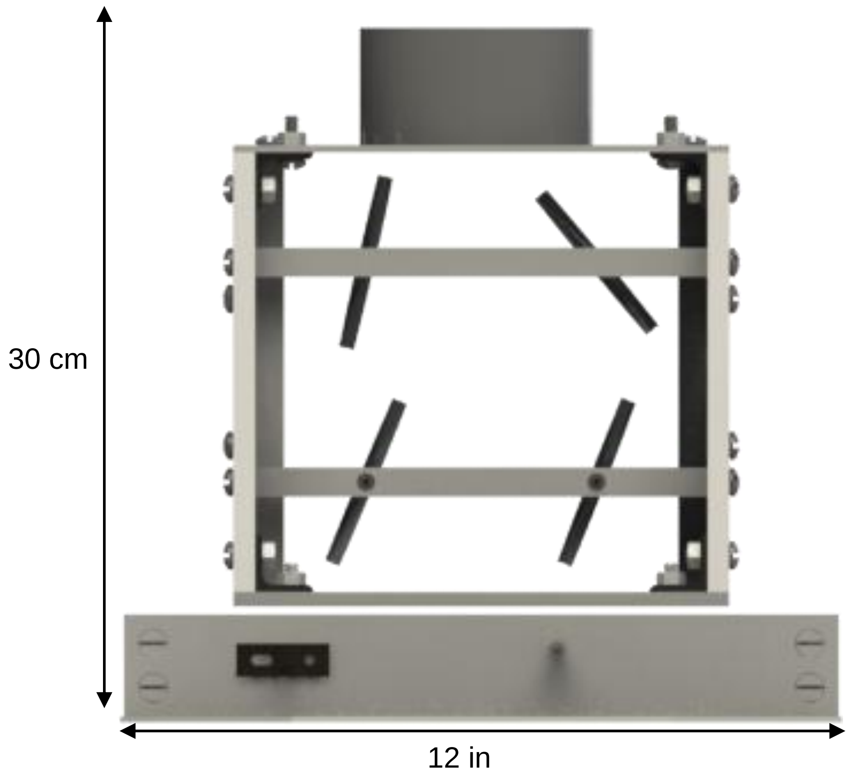
- Establish communication with system
- Monitor CosmoCam to confirm autonomous wind alignment and propeller rotation
- Monitor temperature downlink to confirm optimal system health and performance

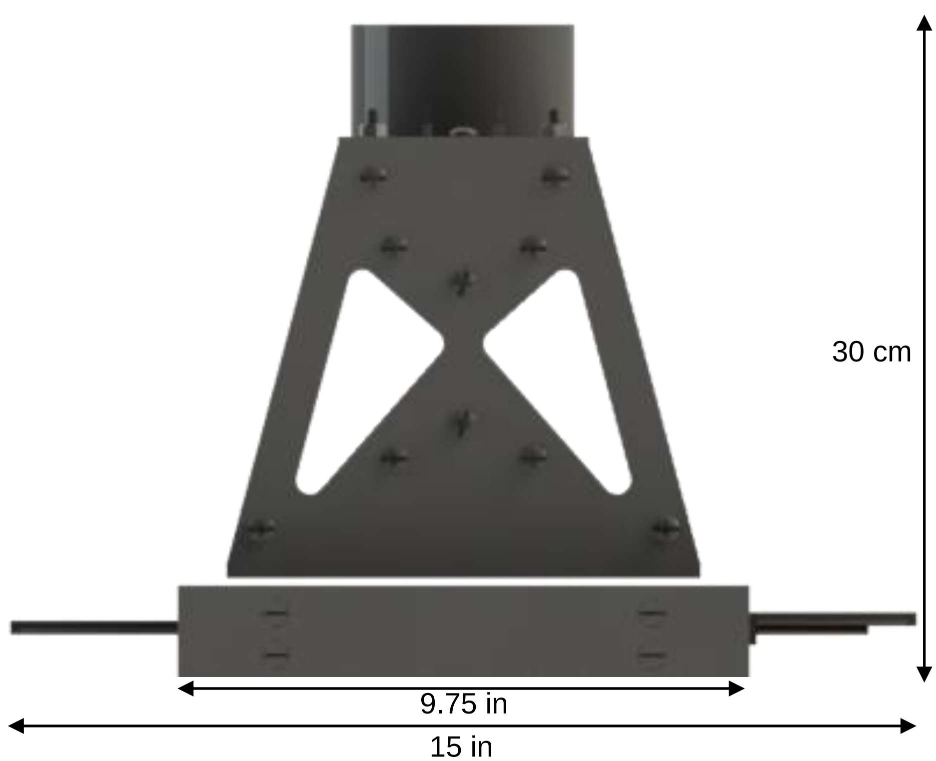
Coast (Max Altitude)

- Monitor CosmoCam in order to potentially manually realign chassis in direction of movement of perceived wind maximum as wind speeds may be to low for autonomous operation.

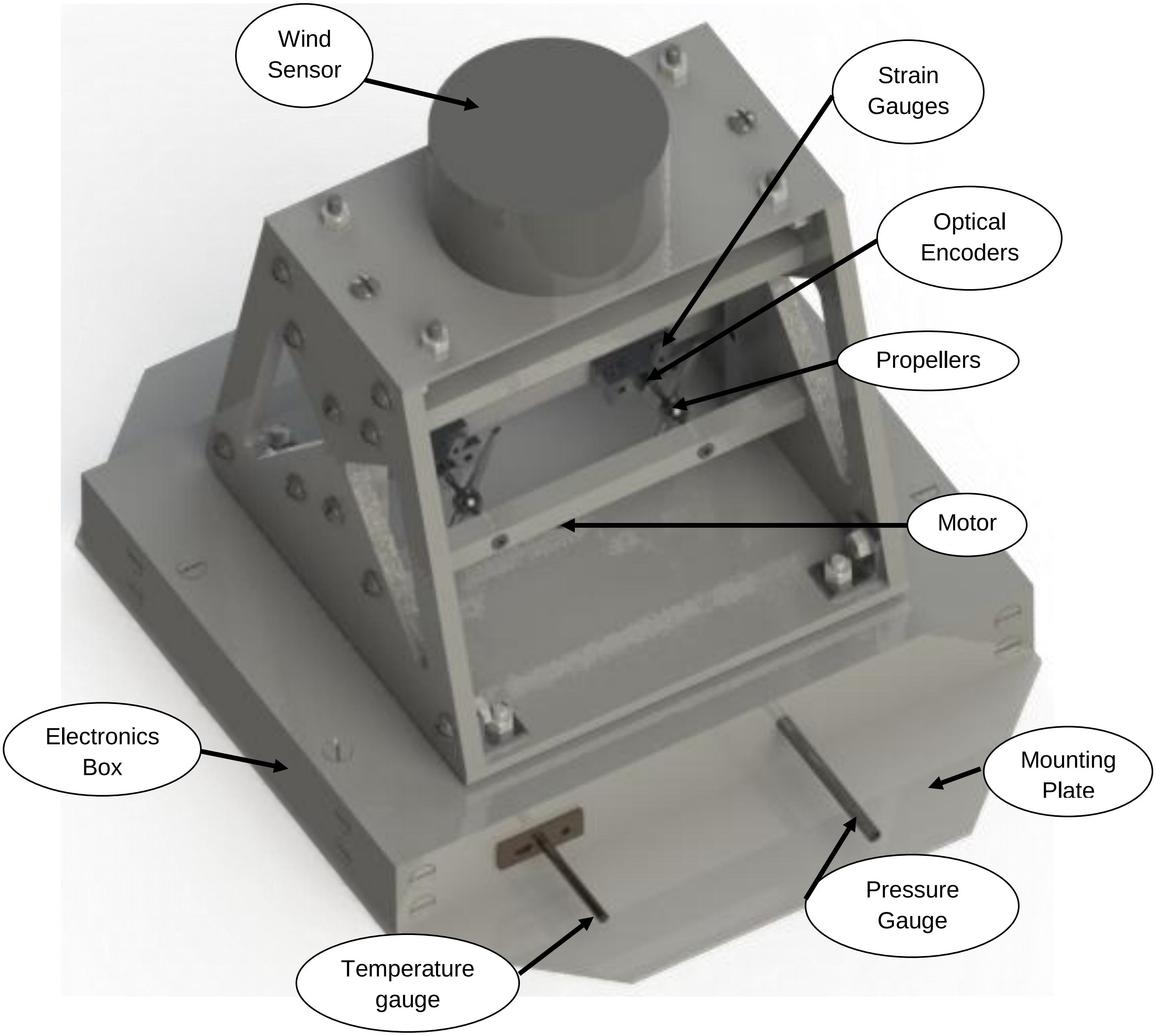
V. Preliminary Drawings

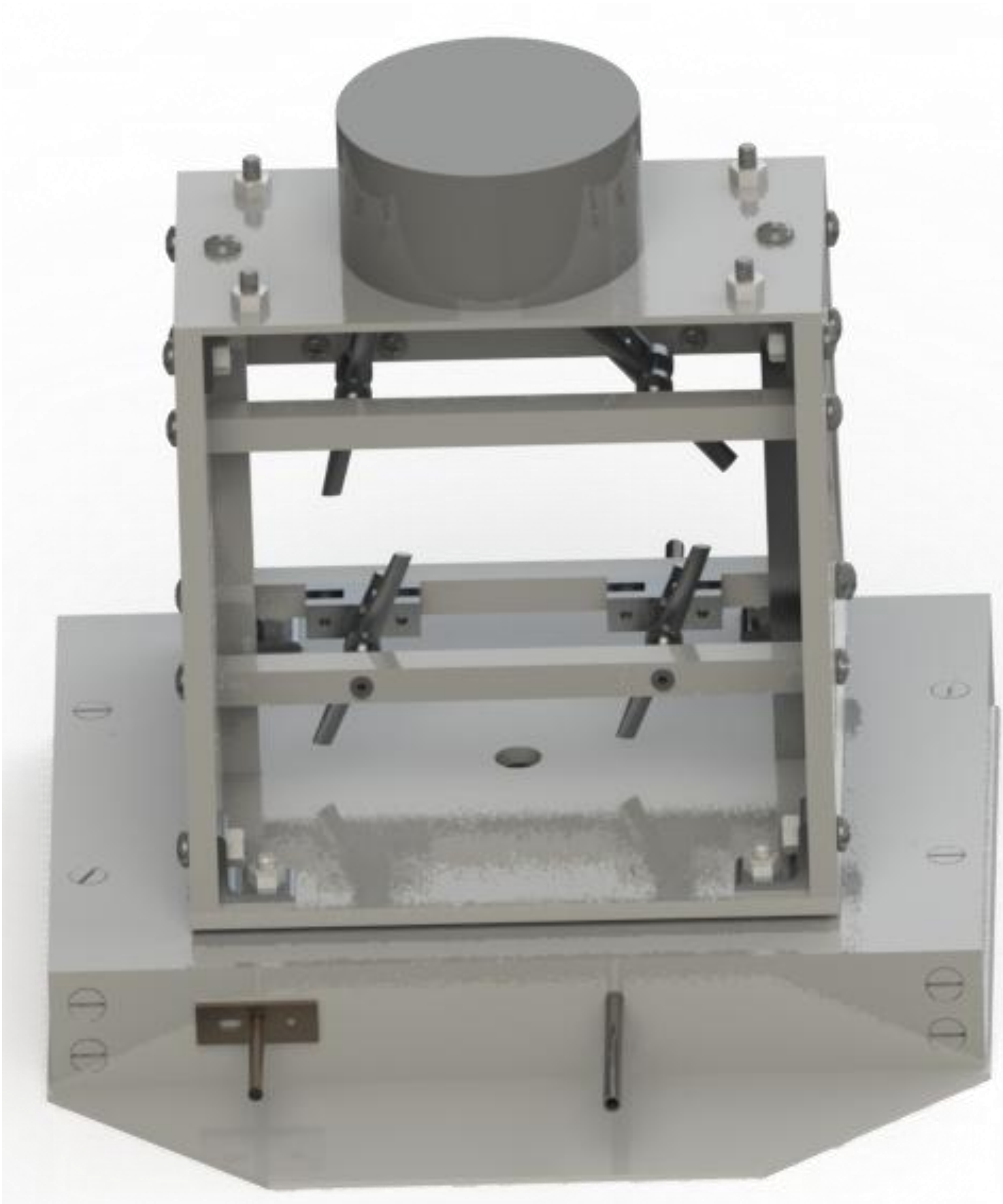
Front & Side Dimensions:

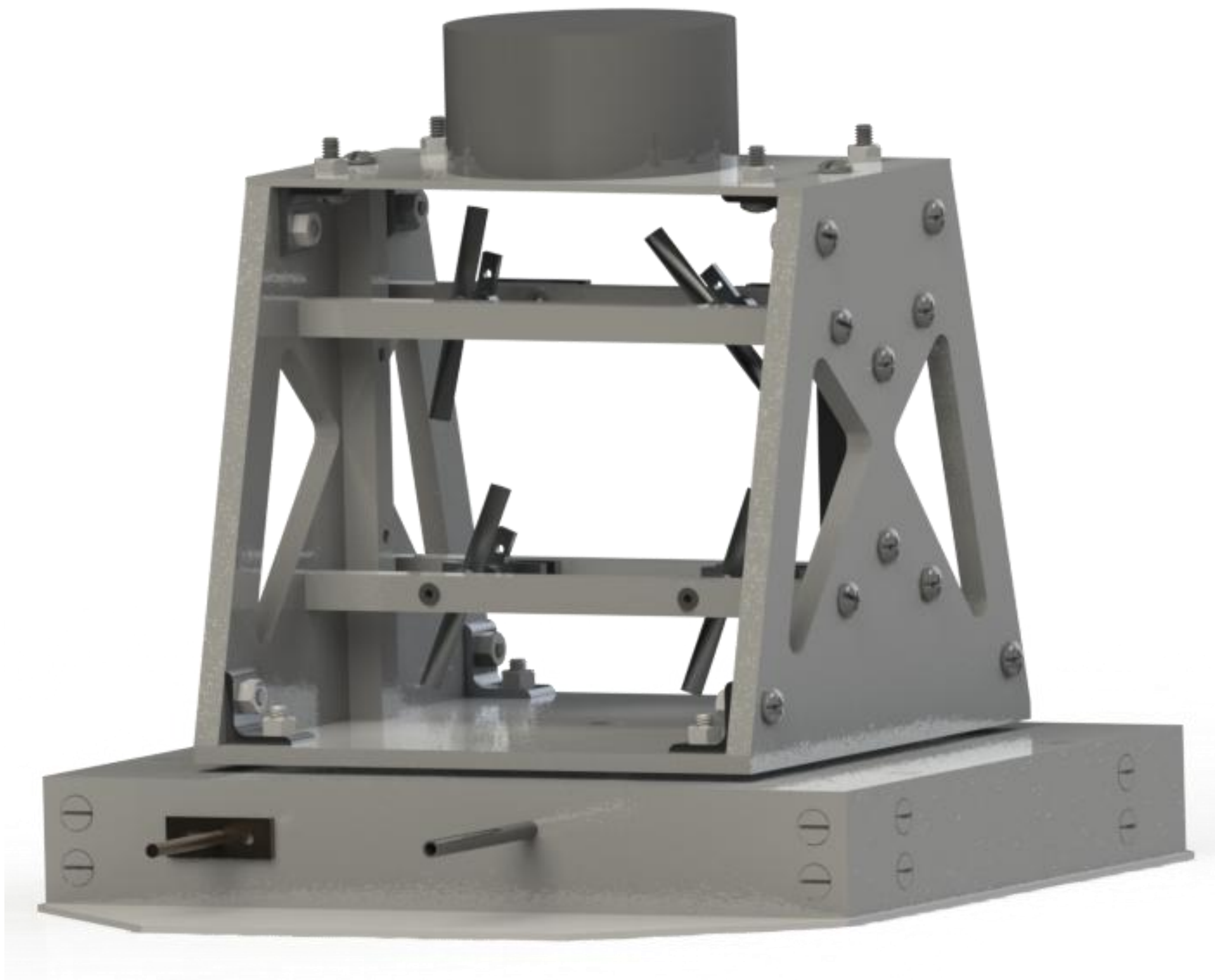




Modeled Drawings:







System Block Drawing: