SNOWCAT

System Naturally Observing Windborn Carbon & Aerosol Transportation

Manufacturing Readiness Review

February 20th, 2017

Mission Overview

Background: Black carbon deposition on snow reduces snow albedo (amount of reflected light), contributing to worldwide melting of ice.

Mission Statement*: SNOWCAT will gather environmental data and autonomously collect physical dust samples during its one month deployment in Svalbard, Norway.*

Roberto Venturini, *European Environmental Agency*, 2016

Objectives:

1. Deploy on the surface of Svalbard for a month with minimal human interactions.
2. Provide environmental data as a function of time.
3. Collect dust samples that are distinguished by time of collection.

Scope of Mission

MODEL 1:

King George Island (Antarctica), January Deployment

<u>Design Trait</u>	*<u>System Benefit</u>*
● 1 week deployment period **● Compared three different capsule designs** **● All capsules are always open** **● Sail swings to face wind**	**● Decision of which flute design is most efficient** **● Test electronics power and sensors and storing of data** **● Test bearing and sail and system's ability to react to wind change**

Scope of Mission

MODEL 2:

Svalbard (Norway), April Deployment

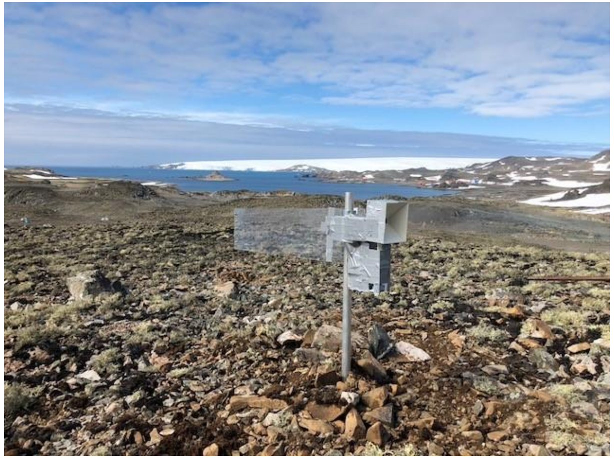
Design Trait

- **1 month deployment period**
- **Best flute from Model 1**
- **Adding motor to control dust collection on timely basis**
- **Electronics board printed and designed for mission**
- **Sensors integrated and logging values**
- **Aluminum structure and collection system**

System Benefit

- **Controlled dust sampling**
- **More Comprehensive data**
- **Stronger more durable structure**
- **Improved efficiency of bearings and sail to increase likelihood of reacting to wind**

Summary of Model 1



Successes

- Rotation into wind (sail, bearings)
- Demonstrated system ability to collect dust
- Identified areas of improvement and direction for Model 2

Lessons Learned

- **Structures:** Flutes should be metal and have better interface to inlet, need better structural durability and tolerances, improve ease of access
- **Electrical:** Spend less time on development board and more time on software and documentation, implement designed power system
- **Structures:** Clearer idea of requirements so structures and electrical designs are cohesive

Systems

Bekah Haysley and Will Butler

Requirements

Science Objective	Requirement
Investigate effect of black carbon deposition on snow albedo/melting in cryospheric regions	0.1: Deploy on the surface of Svalbard for a month with minimal human interaction
Understand how the dust (in particular, the black carbon) is transported	0.2: Provide environmental data as a function of time
Classify the composition of the dust deposited on the surface of snow and ice in cryospheric regions	0.3: Collect dust samples that are distinguished by time of collection

Minimum Criteria For Success (Model 2)

	Success Criteria	Pre-Deployment Verification
1	Collection chamber rotates to face the wind.	Day-in-the-life environmental testing. Success of Model 1 (using same bearings and bigger sail).
2	Able to power the system for a full month.	Both instantaneous power testing and system power testing. Estimations and calculations for power budget. Electronics cold testing.
3	Collect 4 different dust samples that are distinguished by time of collection.	Planned day-in-the-life environmental testing, motor and software testing.
4	Record environmental data as a function of time.	Sensor and software testing.
5	Dust collector remains structurally sound for the duration of the mission.	Day-in-the-life environmental testing. Success of Model 1.

Team Timeline

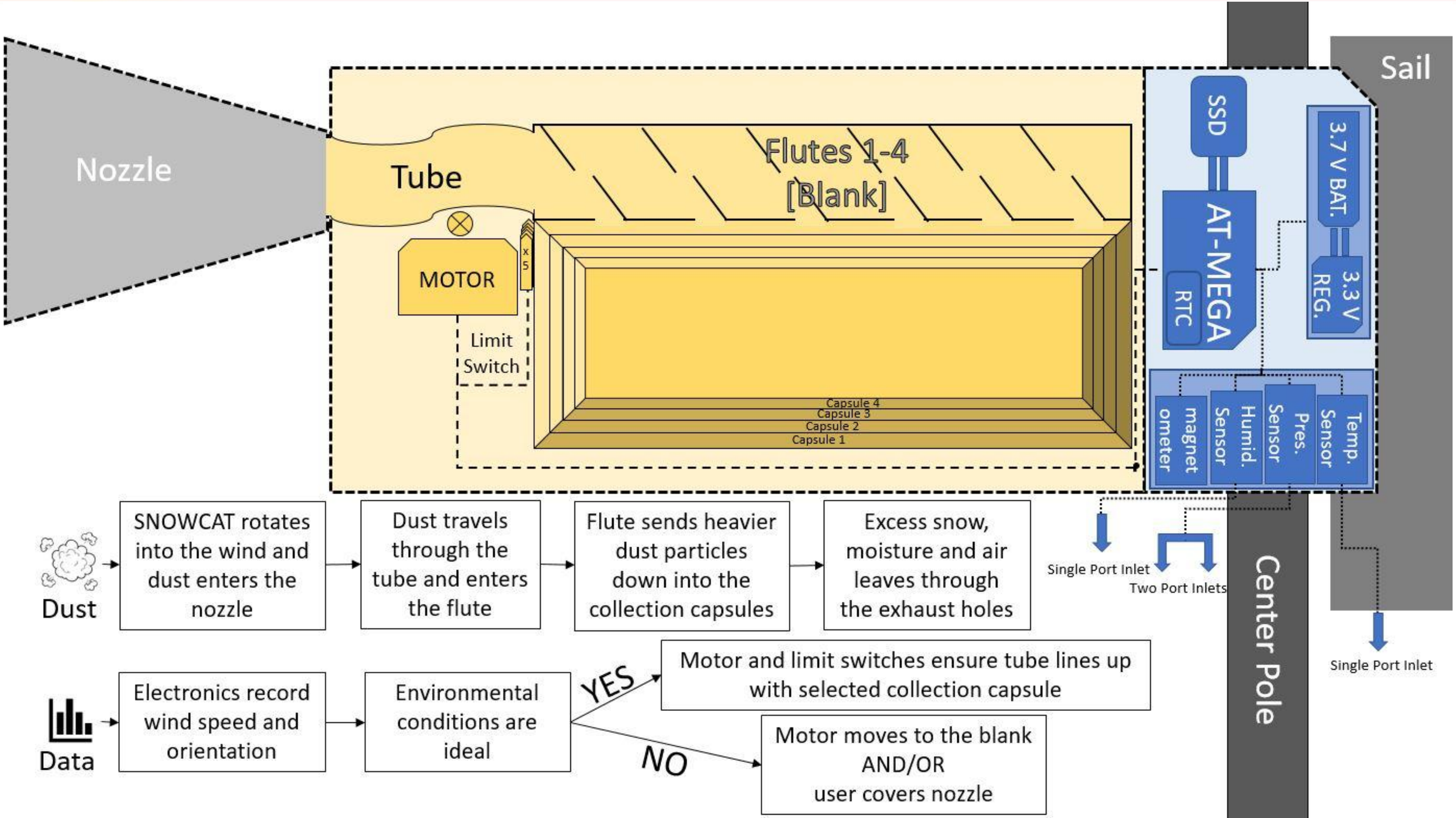
Milestones

Manufacturing Readiness Review

Environmental Test Readiness Review

Deployment Readiness Review

Functional Block Diagram



Timeline for Capsule Changes

- Blank Usage/Options
  - Blank as a drain
    - Allow for flow to enter and immediately exit
    - Pro: Moisture will enter and exit system
    - Con: Moisture could build up and clog system
  - Blank as a block in flow
    - Completely block flow through system
    - Pro: High pressure at nozzle may stop moisture from entering system
    - Con: Without wind there is no high pressure meaning snow or ice will fill nozzle
- Environmental Criteria for Switching to Blank
  - Temperature should be below freezing
  - Average relative humidity for Svalbard is ~75%
    - We think ~85% would ensure precipitation
  - Wind greater than 30mph would cause blowing snow which could clog system

TIMELINE: The table below details the active times for each of the collection chambers.

Chamber No.	Begin Active Period	End Active Period
1	Day 1 Hour 0	Day 7 Hour 24
2	Day 8 Hour 0	Day 14 Hour 24
3	Day 15 Hour 0	Day 21 Hour 24
4	Day 22 Hour 0	Day 28 Hour 24
Blank	N/A	N/A

CRITERIA: The blank chamber may become active any time that all of the below criteria are met.

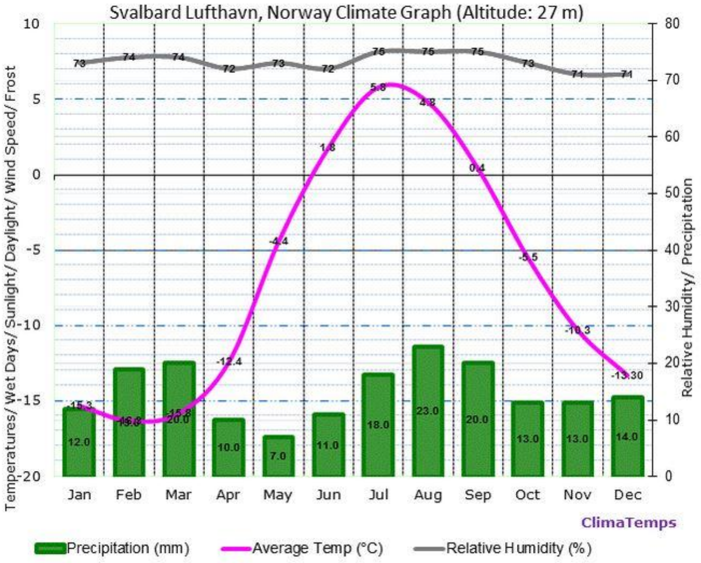
Temperature	Humidity	Wind Speed
-40C < T < 0C	~85%	> 30mph

Annual Data for Svalbard

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Precipitation mm (in)	12 (0.47)	19 (0.7)	20 (0.8)	10 (0.4)	7 (0.3)	11 (0.4)	18 (0.7)	23 (0.9)	20 (0.8)	13 (0.5)	13 (0.5)	14 (0.6)	180 (7.1)
Precipitation Litres/m² (Gallons/ft²)	12 (0.29)	19 (0.47)	20 (0.49)	10 (0.25)	7 (0.17)	11 (0.27)	18 (0.44)	23 (0.56)	20 (0.49)	13 (0.32)	13 (0.32)	14 (0.34)	180 (4.41)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Temperature °C (°F)	-15.3 (4.5)	-16.3 (2.7)	-15.8 (3.6)	-12.4 (9.7)	-4.4 (24.1)	1.8 (35.2)	5.8 (42.4)	4.8 (40.6)	0.4 (32.7)	-5.5 (22.1)	-10.3 (13.5)	-13.3 (8.1)	-6.7 (19.9)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Relative Humidity (%)	73	74	74	72	73	72	75	75	75	73	71	71	73.2
Average Dew Point Temperature °C (°F)	-18.7 (-1.6)	-19.5 (-3.1)	-19 (-2.2)	-16 (3.2)	-8.1 (17.5)	-2.4 (27.7)	1.7 (35.1)	0.7 (33.3)	-3.1 (26.4)	-9.1 (15.6)	-14.1 (6.6)	-17 (1.4)	-10.4 (13.3)
Interpretation	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry



http://www.svalbard-aero.climatemps.com/may.php

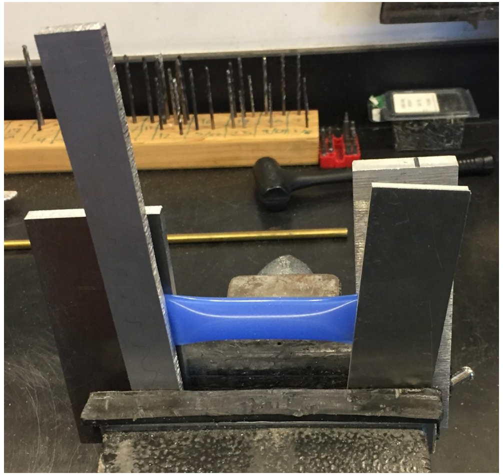
Critical Technical Issues

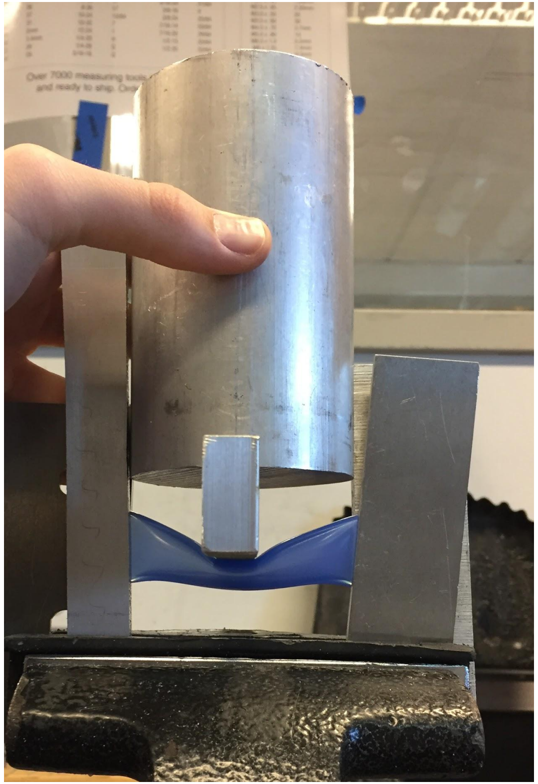
2/7/18	**Science**	**2**	Need to be able to distinguish when it is ok to collect vs. when it is snowing	**Open**
2/7/18	**Science**	**2**	Avoid the creation of a pitot tube	**Open**
2/7/18	**Science**	**1**	Nozzle or motor or flutes icing over	**Open**
2/7/18	**Electronics**	**1**	Need enough battery/power for a month long deployment	**Open**
2/7/18	**Electronics**	**3**	Cold affecting the sensors and motors	**Open**
2/7/18	**Structures**	**1**	Motor fails to align the inlet with the flute - Possible need for potentiometer or logic gates	**Open**

Tube Cold Test Results

Tube #	Height (i)	Height (f)	Deflection
Tube 1 (Room Temp.)	20.6375 mm	9.525 mm	11.1125 mm
Tube 2 (Room Temp.)	19.05 mm	11.1125 mm	7.9375 mm
Tube 1 (8℉ = -13.33℃)	12 mm	3 mm	9 mm
Tube 2 (Wet) (8℉ = -13.33℃)	14.5 mm	8.5 mm	6 mm

TOTAL WEIGHT:	17.413 N





Systems Next Steps

Task	Date Start	Amount of Time	Projected Finish Date
Sail calculations for dimensions	02/21/2018	1 week	02/28/2018
Prototype motor and tubes	02/21/2018	2 weeks	03/07/2018
Subsystem integration	03/28/2018	1 week	04/04/2018
Subsystem testing (Cold, day-in-the-life,...)	04/04/2018	1 week	04/11/2018

Structures

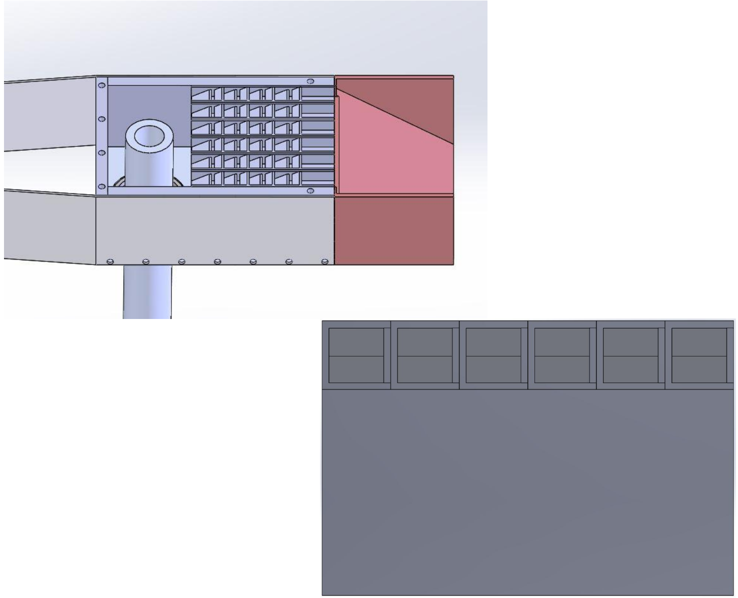
Sami Palma and Collin Doster

Requirements

Science Requirement	Mechanical Trait
0.1: Deploy on the surface of Svalbard for a month with minimal human interaction	• Base solution: extruded aluminum • Blank capsule for harsh environmental conditions • End product easily separable for ease of transport
0.2: Provide environmental data as a function of time	• Provide a space for electronics, sensors, and batteries • Electronics easily accessible with removable front cap • Sensors incorporated into structure for necessary environmental data
0.3: Collect dust samples that are distinguished by time of collection	• Provide a collection box with separable samples • Provide a motor to translate along x-axis to collect at different periods • Incorporate a flute system in order to collect dust ranging from micrograms to milligrams • Provide a chamber nozzle to allow air to flow through chamber

Design Updates & Modifications

MODEL 1 - January 2018

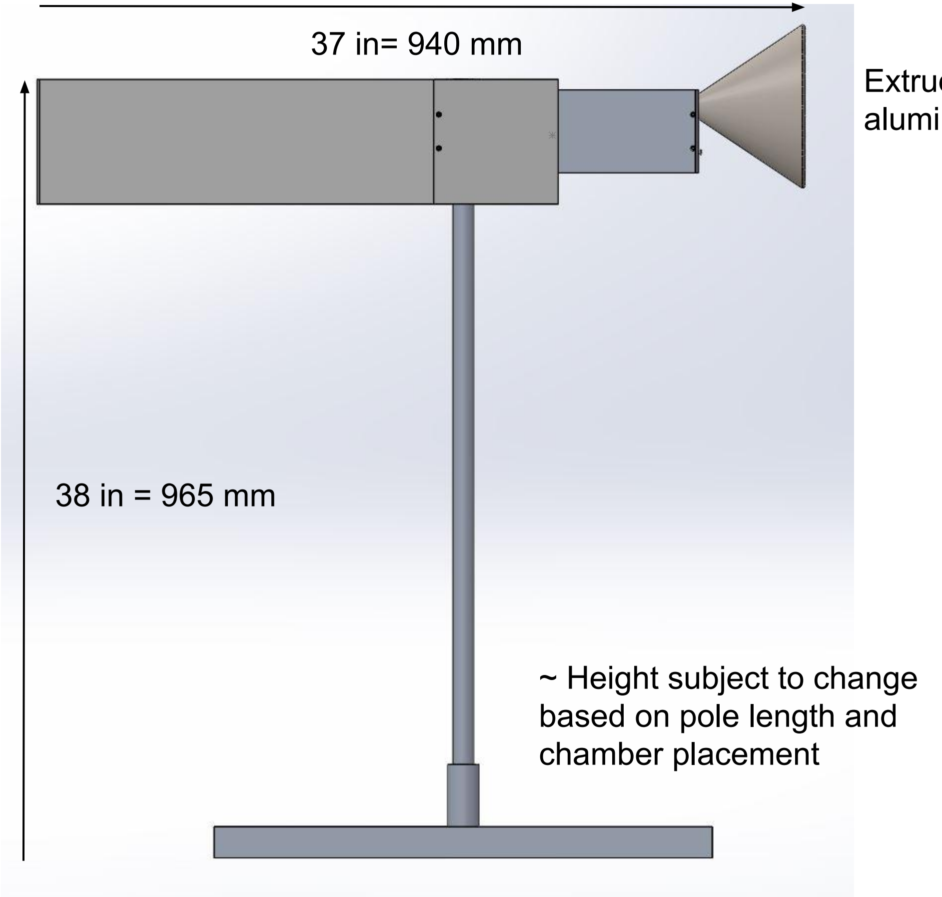


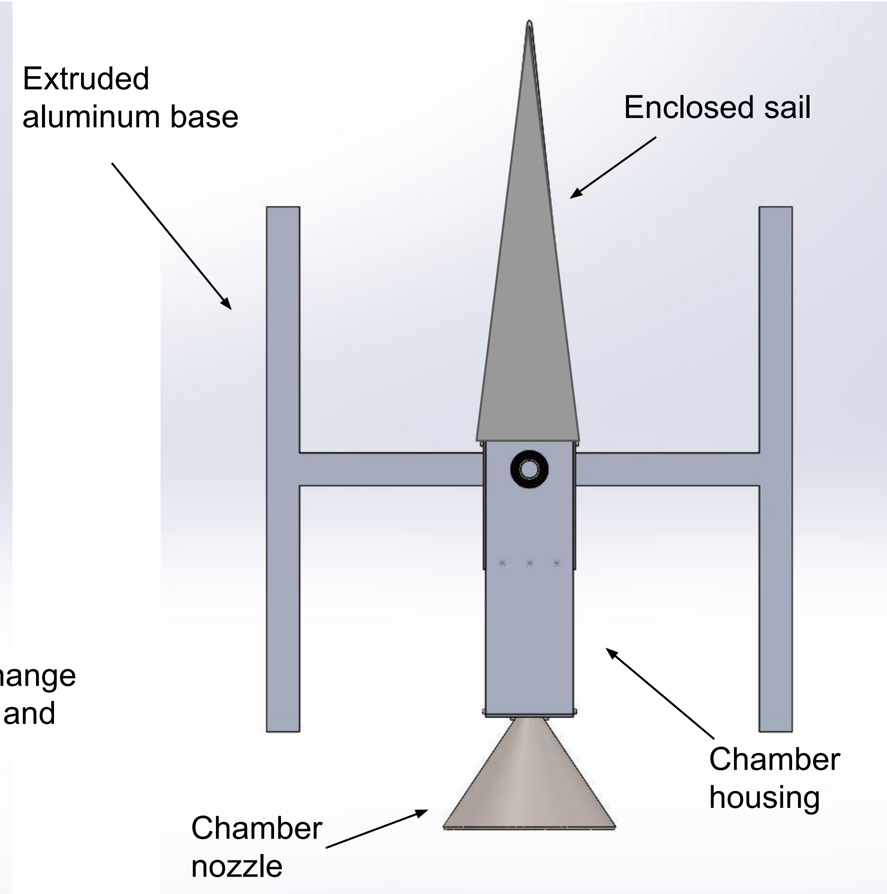
Purpose: To test flutes and distinguish best flute system

MODEL 2 - May 2018

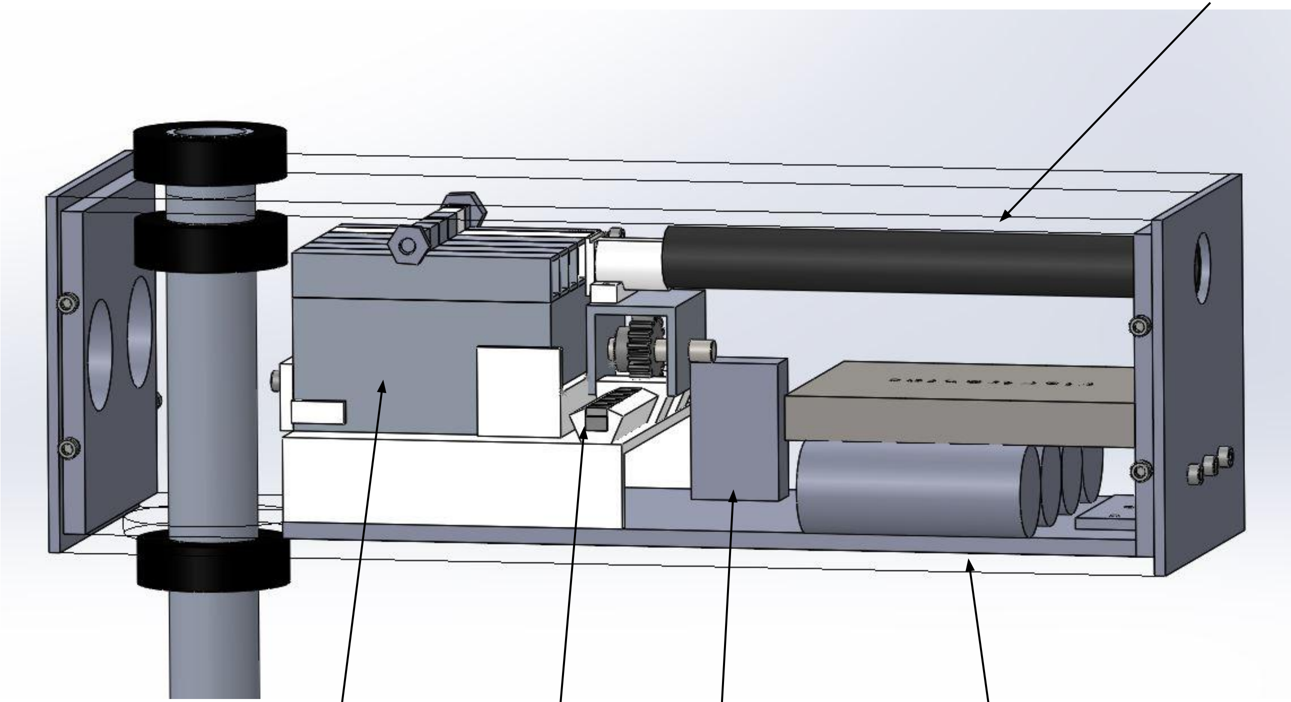
- Critical Changes:
  - Incorporate a motor to distinguish between samples
  - 4 collection units → 4 samples per mission to decrease size of product and collect a viable sample of dust
  - 1 blank for inclement weather conditions
  - Incorporate electronics with full sensor board and the use of actual batteries to collect full environmental data and move motor
  - Aim for mass manufacturability for the future products

Design Overview





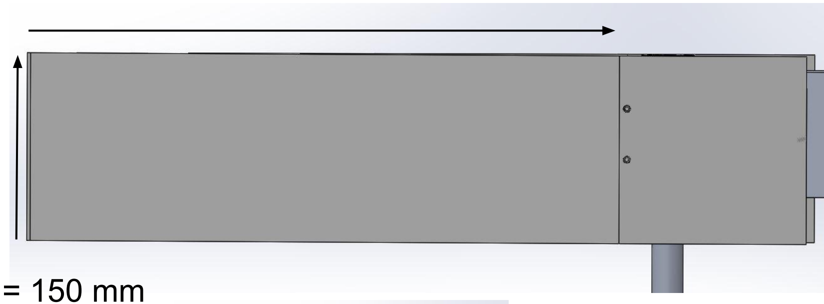
Design Overview



Specific Parts

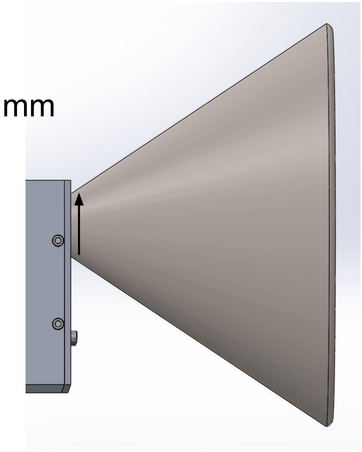
- Sail
  - Aluminum sheet metal
  - Secured to chamber with 6-32 hex screws
- Nozzle
  - Funnel from McMaster-Carr
  - Modified to fit our system
  - Secured on with L-brackets on inside and outside
- Fasteners
  - 6-32 hex screws
- Bearings
  - Shaft diameter: 1”, Housing Diameter: 2”
  - Lubrication Free Plastic Flanged Ball Bearing
  - Rated to -40 C
  - Maximum speed: 700 rpm
  - Maximum dynamic radial load: 90 lbs
  - Utilizing same thrust bearing as in MODEL 1, as the same set collar

24 in = 610 mm



6 in = 150 mm

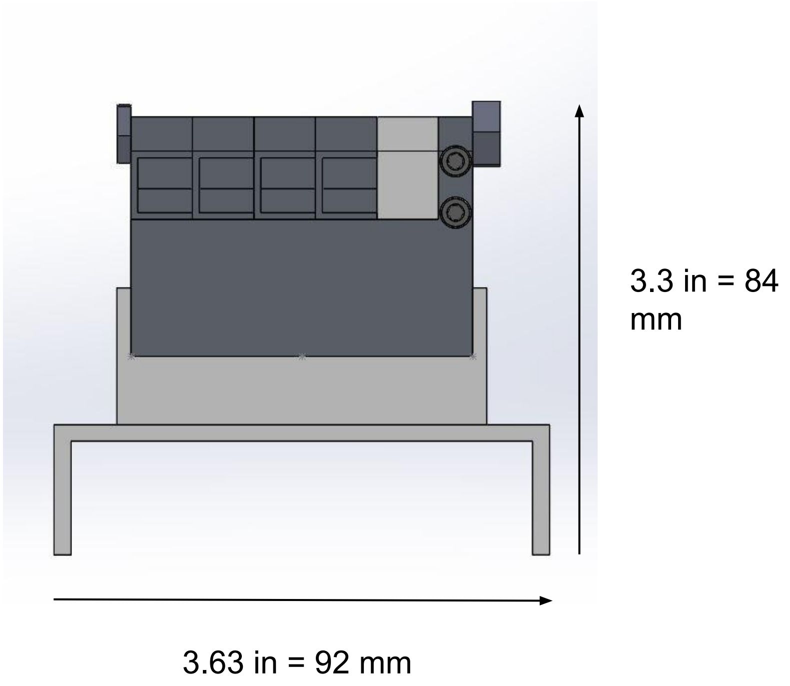
0.5 in = 13 mm



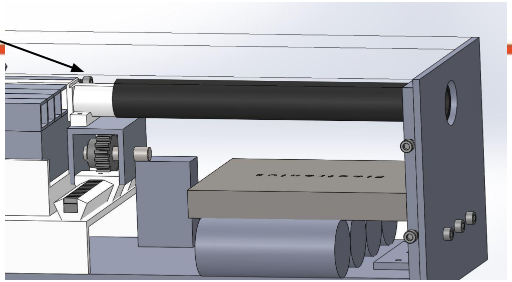
6.5 in = 165 mm

Ease of Access

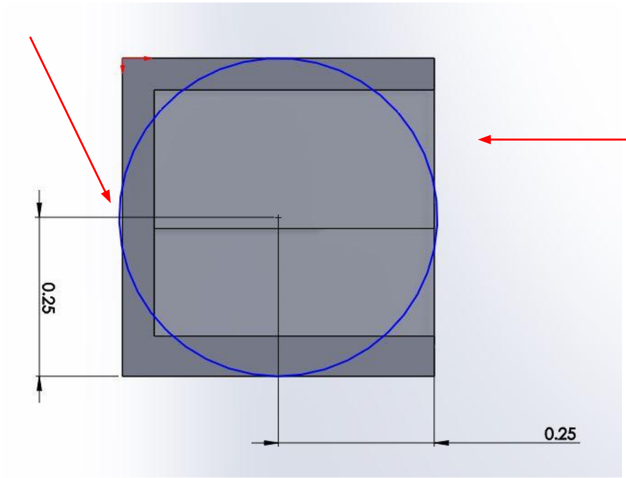
- Capsules
  - On top of removable tray that comes out through front
  - Connected to flute system
  - Collection units able to snap off from flute system for dust removal
  - Whole collection system slides out through front of chamber
- Electronics, switches, and LEDs
  - In front of collection box
  - Slide out for ease of access with capsule system
- Batteries
  - On bottom of electronics
  - Slide out with rest of inside system for easy access and replacement



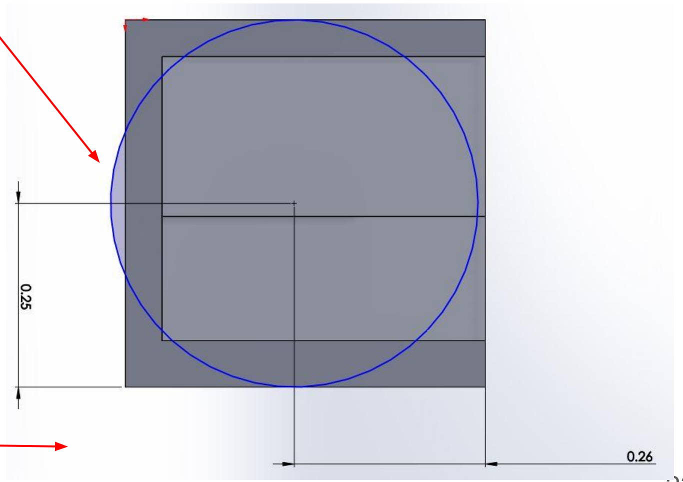
Critical Interfaces



- Tube has ID: 0.5 in = 13 mm
- Square flute has edge length of 0.44 in = 11.2 mm
  - Limit of 0.01 in = 0.254 mm on each side
  - Past this, at risk of contamination
  - Solution 1: Limit switches at the end of each flute to signify the end of each flute → precisely know our position
  - Solution 2: Tube to flute interface ID: 0.3 in = 7.6 mm



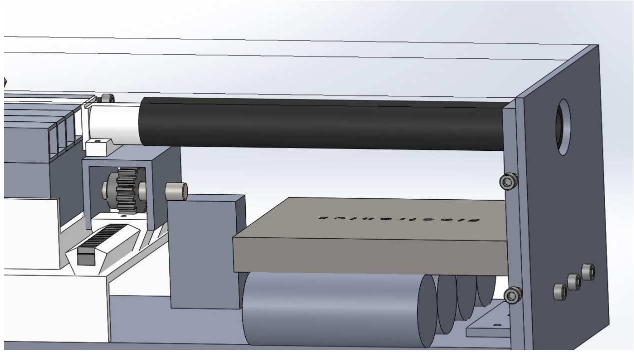
Tube straight on flute

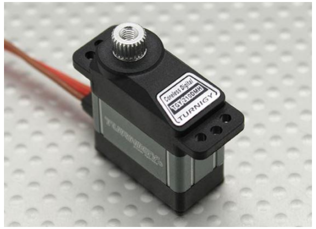


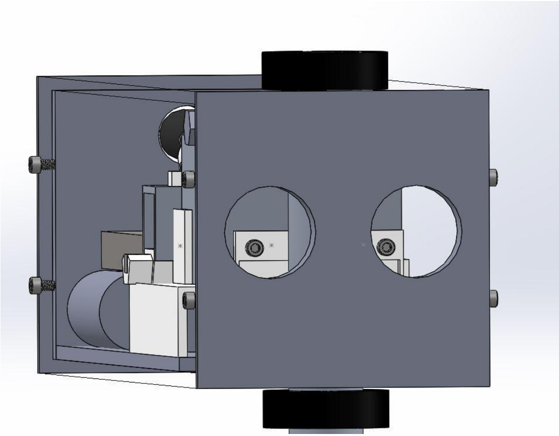
Tube off of tube by 0.01 inches

Critical Interfaces

- Tube:
  - Length: 5.5 inches
  - Cold rating: -40 C
  - Prototyping and testing: Cold testing
- Motor:
  - Servo motor
  - Estimated torque: 3.1 kg/cm = 43 oz/in.
  - Testing: Current draw
  - Future Testing: Tube, rack & pinion interface
- Exhaust Holes:
  - Placement in back of chamber







Rack & Pinion: Custom or Ordered

Option	Pros	Cons
Custom Designed Rack & Pinion (Delron)	● Designed to our exact specifications ● Mates to interface (between rack & pinion and motor) very well ● Low coefficient of friction	● Extra manufacturing time ● Another custom part
Ordered Rack & Pinion (Tetrix Robotics)	● Ordered ● Only modifications to the part	● Need to lubricate it so it does not freeze/stick ● Need exact measurements for 3D printed interfaces

Blank Flute: Block or Drain?

Option	Pros	Cons
Blocked Blank Flute	● Weight cuts ● Ideally, no moisture enters the system at all	● Air flow might still enter and clog the chamber nozzle ● Potential risk for collection outside the blank capsule
Drained Blank Flute	● Outlet for any moisture entering the system ● Does not impede air flow	● Allowing moisture into capsules → possible problem of accumulation ● Potential problem of freezing in the capsules

Manufacturing Plan

Custom Part	Material	Method of Manufacturing	Estimated Time
Chamber Housing (box, end caps)	Aluminum	Mill	2 weeks
Flutes	Aluminum	CNC	2 weeks
Collection Box	Aluminum	CNC	1 week
Sail	Aluminum	Mill	1 week
Loading Tray	Aluminum, PLA	Mill, 3D Printing	1 week
Rack & Pinion connections	PLA	3D Printing	1 week

Manufacturing Plan

Ordered Part	From/Part Number	Modifications
Chamber Nozzle (Funnel)	McMaster-Carr	Secure to chamber with L-brackets
Tube	McMaster-Carr	Cut to desired length
Central Pole	Online Metals	Add holes for base attachment
Motor	Hobby King	Modify for continuous rotation
Rack & Pinion	Tetrix Robotics	Adjust to actual length and align with motor system
Fasteners, Bearings, Set Screw Collars	McMaster-Carr	None

Future Mass-Manufacturing Plan

- Flutes
  - Injection molding → mass manufacturability plans
  - Injection molding: creating a cast for the flutes and collection chamber that could then be used to create more flutes and chambers on a massive basis
- Base
  - Ground screw
  - Mass order to make the cost worth it
- Sail
  - Weld in the future for secure attachment
  - CON: not as easily transported to deployment site
- Nozzle
  - Weld in the future for secure attachment
  - CON: not as easily transported to deployment site

Testing

- Past testing:
    - MODEL 1 Testing
    - Showed us viability of MODEL 1 including base, sail, flute system, nozzle, and bearing
    - Illustrated that current system for collecting dust will work without a motor
- Future testing:
    - Motor testing: to test the torque of motor and ensure that is sufficient to move the tube to different samples
    - Tube testing: to test that the tube does not impede dust collection and will not stop functioning after continued use
    - Cold testing: to test that both the motor and the tube survive the frigid temperatures expected at deployment in order to continue the mission requirements

Structures Budget

Component	Cost ($)	Already Spent ($)
Motor	51.82	51.82
Raw Material (Aluminum)	151.45	0
Raw Material (3D Printing)	50	0
Nozzle	7.30	7.30
Tube	11.80	11.80
Rack & Pinion	29.20	29.20
Central Pole	33.47	0
Fasteners (including screws and bearings)	82.02	0
Total	550 (including S&H estimate)	100.12
Allowed	600	

Structures Next Steps

Task	Date Start	Amount of Time	Projected Finish Date
Manufacturing Drawings	02/21/2018	1 week	02/28/2018
Order parts	02/21/2018	2 weeks	03/07/2018
Testing prototypes	02/21/2018	1 week	02/28/2018
CNC’d parts	02/21/2018	2 weeks	03/07/2018
Begin hand manufacturing	03/07/2018	4 weeks	03/28/2018
Begin assembly	03/28/2018	1 week	04/04/2018
Subsystem testing	04/04/2018	1 week	04/11/2018
Make changes based on testing results	04/11/2018	1 week	04/14/2018

Electrical

Owen Lyke and Riley Hadjis

Electrical Requirements

Science Objective	Requirement	Design Traits
Quantify correlation of dust collection data to environmental conditions.	**0.2:** The Cryo-Aerosol Dust Collector shall record data that will link dust deposition patterns to wind events and atmospheric patterns.	Onboard microcontroller to sample sensors, record data, and control dust collection.
Record environmental conditions.	**1.21:** The Cryo-Aerosol Dust Collection Team shall record the time stamp, location, wind speed, wind direction, sample height from ground, temperature, and humidity.	Real time clock, differential pressure sensor, magnetometer, temperature sensor, and humidity sensor.
Control dust collection period.	**1.25:** The Cryo-Aerosol Dust Collector shall have the ability to start and stop dust collection selectively.	Collector selecting mechanism controlled by microcontroller, function determined by program loaded by the user.
Improve temporal resolution of dust collector.	**2.21.1:** The Cryo-Aerosol Dust Collector shall record the sample interval for each of the environmental sensors.	Real time clock will record the sample interval along with each measurement.
Characterize dust transport in different heights.	**2.21.2:** The Cryo-Aerosol Dust Collector team shall record wind speed as a function of height above the ground.	Wind speed will be recorded at each module, each module will be pre-programmed with its deployment height.
Enable long term data collection.	**2.22.1:** The system shall have enough power to operate for a one month deployment period.	A $LiNiMnCoO_2$ rechargeable battery will provide reliable long-term performance in an antarctic environment.

Ambiguous Design Traits

- Data logging duty cycle of sensors
- How often will chambers be switched
- How sensitive is the “blank” chamber activation (this is largely important because of the power consumption)
- What information exactly is required for a status check?
  - (I think: rough battery level indication, logging status (logging or not), and maybe an indication of SD full)

Schematic - Power Distro Detail

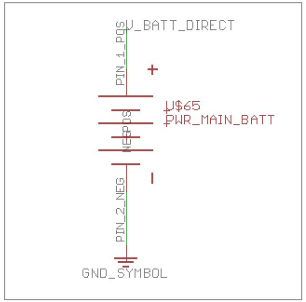
Two main power concerns:

- 3.3V source for sensors, SD, and uC.
- Raw battery voltage for servo

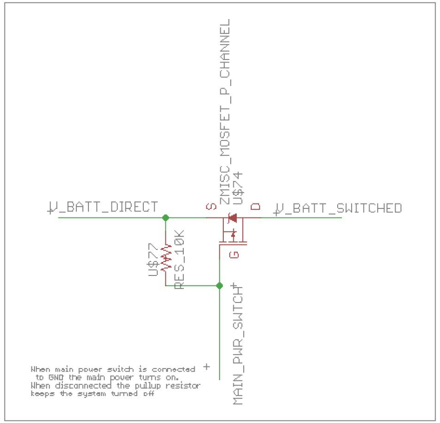
Four main switchable “zones” to reduce current draw

- **Main:** connects and disconnects the entire system from the battery.
- **Servo:** disconnects servo from power when not in use.
- **High Draw Sensors:** disconnects the SD card, pressure sensor, and battery voltage divider from power when not in use.
- **Low Draw Sensors:** separate switch allows polling of some environmental conditions without powering high draw sensors

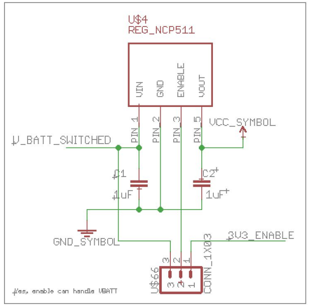
Battery (2 POS CONN)



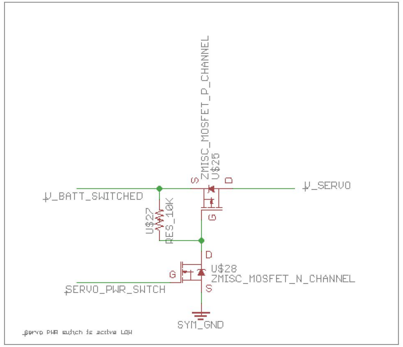
Main Power Switch Circuit



3.3V Regulator



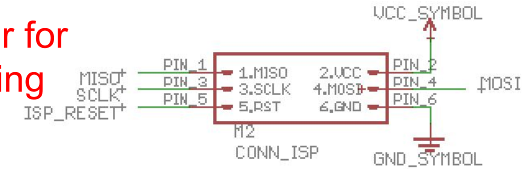
Servo Power Switch

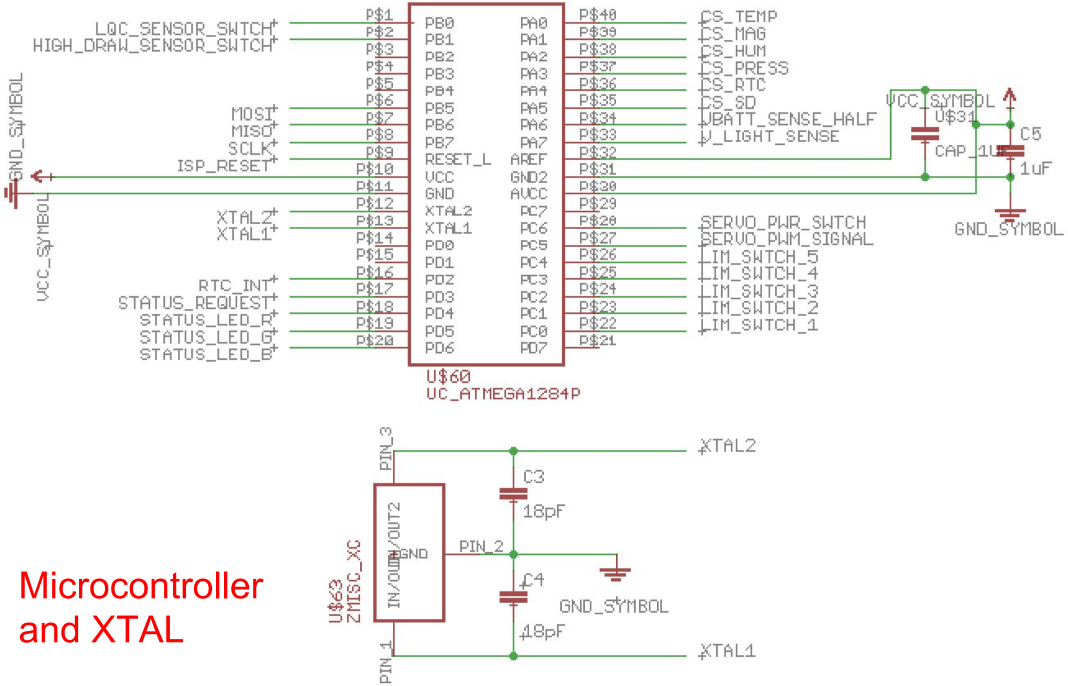


Schematic - Microcontroller

- Programming over ISP with AVR ISPmkII
- Low power external oscillator
- Interrupts for limit switches, RTC, and status request inputs
- SPI bus used for sensors and SD card, along with CS lines
- Digital pins used to control MOSFET pair power switches
- Servo signal output
- RGB status LED output

ISP Header for Programming



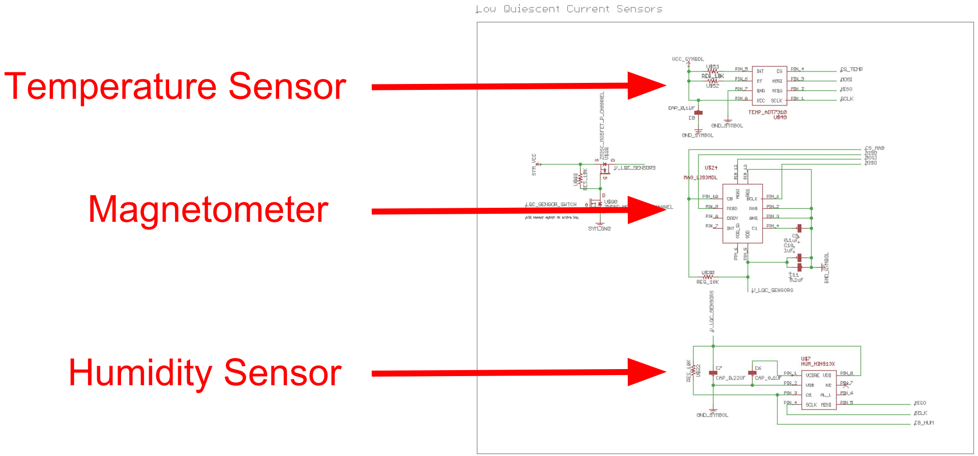


Microcontroller and XTAL

Schematic - Sensors and SD

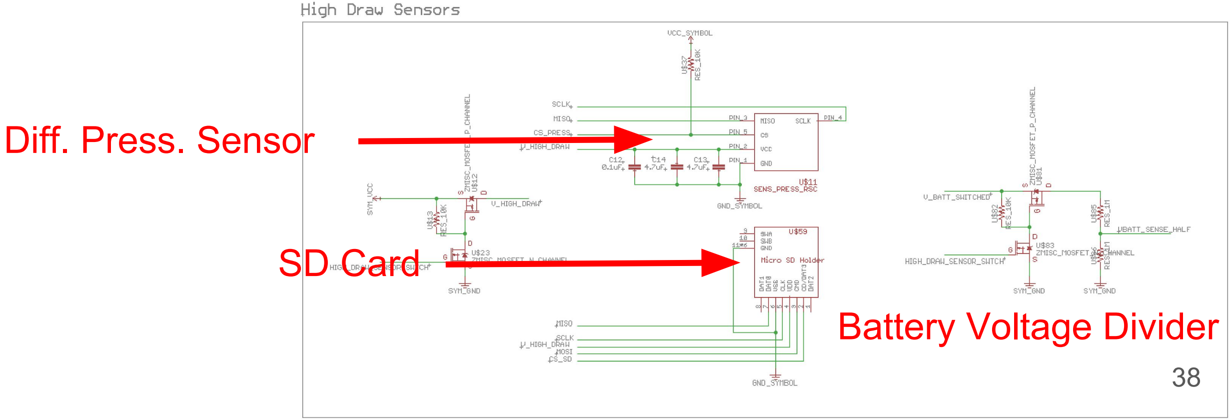
SPI Bus Sensors:

- Windspeed (diff. press.)
- Wind Direction (magnetometer)
- Air Temperature
- Humidity
- SD Data storage

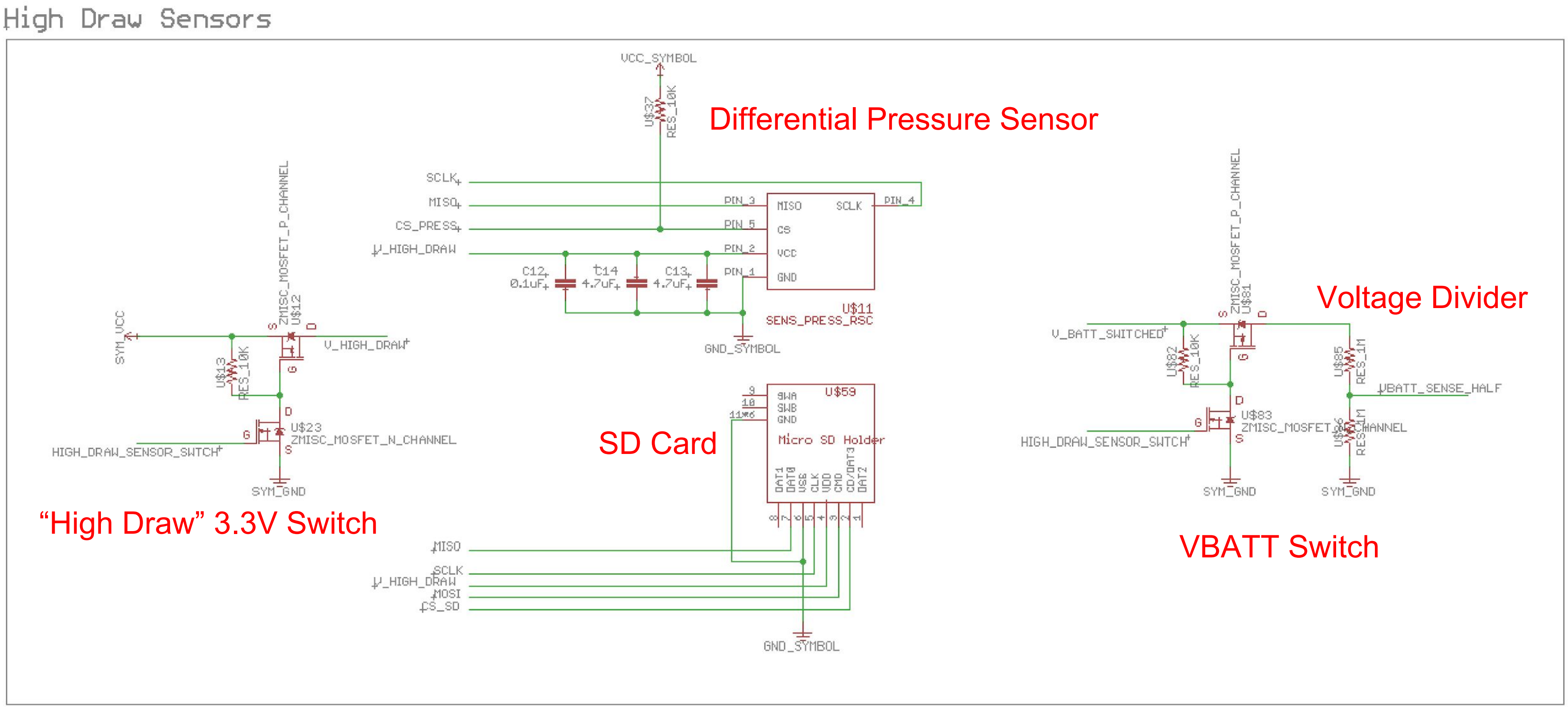


Analog Sensors:

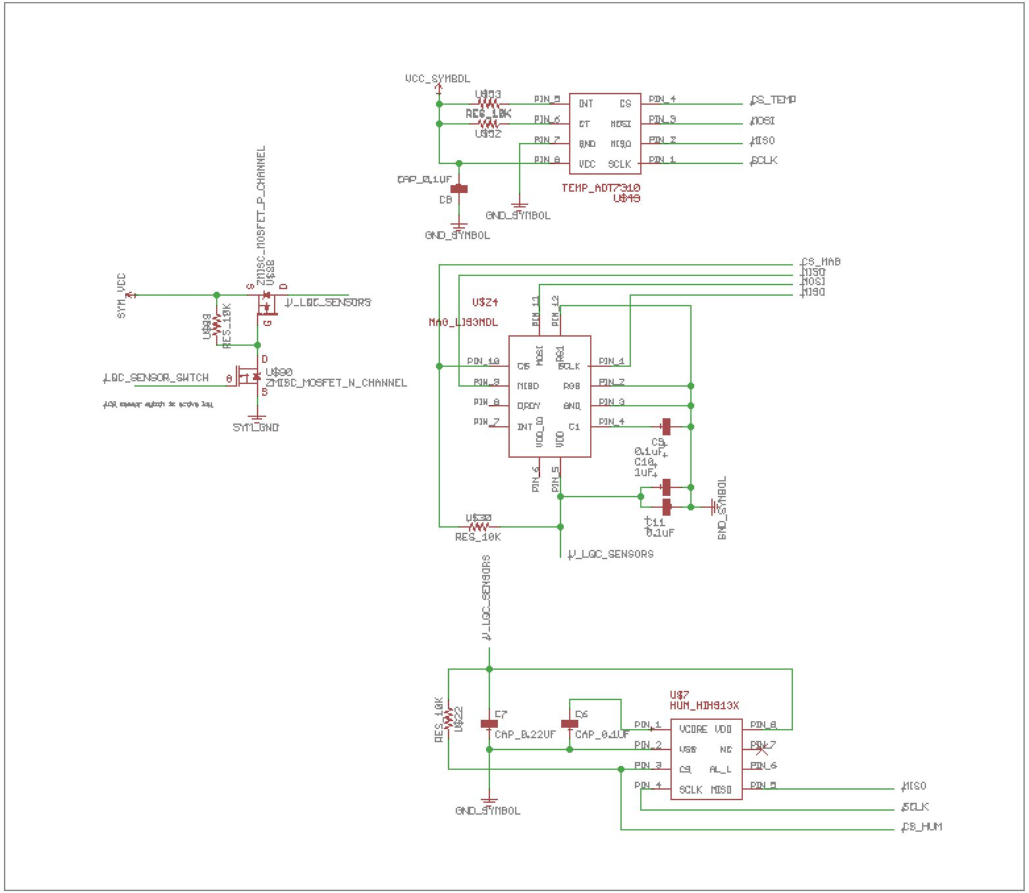
- ½ Battery voltage
- Photodiode



Schematic - High Current Sensors



“Low Draw” 3.3V Switch

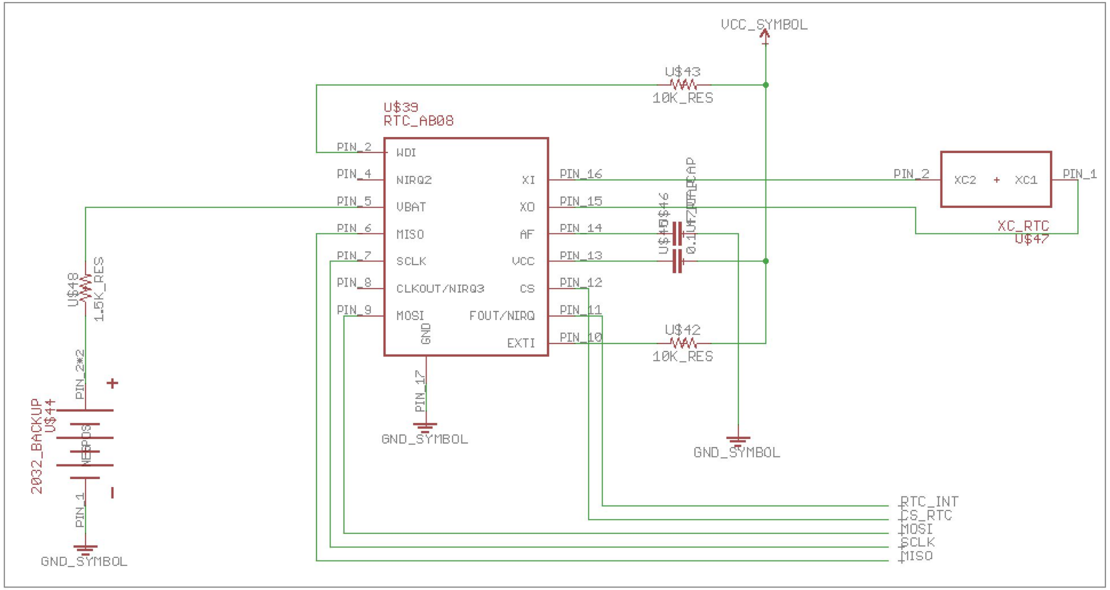


Temperature Sensor

Magnetometer

Humidity Sensor

RTC (ALWAYS POWERED)



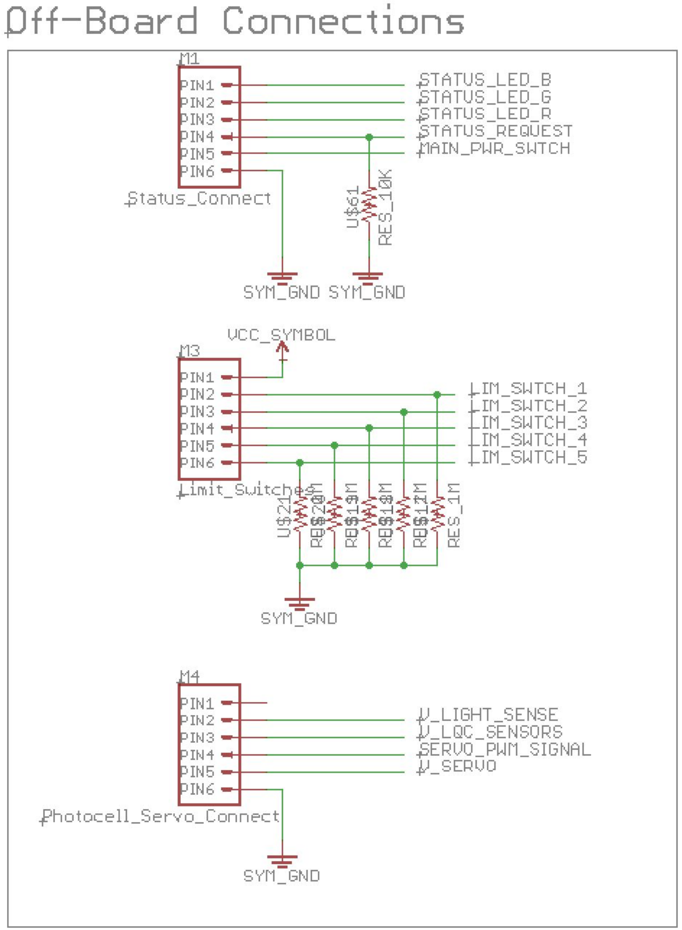
RTC Power Sources:

- 3.3V regulator when system is on
- Backup battery cell when system is off

RTC interrupt pin connected to external interrupt of the microcontroller to provide wake-up messages at the desired time

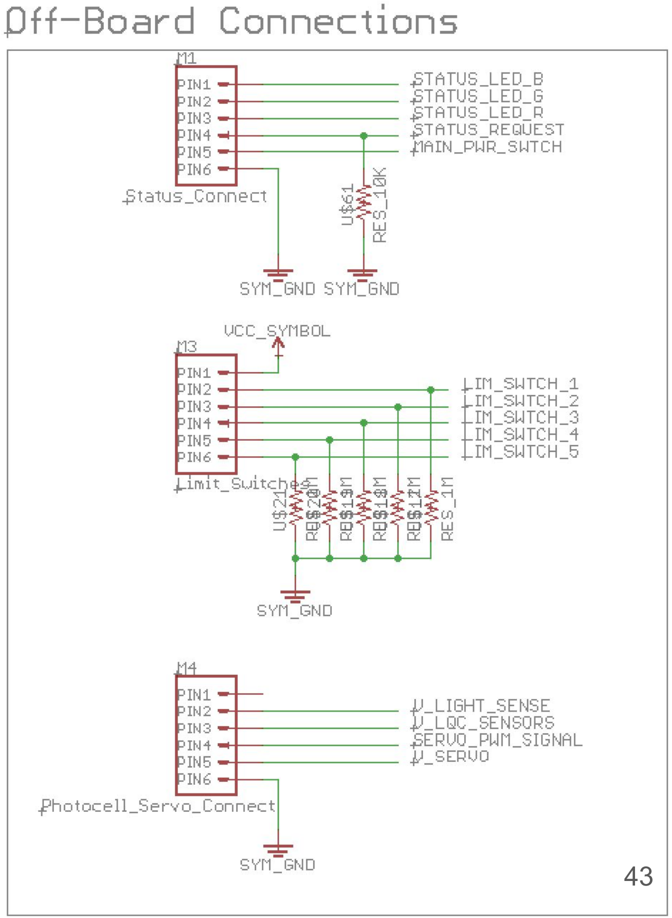
Schematic - Servo Control

- Servo will be powered directly by the battery voltage and the input signal will come from the uC at 3.3V. This has been tested.
- 1M ohm pull-down resistors used to reduce current leakage from limit switches.



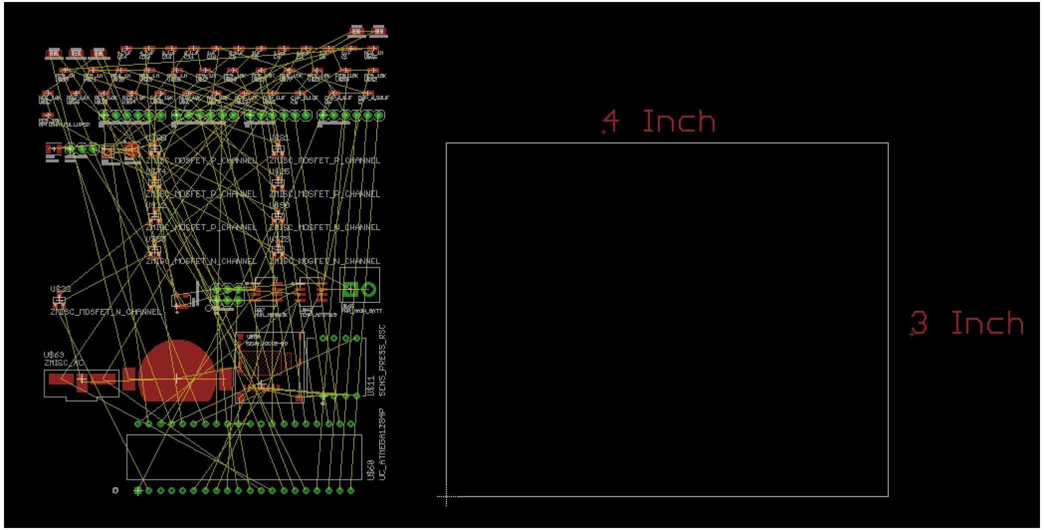
Schematic - Interfaces

- Toggle switch (locking) is used to completely disconnect the battery, or to power up the system.
- Pushbutton switch is used to request a status update
- LED (R,G, or Y) is used to indicate the status of the system (6 possible codes, 3 colors and either solid or flashing)
  - Logging, nominal
  - Logging, low battery
  - Not logging, SD full
  - Not logging, general error
  - No response (OFF)
- Not pictured: FTDI connection for serial communication to computer



Board Layout

- Packages for sensors have been checked for board layout and routing
- Preliminary layout provided an estimate of required volume of 4”x3”x2” The 2” dimension is in case the Eagle board size restriction necessitates a two-layer design.
- This volume does not include the volume of the batteries, which is 4 of 1”x1”x2.5” volumes in any necessary configuration
- Route will occur according to the design rules for SeeedStudio in order to ensure the PCB is manufacturable.



Testing - Introduction

Testing falls into three categories:

- Power testing
- Sensor verification + calibration
- Use of the sensor / DITL testing

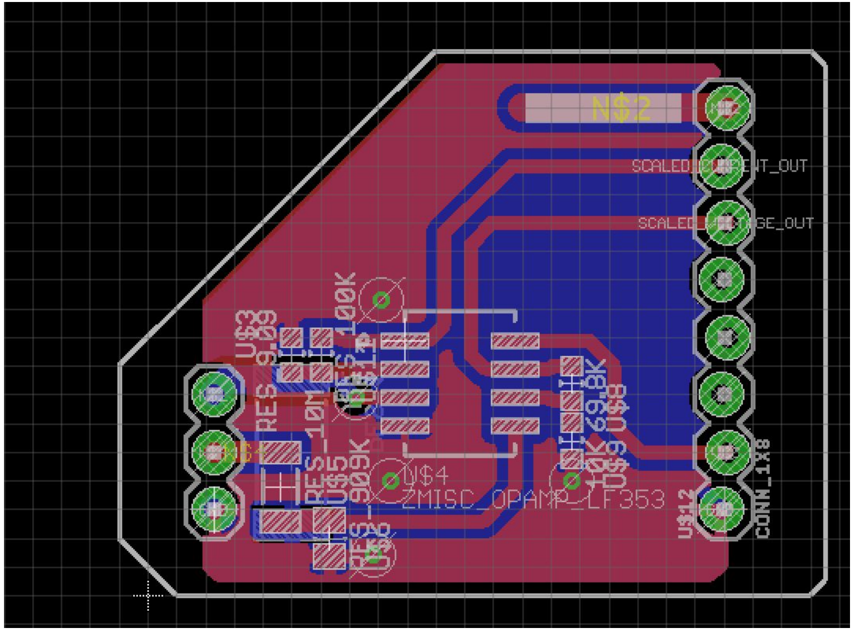
Testing - Power Consumption

Goal: Prove that the sensor can last as long as required (1 month) and also characterize the battery voltage to energy capacity curve at temperature.

How: Use a separate datalogger to measure the voltage of and current out of the battery over time, then deploy the system as it would be for real. Use the data to determine the threshold voltage at which the status will change to “low battery”

Status:

- Signal conditioning board designed
- Sparkfun Logomatic V2 datalogger in possession
- Cold chambers available for testing at NSIDC



Testing - Sensors / Calibration

Sensor	Test Method	Planned Calibration	Test Location
SD Card	Write and verify text files	None	Space Grant
Windspeed	Stream data to serial port	Wind tunnel testing	ITLL Wind Tunnel
Wind direction	Stream data to serial port	None	Space Grant
Temperature	Stream data to serial port	Ice water slurry	Space Grant
Humidity sensor	Stream data to serial port	None	Space Grant
Real Time Clock	Stream data to serial port	Drift measure over DITL	NSIDC
Photodiode	Stream data to serial port	None	Space Grant (Outdoors)
Chamber Position	Observe movement	Measure precision, adjust limit switch position	Space Grant

Testing - User Interface / DITL

Goal: Prove operation of the sensor in replication environment and usability by researchers in cold weather gear

How: Integrate electronics into structural system along with battery. Follow the procedure for deployment and take notes. Perform a status inquiry, note whether message was understandable. Turn off the sensor and make note of difficulties in transferring data to a computer.

Status:

- Tentatively planned for April 10 at NSIDC

Electrical Budget Review

Component	Cost Per Sensor ($)	Already Spent ($)
Individual Electronic Comp.	161.30	350.14
Batteries	52.80	52.80
PCB Production	50	0
S&H	0	20.89
Total	264.1	423.83
Allowed	450	450

The components listed are enough to produce two models, one for testing and one for deployment, however the allowed budget is for one model, so the apparent overrun is acceptable.

Electronics Next Steps

Task	Date Start	Amount of Time	Projected Finish Date
Final schematic review	2/20/18	2 days	2/22/18
Route board	2/22/18	5 days	2/27/18
Order boards	2/27/18	0 days	2/27/18
Begin code development	2/27/18	NA	NA
Receive boards, populate	3/13/18	7 days	3/20/18
Preliminary testing	3/20/18	2 days	3/22/18
Sensor calibration	3/27/18	2 days	3/29/18
Power testing	4/3/18	2 days	4/4/18
DITL testing	4/10/18	7 days	4/20/18

Conclusions

Budget Overview

Model 2 Budget Overview

Electronics Component	Amount ($)
Order E1	64.7
Order E2	359.13
Total	423.83
Allowed	450

Structures Component	Amount ($)
Order S1	51.82
Order S2	29.2
Order S3	19.1
Total	100.12
Allowed	600

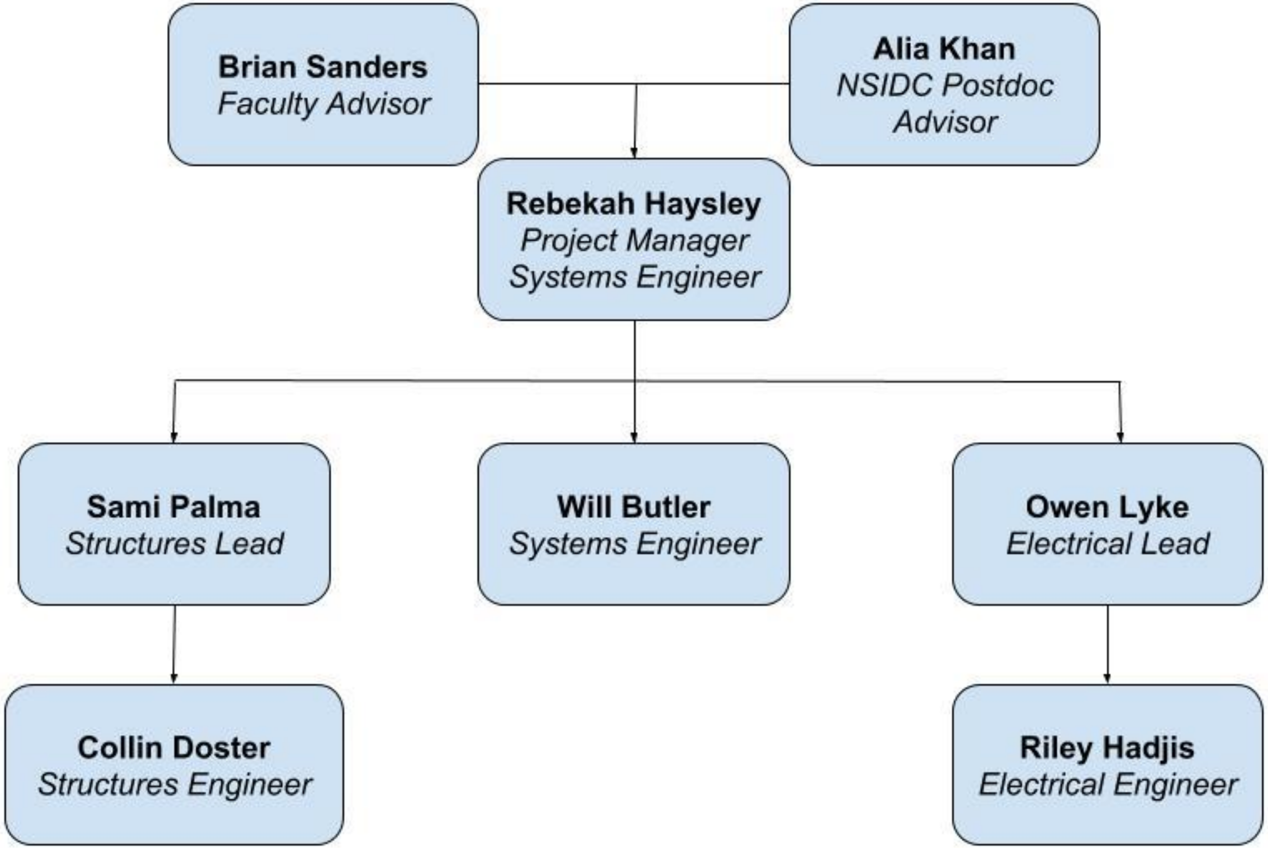
Systems Component	Amount ($)
Total	0
Allowed	50

Margin	Amount ($)
Total	0
Allowed	50

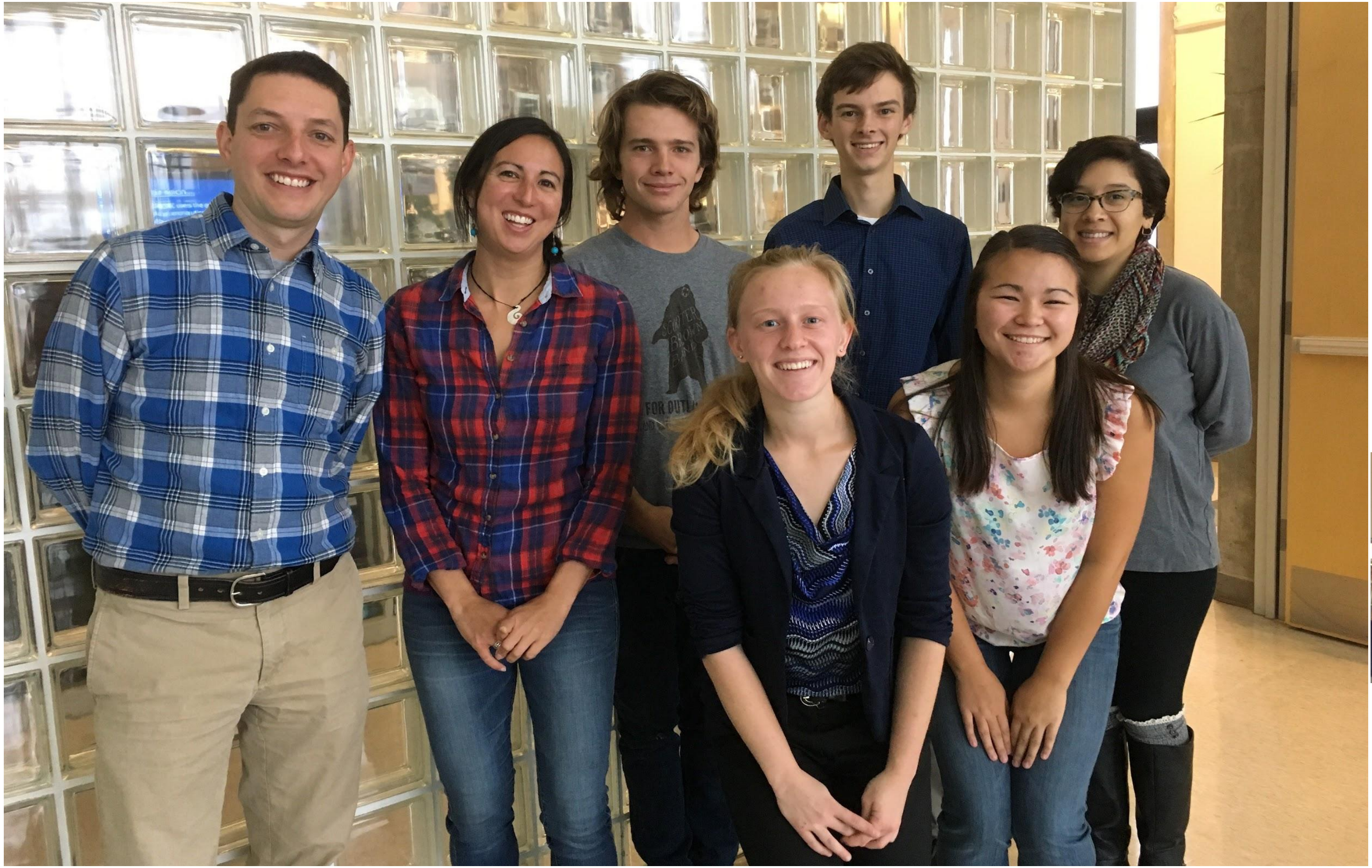
Overall Budget	Amount ($)
Total	523.95
Overall Budget	1150

Notes

Team Structure



Team Picture!



Thank you!

Questions?

Sources

Cryo Dust Collection and NSIDC

Khan, A. L., S. Wagner, R. Jaffe, P. Xian, M. Williams, R. Armstrong, and D. McKnight (2017), Dissolved black carbon in the global cryosphere: Concentrations and chemical signatures, Geophys. Res. Lett., 44, doi:10.1002/2017GL073485.

http://www.soilerosionproducts.com/products/bsne2/

https://www.eea.europa.eu/highlights/black-carbon-better-monitoring-needed