STAR

Satellite Testbed for Attitude Response

Matt Hong, Nick Andrews, Dylan Cooper, Colin Peterson, Nathan Eckert,
Sasanka Bathula, Cole Glommen

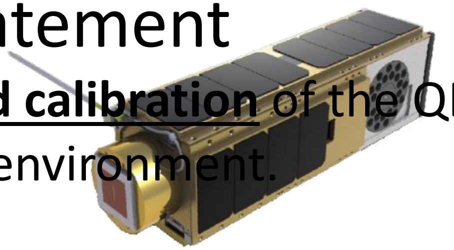
Introduction

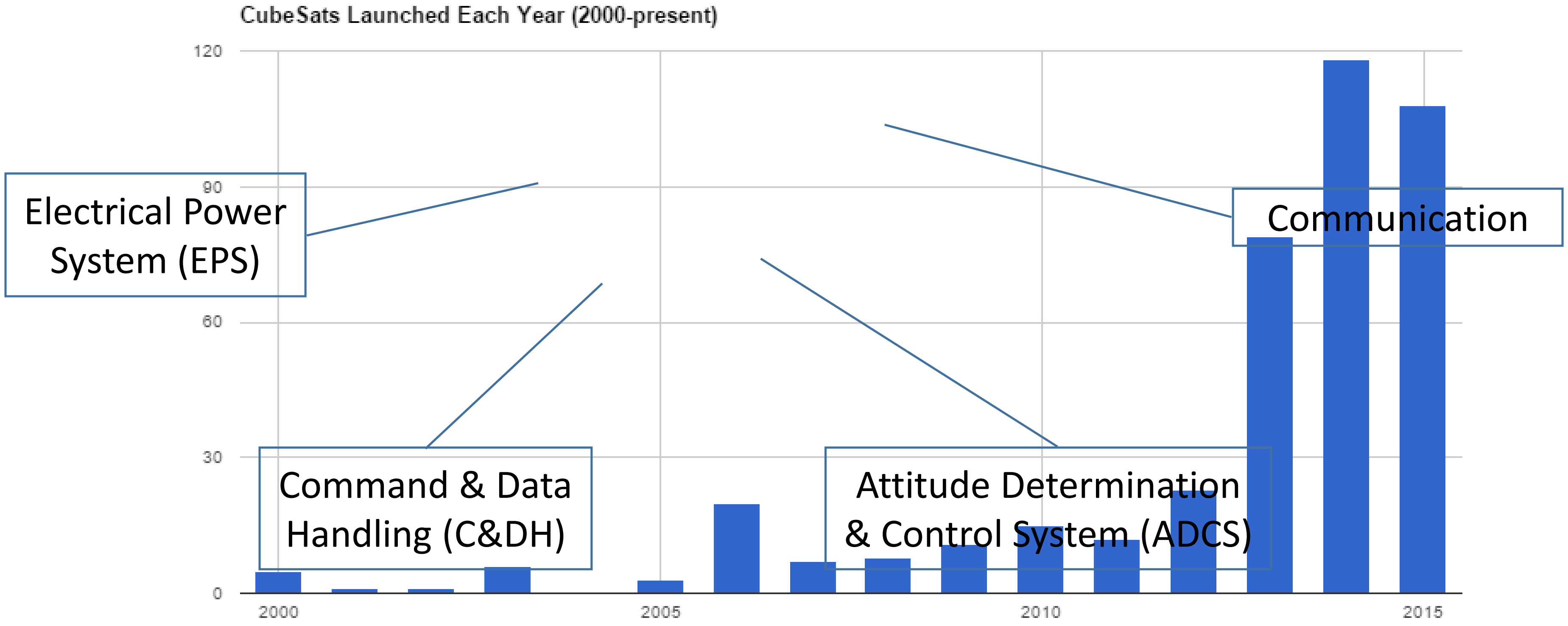
CubeSat

- Small scale satellites used for space research
- Feasibility of scientific research
- Low budget missions
- Significance of ground testing

Problem Statement

Develop a **test suite** that will allow for the **validation and calibration** of the QB50 Attitude Determination and Control System based (**ADCS**) on simulated mission environment.

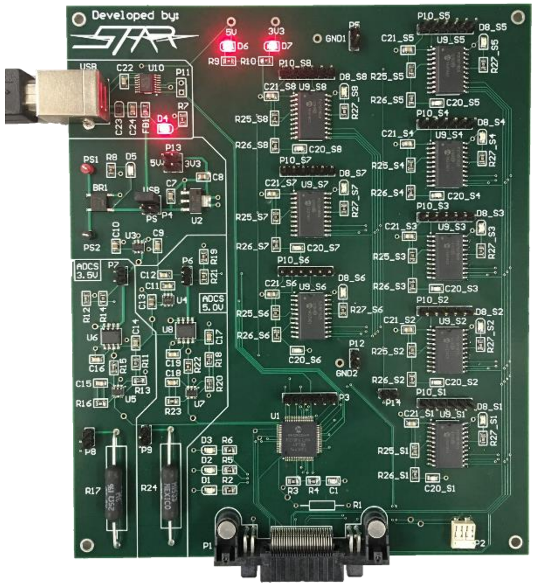




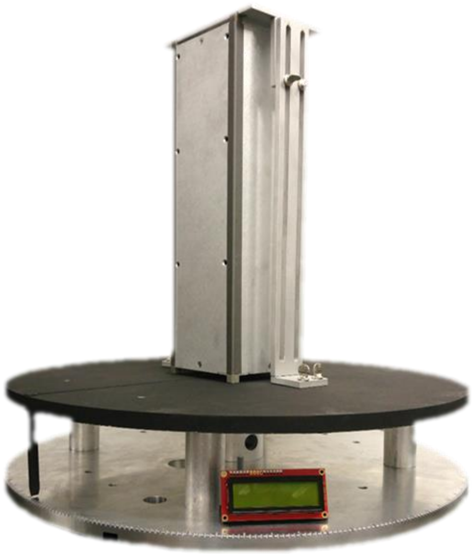
Project Overview

- Develop an ***interface board*** that will allow for a hardware-in-the-loop simulation by running a simulation on the ADCS board.
- Develop a ***turntable*** apparatus for Sun sensor calibration.
- Develop ***test apparatus*** to test functionality of magnetorquers.

①



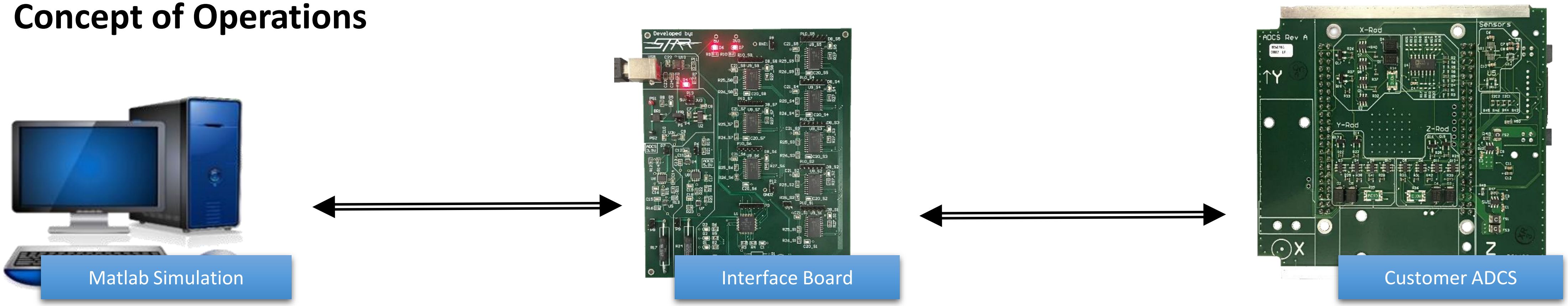
②



③

Interface Board

Concept of Operations



3. Log necessary data for analysis

1. Send Simulation data to Interface Board

2. Emulate sensor readings to ADCS Board

Levels of Success

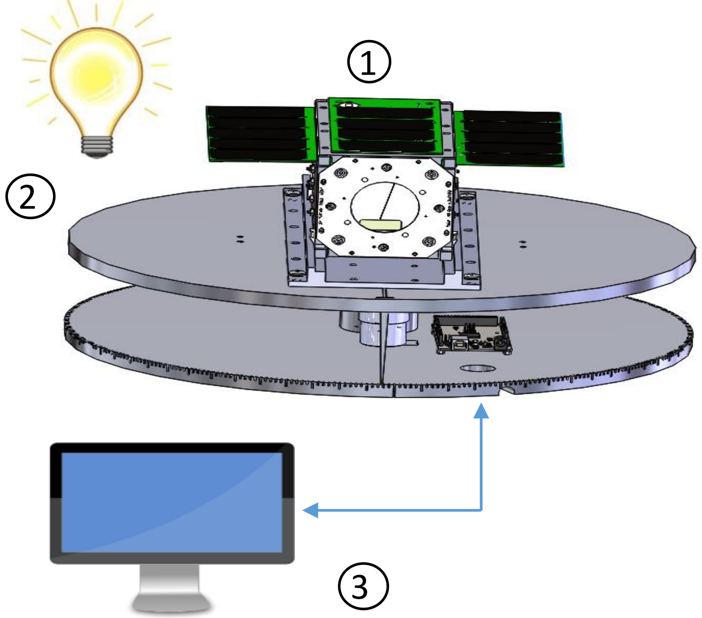
Level 1	- Create an interface board that sens digital sensor data to customer ADCS board - Computer and interface board will communicate over USB
Level 2	- Add a graphical user interface (GUI) that allows user to disable sensor - Log CubeSat simulated dynamics
Level 3	- Feed magnetorquer output back into simulation

Critical Project Elements

CP.1	- Get top plate reflectance rate < 5% (3%)

Sun Sensor Turntable

Concept of Operations



1. **Integrate CubeSat**
2. **Rotate turntable**
3. **Compare table angle to angle reported by CubeSat**

Levels of Success

Level 1	- Create a turntable with +/- 0.5 degree accuracy
Level 2	- Motorize turntable
Level 3	- Develop automated control

Critical Project Elements

CP.1	- Get top plate reflectance rate < 5% (3%)

HelmHoltz Cage

Concept of Operations

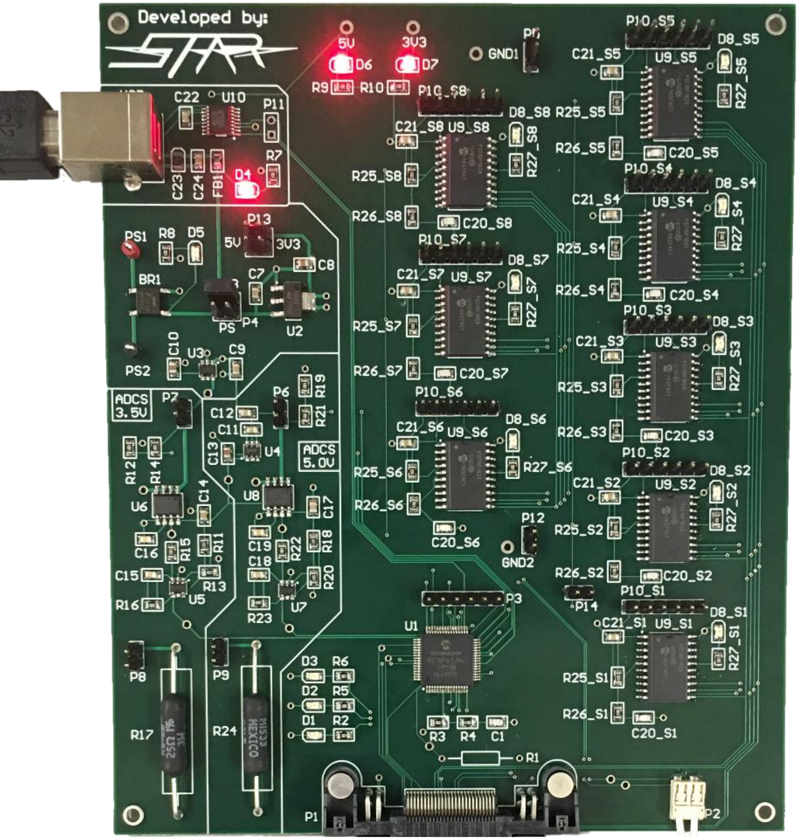
1. **Integrate CubeSat**
2. **Rotate CubeSat without magnetorquer**
3. **Rotate CubeSat with magnetorquer**
4. **Compare results**

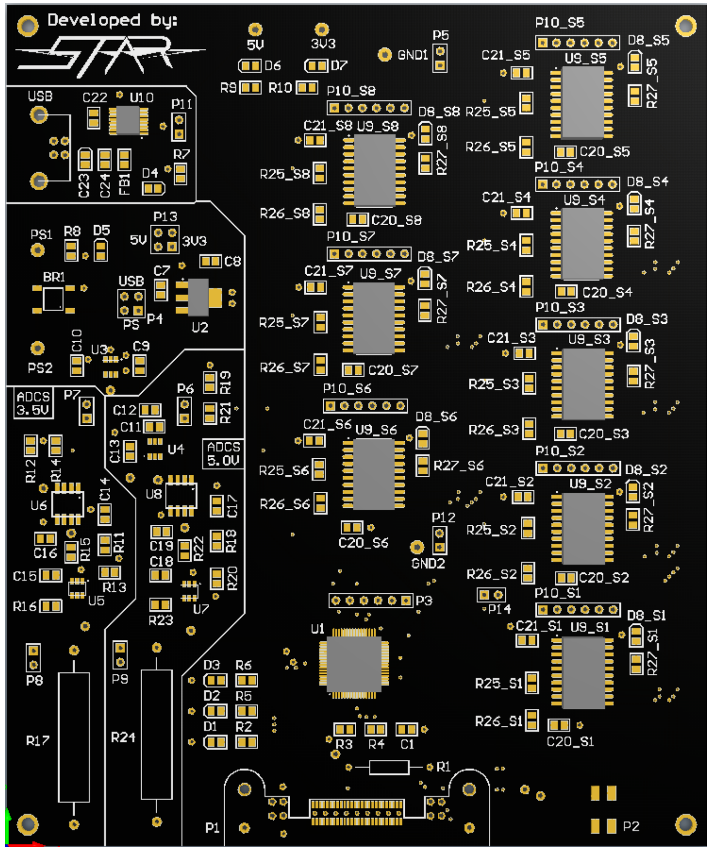
Levels of Success

Level 1	- Verify functionality of magnetorquer
Level 2	- Fit in standard laboratory

Critical Project Elements

CP.1	- Minimize torque on line
CP.2	- Prevent line from snapping

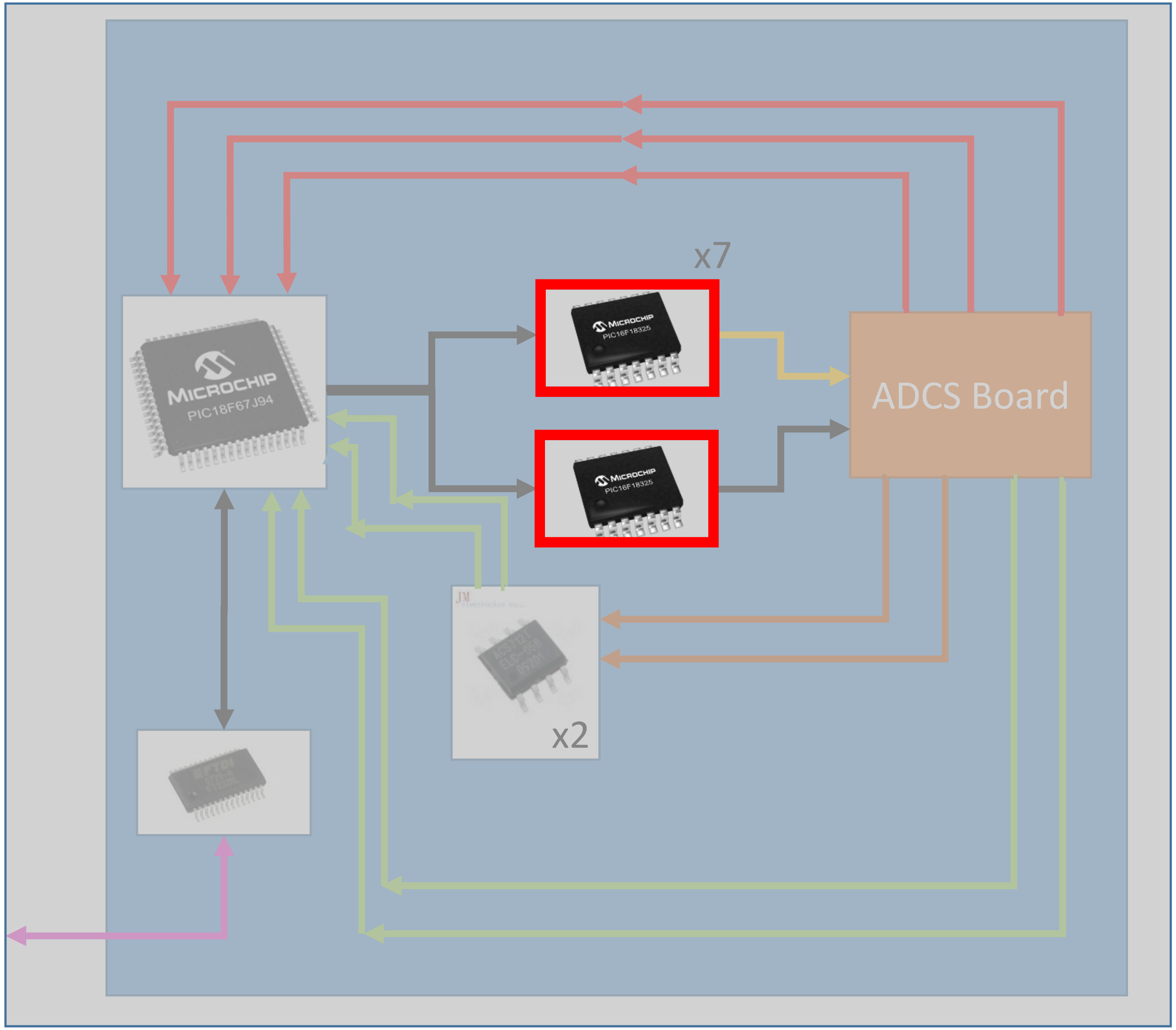




Interface Board

Testing Overview and Results

Overall Required Functionality



Changes since Test Readiness Review

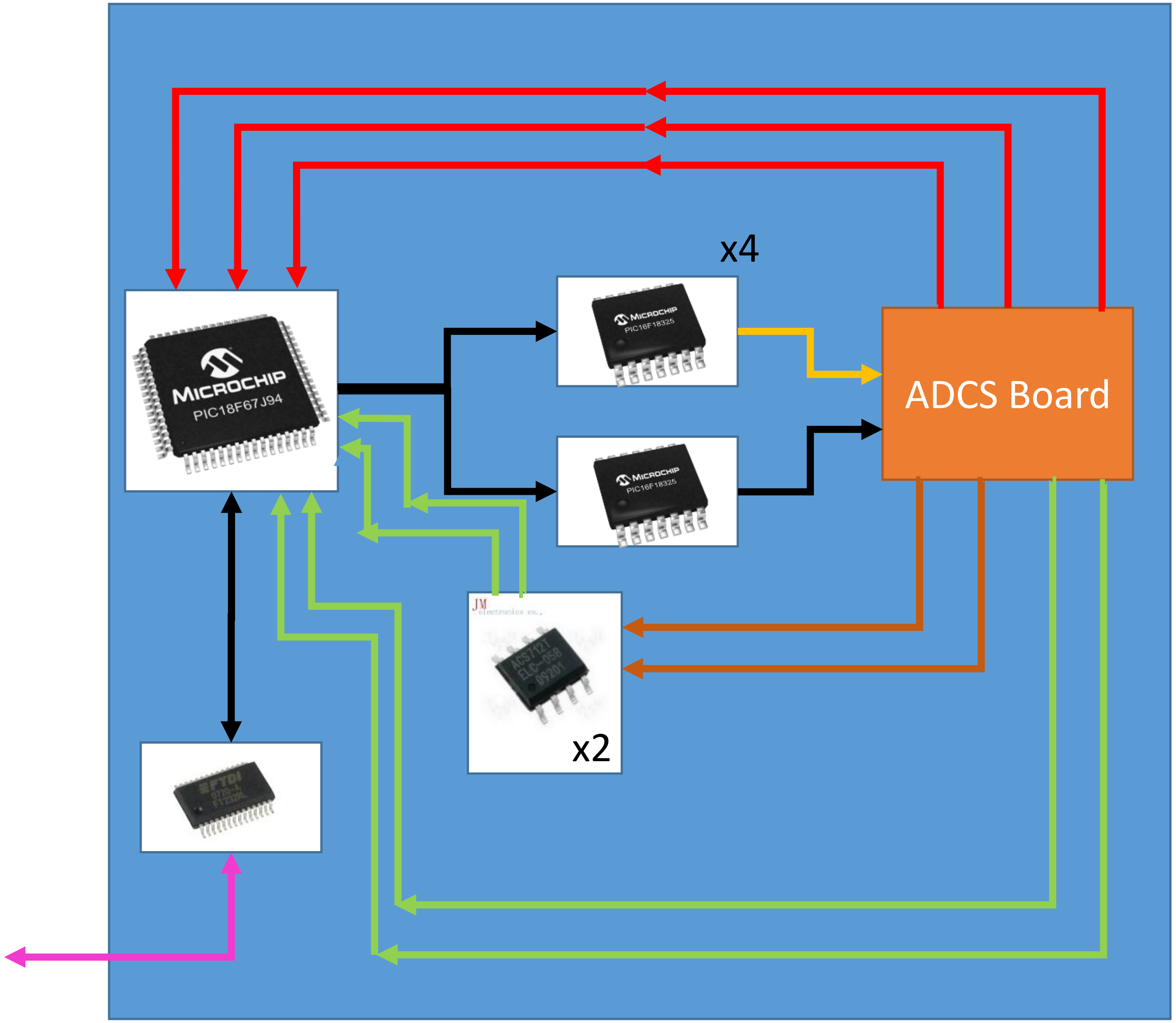
PIC16F1847 substituted with PIC16F1829

- USART and I^2C could not be multi-plexed to different pins
- After board re-design, functionality was not affected

Board Re-design

- Changed to accommodate new slave microcontrollers

Overall Required Functionality

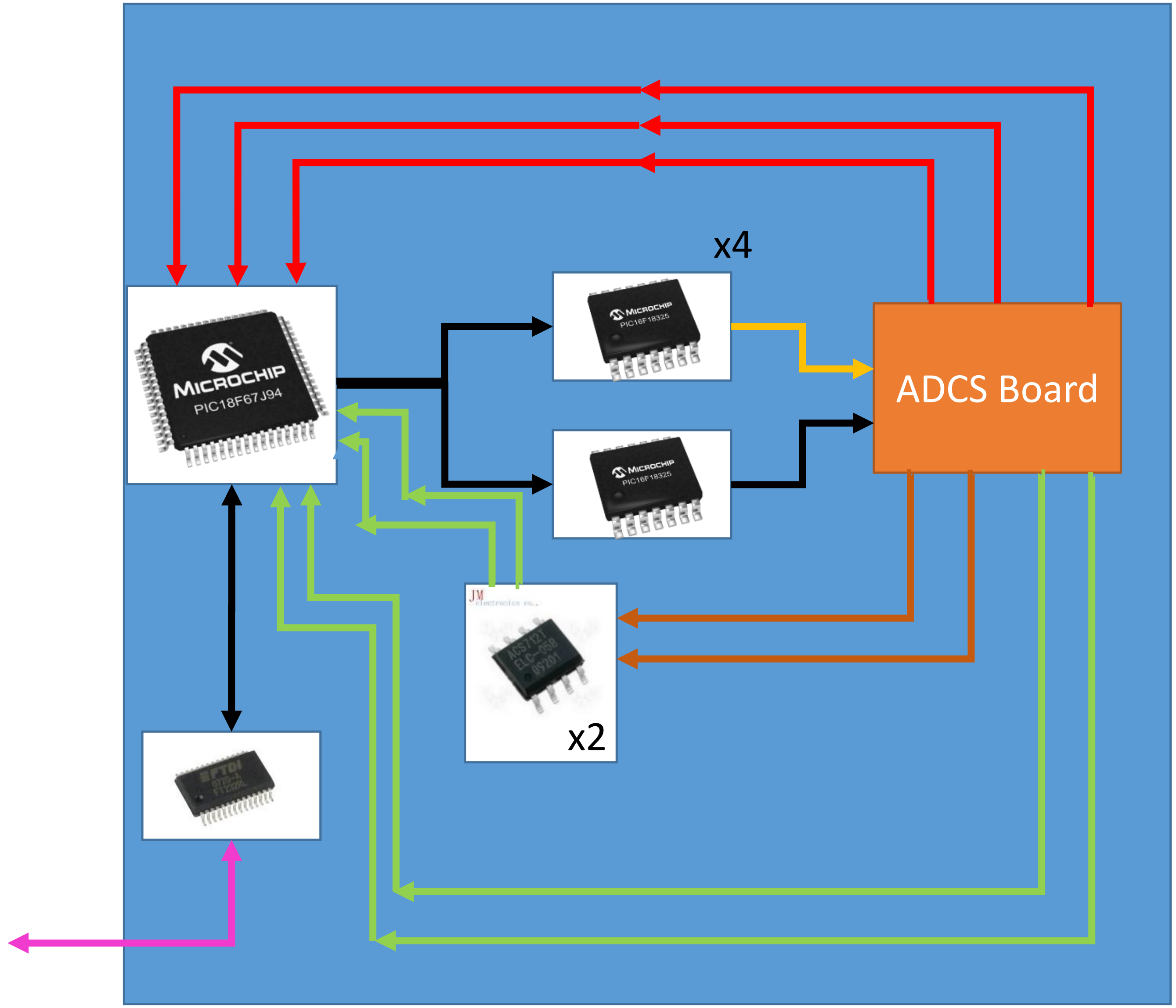


Requirements:

- Send sensor data at 10 Hz frequency
- Record voltage and current measurements over 3.3V and 5V lines at 5% accuracy
- Record magnetorquer PWM response at 10% accuracy

Transmitted Sensor	Sent Over ____
Sun Sensors (x15)	I^2C
GPS (X,Y,Z)	USART
Magnetometers (X,Y,Z)	I^2C
Rate Gyros (X,Y,Z)	I^2C
Received Data	
Magnetorquer Response as PWM Signal (X,Y,Z)	
3.3V line voltage	
3.3V line current	
5V line voltage	
5V line current	

Testing Status Overview *



Test	Status	Description

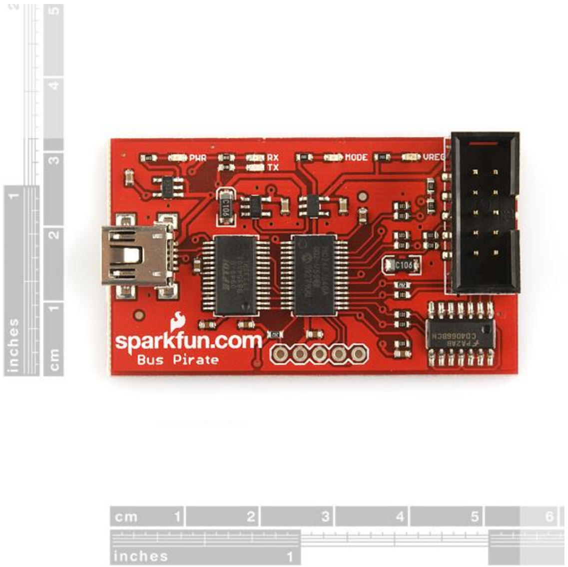
*As of 4/18

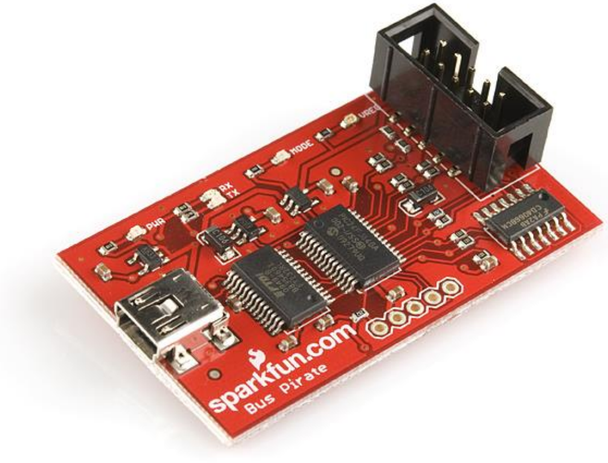
Slave Microcontrollers to ADCS

Slaves send data through into customer's ADCS processor

Testing Status: **COMPLETE**

- Bus Pirate
  - Functionally similar to ADCS
  - Includes I^2C Communication
  - Can send and receive data





Interface Board – I^2C verification

Example with LIS3MDL magnetometer

Table 14. Transfer when master is receiving (reading) one byte of data from slave

Master	ST	SAD + W		SUB		SR	SAD + R			NMAK	SP
Slave			SAK		SAK			SAK	DATA		

Table 16. Register address map

Name	Type	Register address		Default	Comment
		Hex	Binary		
OUT_X_L	r	28	0010 1000	Output	
OUT_X_H	r	29	0010 1001	Output	
OUT_Y_L	r	2A	0010 1010	Output	
OUT_Y_H	r	2B	0010 1011	Output	
OUT_Z_L	r	2C	0010 1100	Output	
OUT_Z_H	r	2D	0010 1101	Output	

Legend:

- ST = Start bit
- SAD = Slave Address
- W = Write bit
- SUB = Sub Address
- SR = Restart bit
- R = Read bit
- NMAK = Not Master Acknowledge
- SP = Stop bit
- SAK = Slave Acknowledge

Interface Board – I^{2}C verification

Example with LIS3MDL magnetometer

```
(1)
Searching I2C address space. Found devices at:
0x02(0x01 W) 0x03(0x01 R) 0x04(0x02 W) 0x05(0x02 R) 0x08(0x04 W) 0x09(0x04 R)
0x10(0x08 W) 0x11(0x08 R) 0x20(0x10 W) 0x21(0x10 R) 0x40(0x20 W) 0x41(0x20 R)
0x80(0x40 W) 0x81(0x40 R) 0xFE(0x7F W) 0xFF(0x7F R)
```

Discovered Devices

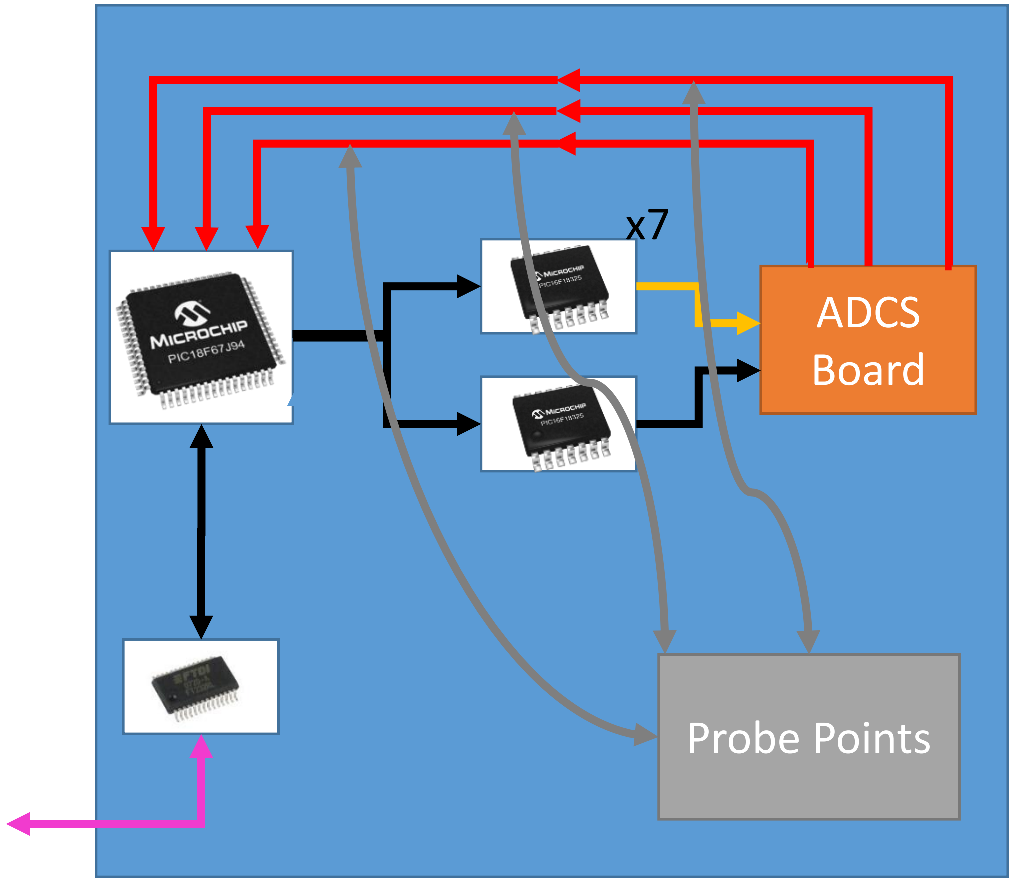
```
I2C>[0xFE 0x0F [0xFF r]
I2C START BIT
WRITE: 0xFE ACK
WRITE: 0x0F ACK
I2C START BIT
WRITE: 0xFF ACK
READ: 0x55
NACK
I2C STOP BIT
I2C>
```

Table 14 Transf r when maste is re eiving (readir g) one yte of ata fror sla e

Master	ST	SAD + W		SUB		SR	SAD + R			NMAK	SP
Slave			SAK		SAK			SAK	DATA		

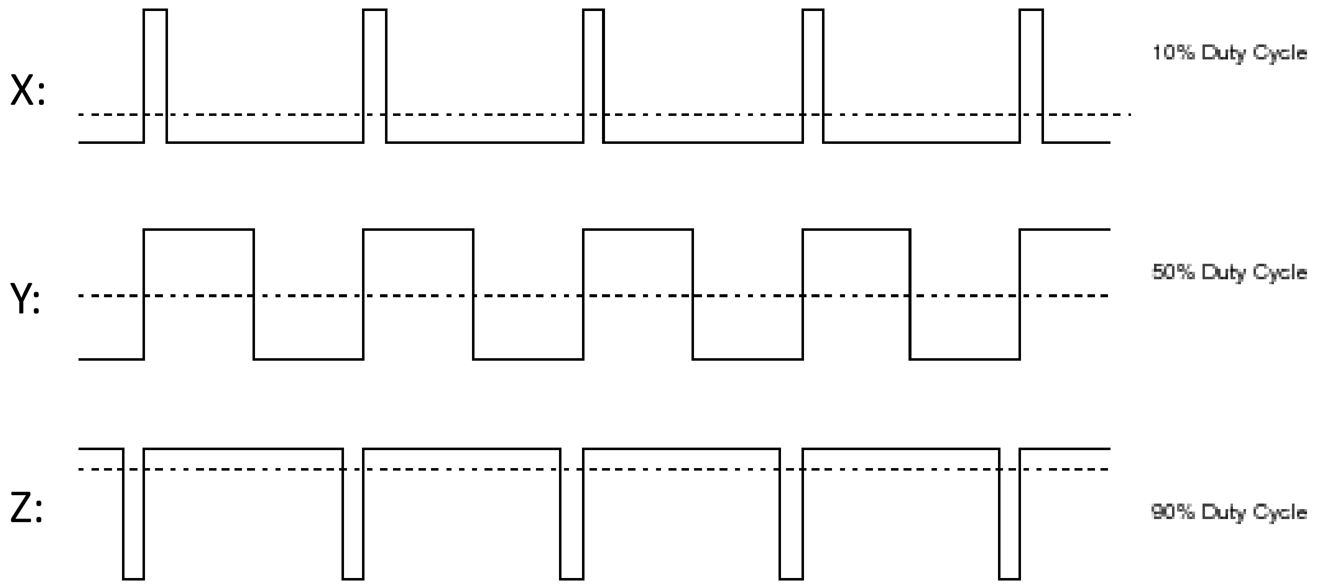
Magnetorquer PWM → Master Microcontroller

Record timing of magnetorquer pulse width modulation

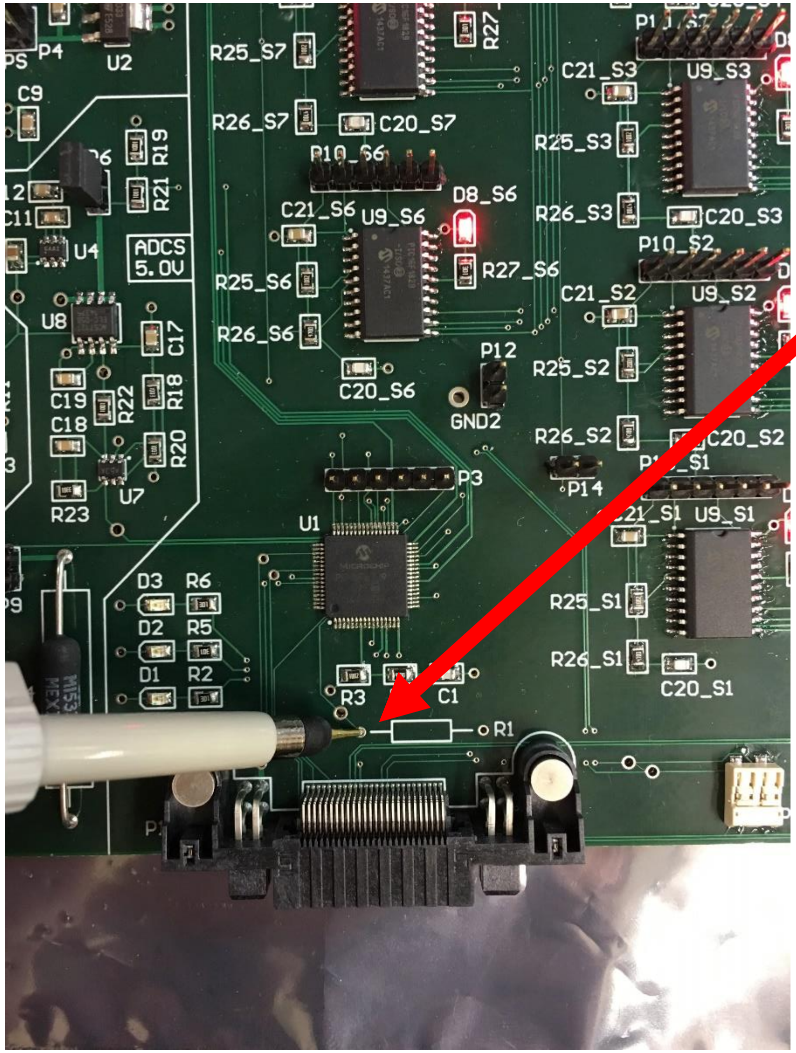


Testing Status: **PARTIALLY COMPLETE**

- Duty cycle is being captured, inconsistent duty cycle read



Interface Board – PWM Capture



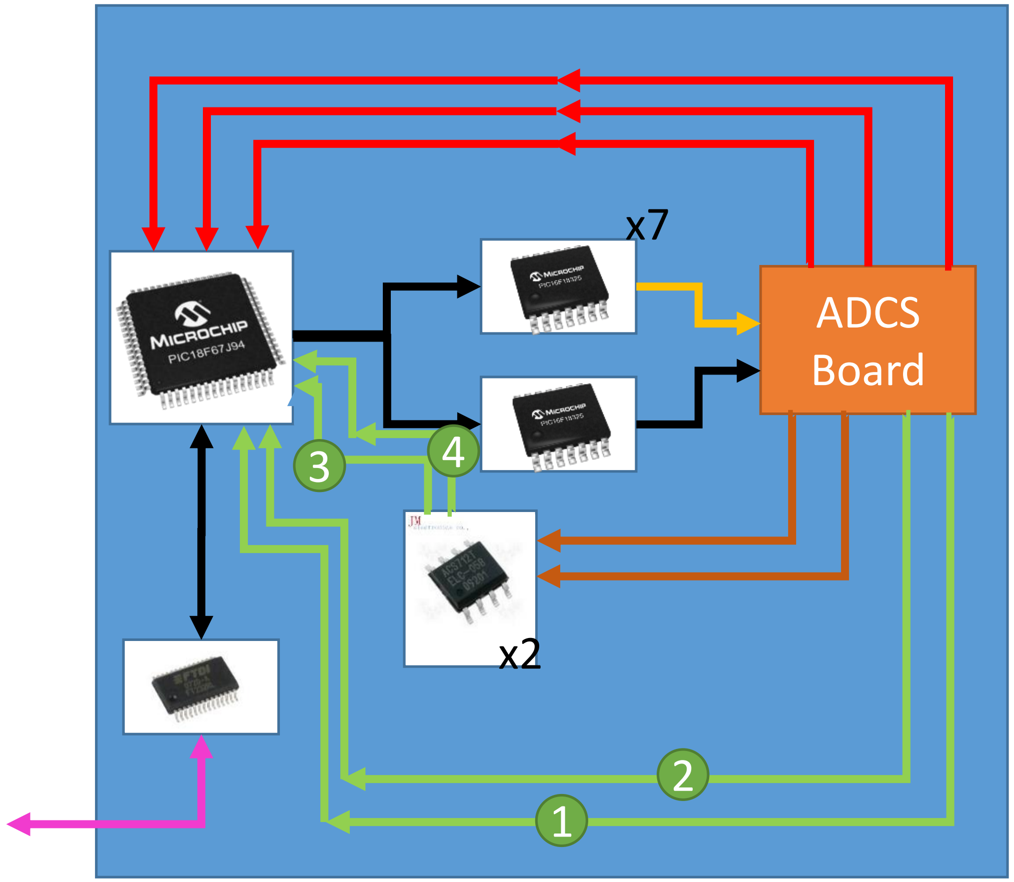
- Function Generator was used to generate a 5Vpp PWM signal with a +2.5V offset and frequency of 1kHz.
- Duty cycle measured by master microcontroller with 10 samples averaged together
- Duty cycle was varied between 25% and 75%

	Actual Duty Cycle	25%	50%	75%
Measured Duty Cycle	Min	24.27	48.14	74.31
	Average	25.46	48.9	75.43
	Max	31.89	51.22	76.53
	ERROR	1.8%	2.2%	0.5%

*Agilent 33120A function generator has 1% frequency errors.

ADCS Power Draw

Master microcontroller measures current and voltage



Testing Status: COMPLETE

- All voltages are read in and converted correctly

Point	Line	Measuring
1	3.3V line Raw Voltage	Voltage [V]
2	5V line Raw Voltage	Voltage [V]
3	3.3V line Current	Current [A]
4	5V line Current	Current [A]

Interface Board – Power Measurements

3.5 Volt Power Line

	Interface Board	Agilent Multimeter	Errors
Current	140 ± 6.9 mA	138 mA	1.4%
Line Voltage	3.49 ± .005 V	3.50 V	0.3%
Calculated Power	0.488 ± .049 W	0.483 W	1.0%

5 Volt Power Line

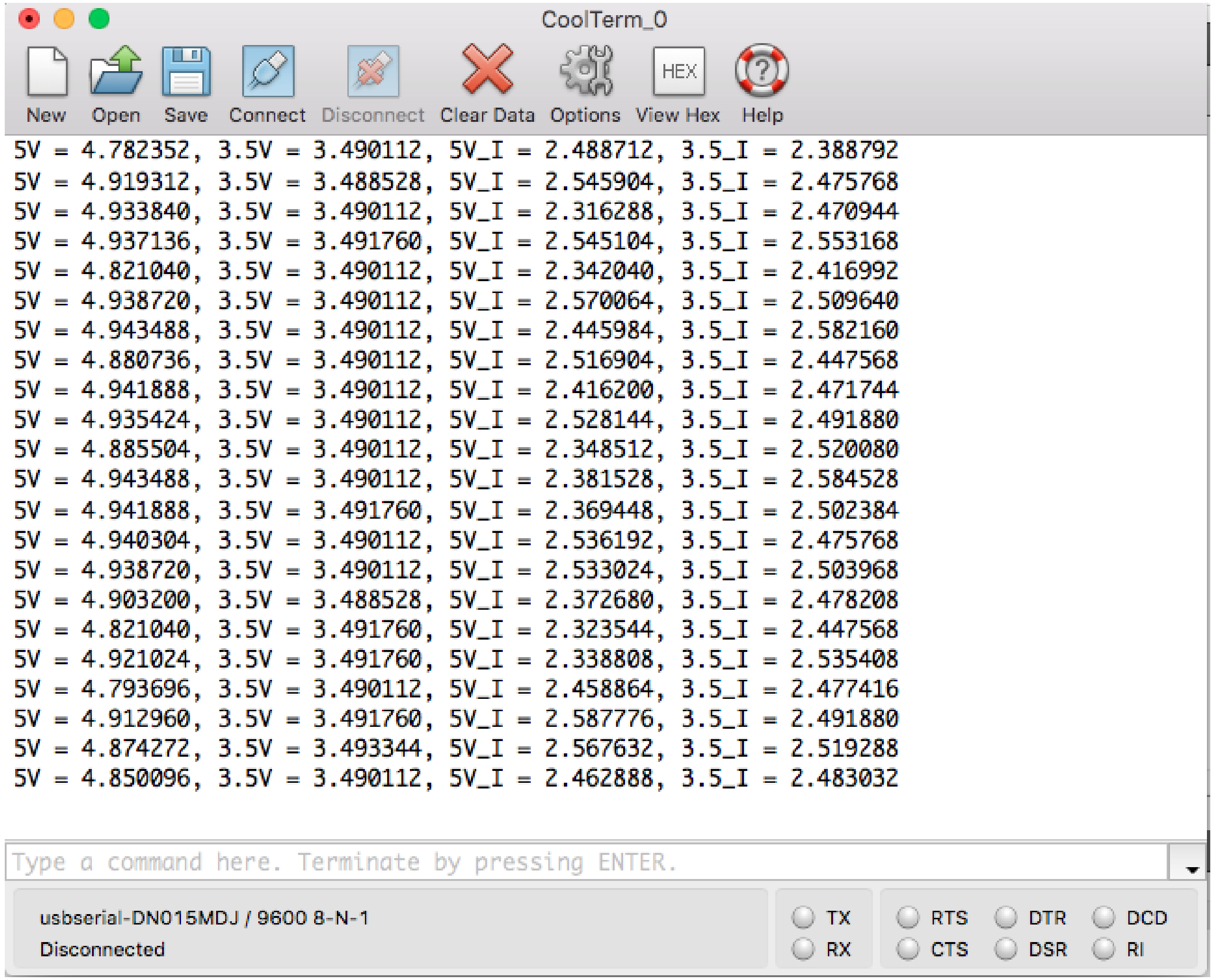
	Interface Board	Agilent Multimeter	Errors
Current	191 ± 12.5 mA	189 mA	1.1%
Line Voltage	4.92 ± .008 V	4.92 V	0.2%
Calculated Power	0.939 ± .065 W	0.929 W	1.0%

-Data is averaged over 9100 samples

*Fluke 87-iii multimeter has a ~ 0.2% current error and a ~0.05% voltage errors.

Master Microcontroller → PC

Master microcontroller communicates data back to PC over USART



Testing Status: COMPLETE

- Data is being communicated

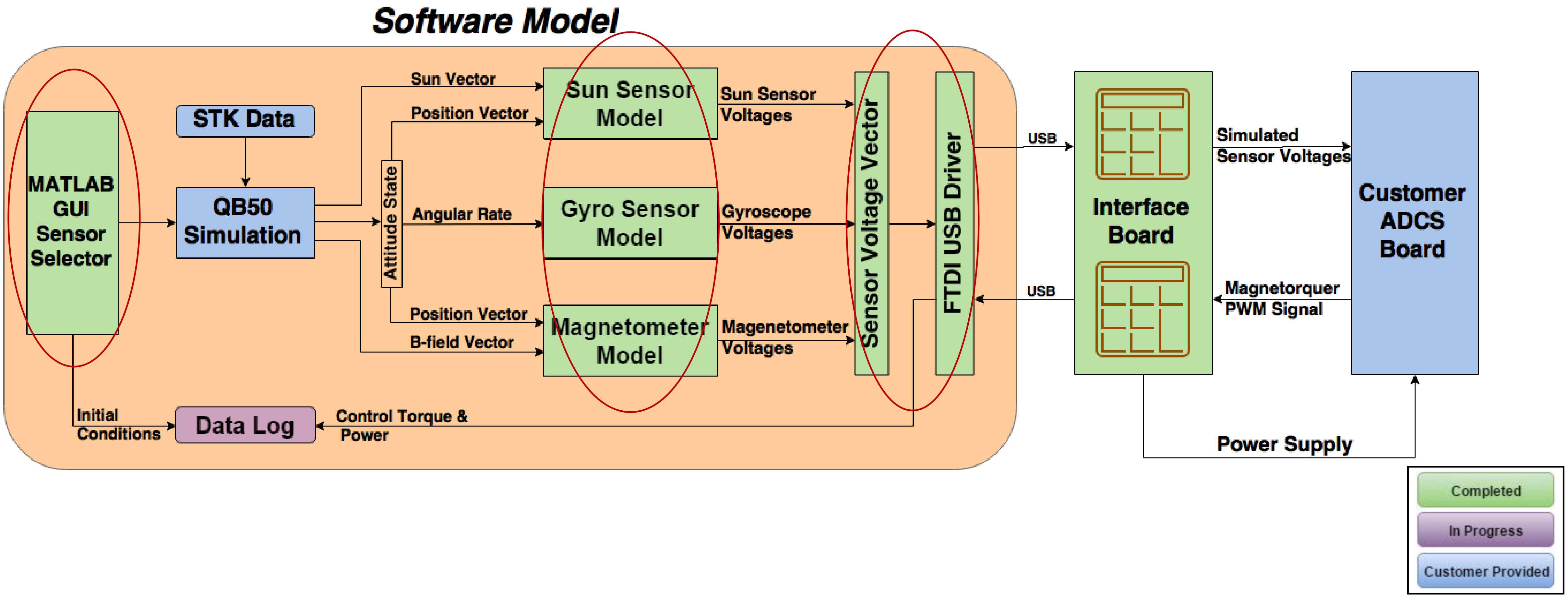
Software System

Requirements:

I. Calibrate QB50 simulation data for sensor emulation.

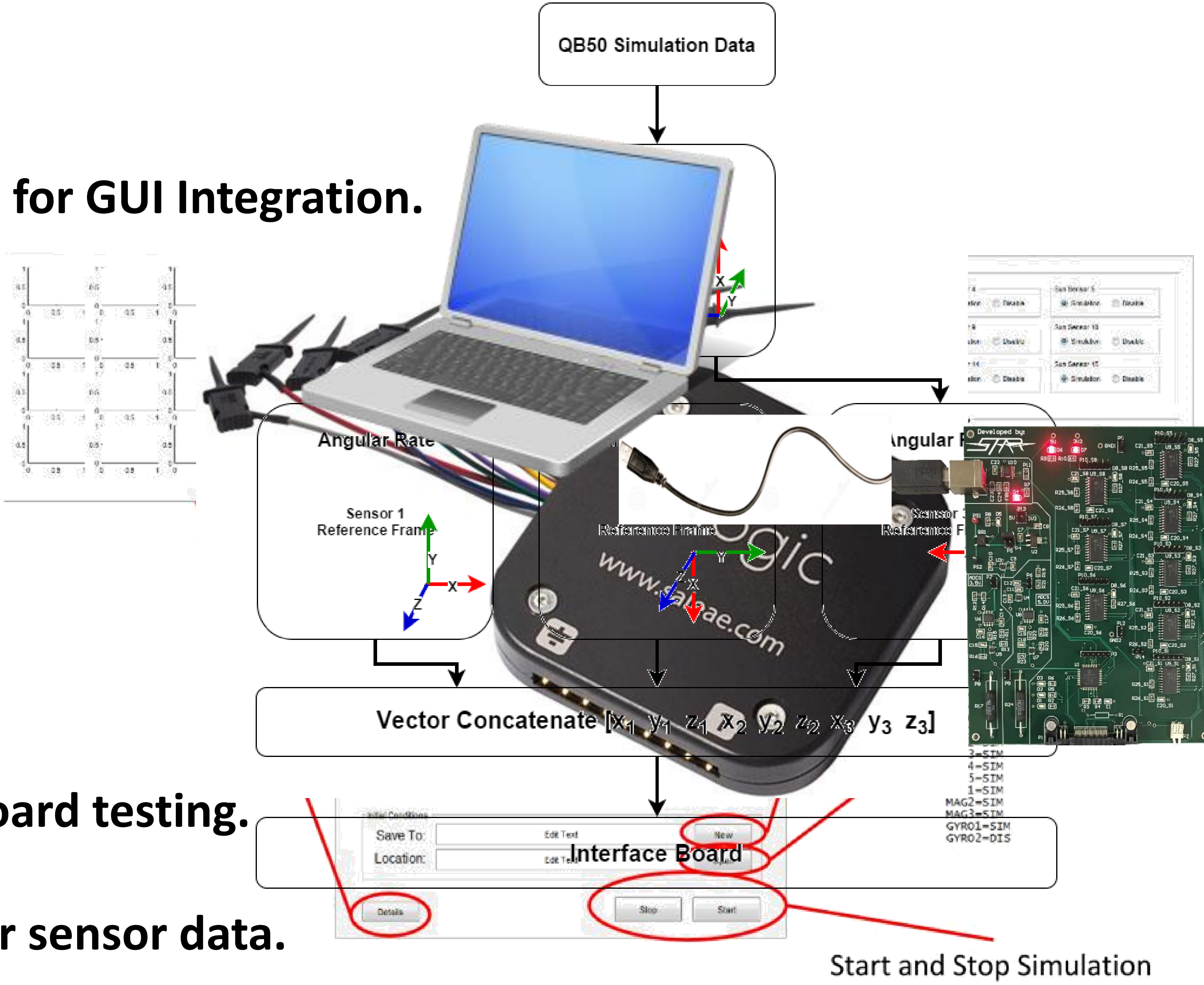
II. Communicate sensor data to interface board.

III. Implement GUI for starting simulation with initial sensor conditions.



Software Current Status

- ✓ **GUI Interface Built.**
- ✓ **Modified QB50 Grad Simulation for GUI Integration.**
- ✓ **FTDI Drivers verified**
  - **Windows 7 and later**
  - **D2XX ver. 2.12.12**
  - **VCP ver 2.12.12**
  - **Mac OS X 10.9 and later**
  - **D2XX ver 1.2.2**
  - **VCP ver 1.2.2**
- ✓ **Code developed for Interface Board testing.**
- ✓ **Developed calibrated models for sensor data.**



Software – FTDI Driver Test

Purpose: Confirm data link with interface board

Test equipment:

- Interface Board
- MATLAB® Software
- FTDI Drivers

Procedure:

- Establish communication with FTDI Drivers
- Pass data to interface board
- Verify data received with digital logic analyzer

Validation:

- Verify MATLAB® can communicate with interface board

Risk Reduction:

- Confirms communication Data-link

Results:

- Transmitted data received by digital logic analyzer
- Data received matches data transmitted

Software – Sensor Model Verification

Purpose: Verify calibrated sensor model

Test equipment:

- MATLAB®
- QB50 Simulation developed by Grad Team

Procedure:

- Obtain sensor data by running QB50 Simulation
- Pass data to calibrated sensor models
- Compare output from sensor models with transformations done by hand

Validation:

- Verifies the calibration of sensor models for instrumented orientations

Risk Reduction:

- Verifies simulated sensor data is corrected for sensors on QB50 ADCS.

Results:

- Transformation matrices computed by hand match data generated in MATLAB
- Sensor output from MATLAB sensor models match with data computed by hand

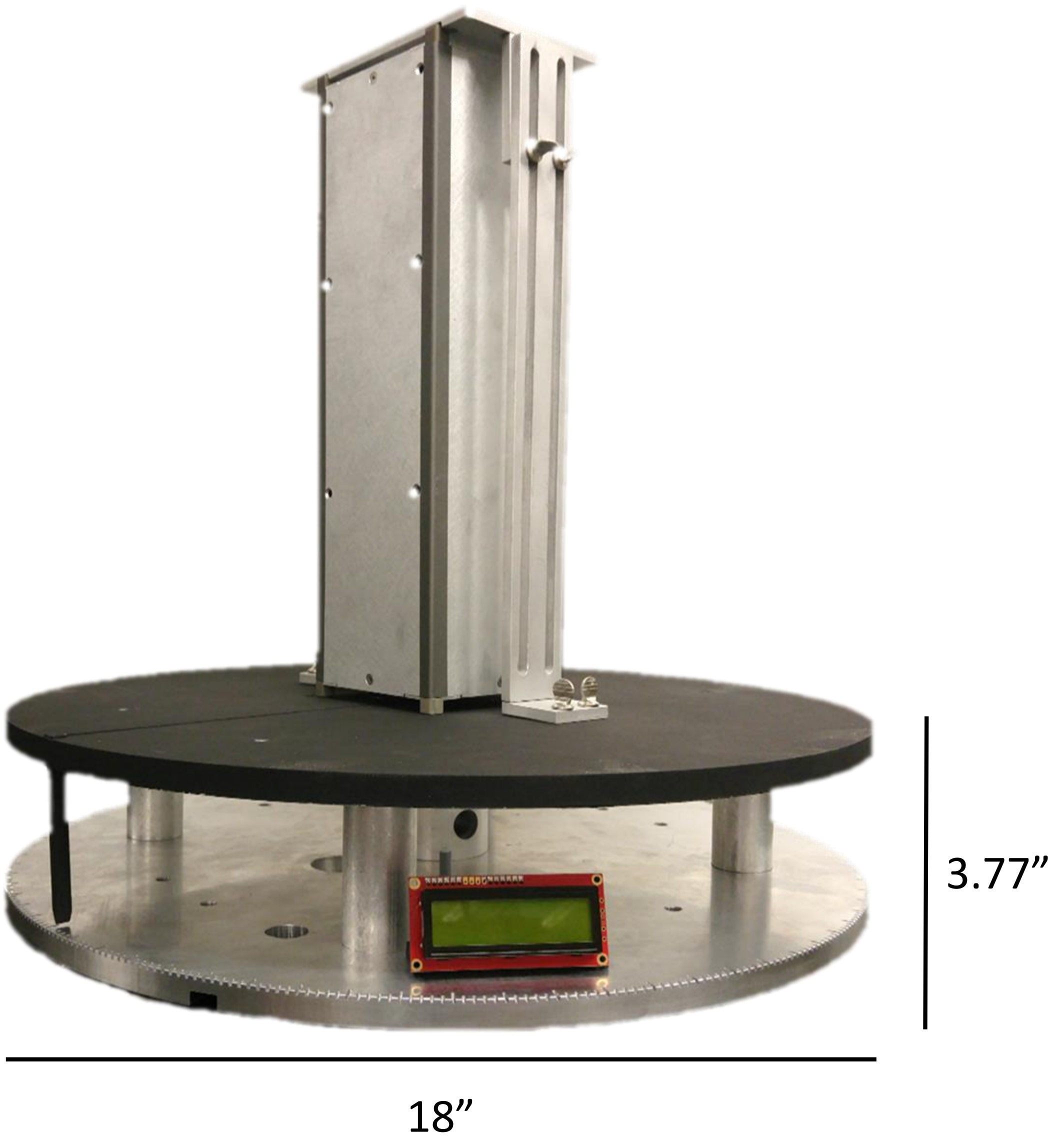
Software Pending Tasks*

Task	Estimated Time (Hours)	Margin (Hours)
Integrate & test sensor models	10	8
Transmit simulated sensor data to Interface Board	5	2
Compute Control Torque from PWM signal	3	2
Log Control Torque and Power Consumption Data	2	1
ADCS system test with Interface Board	15	5
TOTAL	**35**	**18**

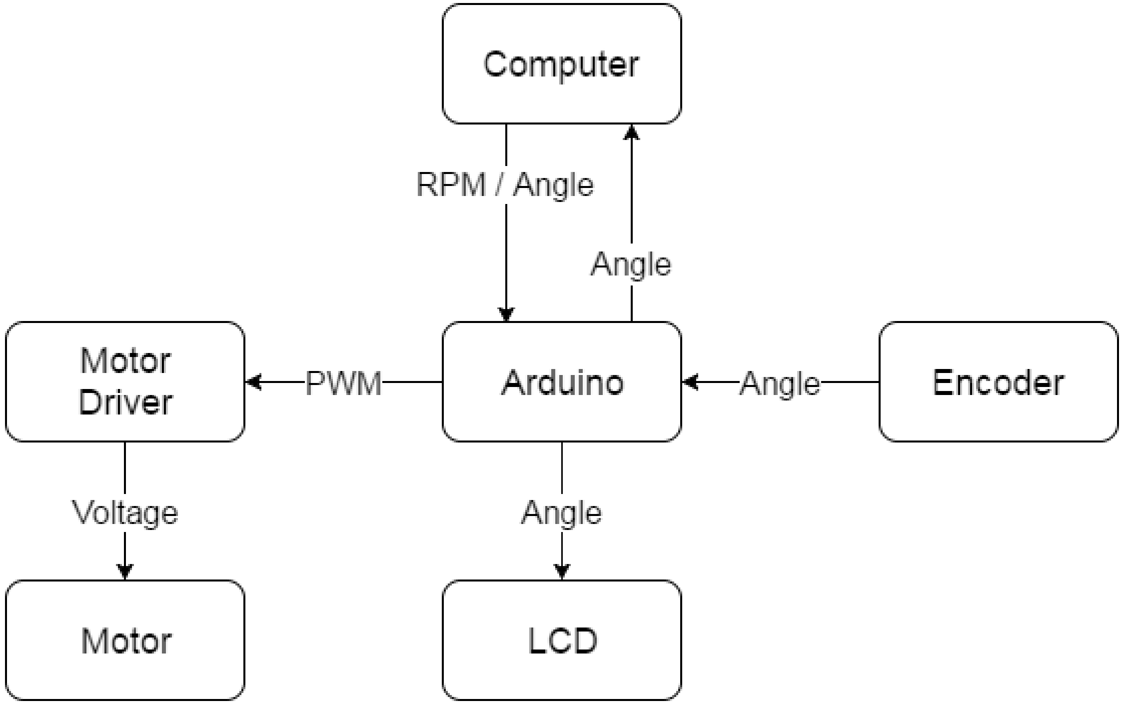
*as of 04/19/2016

SS Turntable

Turntable – Design Description



- 18” diameter plates, 3.77” height
- 23 lbs
- Built from aluminum
- 1:2 gear ratio
- 4 posts to prevent tilting



Turntable – Test Overview

Requirements

Requirement	Description
FR.1	A turntable shall have a resolution of 1 degree.
FR.2	A turntable shall have an accuracy of ±0.5 degree.
FR.3	The turntable shall rotate for 10Hz sun sensors to sample at least once per degree. (<5/3 RPM)

Tests

Test	Description	Requirements Verified
1	Match angle etchings with encoder reading	FR.1, FR.2
2	Rotate at constant angular rate	FR.3

Turntable – Angle Accuracy Test

Purpose: Confirm angle etchings match angle read by encoder

Procedure:

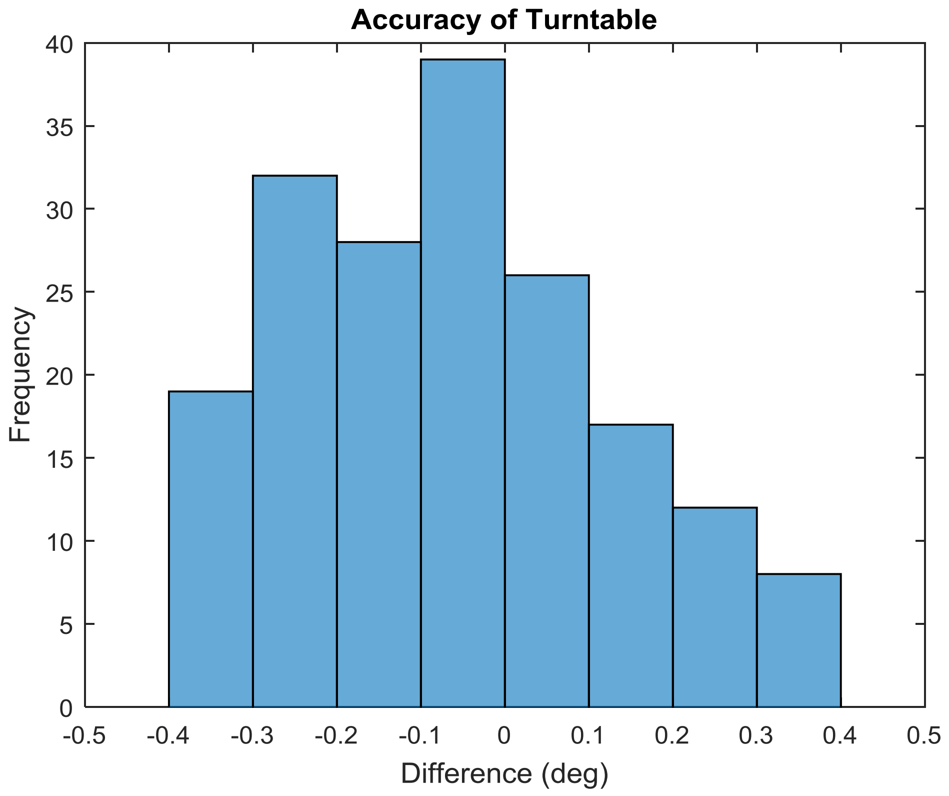
- Zero turntable
- Manually rotate turntable to each angle etching from 0 to 180°
- Compare physical and electronic angle reading

Verification:

- Verifies turntable can read at 1 degree resolution
- Verifies turntable has an accuracy of ± 0.5°

Turntable – Test Results

Physical Angle (deg)	Encoder Angle +/- 0.08 (deg)	Difference (deg)
0	0	0
1	1	0
2	2	0
3	2.9	-0.1
4	3.9	-0.1
5	5	0
⋮	⋮	⋮
175	175.1	0.1
176	176	0
177	176.9	-0.1
178	177.9	-0.1
179	178.8	-0.2
180	179.7	-0.3



Requirement	Description	Verification
FR.1	A turntable shall have a resolution of 1 degree	Verified
FR.2	A turntable shall have an accuracy of ±0.5 degree	Verified

Turntable – RPM Test

Purpose: Confirm turntable can rotate less than 5/3 RPM

Procedure:

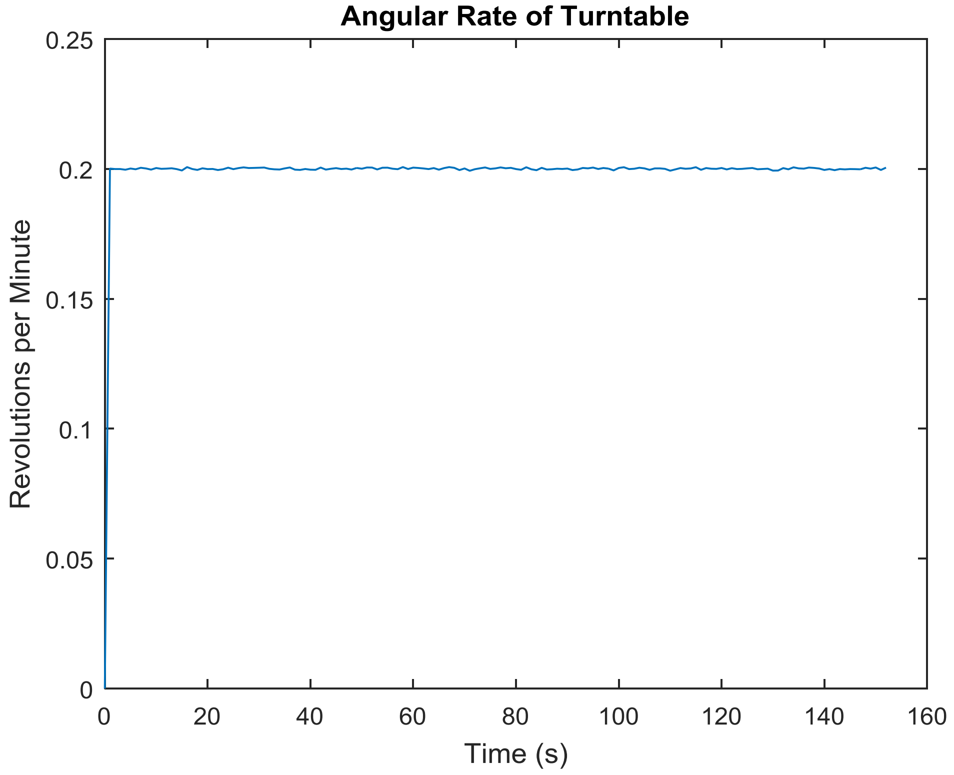
- Set table to rotate at desired RPM in GUI
- Measure time for rotation
- Compare desired and measured RPMs

Verification:

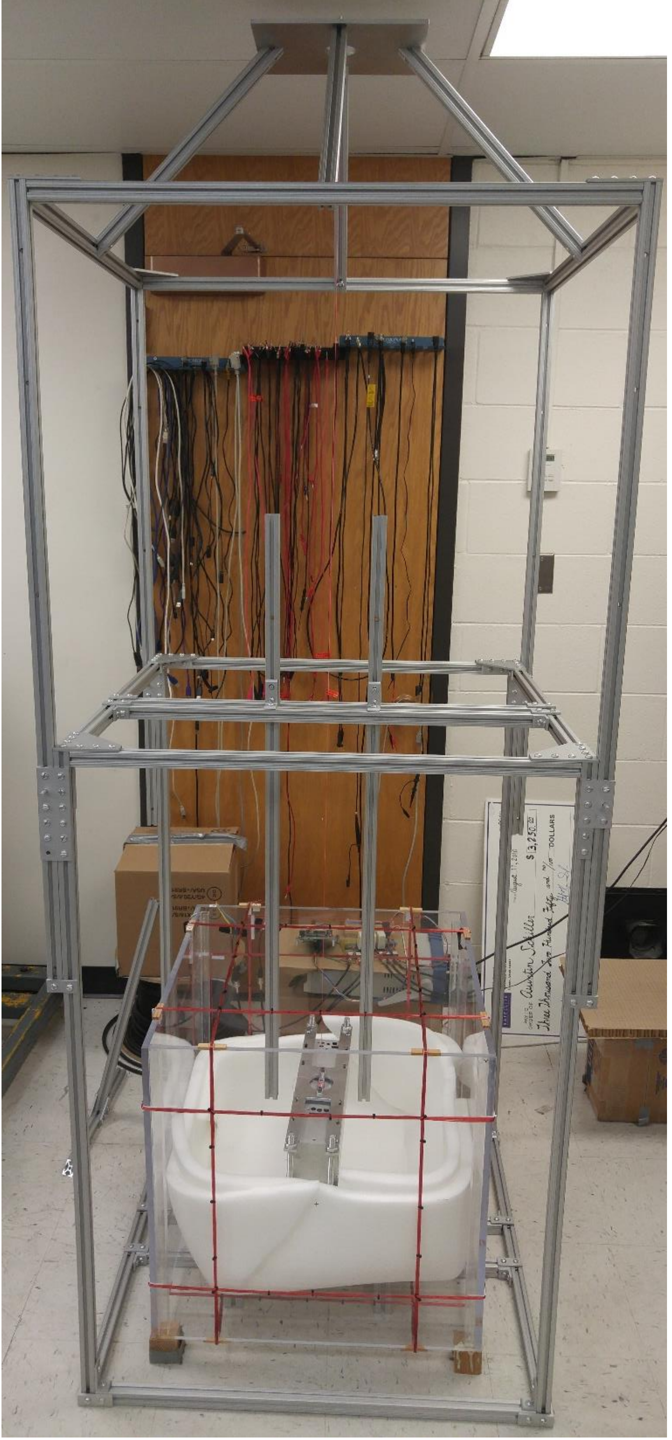
- Verifies table will rotate for 10Hz sun sensors to sample at least once per degree

Turntable – Test Results

Desired RPM	Expected time for ½ revolution (s)	Actual time for ½ revolution (s)	Calculated RPM
0.2	150	152	0.197
0.3	100	101	0.297
0.4	75	75	0.4
0.5	60	63	0.476

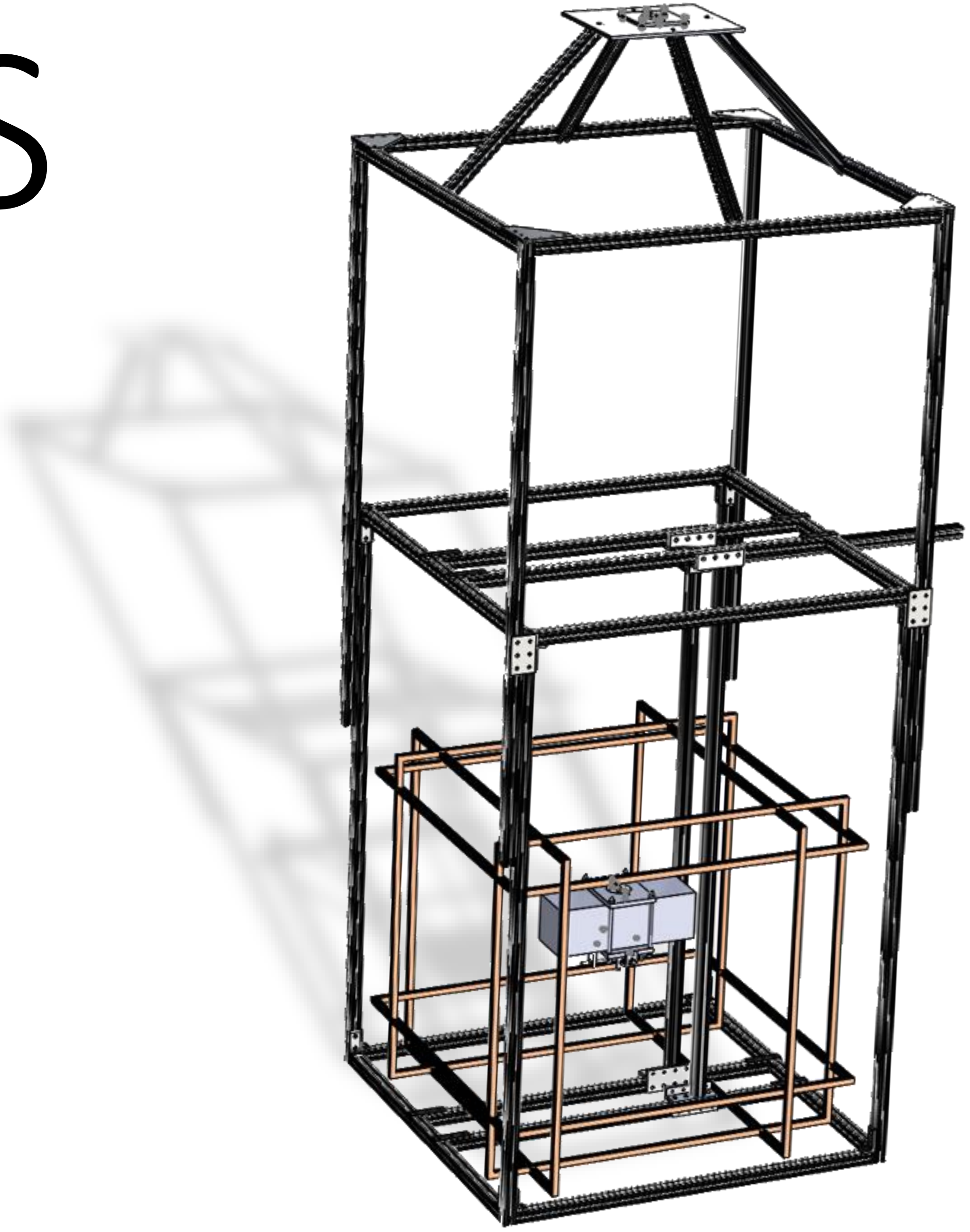


Requirement	Description	Verification
FR.3	The turntable shall rotate for 10Hz sun sensors to sample at least once per degree.	Verified



HelCaTS

Helmholtz
Cage
Testing
Structure



HelCaTS Design Description

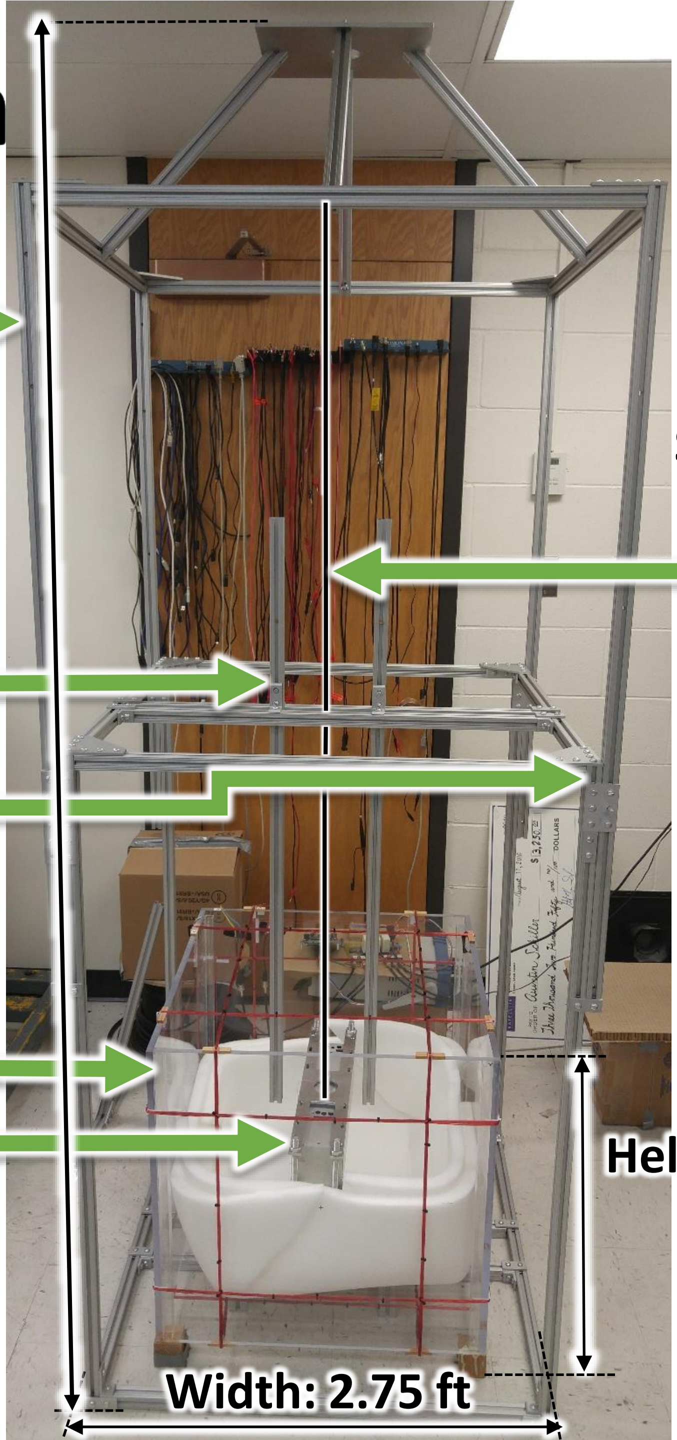
1" Extruded Aluminum Structure

Shown Height: 7.5 ft
Max Height: 8.75 ft
Min Height: 5.25 ft

Locking Mechanism

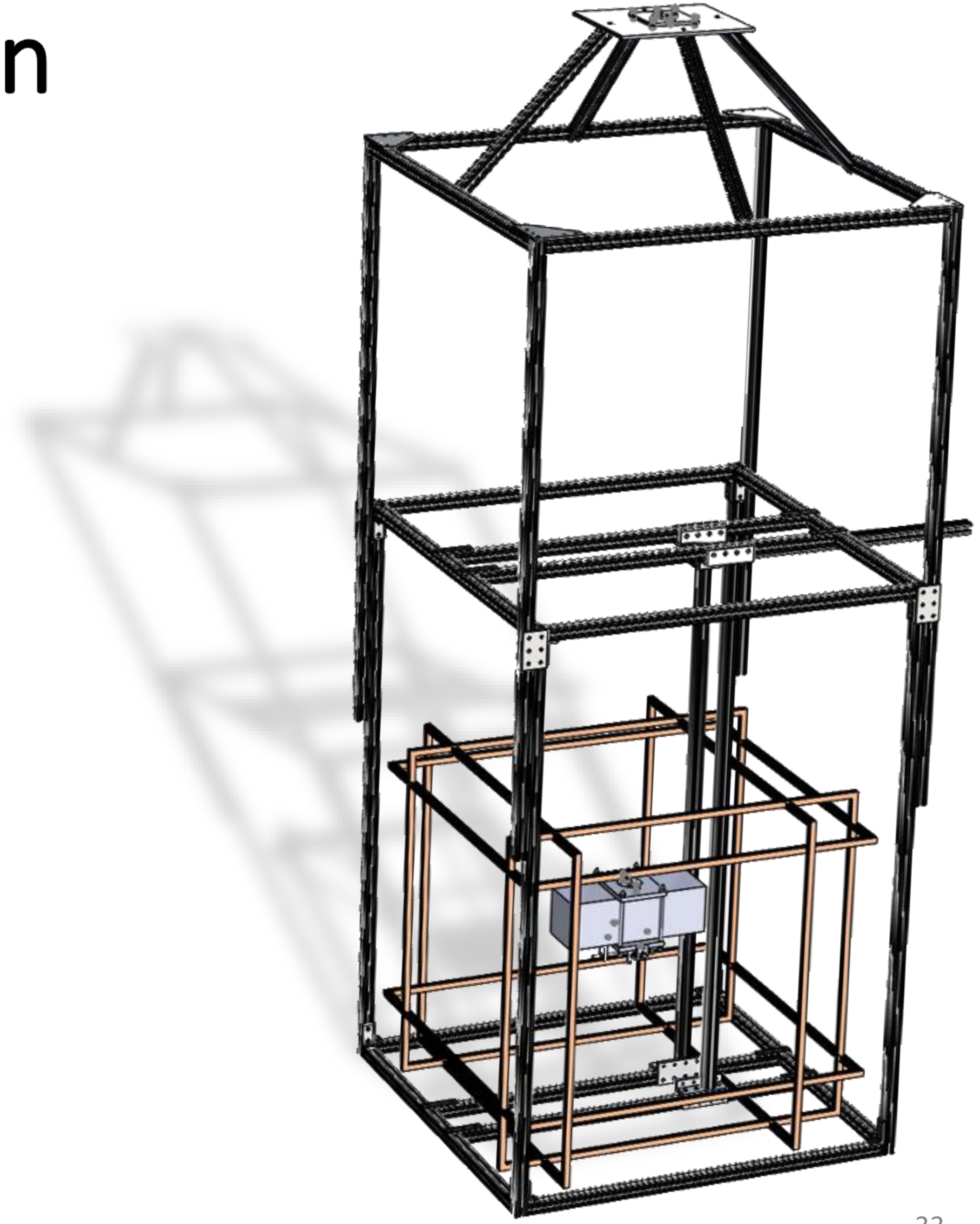
Top can slide to extend/retract

Helmholtz Cage (Provided by Customer)
Satellite (Provided by Customer)



HelCaTS Operational Description

1. Satellite turned clockwise by hand (NO MAGNETORQUERS)
2. Measure time for satellite to rotate back to zero
3. Repeat 1 and 2 counterclockwise
4. Satellite turned clockwise by hand (MAGNETORQUERS ON)
5. Measure time for satellite to rotate back to zero
6. Repeat 4 and 5 counterclockwise



HelCaTS Completed Testing

Validation Testing

- Tested time to rotate of a satellite mass model
- Performed test with the QB50 satellite and its magnetorquers
  - Included Graduate Team

Safety Testing

- Test strength of line and attachment mechanism

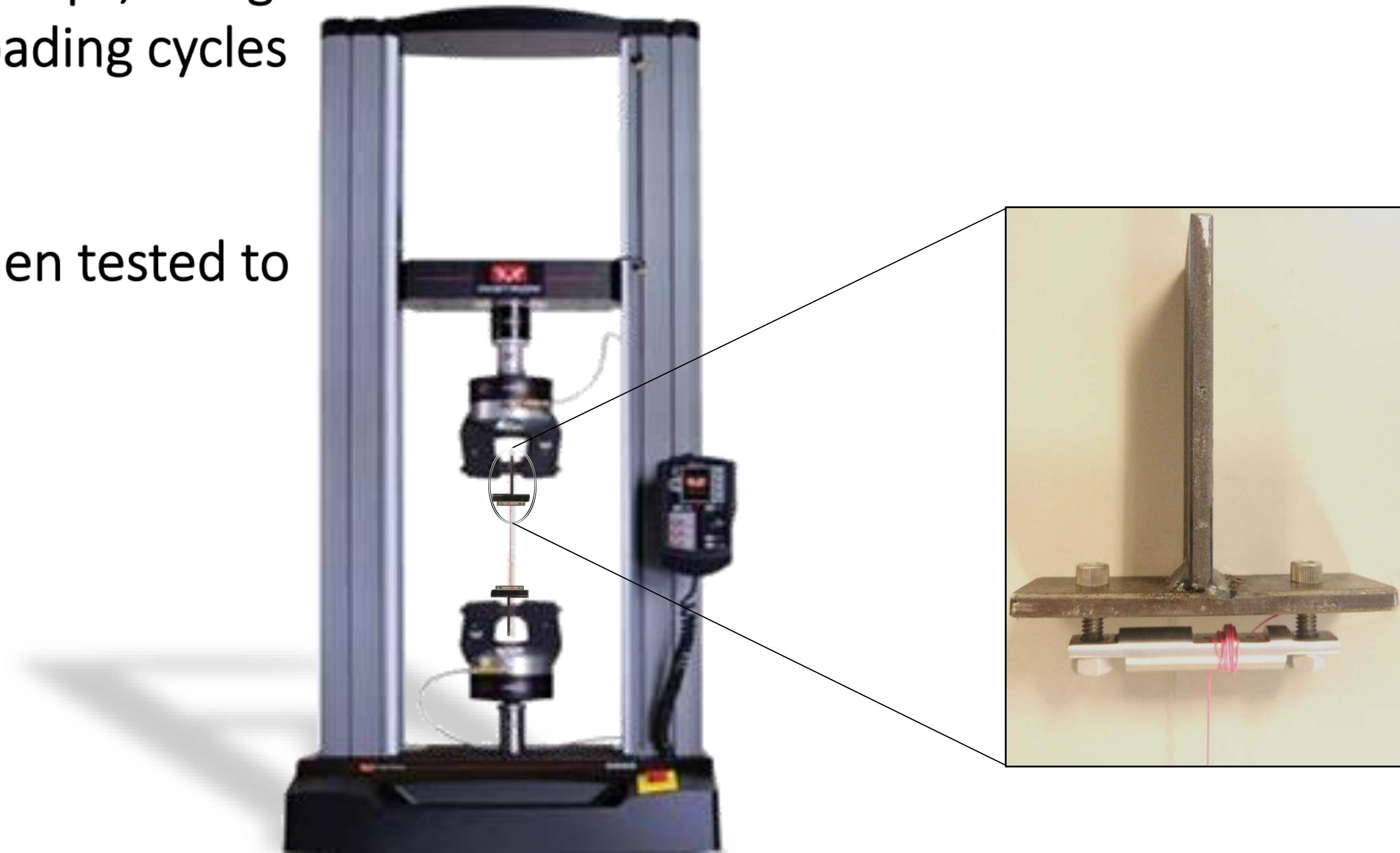
Tensile Test

Test Objective:

- Validate the line can withstand 27 lbs (12.2 kg)
  - Claim from manufacturer
  - Largest satellite mass with clamps, < 5kg
- Examine fatigue from multiple loading cycles

Tests Completed:

- Line tested to failure
- Line loaded to 10 kg 10 times, then tested to failure



Tensile Test

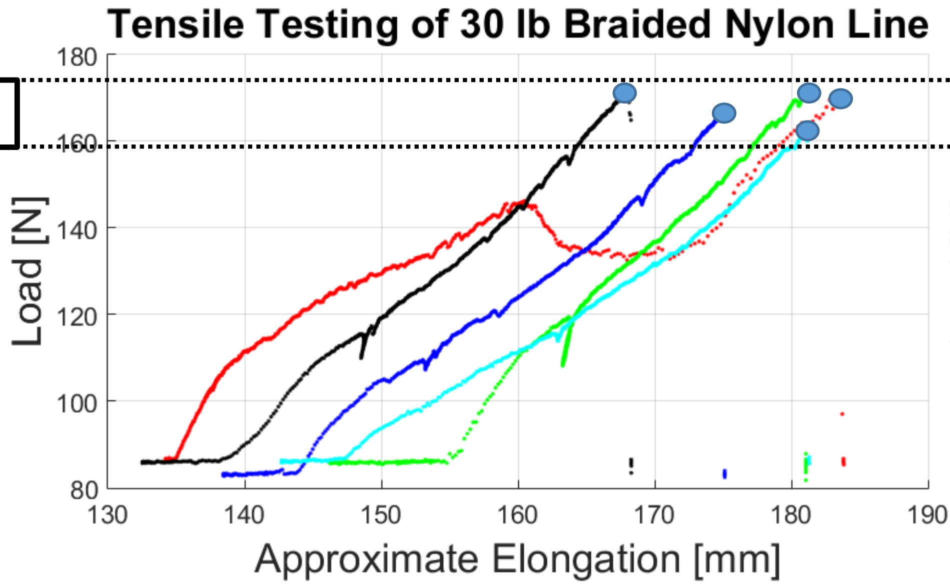
Results:

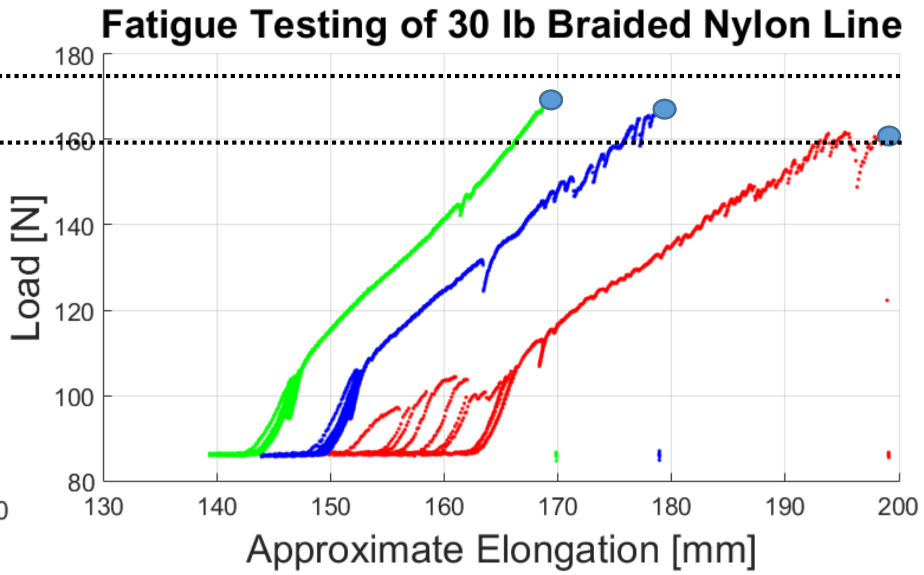
- Expectation: the line, not the attachment method, will fail above 27 lbs (12.2 kg)
- Reality:

Test	Average Failure Point (kg)	Deviation (kg)	Measurement Error (kg)	Load Margin (kg)
Tensile Test	17.1	0.42	+/- 1.8	12.1
Tensile Test After 10, 10 kg loading cycles	17	0.40	+/- 1.8	12

Break Points

All values recorded to +/- 1.81 kg or 17.8 N





Conclusion: Even after loading cycles, the line can handle > 3 x satellite mass

Time to Rotate of Satellite Mass Model

Test Objective:

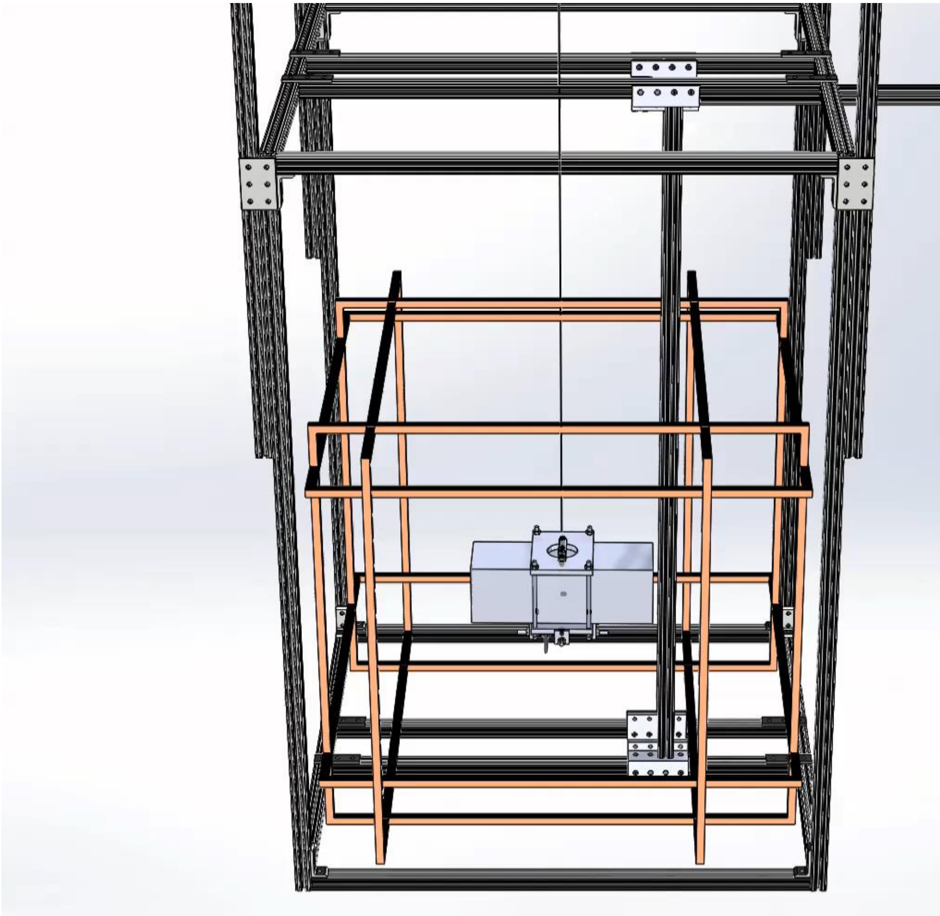
- Validate the time to rotate model

General Procedure:

- Rotate the satellite 360°
- Measure the time it takes to rotate back through 0°
- Perform multiple trials releasing by hand, and with the release mechanism

Expected Results:

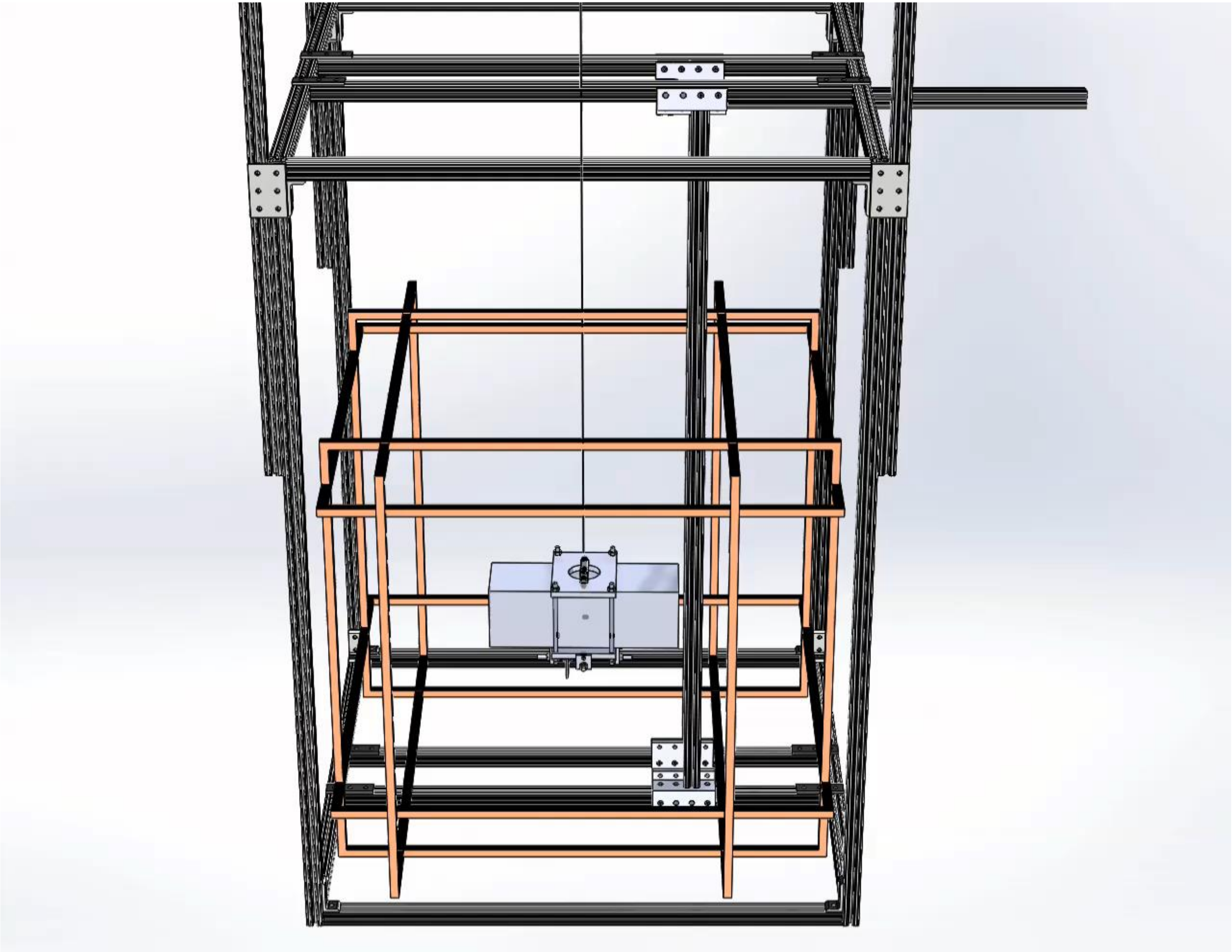
- Time to Rotate ~ 4 minutes 30 seconds
- Slight variation between clockwise and counter-clockwise dependent on the twist in the line.
- The release mechanism will remove any significant variation in time to rotate.



Time to Rotate of Satellite Mass Model

Actual Results

- Please see handout



Performance Test with Satellite and Magnetorquers

Test Objective:

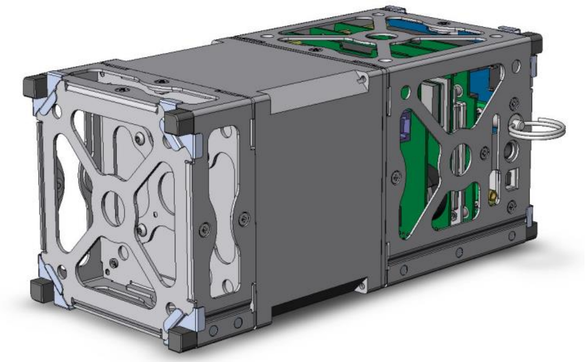
- To validate the time to rotate model with and without magnetorquers

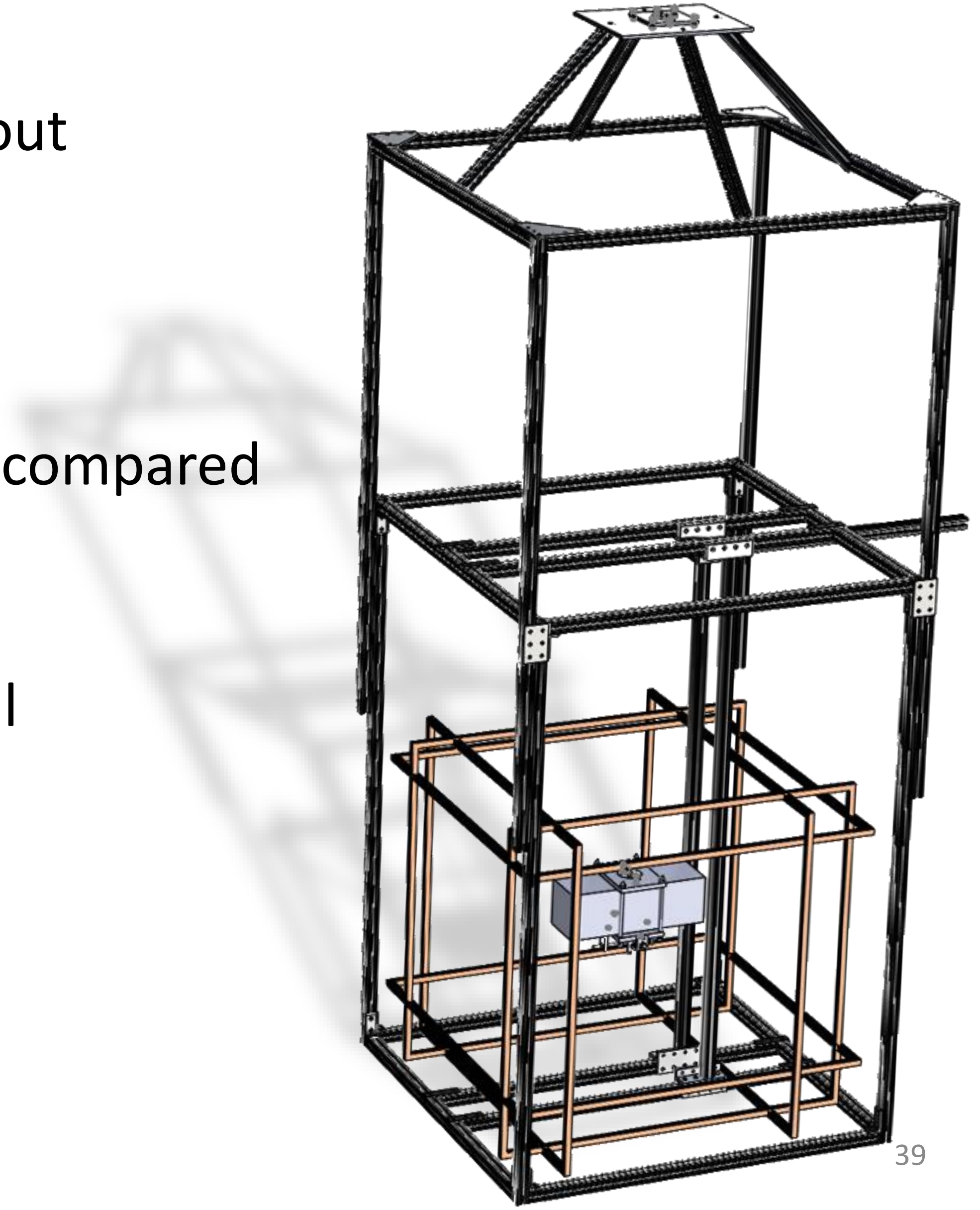
Changes from Previous Test:

- Requires the assembled QB50 cubesat
- Time to rotate with and without magnetorquers is compared

Data Gained:

- Impact of magnetorquers on time to rotate [Critical Project Element]

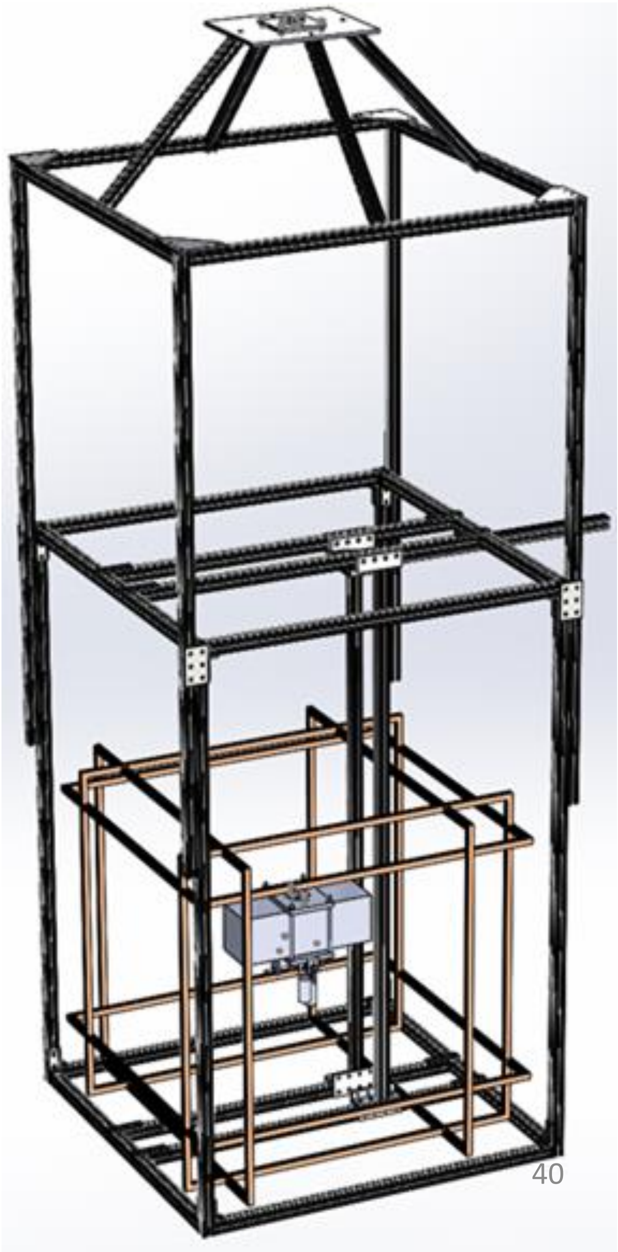




Performance Test with Satellite and Magnetorquers

Expected Results

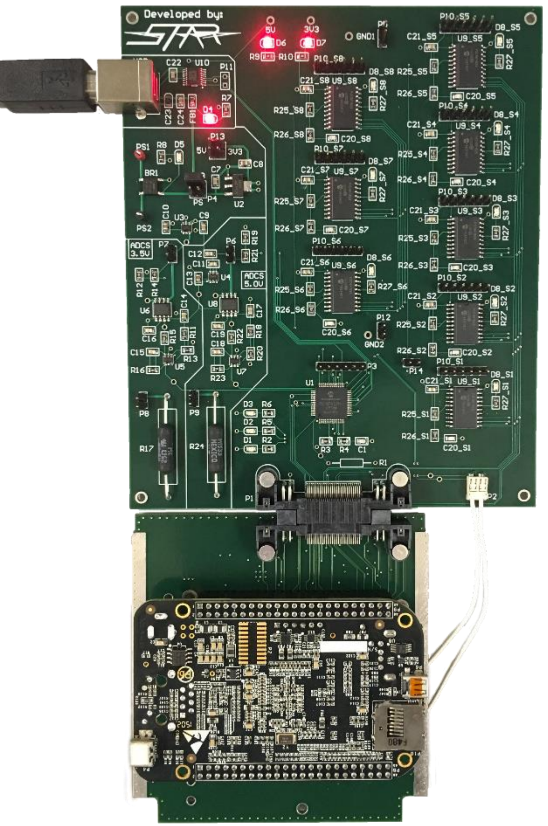
Acting Torque (τ)	Time to Rotate	Change in Time to Rotate
τ_{Line}	4 min 30 sec ± 7.5 sec	0
$\tau_{Line} + \tau_{Sat}$	3 min 50 sec	-40 seconds
$\tau_{Line} - \tau_{Sat}$	5 min 35 sec	+60 seconds



Actual Results

- Please see handout

Systems Engineering – Design Approach & Lessons Learned



Design Requirements Flowdown

Interface Board

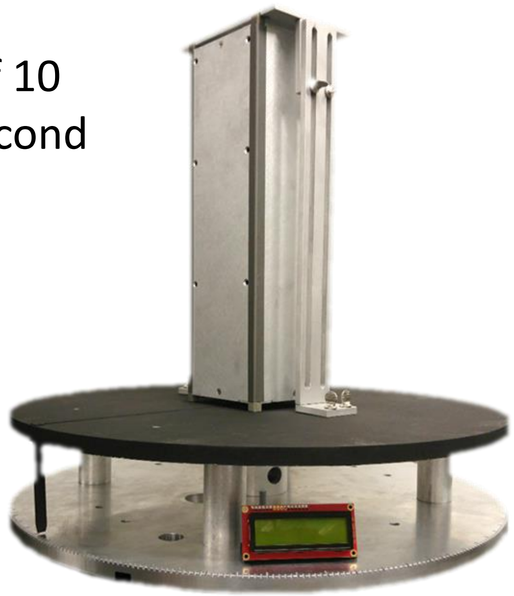
- Data Processing
- PWM calculations

- 10 Hz frequency
- Power measurement (3.3V, 5V voltage and current)

Sun Sensor Turn Table

- 0.5° accuracy of rotation

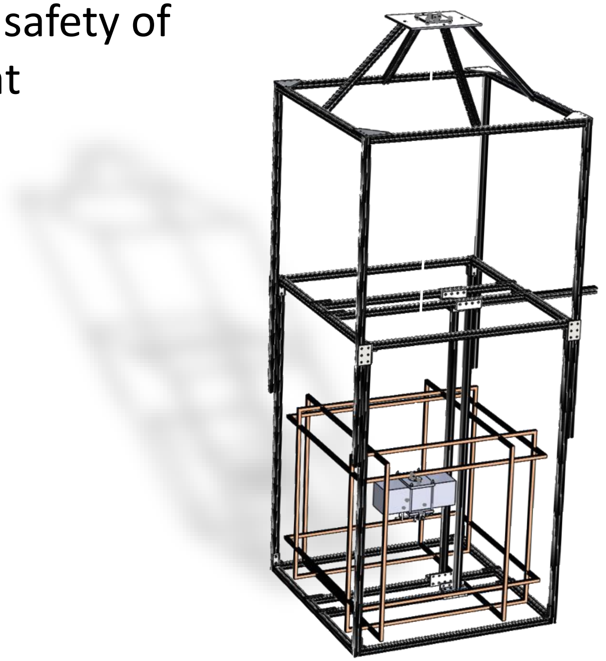
- 1 sample per degree
- Max rate of 10 degrees/second



Helmholtz Cage Testing System

- Magnetorquer Functionality

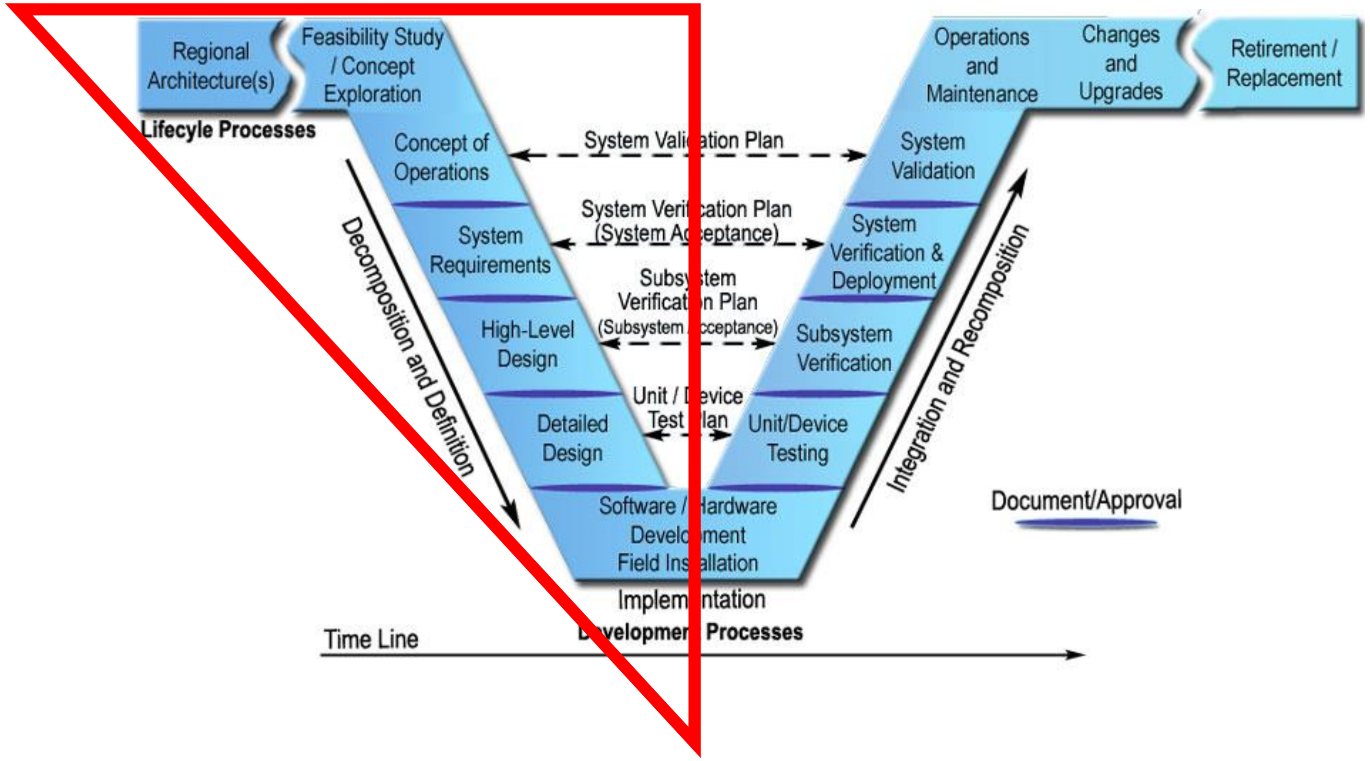
- Ensure safety of CubeSat



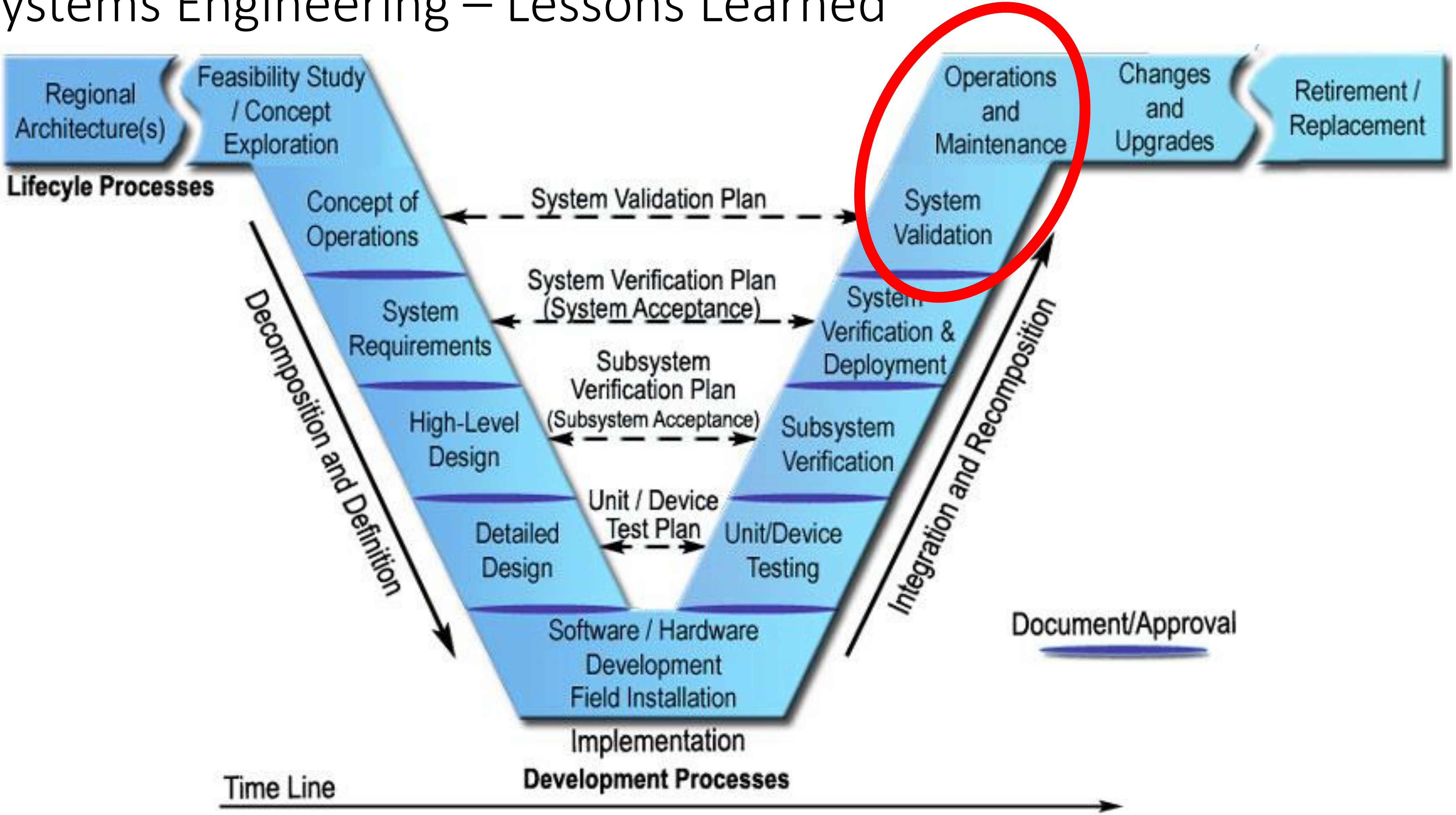
Systems Engineering – Initial Design

Original Trades

- Microcontrollers
- Software & GUI
- SSCT – Rotational Input
- SSCT – Angular Position Sensor
- HH Cage – Suspension Method



Systems Engineering – Lessons Learned



Systems Engineering – Risk Management

Severity → / Likelihood ↓	1	2	3	4	5
5					
4					
3	C*		C, D*	D	
2		G	A*	A	B, F
1	G*		E*	E	B*, F*

#	Risk	Mitigation
A	QB50 Sensor model not available	Development of basic sim to pass constant data to board
B	Interface board not ready	Schedule to finish early with margin
C	Matlab FTDI driver failure	Create virtual serial port object on USB using DAQ toolbox
D	Lead time for low reflectance coating	Machine coated parts first
E	EM interference between electronics	Top aluminum board will prevent disturbances
F	HH Cage line snaps	Use line with significant safety factor (2)
G	Air gust disrupts HH test	Plexiglas surrounds Helmholtz Cage

Systems Engineering – Risk Management

Severity → / ***Likelihood ↓***	***1***	***2***	***3***	***4***	***5***
5					
4					
3	**C***		**C, D***	**D**	
2		**G**	**A***	**A**	**B, F**
1	**G***		**E***	**E**	**B*, F***

	#	**Risk**	**Mitigation**
√	A	QB50 Sensor model not available	Development of basic sim to pass constant data to board
X	B	Interface board not ready	Schedule to finish early with margin
√	C	Matlab FTDI driver failure	Create virtual serial port object on USB using DAQ toolbox
√	D	Lead time for low reflectance coating	Machine coated parts first
√	E	EM interference between electronics	Top aluminum board will prevent disturbances
X	F	HH Cage line snaps	Use line with significant safety factor (2)
√	G	Air gust disrupts HH test	Plexiglas surrounds Helmholtz Cage

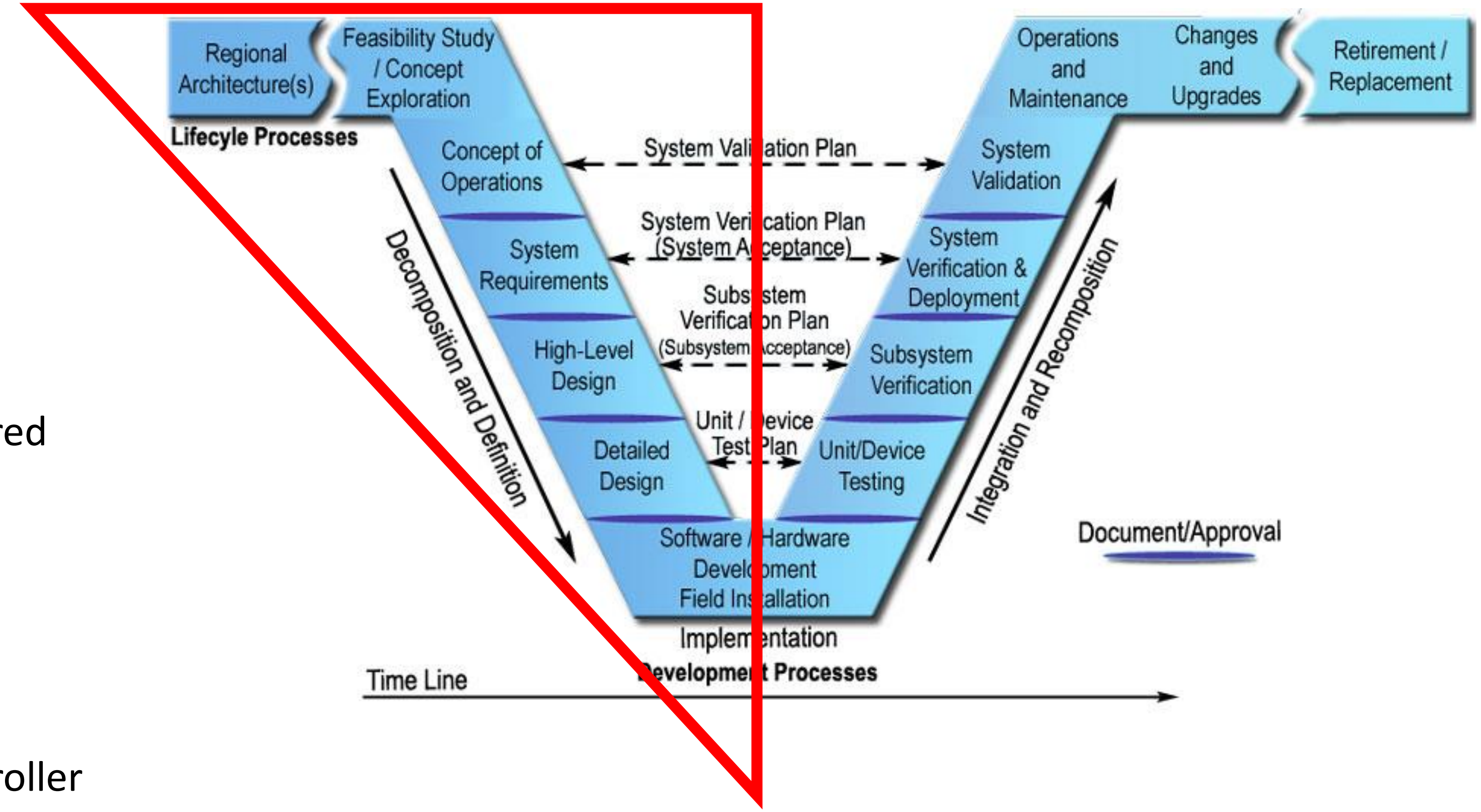
Systems Engineering – Lessons Learned

Where did we go wrong?

Unexpected delays –

- Failure to check Errata for required components
  - Master µC I/O Pins
  - SSCT magnetic encoder

- Unclear documentation on functionality of slave microcontroller
  - USART and I^2C could not be placed on separate pins

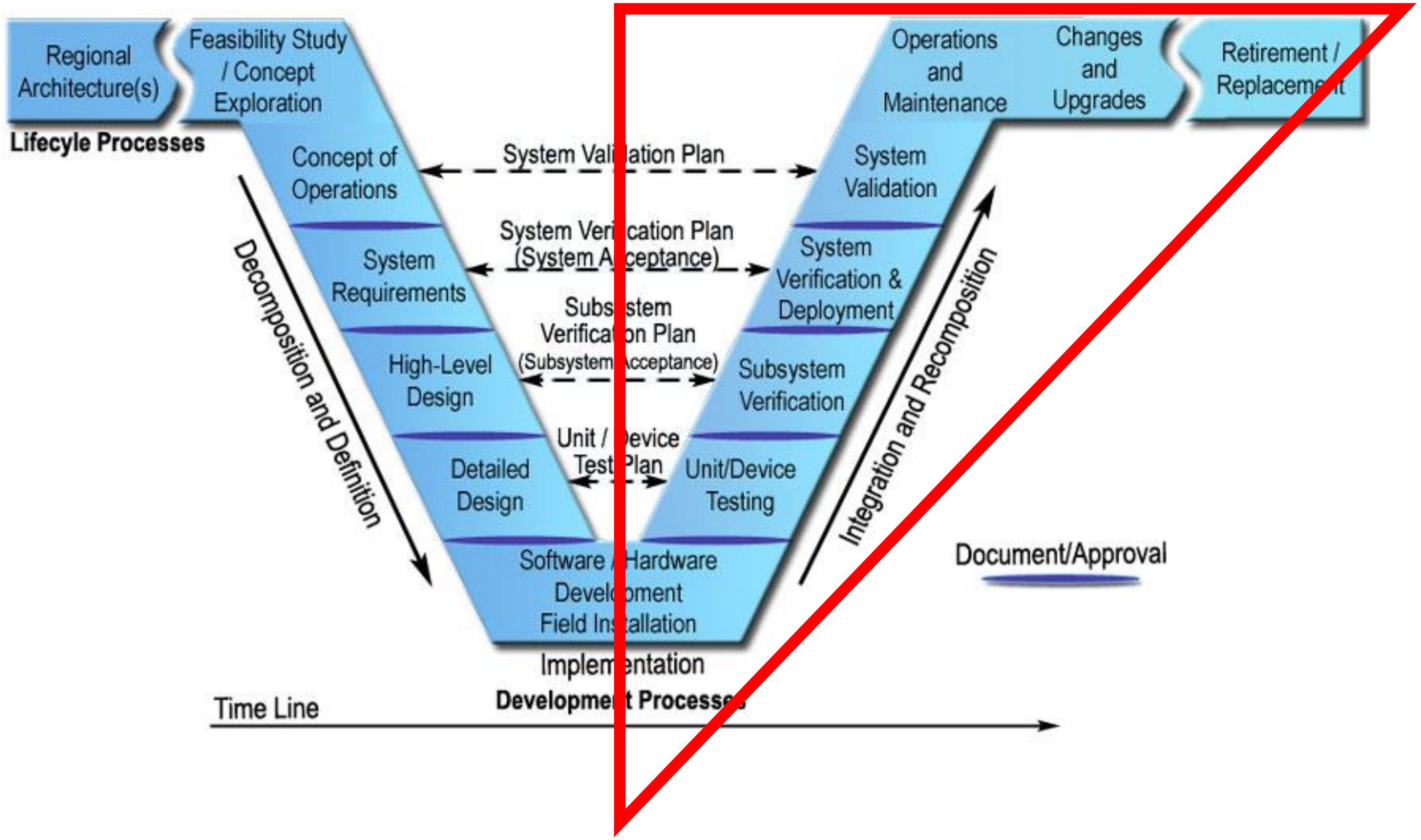


Systems Engineering – Lessons Learned

Where did we go wrong?

Ambitious Timeline–

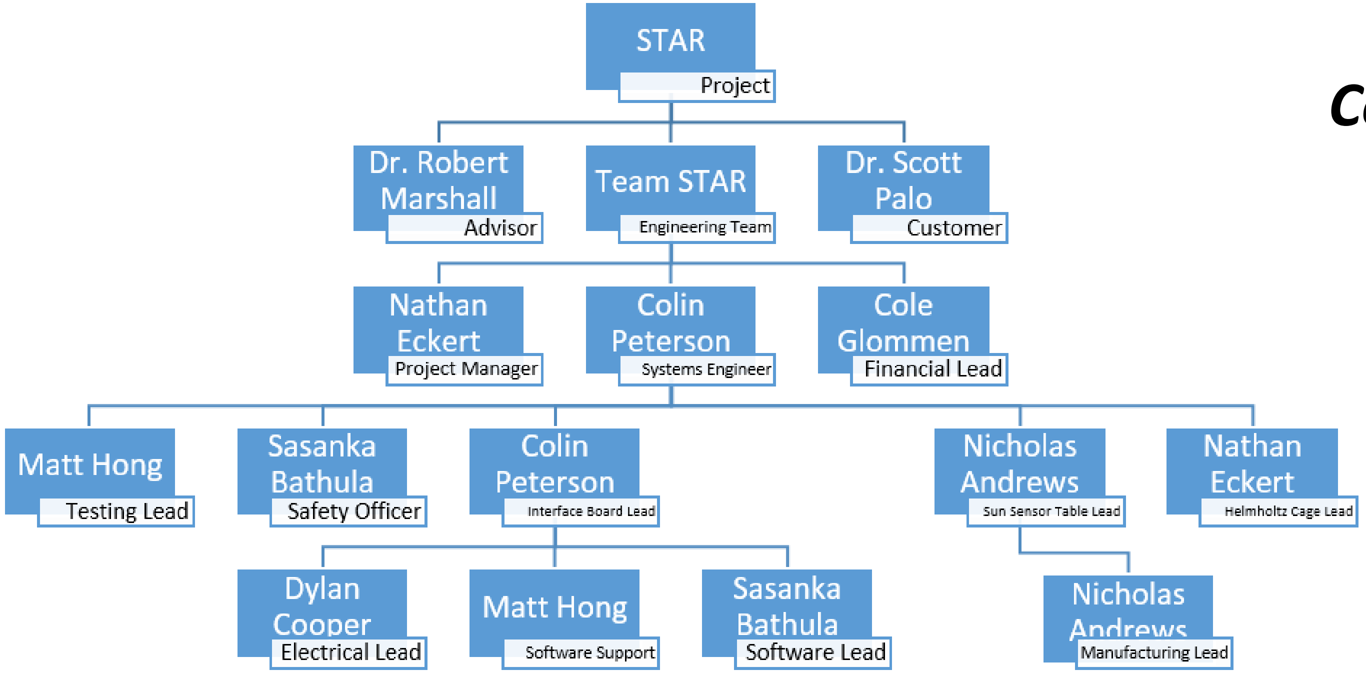
- Software took much longer than originally anticipated
- Small configuration problems cascaded into lengthy delays
- Unanticipated board revision pushed V&V past original due date
- Subsystem verification did not directly apply to full system verification



Project Management

Management approach and summary, Final Budget Overview, Industry Cost Comparison

Project Management Approach



Work Structure

- Sub-project leads took responsibility for work on sub-projects
- PM assigned extra tasks to available members or took volunteers

Communication

- Regular team and advisor meetings to coordinate work and update on progress
- Sub-project groups regularly coordinated detailed work
- Open communication channels with customer and graduate team
  - Various meetings to discuss progress and future work
  - QB50 Graduate team members available regularly
- Phone and email communication was integral in maintaining organization
- Google Drive organized individual work and group assignments

Final Project Management Summary

Successes

- Regular team meetings kept everyone updated on all work
- Customer availability allowed for major decisions and approvals to be made efficiently
- Interest based leads ensured intrinsic motivation
- Successful project completion

Difficulties

- Small team
- Team dynamics
- Maintaining effective communication outside of meetings
- Schedule and budget estimations
- Equal work allocation

Lessons Learned

- Schedule slip is inevitable and must be planned for
- Early budget estimation is not accurate
- Difficult to stay current with meeting management tasks
- Close proximity to client is valuable to success
- Deliverable deadlines come fast
- Team members have different motivations

Final Project Budget

Sub-Project	CDR Cost Estimate	Final Cost
Interface Board	$656.34	$1,558.88
Sun Sensor Calibration Table	$640.00	$1,117.20
Helmholtz Cage Testing Structure	$950.30	$1,959.64
Management (printing, shipping)	$300.00	$317.48
TOTAL:	***$2,546.64***	***$4953.20 (↑$2,406.56)***

Significant differences

- Gross underestimates on material costs needed to complete project
- ~$500.00 order placed for two copies of incorrect supposed final IB revision
  - Led to extra IB revision
- SS coating cost higher than expected
- Replacement costs for broken/incorrect hardware unaccounted for initially

Industry Cost Estimate

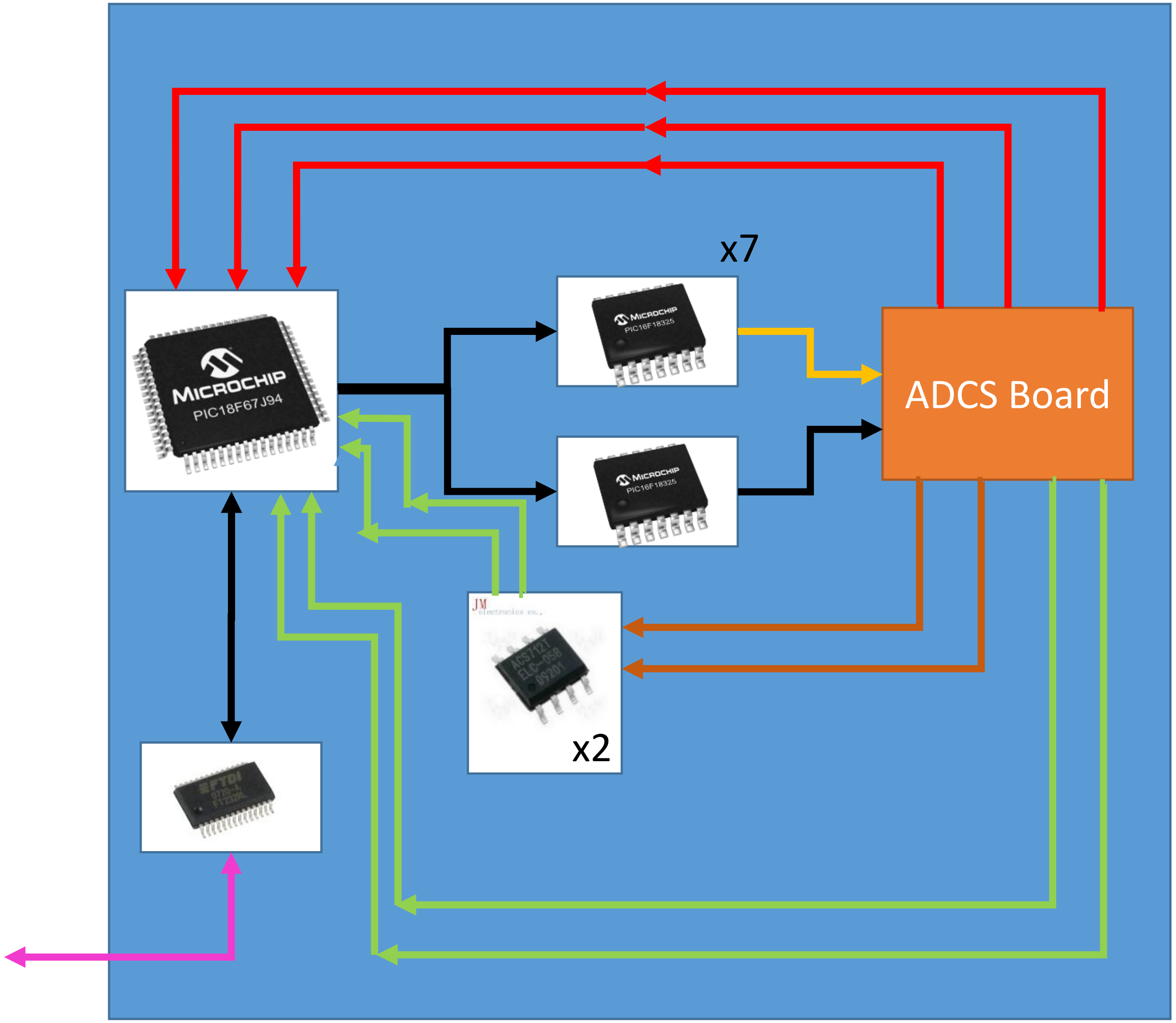
Assumptions

- Entry level Aerospace Engineers- **$65,000** annual salary (exclusive of benefits)
- **2080** hrs/year per person
- Overhead rate of **200%**

Team Members	7
Labor Rate	$31.25/hr
Average Weekly Labor Hours/Team Member	20
Number of weeks	28
Total Project Labor Hours Reported	3,888
Labor Subtotal	$121,500
200% Overhead	$243,000
Materials Cost	$5,000
Total Project Industry Cost	***$369,500***

Backup Slides

Full Board Design (Block Diagram)

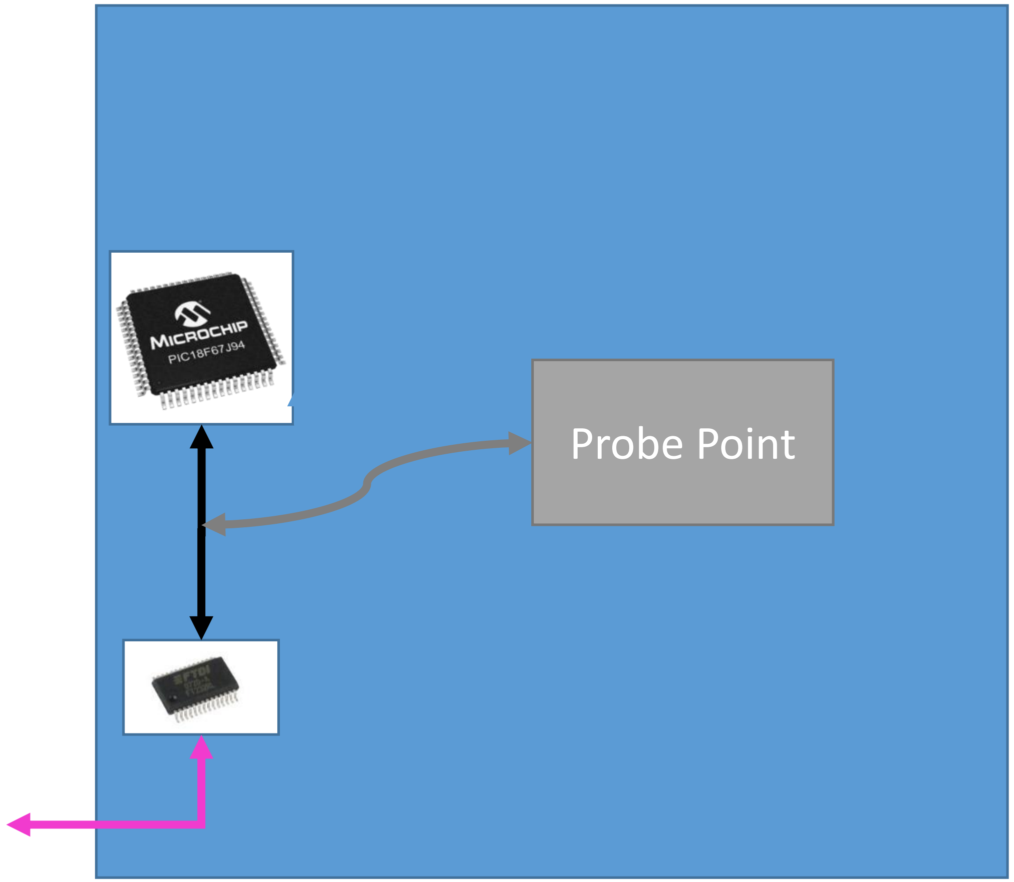


Legend:

- = USART
- = I^2C
- = FTDI – USB
- = FTDI Chip
- = PIC18F67J94 (Master)
- = PIC16F1874 (Slave)
- = PWM Signals (X,Y,Z)
- = Voltage
- = Current
- = Current Sensor

PC → FTDI → Master µC (µC → Microcontroller)

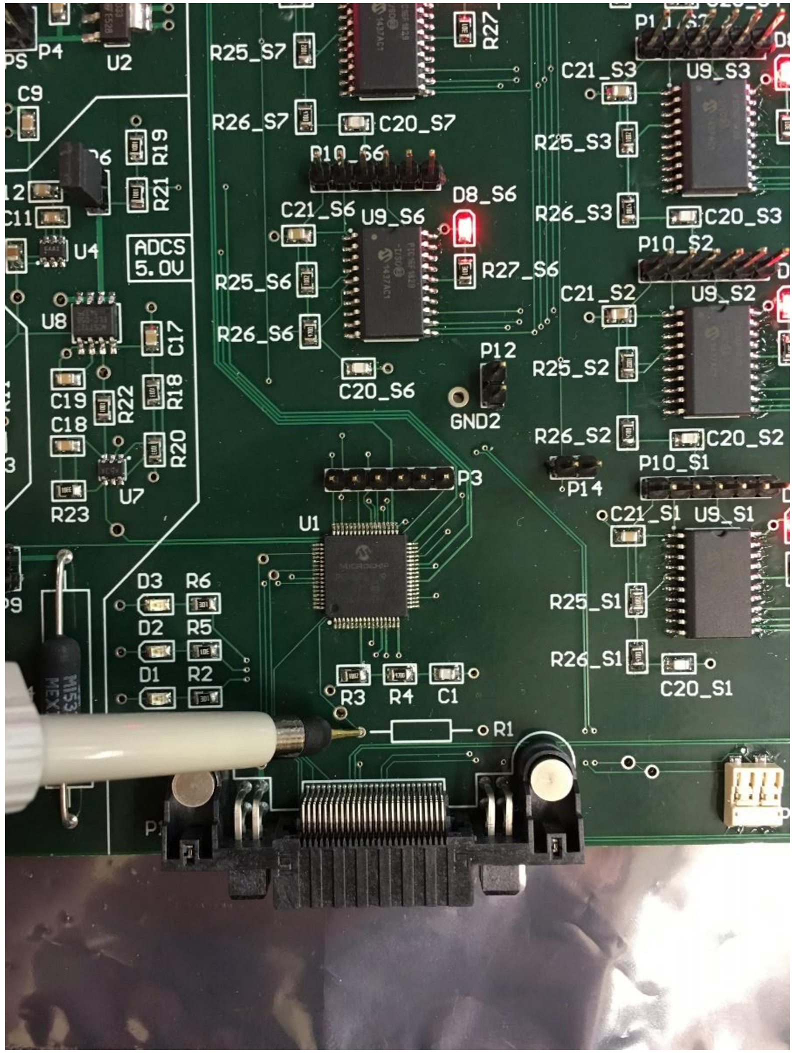
Master Microcontroller reads incoming data over USART line



Testing Status: COMPLETE

- Data is ingested byte-by-byte
- Each byte is relayed to slaves

Interface Board – PWM Capture Round 2



- Identical code
- Identical function generator settings

	25%	50%	75%
Average Value	39%	63%	90%
% Difference	14%	13%	15%

- Team is investigating differences in PWM calculation

*Agilent 33120A function generator has 1% frequency errors.

Interface Board – Power Measurements

3.5 Volt Power Line

	Interface Board	Agilent Multimeter
Current sensor – 0 Amp Output	2.49 V	2.48 V
Dummy Load Output	2.40 V	2.38 V
Current	147 mA	138 mA
Line Voltage	3.49 V	3.50 V
Calculated Power	0.515 W	0.483 W

5 Volt Power Line

	Interface Board	Agilent Multimeter
Current sensor – 0 Amp Output	2.46 V	2.51 V
Dummy Load Output	2.34 V	2.32 V
Current	196 mA	189 mA
Line Voltage	4.93 V	4.92 V
Calculated Power	0.969 W	0.929 W

*Agilent 34401A multimeter has a ~ 0.055% current error and a ~ 0.004% voltage errors.

Turntable – Reflectance and Tolerance

Reflectance

- Tested with LightMeter iPhone app

$$Reflectance = \frac{Board}{Light\ Source}$$
$$= \frac{14\ Lux}{354\ Lux}$$
$$= 3.954\%$$

Tolerance Stack

Max error to satisfy ±0.5° requirement = 0.078”

Component	Tolerance
Bottom Board	0.025”
Shaft	0.007
Top Board	0.033”
Clamps	0.005”
Total	0.07”

Can be reduced to 0.005” by increasing height of precession posts with shims and minimizing deflection of top board (for Top Board)

Test Strength of Attachment and Line

Test Objective: Validate the manufacturer's claims that the line can withstand 30 lbs

Validate the assertion that the attachment mechanism will withstand at least 30 lbs

General Procedure: Line is attached to attachment cylinders at each end, which are attached to testing clamps, and are placed in the Instron tensile testing machine. Test done to failure of the line.

Data Gained: Maximum load of the braided nylon line

Lower limit of attachment mechanism maximum load

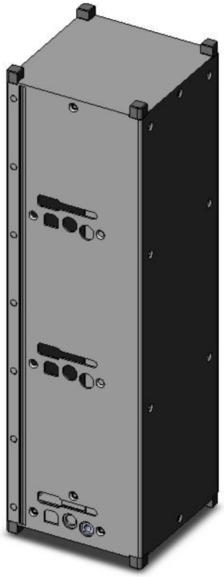
Resources Used: Instron Tensile Testing Machine || Attachment Cylinders || Testing Clamps || Line

Test Time to Rotate of Satellite Mass Model

Resources Used:
- HelCaTS Structure
- Satellite Mass Model
- Cell Phone - video recording

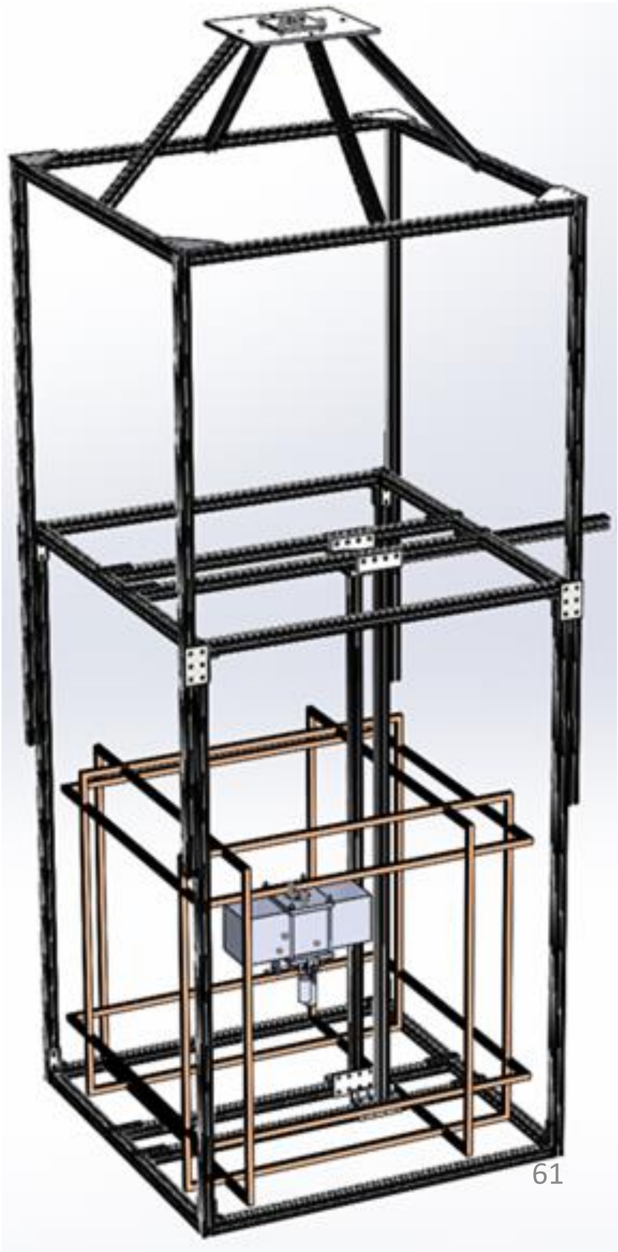
Risk Reduction:
- Provides confidence that the test will perform as intended (reduces risk that initial data was faulty, or that the satellite cannot rotate in a reasonable amount of time)

Status:
- Will be completed 2 weeks after the structure is finished (1 week after the previous two tests).
- Very similar test done in the Fall



3U CubeSat Mass Model

Cell Phone



Test Time to Rotate of Satellite

Test Objective: Validate the time to rotate model

General Procedure: Rotate the satellite 360^{o} and measure the time it takes to rotate back to 0^{o}

Perform multiple trials releasing by hand, and with the release mechanism

Data Gained: Time for satellite to rotate clockwise, counter-clockwise

Variation in time to rotate produced by release mechanism compared to hand-release

Resources Used: HelCaTS Structure, Satellite Mass Model, Cell Phone - video recording

Risk Reduction: Provides confidence that the test will perform as intended (reduces risk that initial data was faulty, or that the satellite cannot rotate in a reasonable amount of time)

Test 5: Performance Test with Satellite and Magnetorquers

Test Objective: To validate the time needed to rotate with the magnetorquers acting with and against the direction of twist.

General Procedure: Rotate the satellite 360^{o}, Turn on the magnetorquers, Measure the time taken to return to 0^{o}, Ensure that the magnetorquers were acting in the direction they were measured

Data Gained: Impact of magnetorquers on time to rotate [Critical Project Element]

Resources Used: HelCaTS Structure || QB50 Satellite including magnetorquers and control software

Test 1: Test Satellite Impact into Foam

Test Objective: To verify that the satellite will not endure more than ?? G's if it falls.

General Procedure: Drop satellite mass model with attached phone from 1' onto foam. Repeat multiple times to obtain confidence

Data Gained: X, Y, and Z Peak acceleration during impact (recording frequency 200 Hz = sample every 0.005 s)

Resources Used: HelCaTS Structure, Cell Phone, Acceleromate PRO, Foam

Risk Reduction: Provides confidence in the foam used to account for satellite impact (reduces risk of satellite breaking if it does fall)

Expected Results: The foam will reduce the satellite's impact acceleration from ??? to

Test 4: Test Effects of Over-Tightening Rods

Test Objective: To find the number of turns, or torque required, to tighten the clamping rods such that the satellite will not slip, but will also not be damaged by the compression.

General Procedure: Place Pumpkin in clamps and measure compression force

Data Gained: Compression force provided as nuts are tightened

Resources Used: Attachment Clamps || Wrench || 4 Load Cells || Data aquisition software

Risk Reduction: Provides confidence that the satellite will not be damaged by over-tightening the rods (reduces risk of satellite damage by over-tightening rods)

HelCaTS Parts

Parts Purchased (Red)

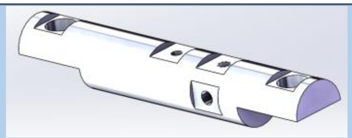
- Extruded Aluminum
- Screws / Nuts
- Threaded Rod

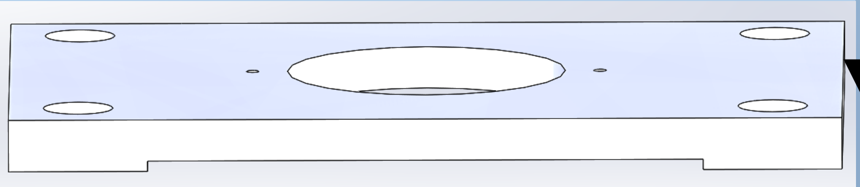
Parts Provided by Customer (Green)

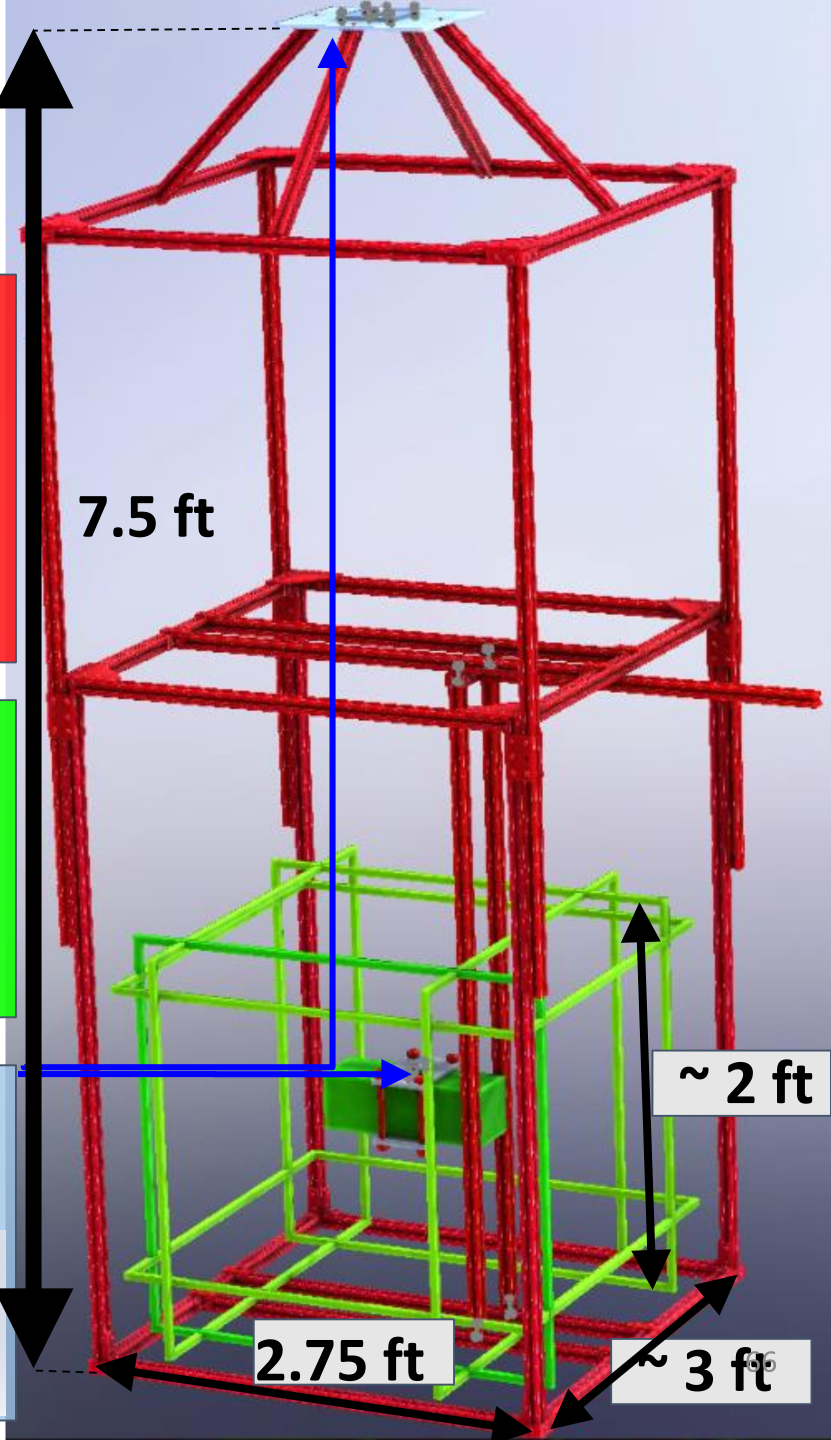
- Satellite
- Helmholtz Cage

Parts Machined by STAR

- Attachment Cylinders
- Attachment Plates

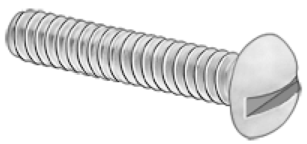


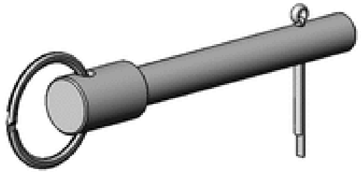




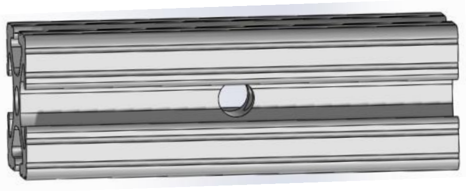
HelCaTS Purchased Parts

- Various Screws, Nuts, and Clevis Pins (all aluminum)



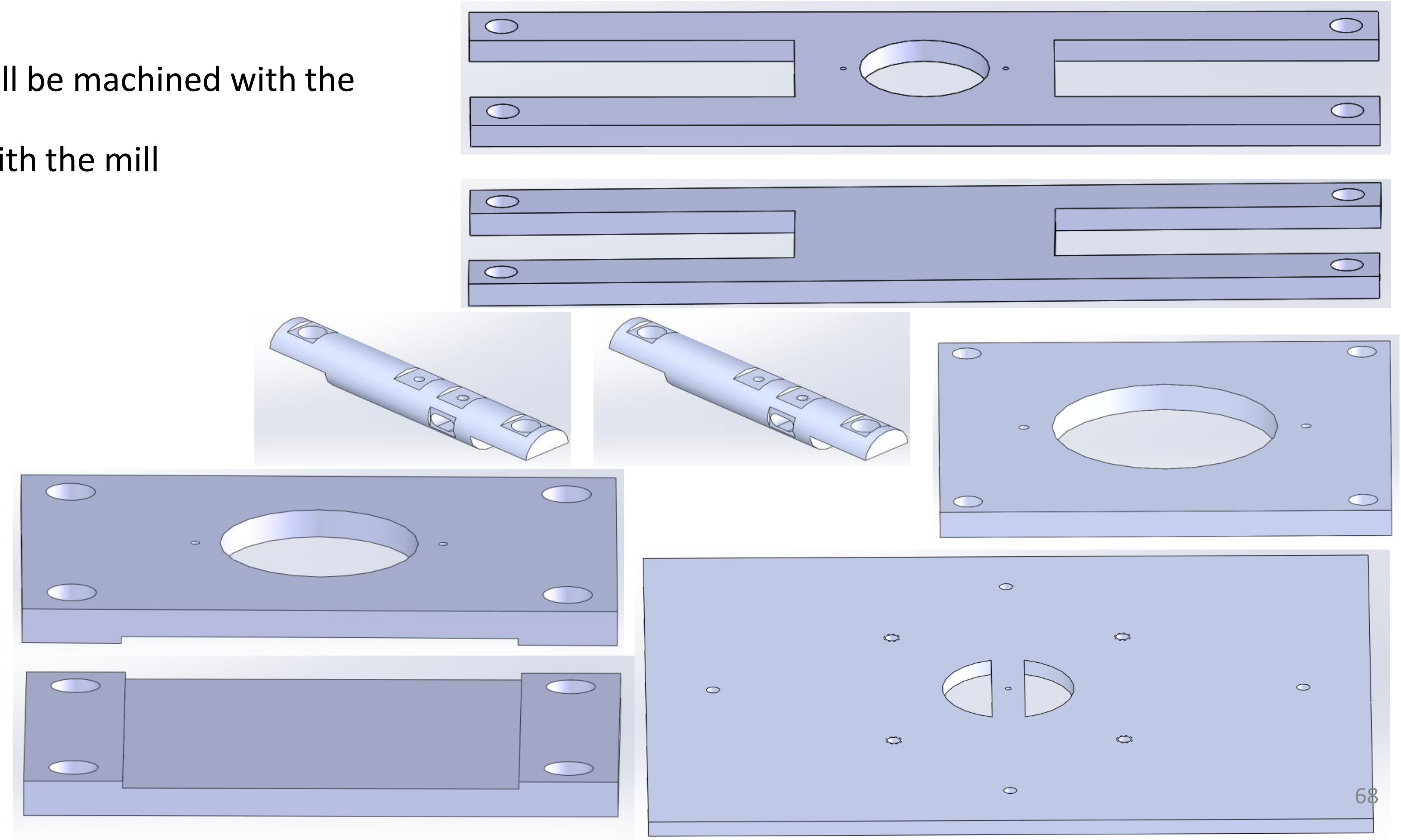


- S… teel … for … extruded Aluminum
- Extruded Aluminum Bars (… 8020)
    - Cut to size 48” ,45.7”, 33”, 31”, 24”
        - (+/- 0.005”)
    - Some Ends Tapped
    - Through holes drilled to pin the sliding mechanism




HelCaTS Manufactured Parts - Overview

8 Pieces in total
All plates are 0.25” thick and will be machined with the CNC
Cylinders are made manually with the mill



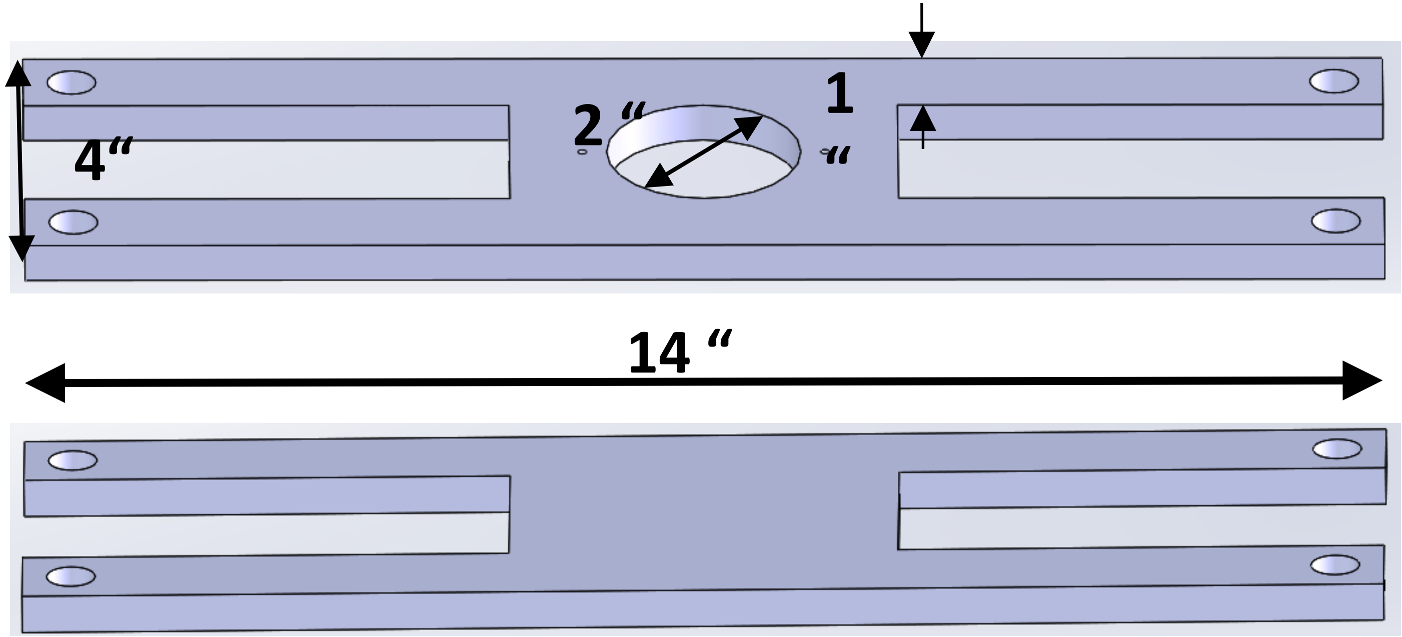
HelCaTS Large Clamp Machining - In Progress

Status: Toolpaths 80% Written

Machining to be done

Machining Order:

- cut out legs
- cut out center hole
- drill holes
- clean outer dimensions



Critical Dimension:

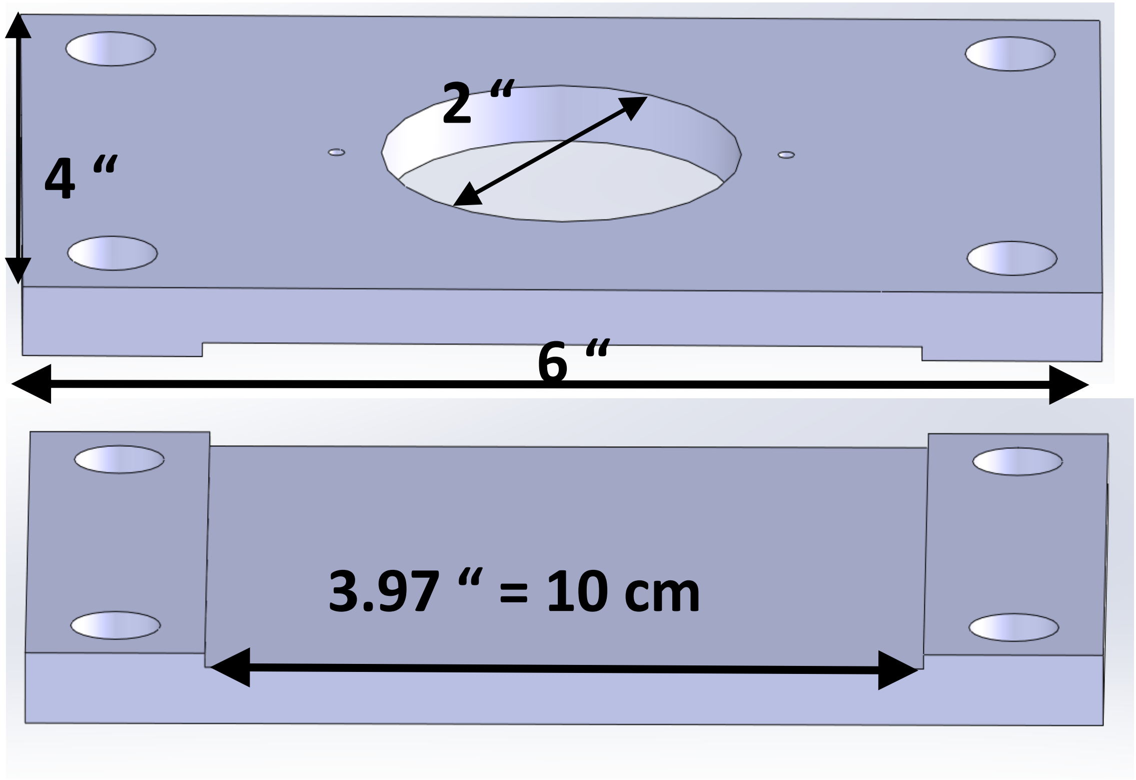
- spacing of ½" holes must be accurate to 0.0156" in each direction
- spacing of tapped ¼" holes must be accurate to 0.008" in each direction

HelCaTS Small Clamp Machining - Finished

Status: Machining Done (will be done Friday)

Machining Order:

- cut out center hole
- drill holes
- clean outer dimensions
- flip over and take down center



Critical Dimension:

- spacing of ½” holes must be accurate to 0.0156” in each direction
- spacing of tapped ¼” holes must be accurate to 0.008” in each direction

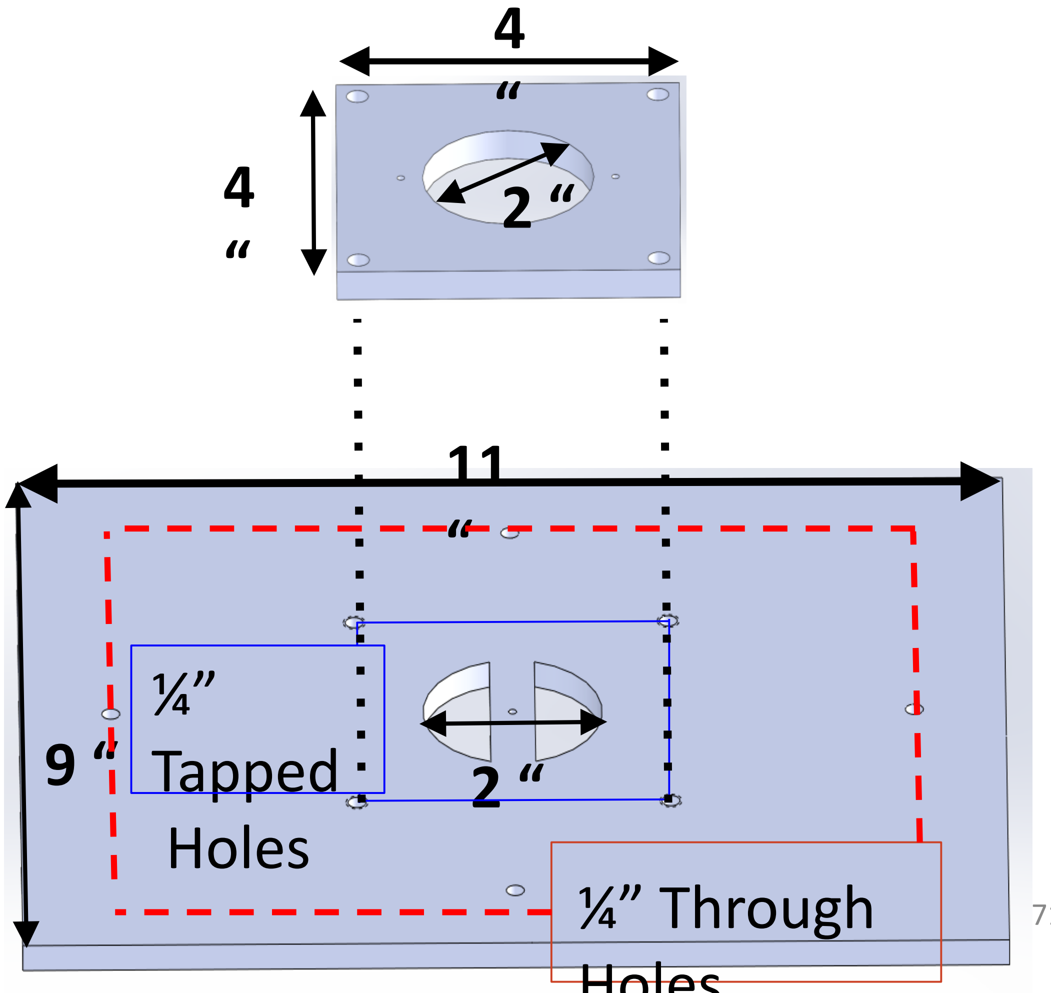
HelCaTS Attachment Plate Machining - To be done

Machining order:

- Take out center holes
- Drill holes
- Clean outer dimensions

Critical Dimensions:

- Plate-to-plate holes must be accurate to 0.008”
- ¼” Tapped holes on top plate must be accurate to 0.1”

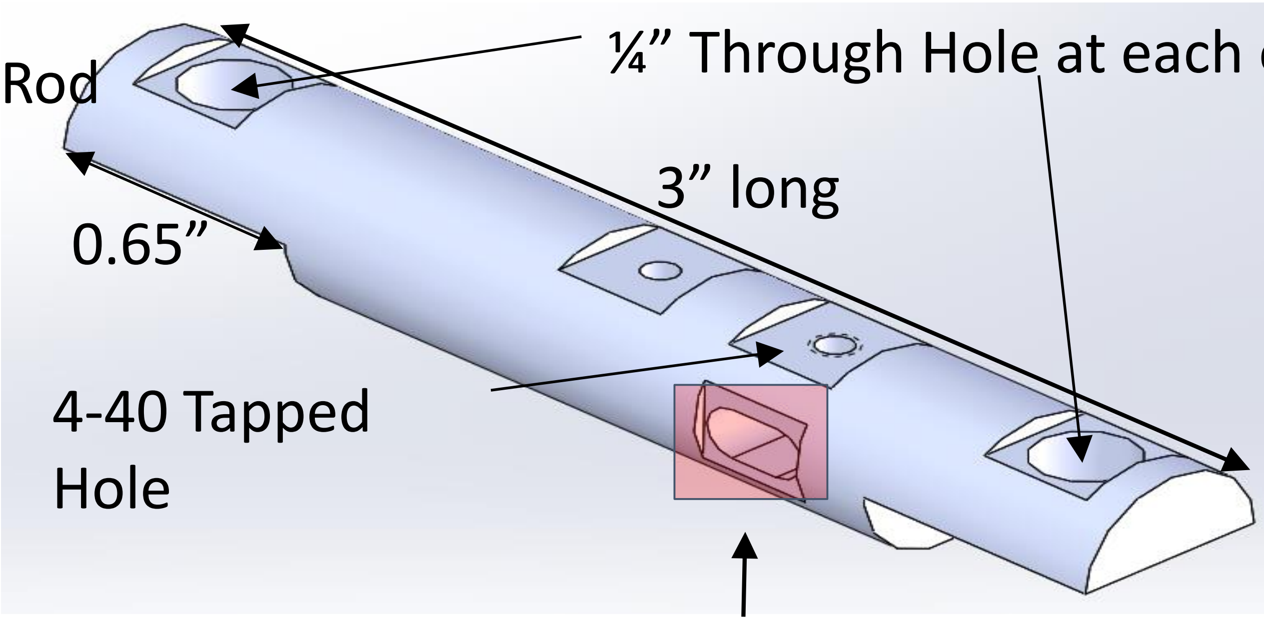


HelCaTS Manufactured Parts - Attachment Cylinder

Status: 1 of 2 Machined

Machining Order:

- Mill Shoulders
- Make slots for hole drilling
- Drill holes
- Slot necessary hole



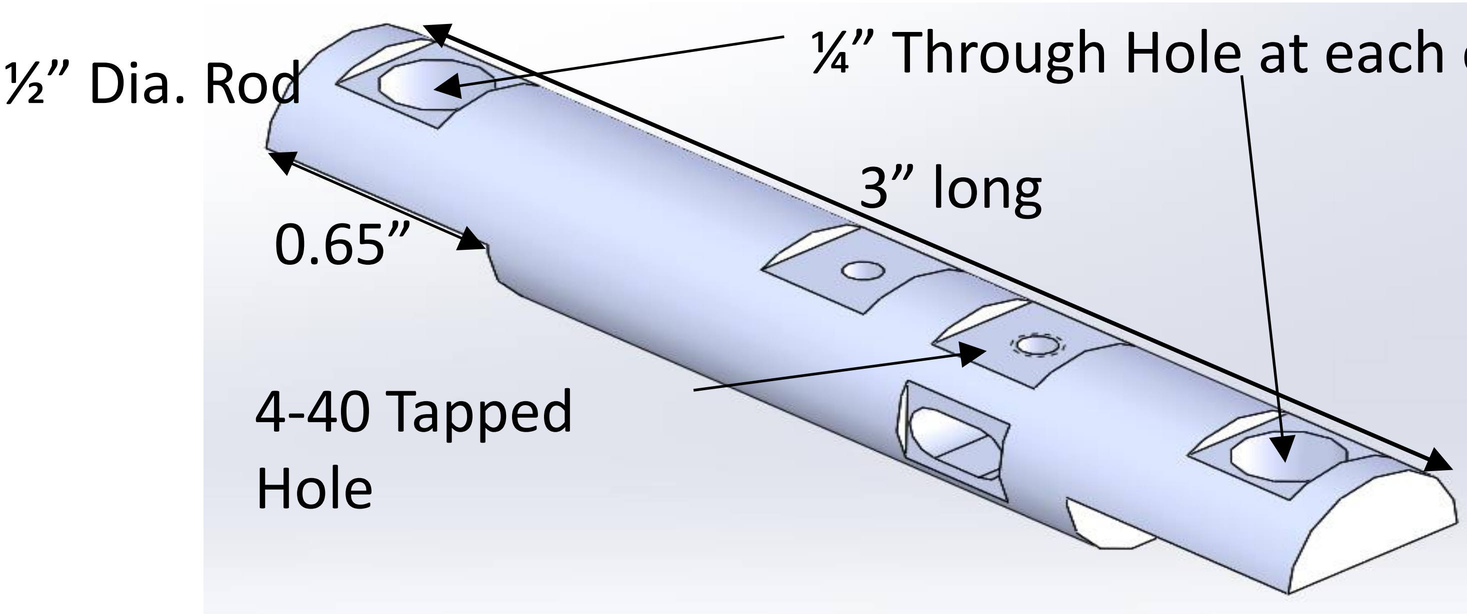
Change: hole now slotted

Slotted hole made by:
- drilling with a #25 bit (0.1495")
- using a 9/64" end mill (0.1406") to slot the hole

HelCaTS Manufactured Parts - Attachment Cylinder

Critical Dimensions:

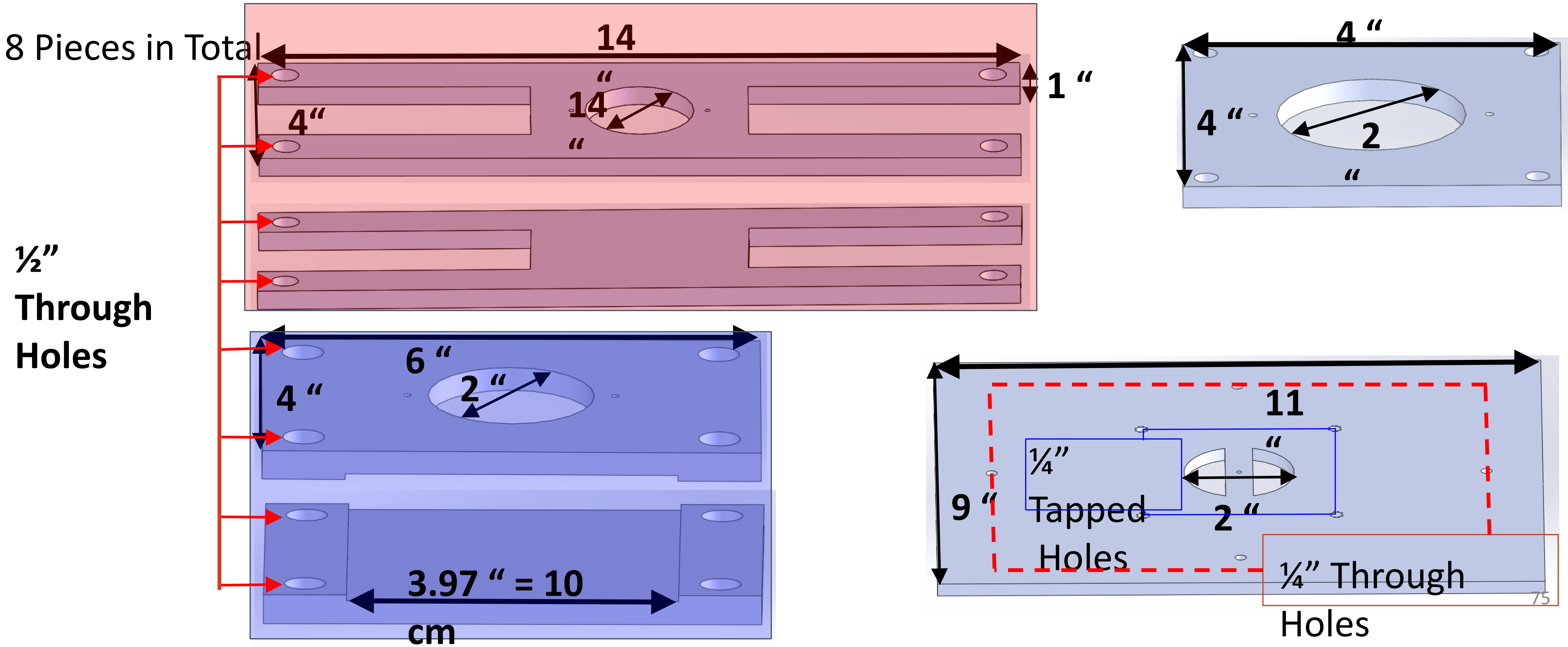
- End holes must be accurate to 0.008”
- Set screw hole and slotted hole must be accurate to within 0.0675

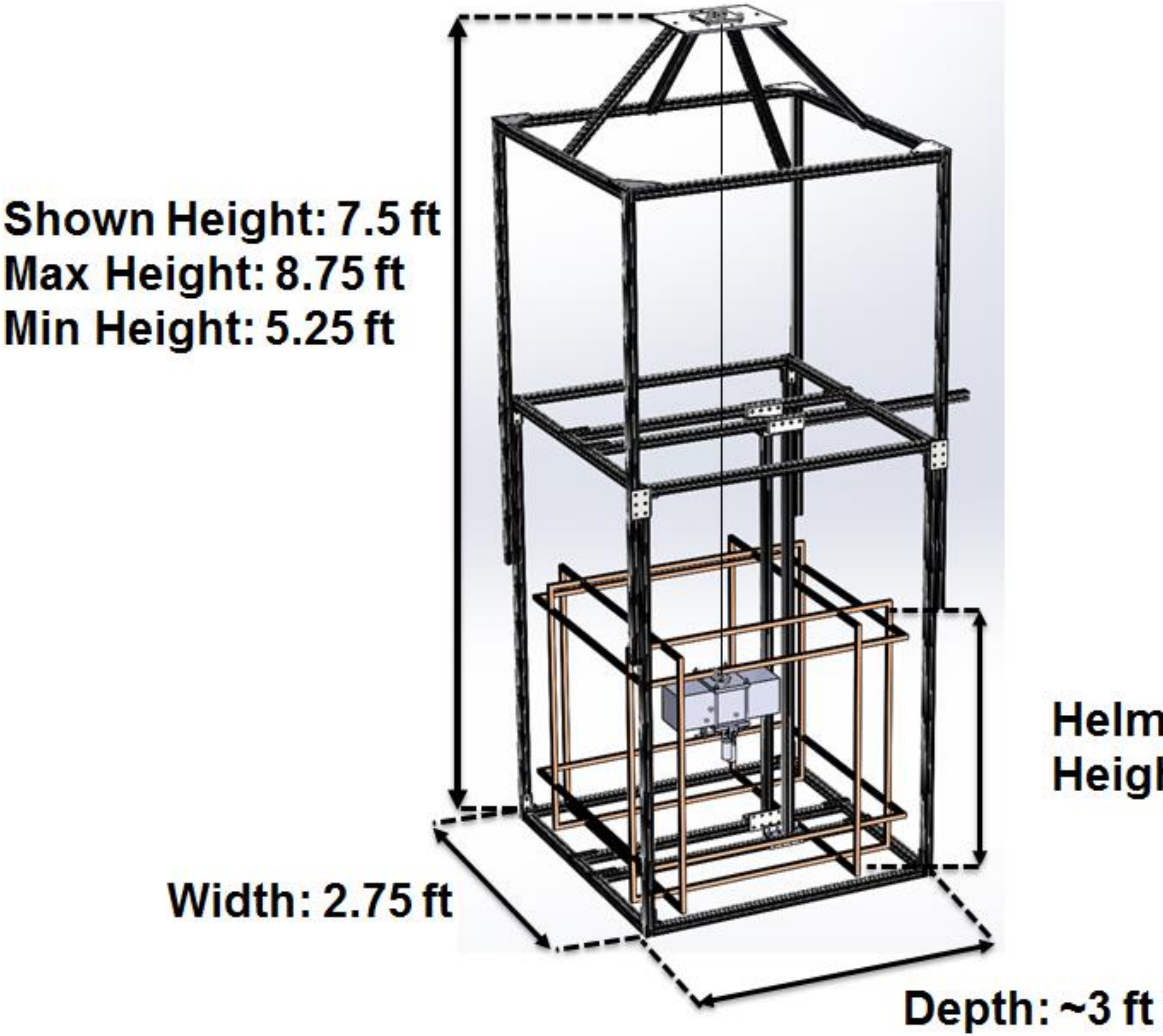


HelCaTS Manufactured Parts - Backup

HelCaTS Manufactured Parts - Backup

Similar colors = similar dimensions
All plates are 0.25” thick and will be machined with the CNC




Shown Height: 7.5 ft
Max Height: 8.75 ft
Min Height: 5.25 ft
Helmholtz Cage
Height: 2 ft
Width: 2.75 ft
Depth: ~3 ft