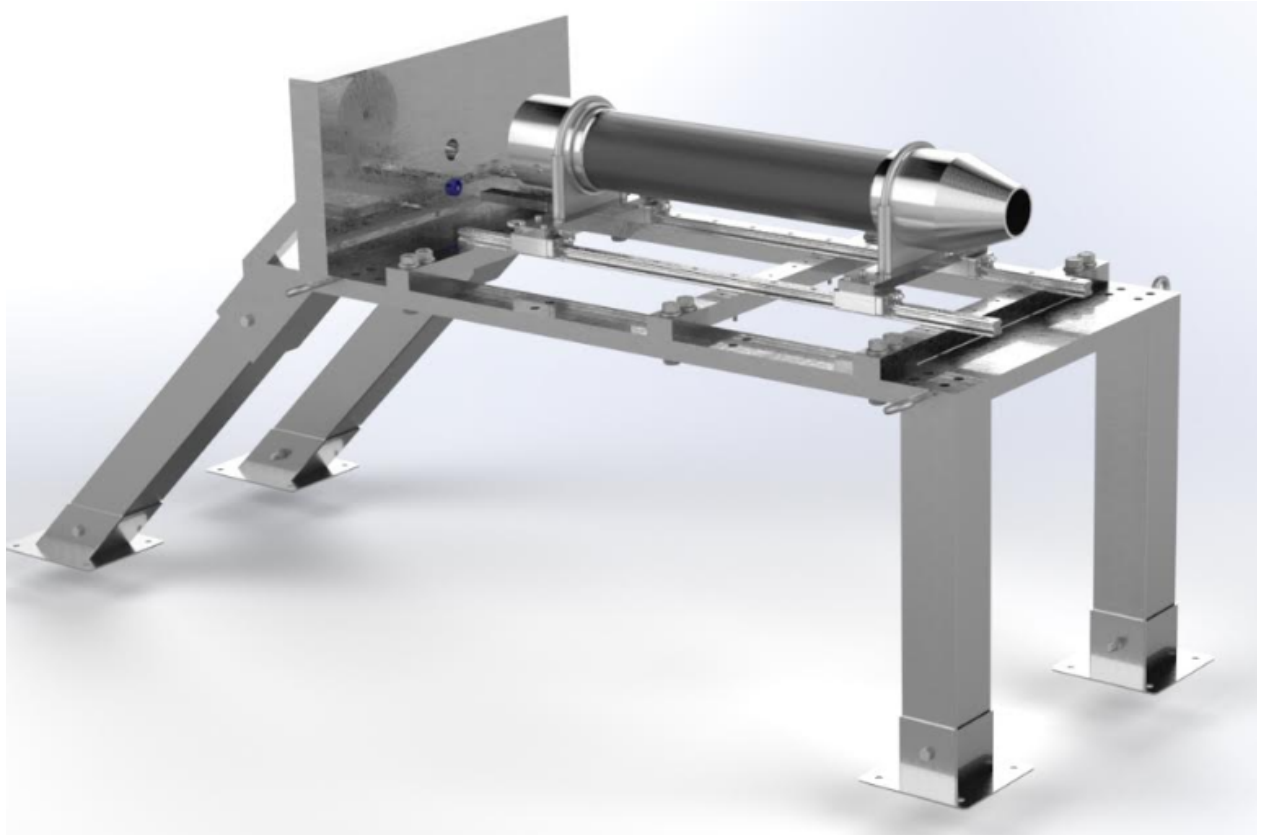
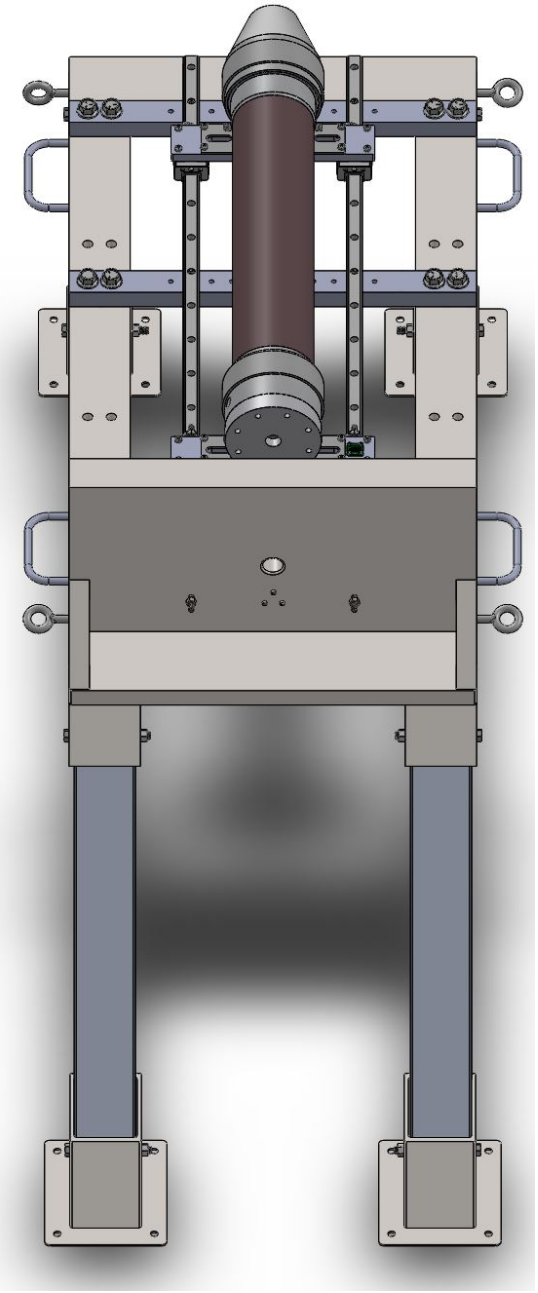
HICKAM MSR



Haleigh Flaherty, Kirill Kravchuk, Tommy Pestolesi, Gerardo Pulido, Dylan Reed, Jaquelyn Romano, Sage Sherman, Olagappan Chidambaram, Nate O'Neill, Angel Ortega, Brian Ortiz, and Savant Suykerbuyk

Agenda

- Overview
- Schedule
- Manufacturing
- Budget



Project Overview

- The goal of project HICKAM (**H**ybrid-rocket **I**nformation-**C**ollection, **K**nowledgebase and **A**nalysis **M**odule) is to design and manufacture a modular, compact, and portable testing platform for hybrid rocket engines.
- Customer vision:
  - A plug-and-play test stand for future hybrid rocket projects
  - Donated to the department for future rocket project use

Levels of Success

Requirements	Mission Goals	Analysis Items
Level 1	Successful test of test stand using simulation of loads	Measure thrust (delay, duration, and maximum), total impulse, mass of rocket engine
Level 2	Successful static cold flow test	Measure nozzle temperature, combustion chamber pressure
Level 3	Successful static hot fire test	Measure of oxidizer flow rate, specific impulse

CONOPS

Hybrid-rocket **I**nformation-**C**ollection, **K**nowledgebase and **A**nalysis **M**odule (**HICKAM**)

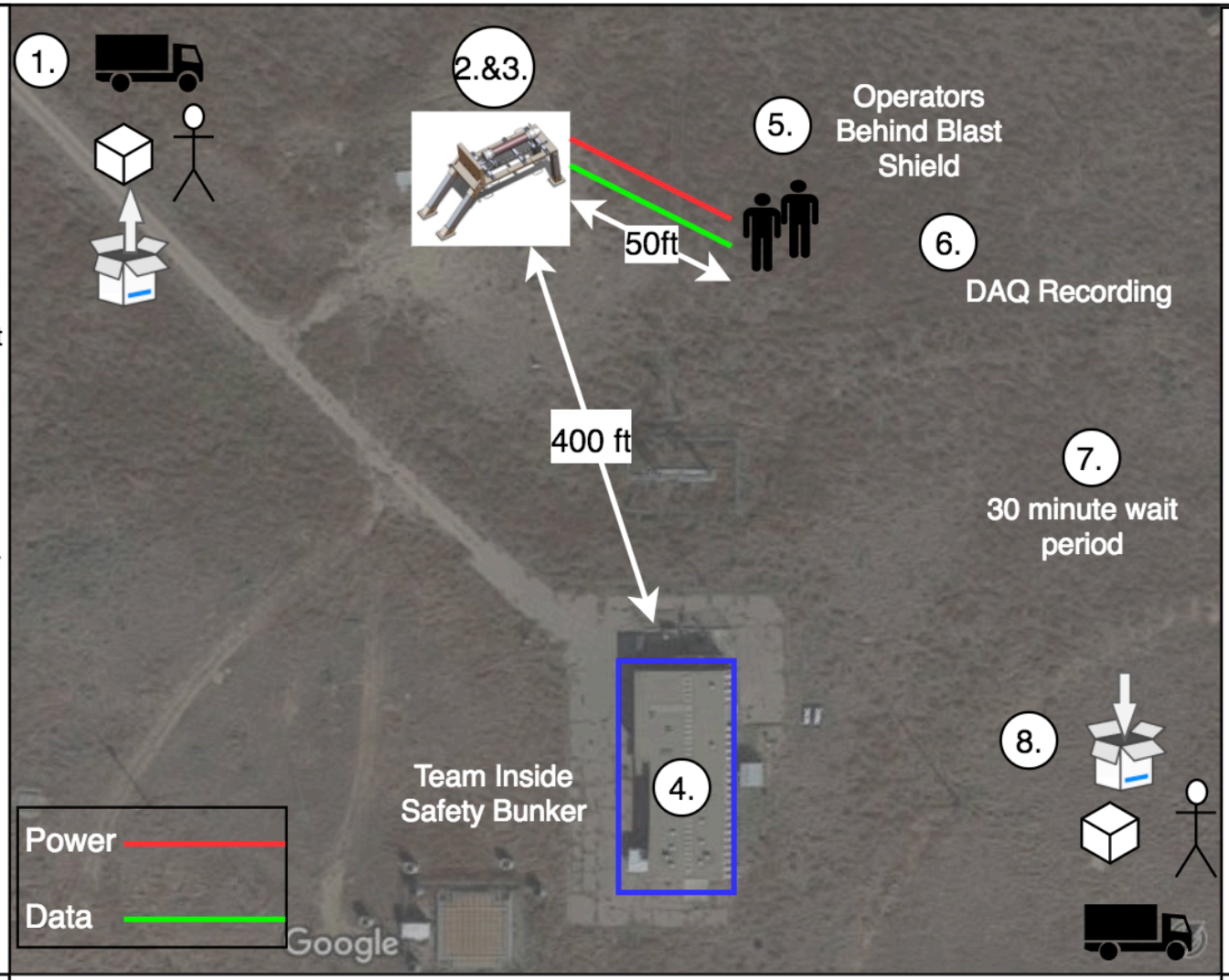
Pre - Test

Step 1 - Transport, unbox, and set up HICKAM at chosen test facility. Secure it to the ground

Step 2 - Integrate test article (rocket engine) to HICKAM

Step 3 - Check system for proper connections, power, and proper valve position

Step 4 - Safety check: check pressures, fail safe procedures, team behind bunker



Post - Test

Step 8 - Disassemble, box, and transport HICKAM

Step 9 - Within 72 hours of PRE-Test start, compile specifications sheet for test article

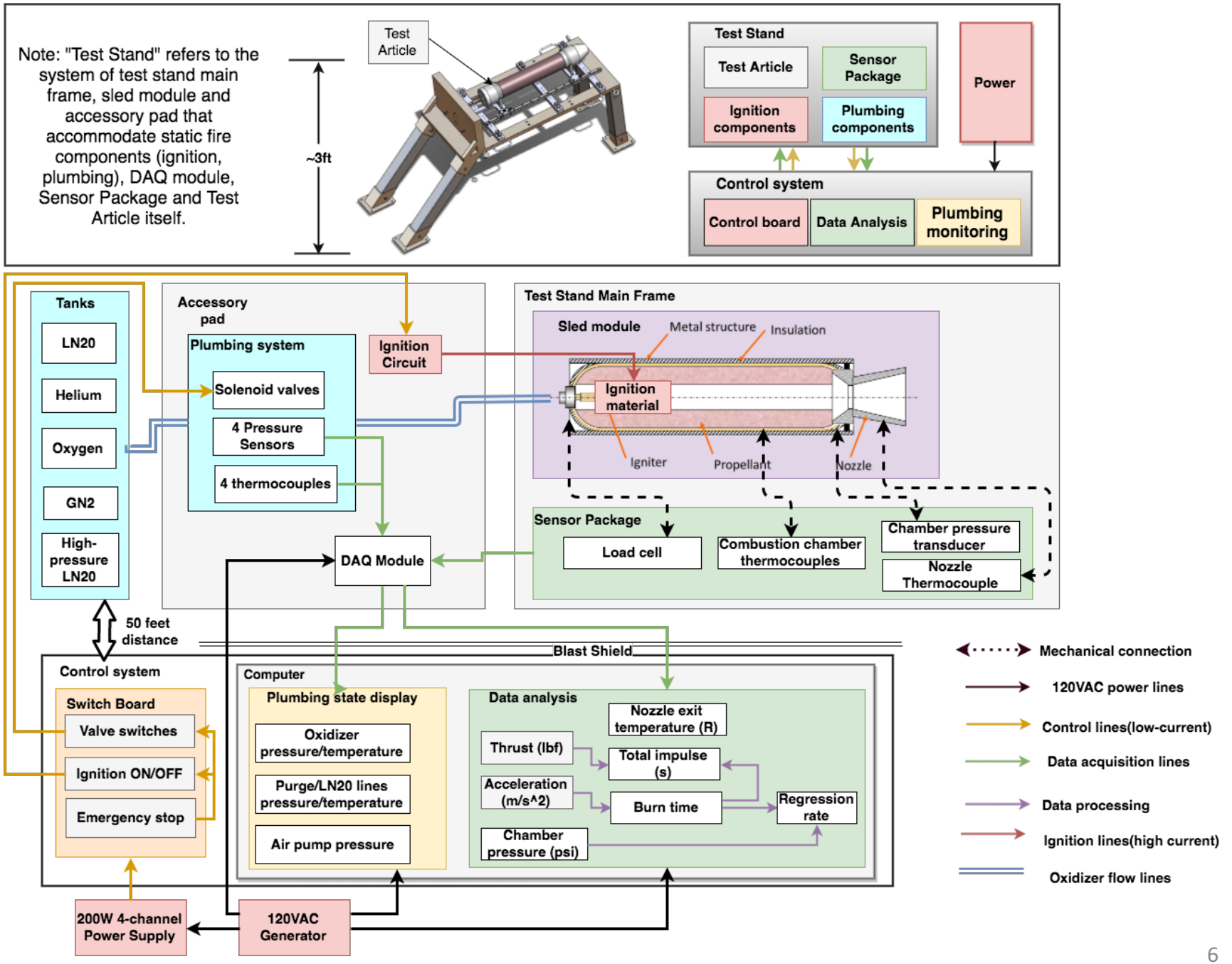
ASEN 4028: Des Practicum

Test

Step 5 - Command to engage DAQ to start recording data, and initiate rocket ignition
Step 6 - DAQ collects data for the 20 second approximate burn and saves it to memory
Step 7 - 30 minute wait time before approaching HICKAM to ensure safety

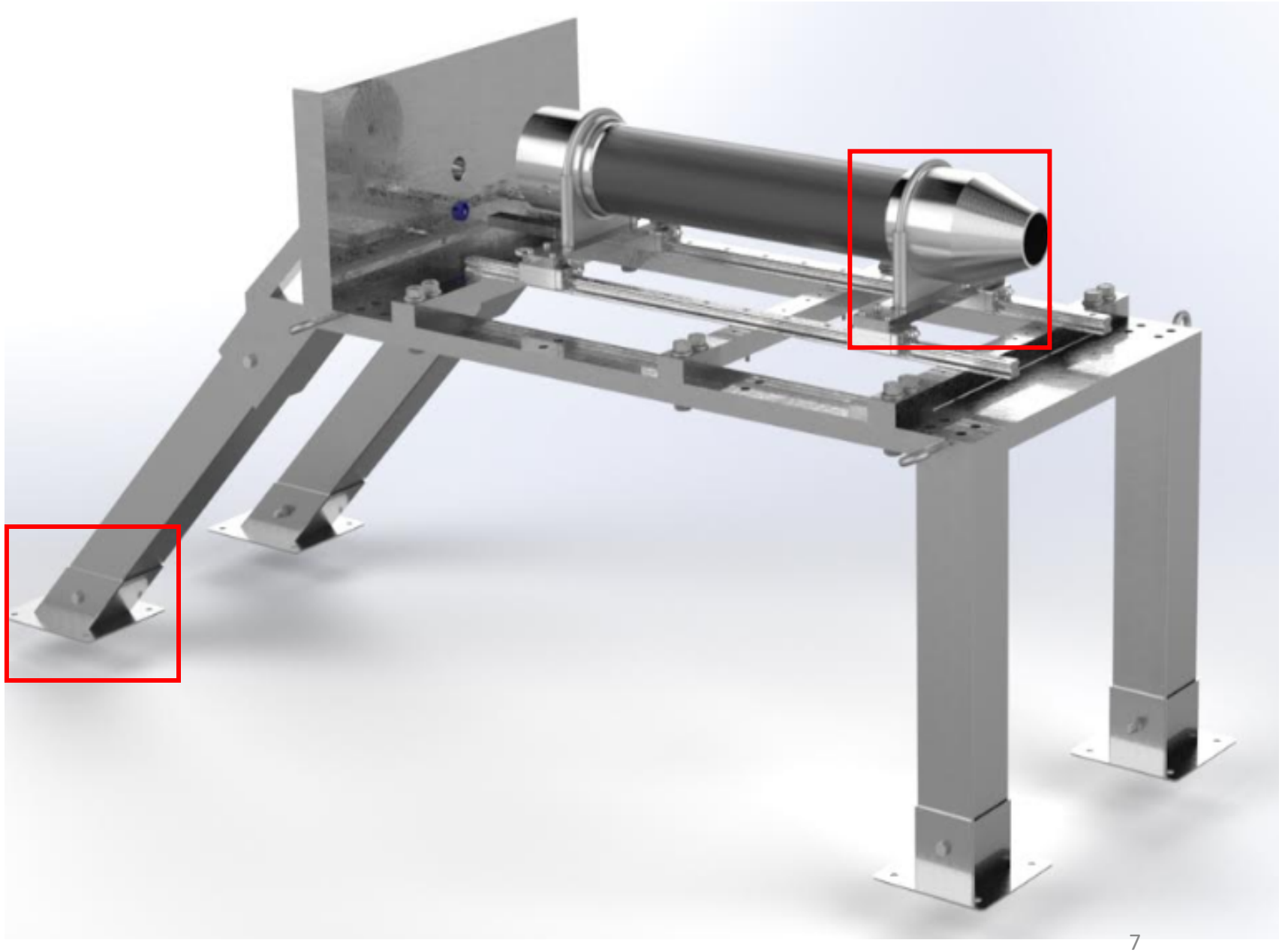
Spring 2018

FBD


Note: "Test Stand" refers to the system of test stand main frame, sled module and accessory pad that accommodate static fire components (ignition, plumbing), DAQ module, Sensor Package and Test Article itself.
Test Article
~3ft
Test Stand
Test Article
Sensor Package
Ignition components
Plumbing components
Power
Control system
Control board
Data Analysis
Plumbing monitoring
Tanks
LN20
Helium
Oxygen
GN2
High-pressure LN20
Accessory pad
Plumbing system
Solenoid valves
4 Pressure Sensors
4 thermocouples
Ignition Circuit
DAQ Module
Test Stand Main Frame
Sled module
Metal structure
Insulation
Ignition material
Igniter
Propellant
Nozzle
Sensor Package
Load cell
Combustion chamber thermocouples
Chamber pressure transducer
Nozzle Thermocouple
50 feet distance
Blast Shield
Control system
Switch Board
Valve switches
Ignition ON/OFF
Emergency stop
Computer
Plumbing state display
Oxidizer pressure/temperature
Purge/LN20 lines pressure/temperature
Air pump pressure
Data analysis
Nozzle exit temperature (R)
Thrust (lbf)
Total impulse (s)
Acceleration (m/s^2)
Burn time
Regression rate
Chamber pressure (psi)
200W 4-channel Power Supply
120VAC Generator
Mechanical connection
120VAC power lines
Control lines(low-current)
Data acquisition lines
Data processing
Ignition lines(high current)
Oxidizer flow lines

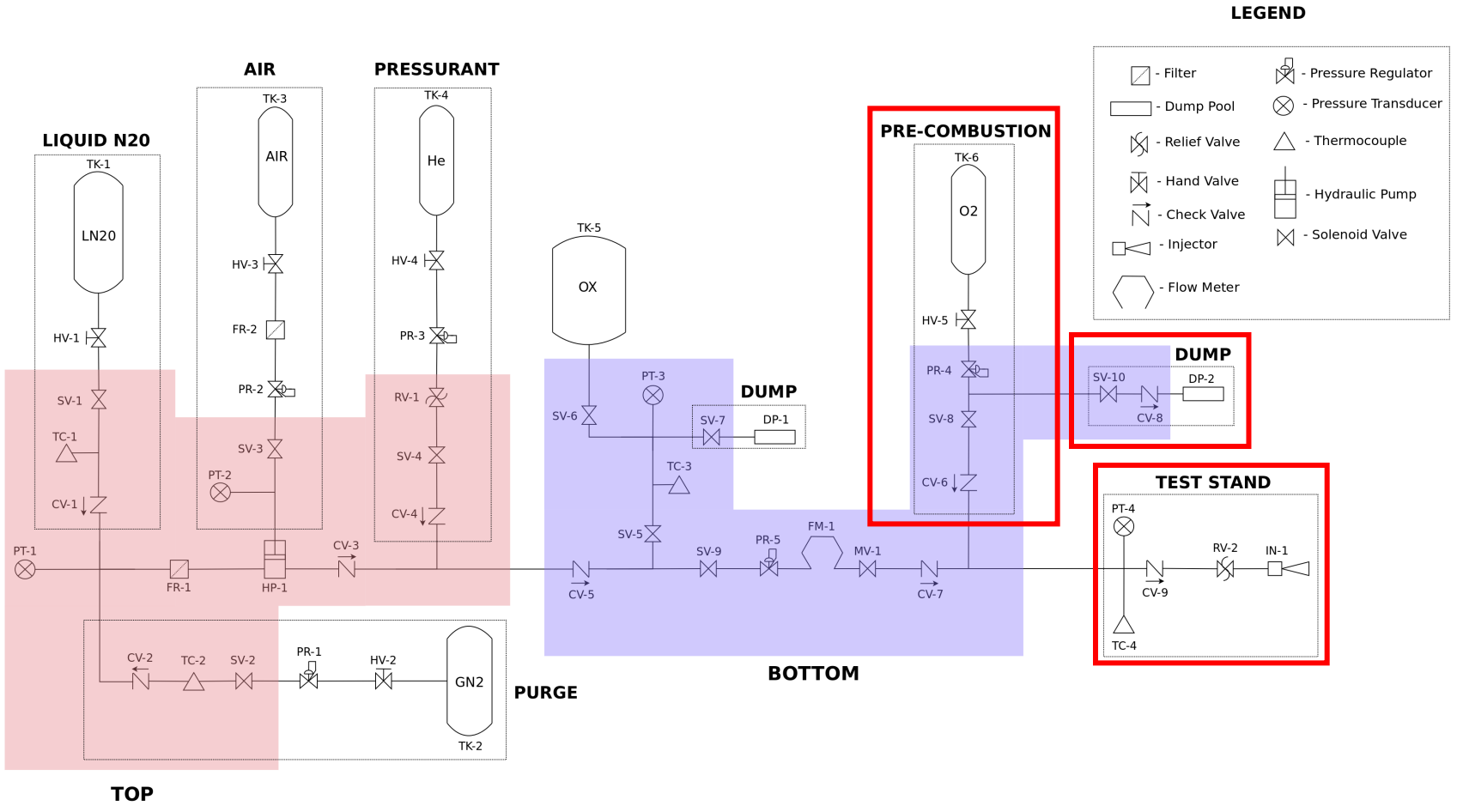
Baseline Design – Test Stand

- Minor Changes
  - Bosses on anchor legs removed from design
  - Reverted back to U-bolts
- Changes due to sizing constraints and cost



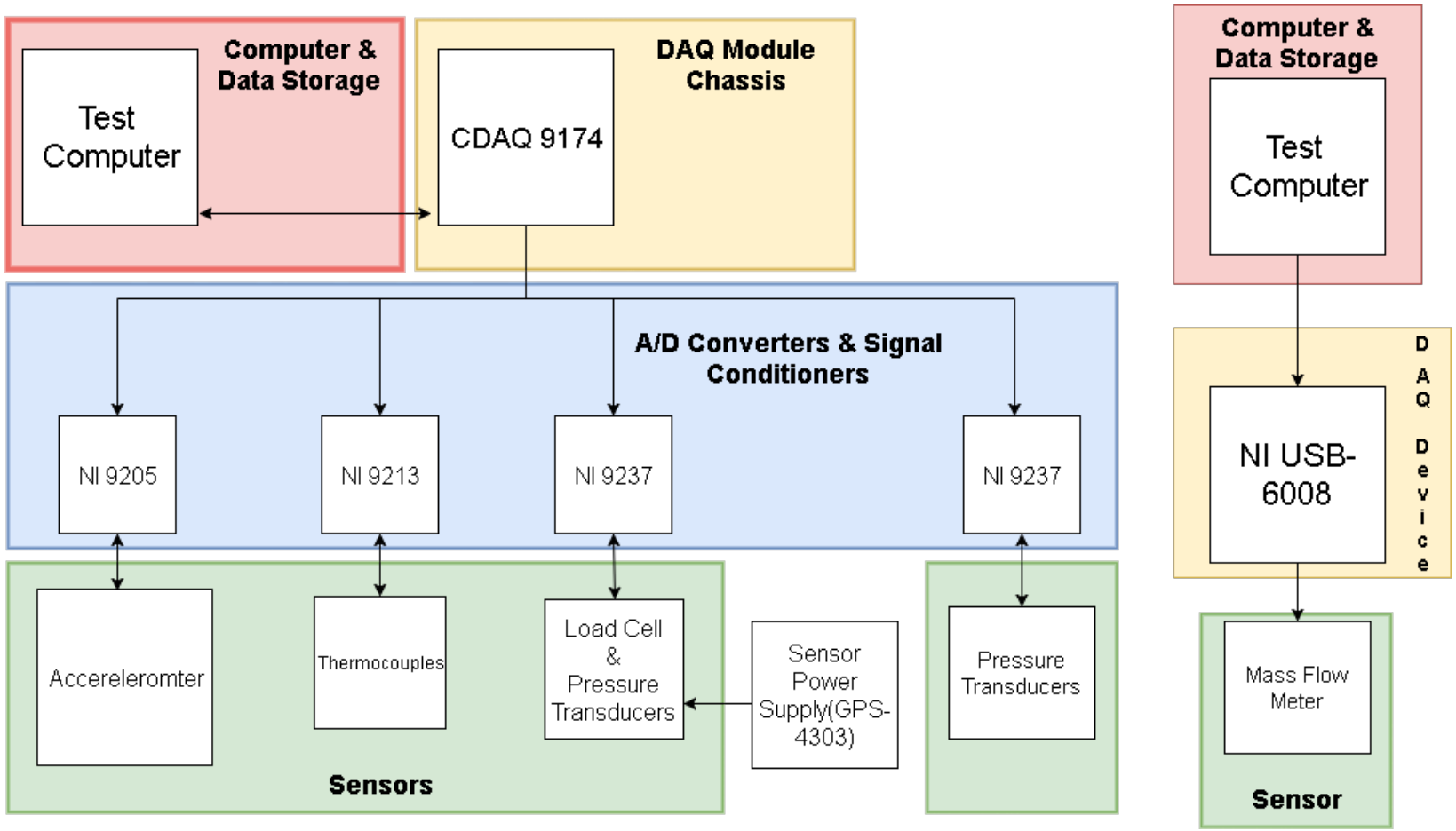
Baseline Design – Plumbing

- **Changes**
  - Pre-combustion moved away from oxidizer tank
  - Pre-combustion dump system added
  - Moved some components onto the test stand
- **Reasons**
  - Avoid more expensive Oxygen rated components from Swagelok
  - Required dump for safety
  - Better accuracy at ensuring N2O is entering as a liquid



Baseline Design – Data Acquisition

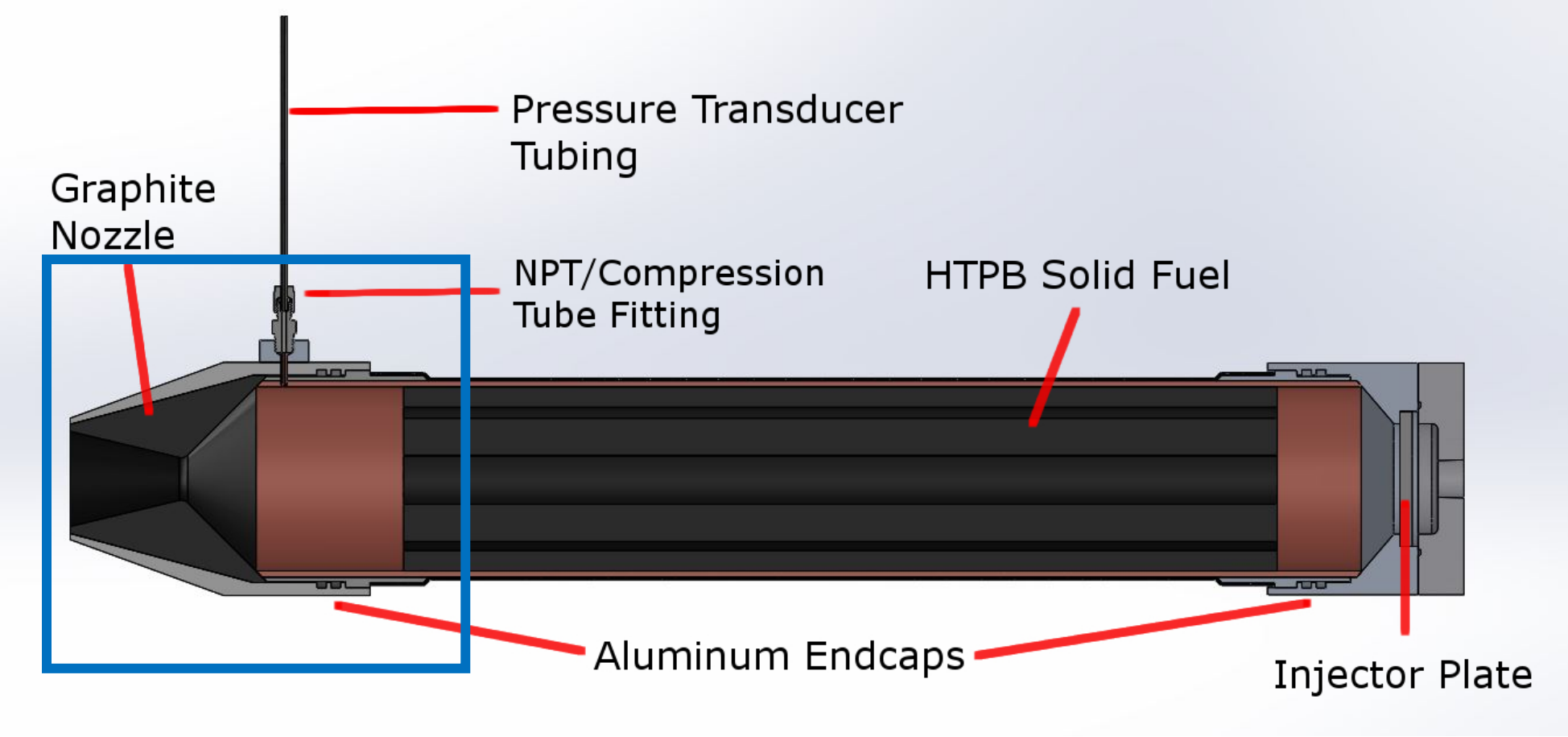
- **Changes**
  - NI 9234 switched to NI 9205
  - CDAQ 9172 switched to CDAQ 9174
  - Mass Flow Meter(MFM) now has own computer.
- **Reasons**
  - Accelerometer was not IEPE, but NI 9234 is meant for IEPE sensors.
  - CDAQ 9172 was only capable of one task
  - MFM already had NI DAQ device.



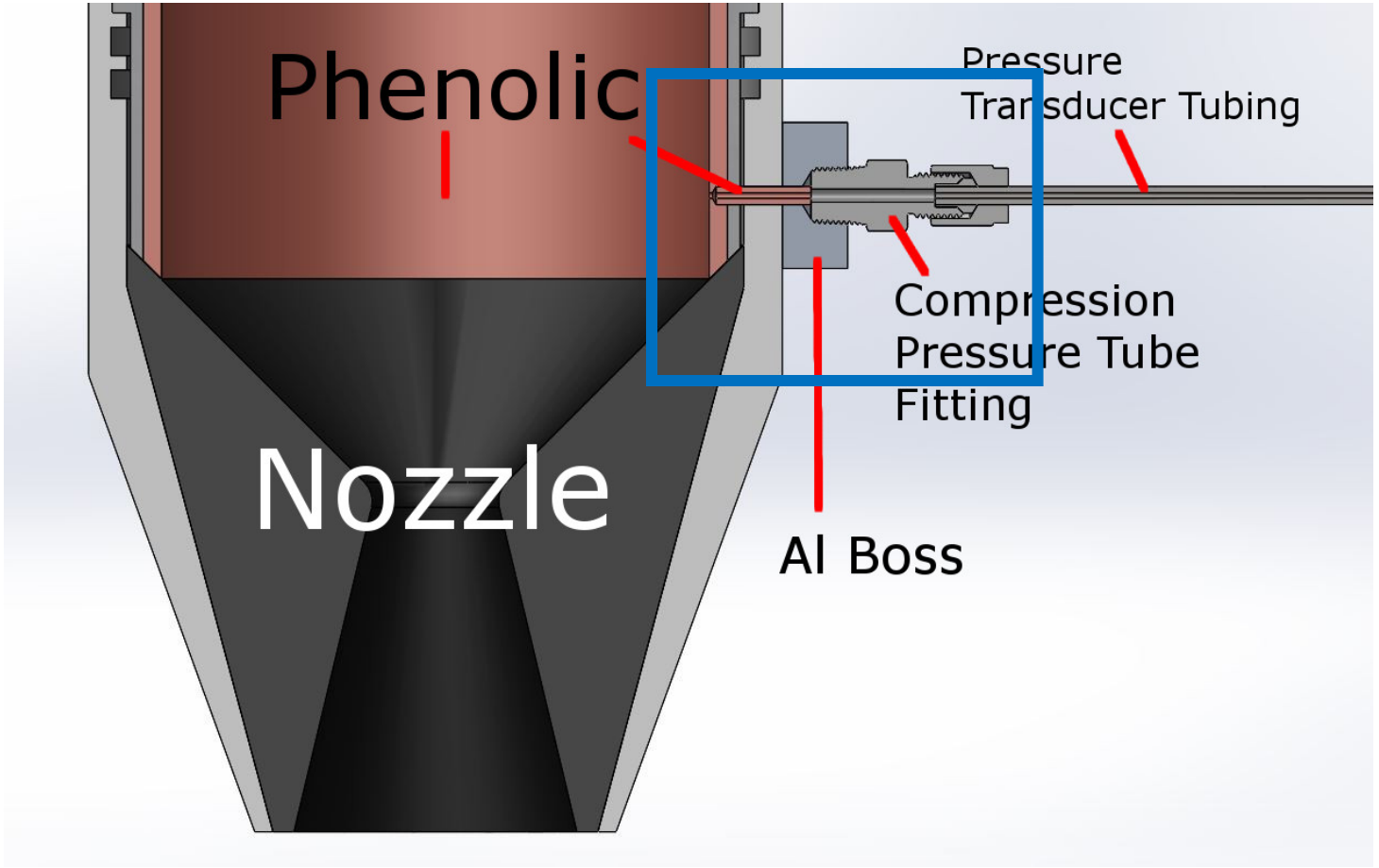
CPE

Rank	Critical Project Element (CPE)	Description
1	Safety	• **Pressure transducer** • Rocket critical failure • Environmental and personnel safety risks
2	Budget	• Costs of four major systems: test stand, plumbing, rocket, and avionics sensors
3	Data Acquisition and Analysis System	• LabVIEW implementation with sensors
4	System Validation using Computational Modeling	• Low fidelity performance characterization model
5	Manufacturing of the Test Stand and Rocket Engines	• Manufacturing multiple components including the test stand, plumbing, and a rocket

CPE: Pressure Transducer



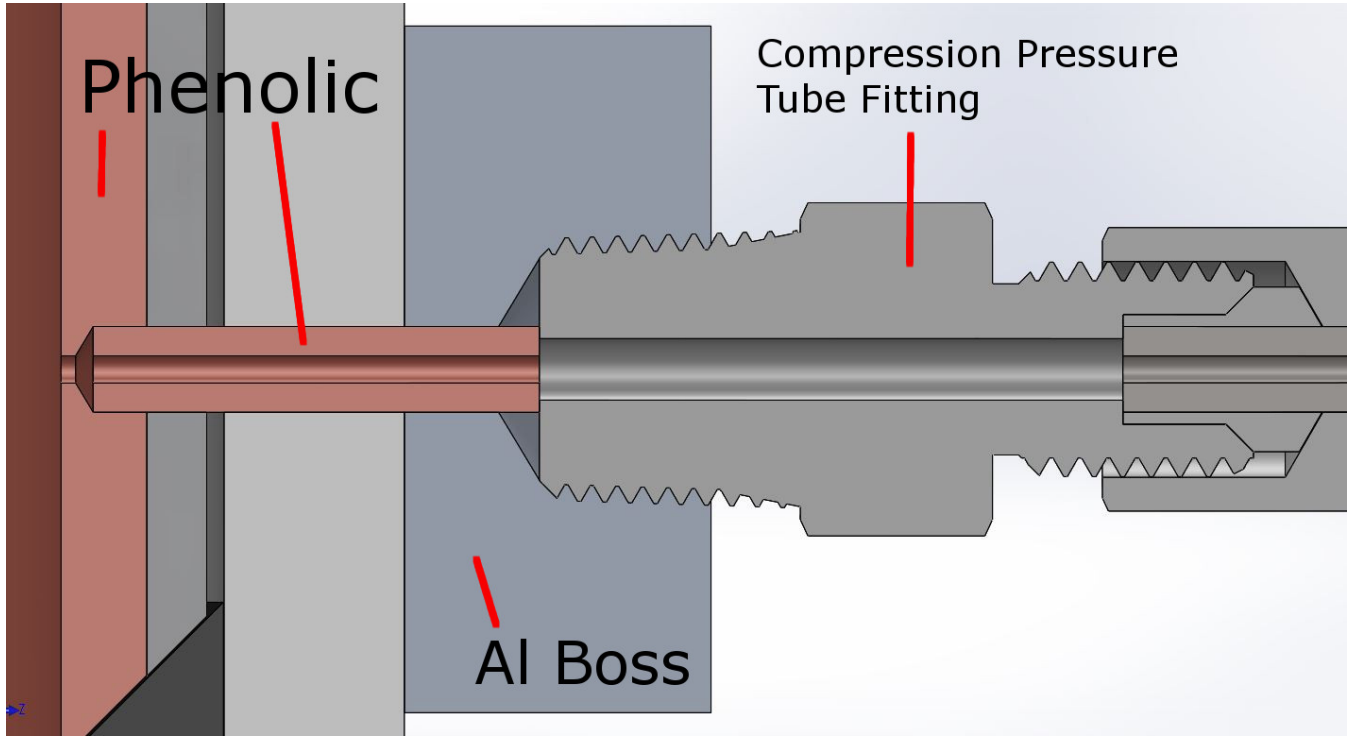
CPE: Pressure Transducer



CPE: Pressure Transducer

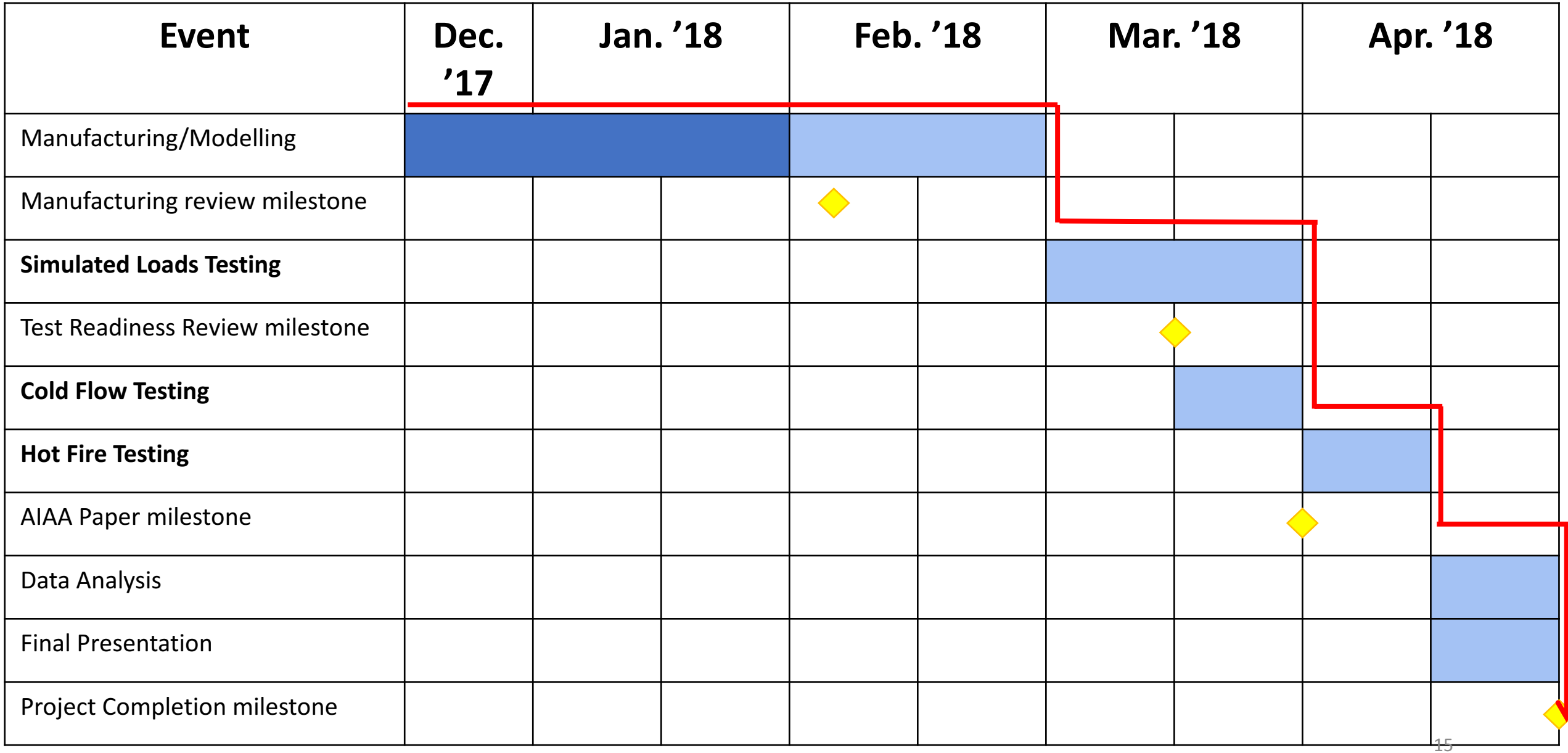
- **Changes**
  - Addition of NPT/Compression Tube Fitting and phenolic/machinable-ceramic tube

- **Reasons**
  - NPT/Compression tube fitting addresses concern about seal integrity
  - Phenolic/Machinable-ceramic tube addresses concern about excessive radiative and convective heat transfer to metal components



Schedule

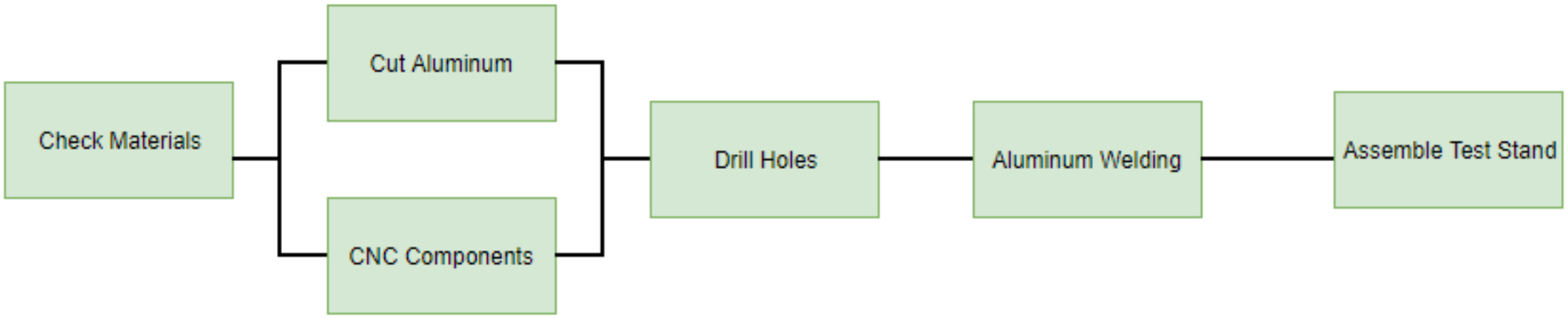
Schedule


Event
Dec. ’17
Jan. ’18
Feb. ’18
Mar. ’18
Apr. ’18
Manufacturing/Modelling
Manufacturing review milestone
Simulated Loads Testing
Test Readiness Review milestone
Cold Flow Testing
Hot Fire Testing
AIAA Paper milestone
Data Analysis
Final Presentation
Project Completion milestone

Manufacturing

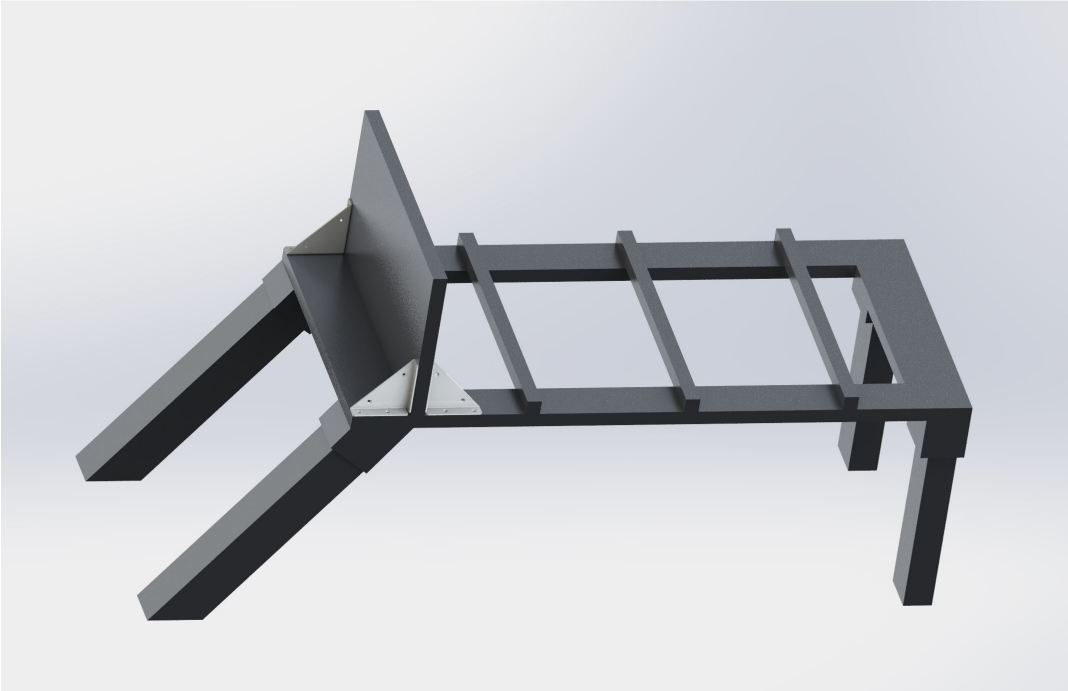
Manufacturing Plan - Test Stand

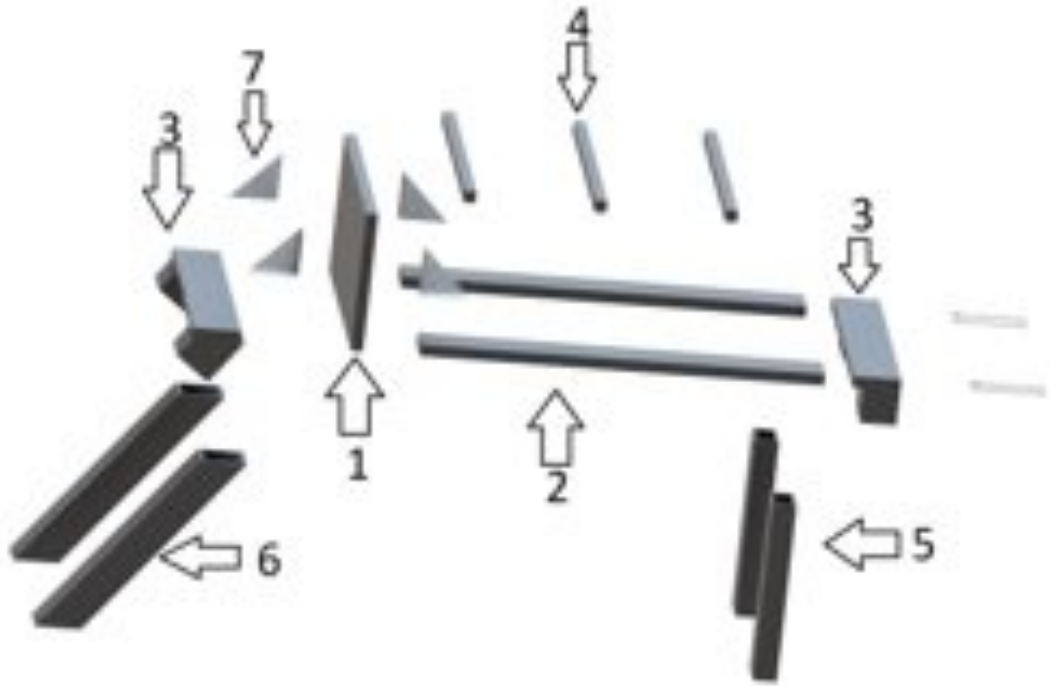
- Scope of tasks
  - Verify appropriate type and amount of material was ordered
  - Manufacture major components using CNC (i.e. Push plate)
  - Work with Matt Rhode for aluminum welding
  - Verify assembly of test stand



Test Stand Completed Work

Component /Quantity	1. Front Plate x1	2. Side Bars x2	3. Flat Plate x2	4. Horizontal Bars x3	5. Rear Legs x2	6. Front Legs x2	7. Brackets x4	Push Plates x2
Dimensions (inches)	20"x12"x1"	34"x3"x1"	20"x4"x1"	20"x1"x1"	15.42"x3"x2"	19.75"x3"x2"	4"x4"x1"	10"x2"x0.5"
Future work	Drilling/ Milling	Drilling	Welding	Drilling	Welding	Welding	None	None

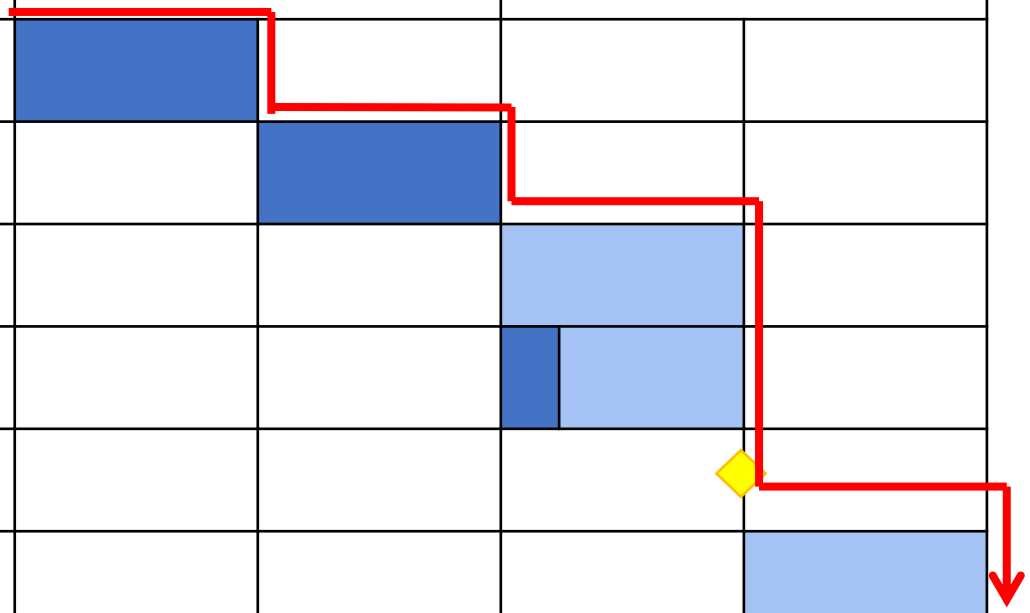




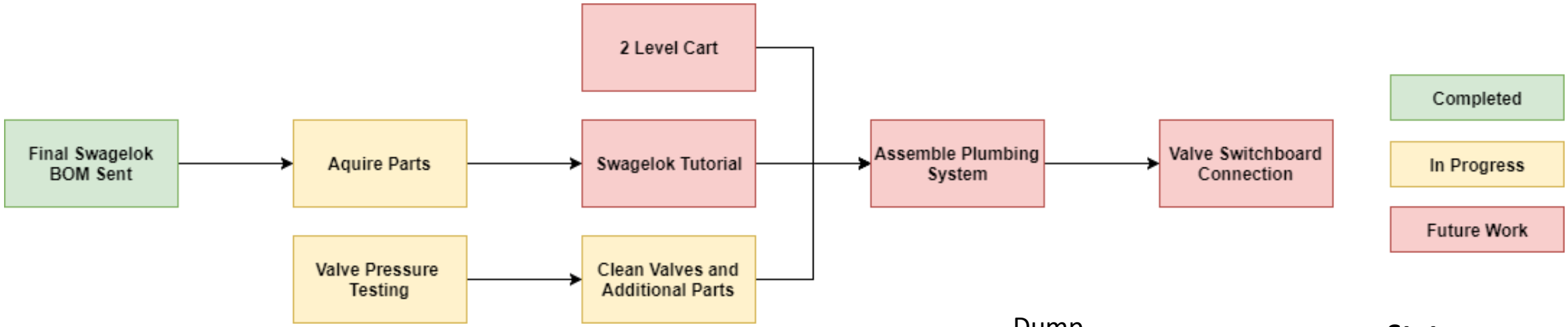
Manufacturing progress: 75% 25% left

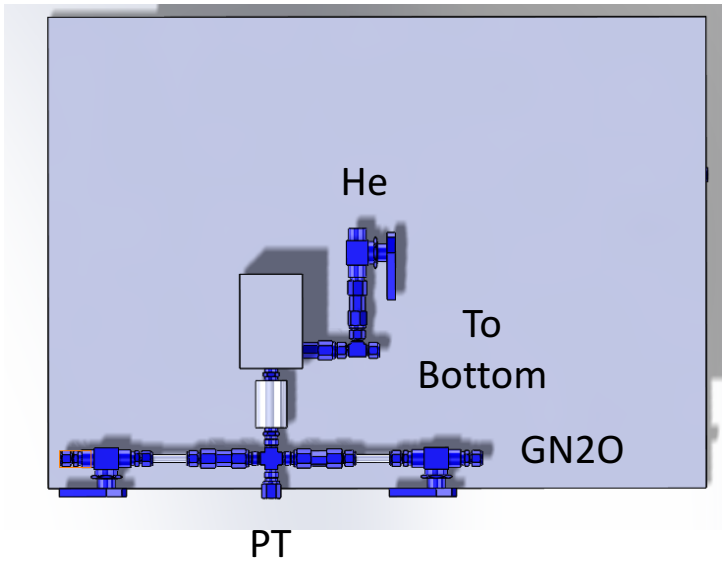
Manufacturing Schedule – Test Stand

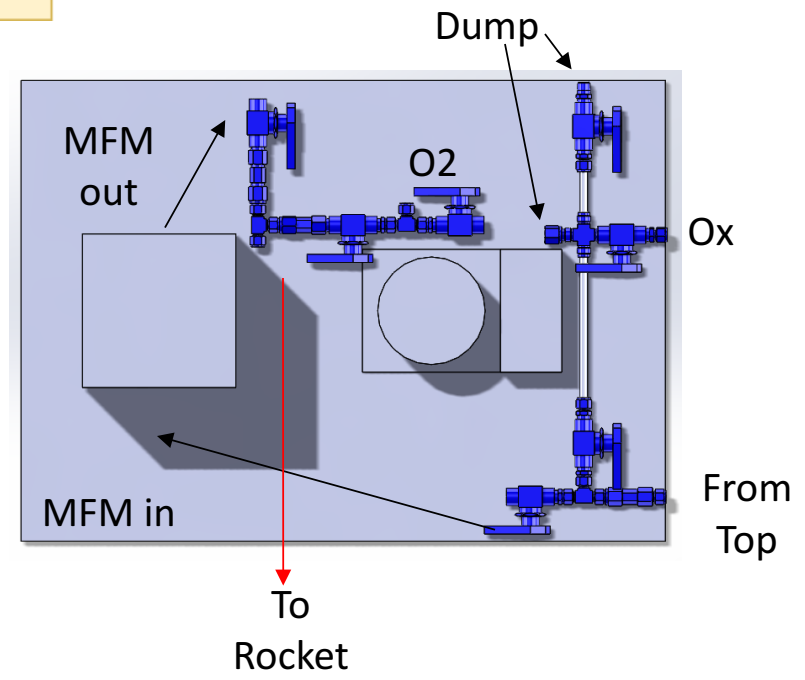
Event	3-4 week Jan. ’18		1-2 week Feb. ’18	
Components check				
Cut, fit, and deburr all components				
Welds for legs				
Drilling of components				
Finish machining milestone				
Assemble test stand				



Manufacturing Plan - Plumbing







Status:

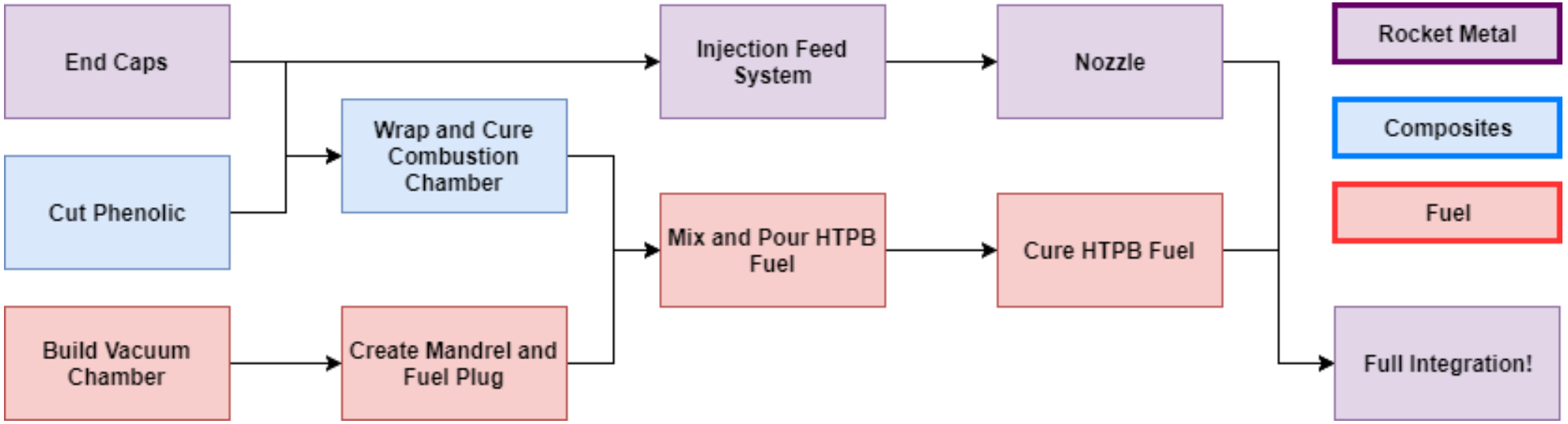
- On time
- Final BOM sent to Swagelok
- Swagelok will let us know when parts are ready
- Swagelok tutorial

Manufacturing progress:

Manufacturing Schedule – Plumbing

Event	2-4 week Feb. ’18			1 week Mar. ’18
Valve pressure testing				
Cleaning of valves and additional parts				
Swagelok tutorial				
Plumbing integration				
Cart assembly and Switch board integration				

Manufacturing Plan - Rocket Motor



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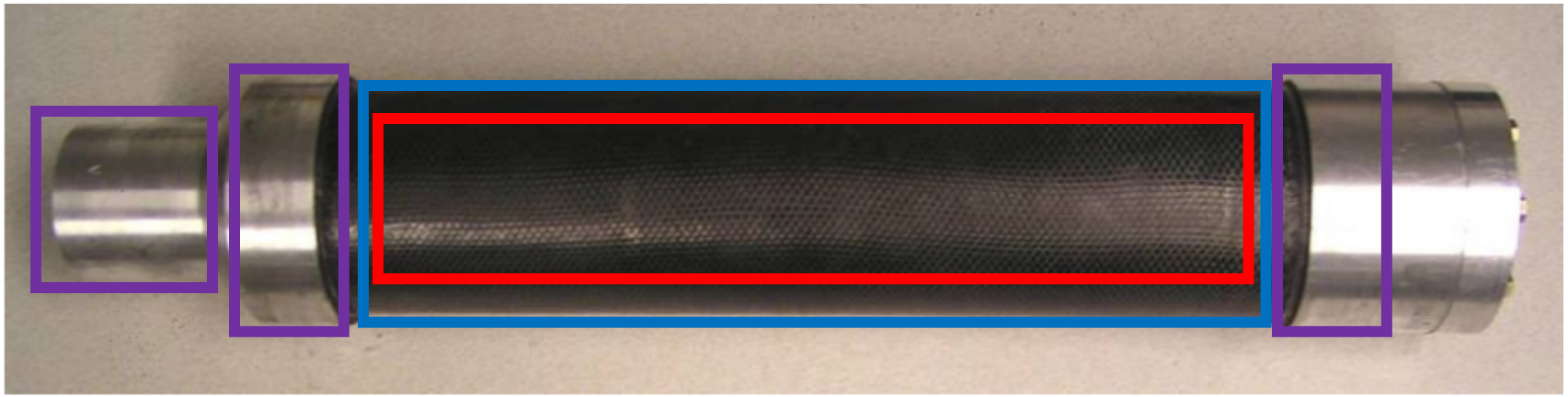


Status:

- On time
- Parts ordered
- Given 3.5 weeks manufacturing at the end of Feb

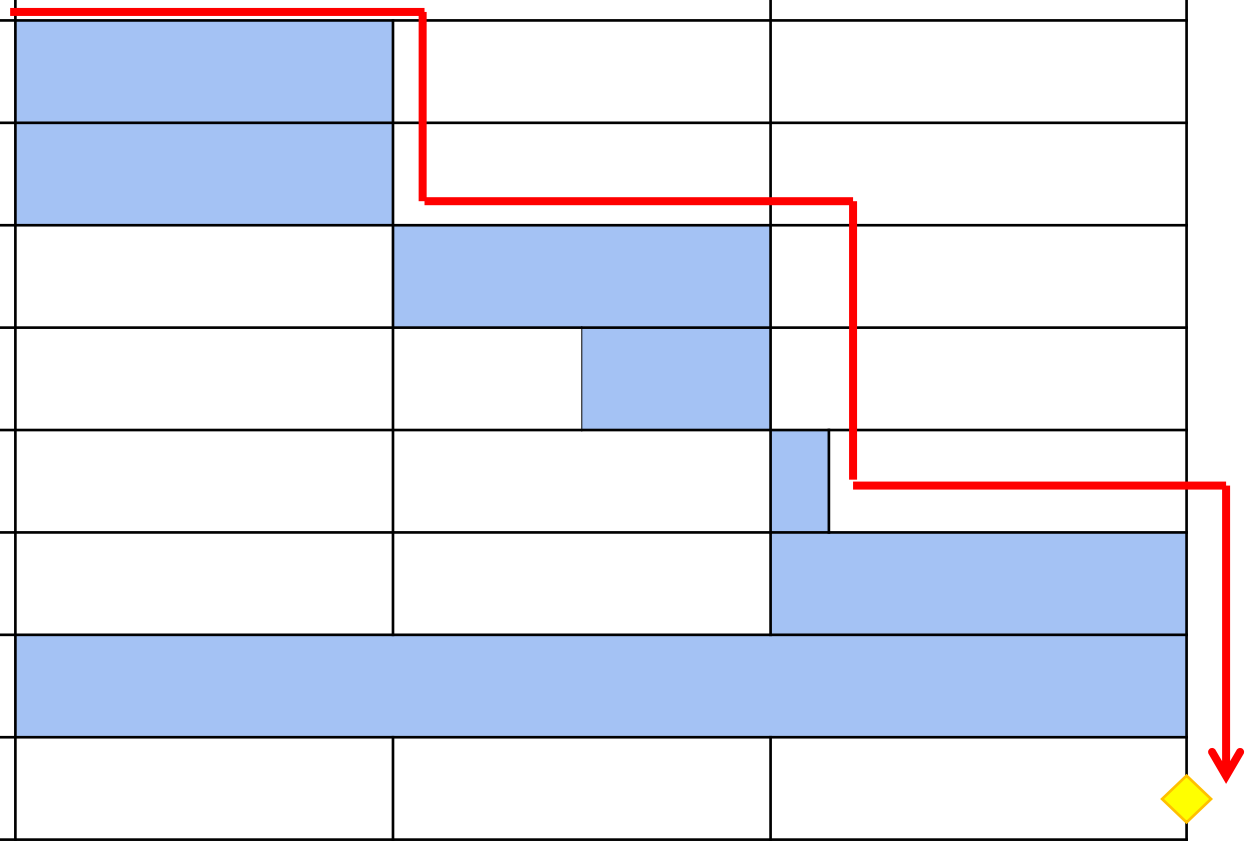
Overall manufacturing progress:

Rocket and Plumbing Concerns

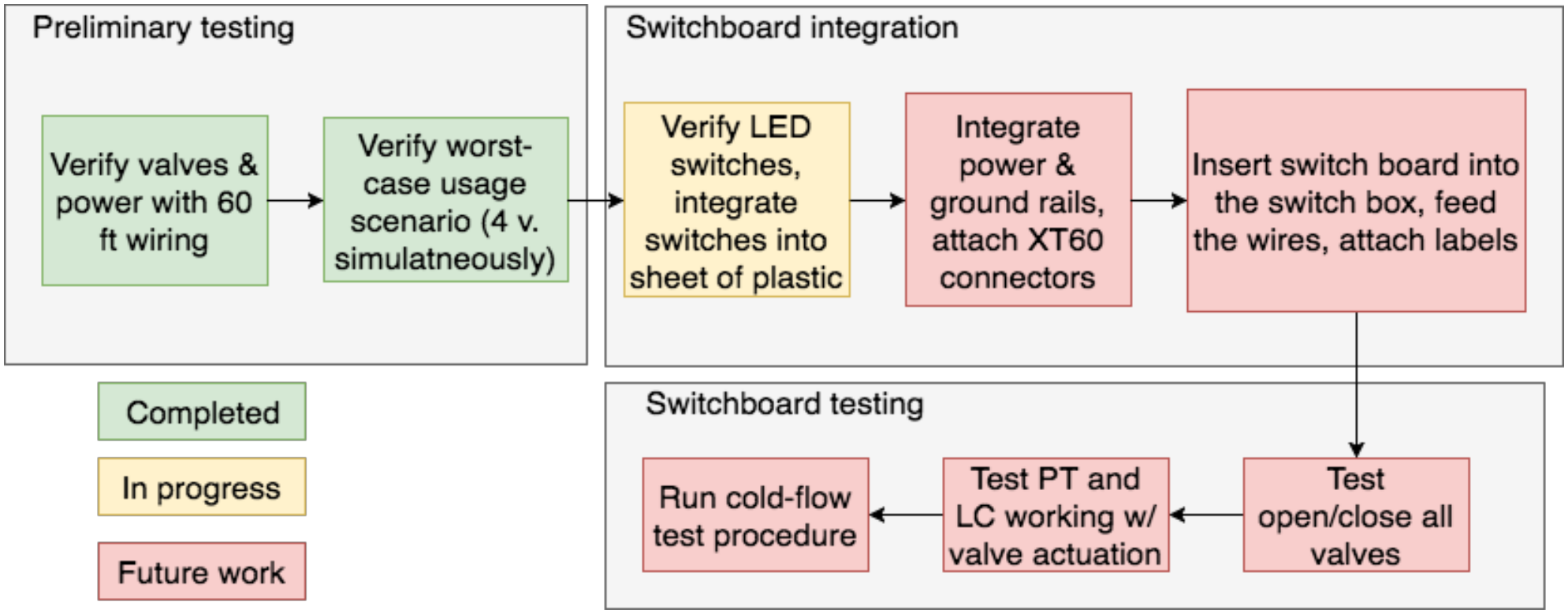
Concern	Solution
• Plumbing parts coming in on time • Rocket manufacturing complexity • Troubleshooting plumbing leaks and valve function	• Stable communication with Rob Carroll • Expert Matt Rhode • CO2 Cold flow and valve Testing
• Machinist and personnel safety	• Proper manufacturing setting for specific rocket components

Manufacturing Schedule – Rocket Motor

Event	3-4 week Feb. ’18		1 week Mar. ’18
Vacuum Chamber			
End Caps			
Phenolic			
Carbon Fiber Wrap			
Fuel Casting			
Fuel cure			
Injector housing, plate, and nozzle			
Full integration milestone			

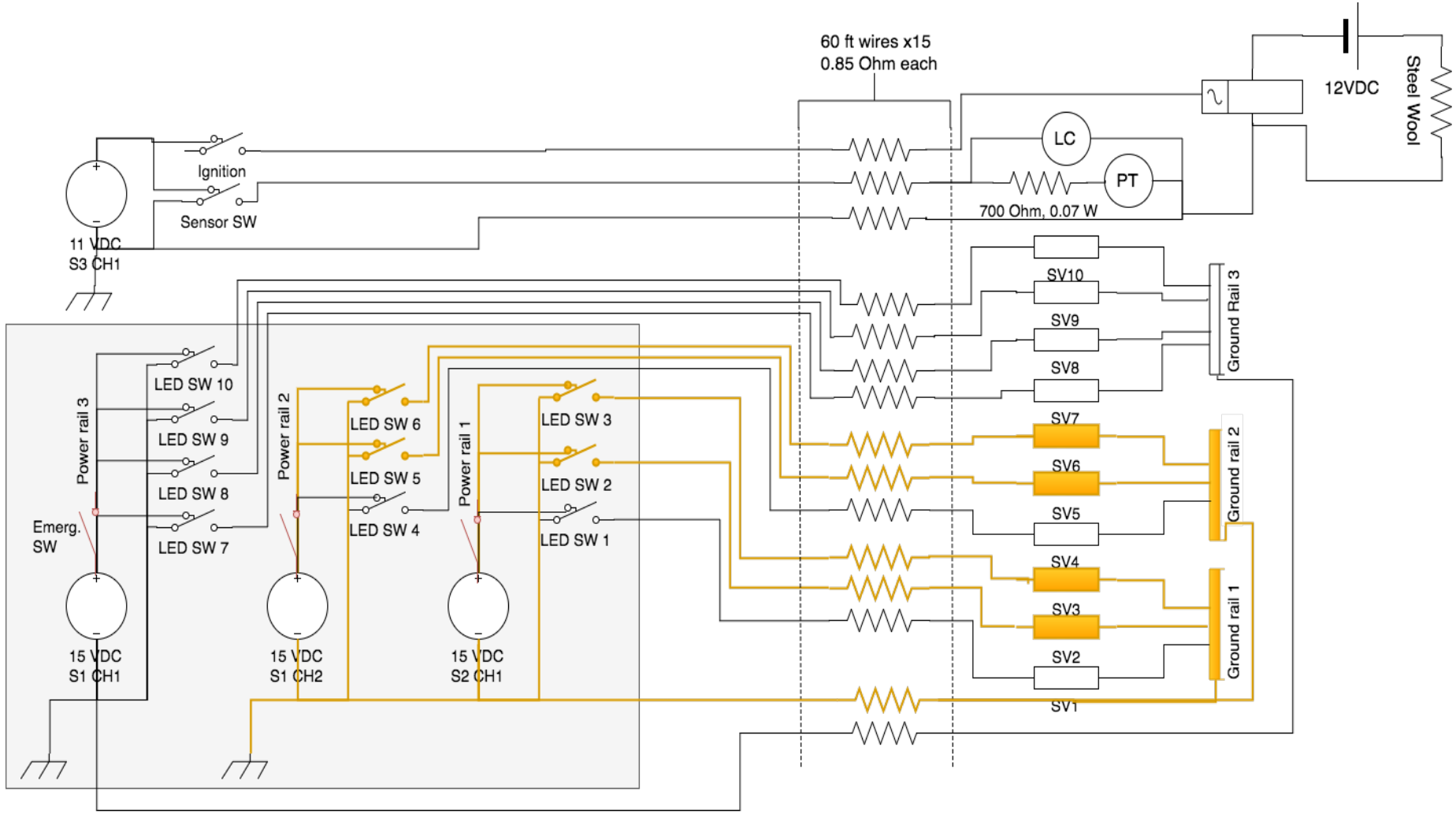


Manufacturing Plan - Power



Power – Tasks Completed

- Everything in orange was manufactured and tested: actuating 4 valves at the same time
- 3 GPS4303 power supplies must be used for meeting power/current requirements: 2 for valves, 1 for sensors.
- x6 60 feet wires were measured and cut.



Manufacturing progress:

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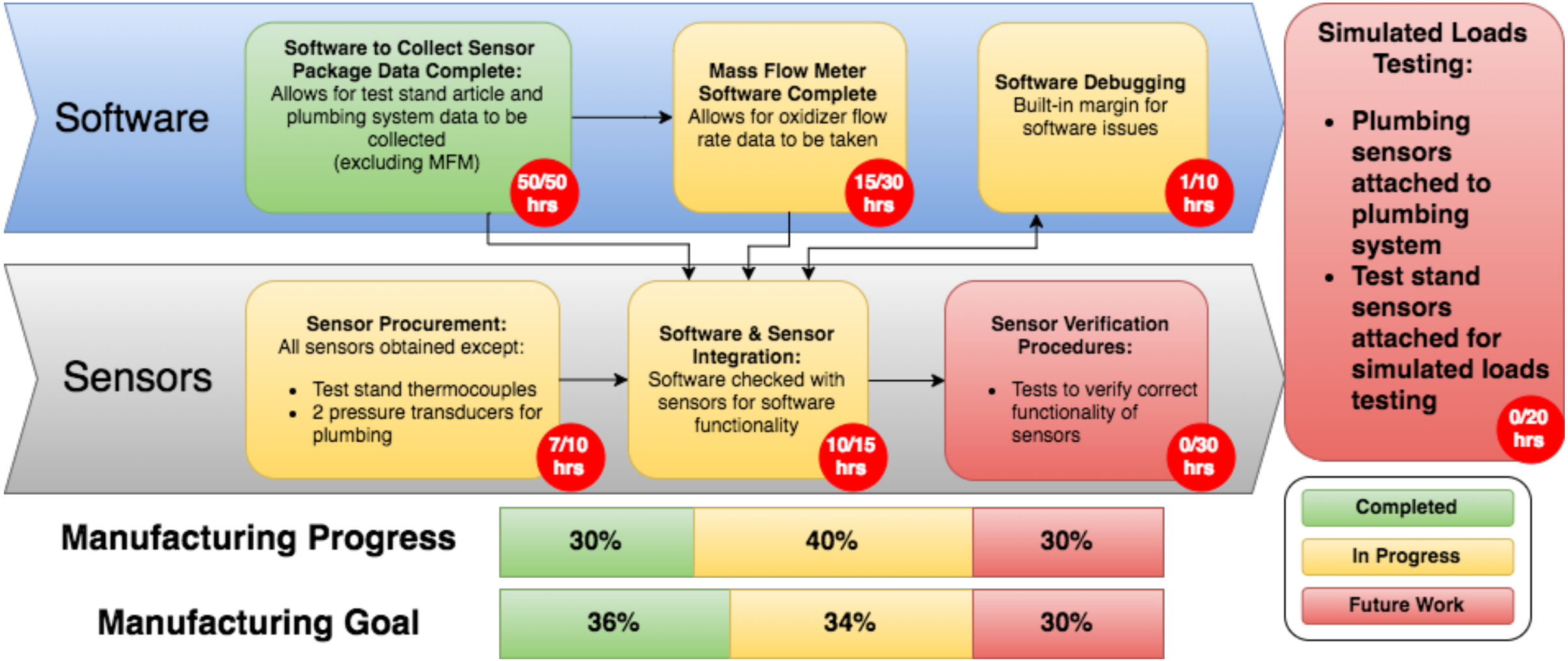
Manufacturing schedule - Power

Event	1-4 weeks Feb ‘18				1-3 weeks March ‘18		
Highest power consumption scenario tested							
Verify that LED switches work with our design							
Integrate switches into a sheet of plastic, cut all the wires to length							
Run tests with supplying power to valves for cold flow procedure, PT and LC power tests							
Integrate the power rail, XT60 connectors and switch board into switch box							
Test cold-flow procedure w/ PT and LC data acquisition							

Manufacturing Plan – Data Acquisition System



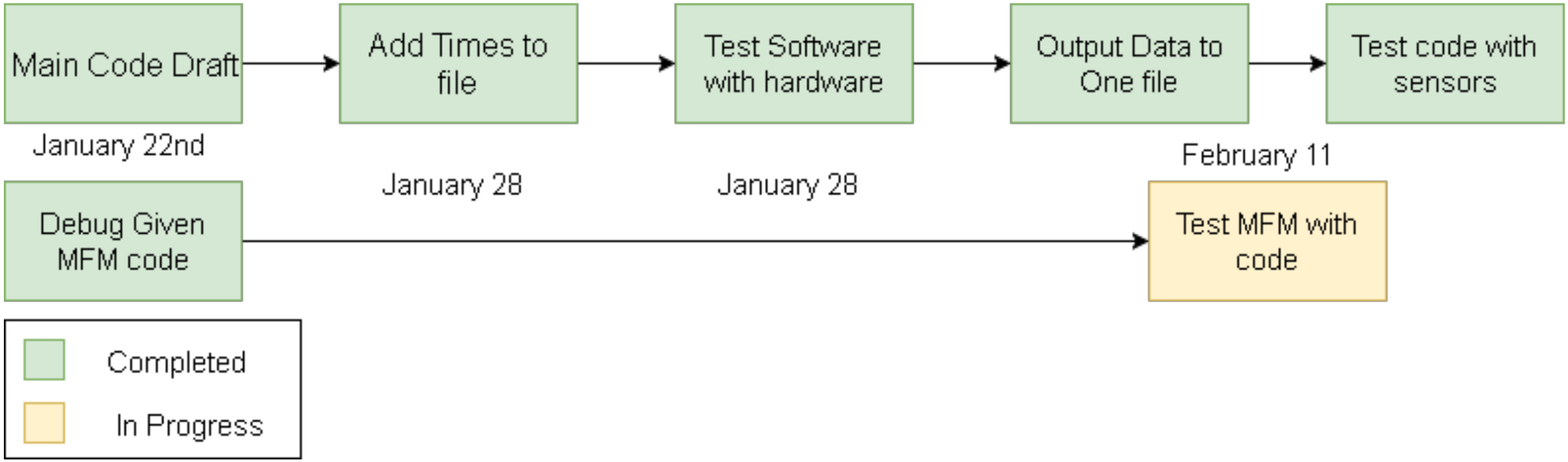
Critical Concerns – Data Acquisition System

Concern	Solution
• Postponed ordering 2 pressure transducers for plumbing system due to financial restrictions • Postponed ordering & manufacturing test stand thermocouples due to financial restrictions	• 1 week built in margin to obtain sensors • Additionally, ahead of schedule by 1 week on testing software with sensors
• Location to verify pressure transducer not established	• In contact with LASP, NIST, and Space Grant about possible verification locations
• Procedure to verify mass flow meter not established	• In contact with manufacturer Emerson to receive assistance on procedure • Final option - measure time for amount of water to pass through meter

Manufacturing Schedule – Data Acquisition

Event	1-4 week Jan. ‘18				1-4 week Feb. ’18			
Procure all sensors								
Sensor and software integration								
Load cell verification								
Thermocouple verification								
Accelerometer verification								
Mass flow meter verification								
Pressure transducer verification								

Software: Tasks



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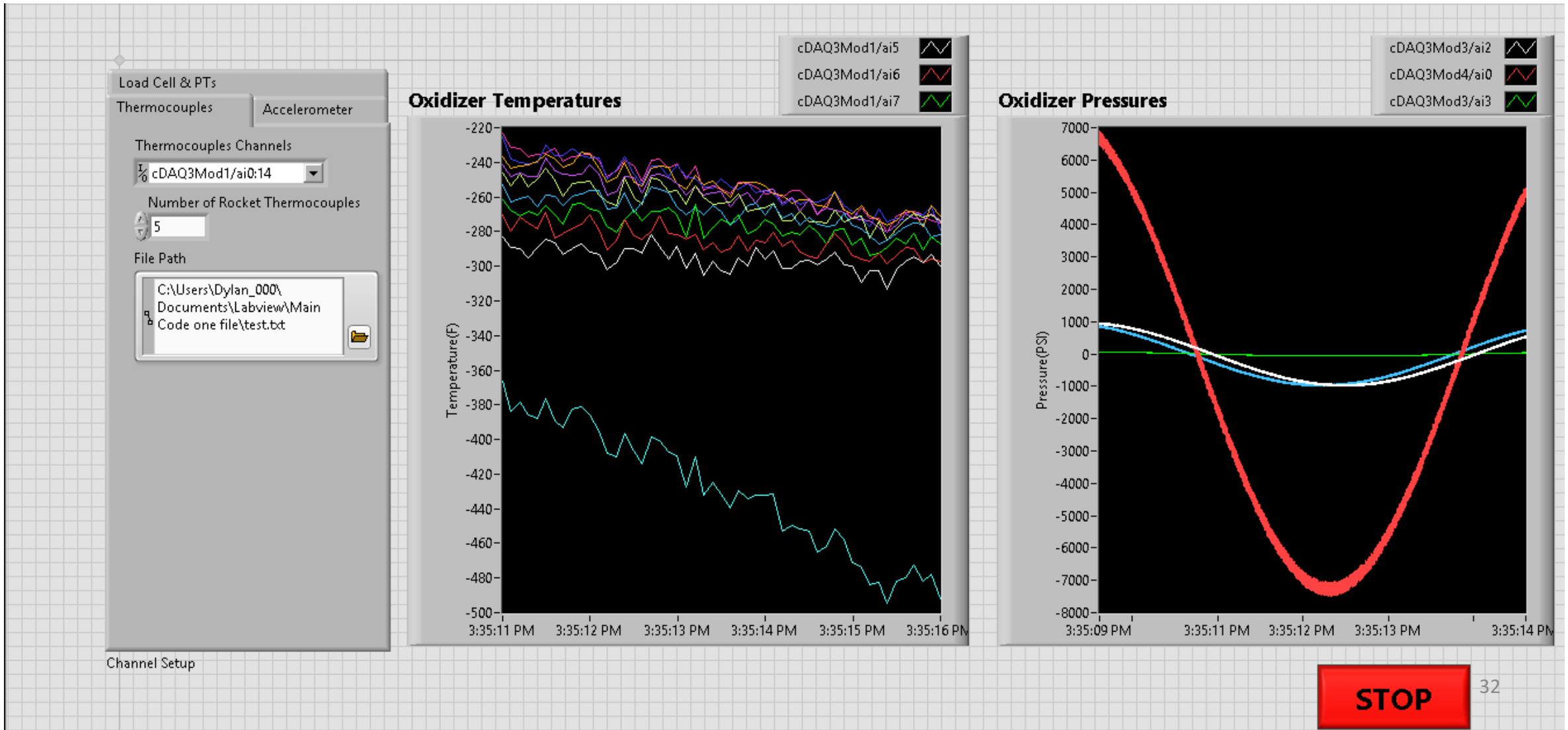
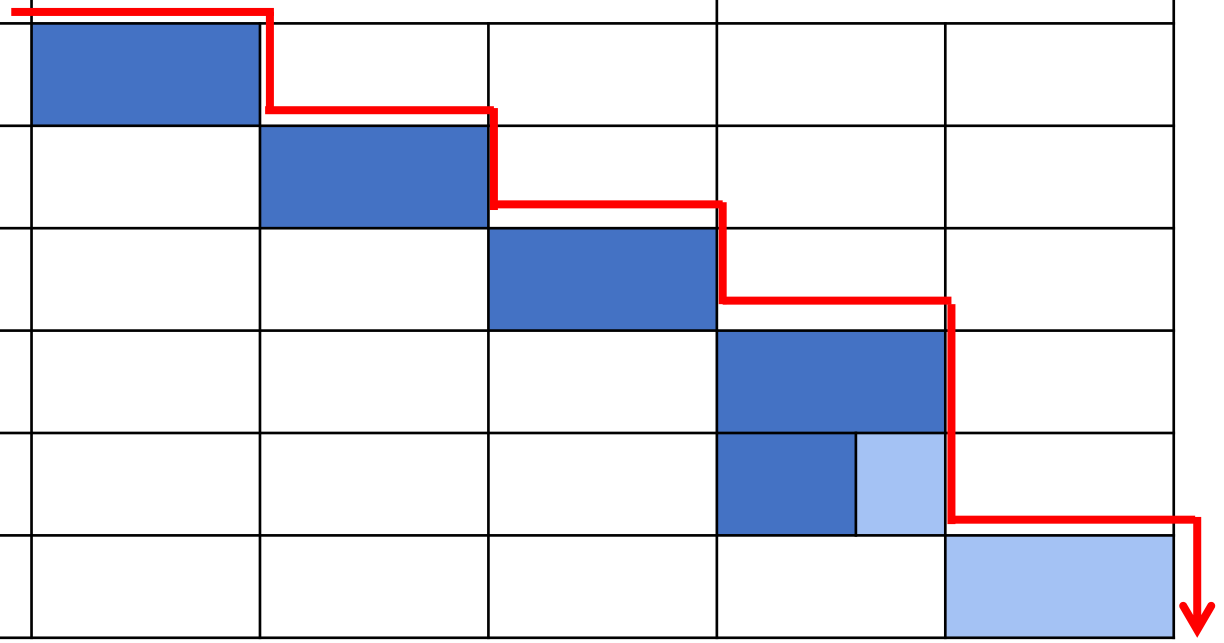
Manufacturing Plan - Software

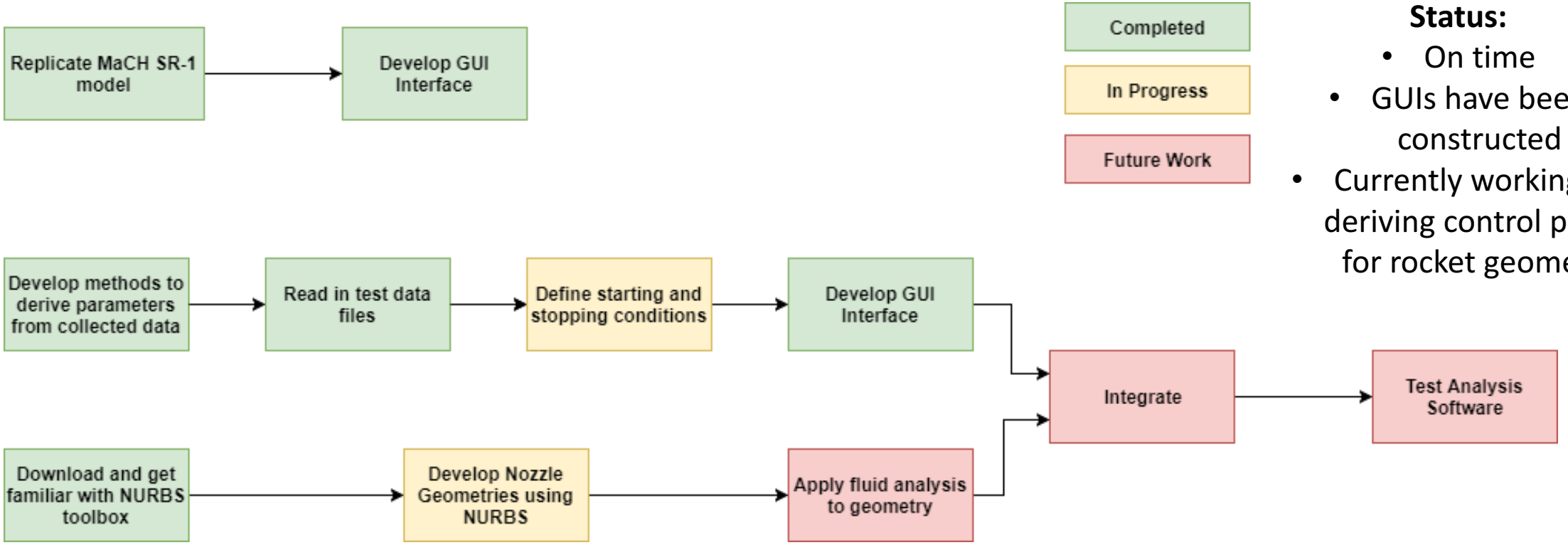


Manufacturing Schedule – Software

Event	3-4 week Jan. ’18			1-2 week Feb. ’18	
Data writes to file and outputs plots					
Tested with hardware					
Tested with load cell and thermocouples					
Tested with pressure transducer and accelerometer					
Debug mass flow meter code					
Tested with mass flow meter					



Manufacturing Plan - Analysis



Status:

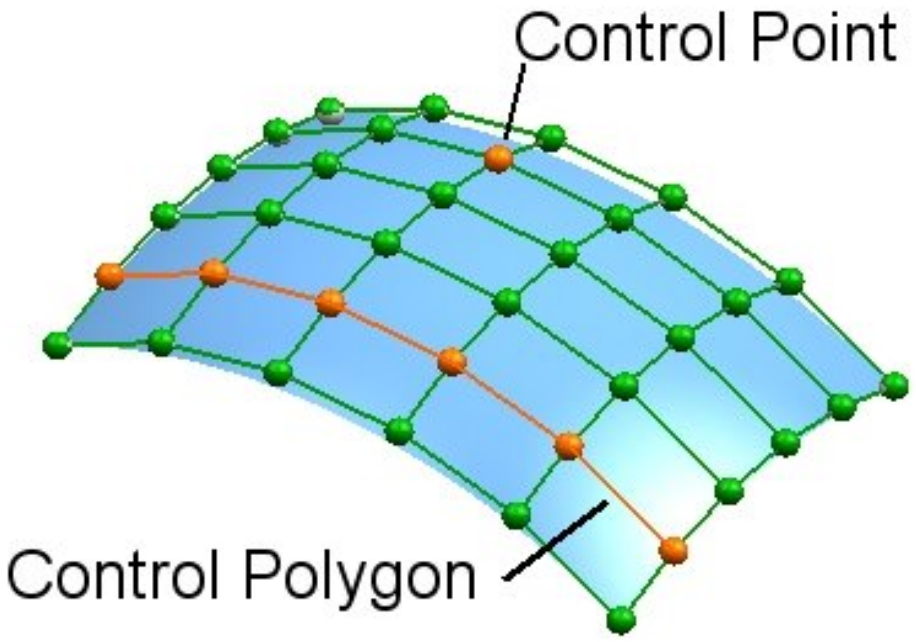
- On time
- GUIs have been constructed
- Currently working on deriving control points for rocket geometry

Manufacturing progress:

Manufacturing Analysis - Challenges

Challenges:

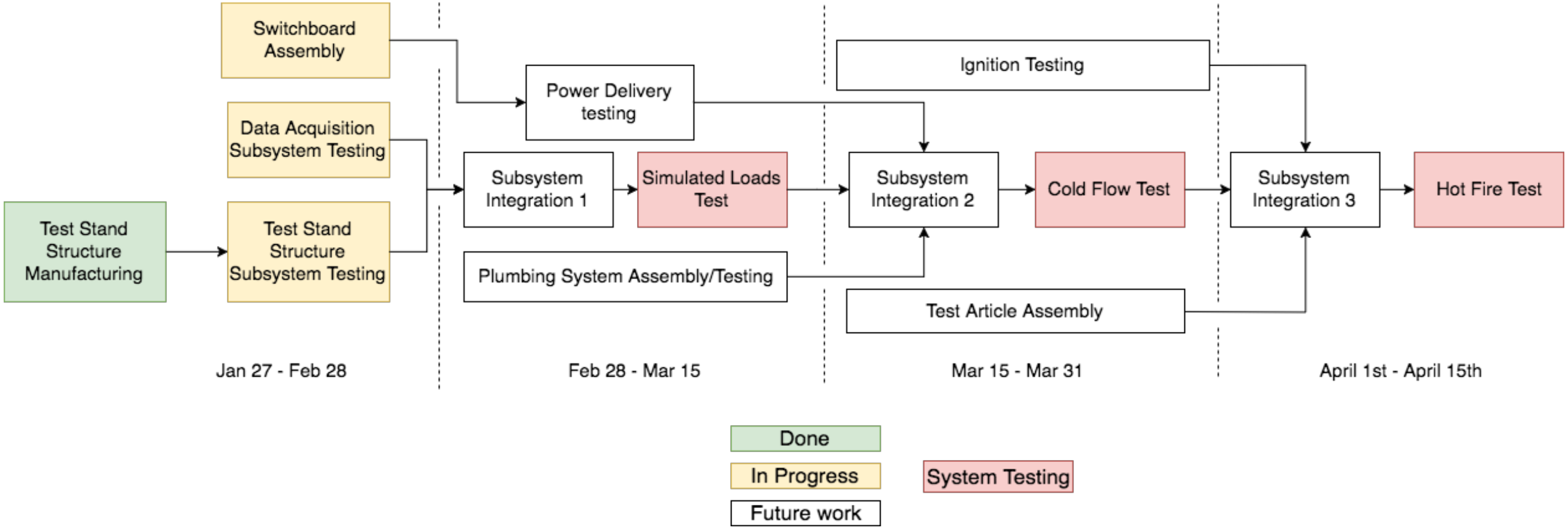
- Deriving the control points for the nozzle geometry
- Defining the steady burn for derived components



Manufacturing Schedule – Analysis Software

Event	2-4 week Jan. ’18			1-4 week Feb. ’18			
GUI made							
Post processing software work							
Read in the data files produced by the DAQ							
Construct a 3D Cone shaped solids with NURBS Toolbox							
Construct a 3D Conical Nozzle with NURBS Toolbox							
Construct a 3D MaCH SR1 nozzle with NURBS Toolbox							
Integrate the file reading, GUI, and post-processing software together							

Full System Integration Plan



System integration progress:

Budget

Budget Status

- Spent: $3,189
  - Remaining Funds: $2,811
- Projected Total Cost: $7,621
- Submitted Funds Request to Department
- Received Donation of Plumbing from Swagelok Denver

Subsystem	Projected Total Cost
Plumbing	$2,654
Test Stand	$1,326
Rocket Motor	$2,308
Data Acquisition	$633
Simulated Loads Test	$200
Shipping	$500
Total	**$7621**

Procurement Status

Arrived

- Test Stand Raw Materials
- Rocket Injector Plate and Endcap Raw Materials
- Switchboard Raw Materials
- Accelerometer

Purchased, Not Arrived

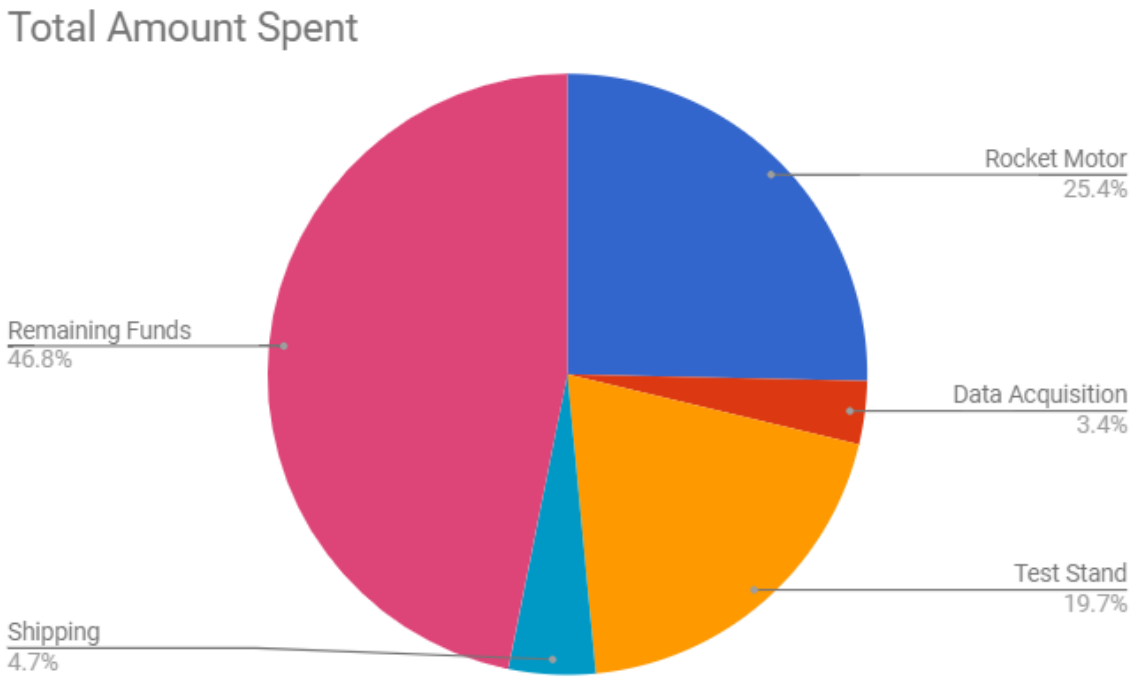
- Graphite Rod for Rocket Nozzle
- Combustion Chamber Raw Materials
- Fuel Casting Raw Materials

Not Yet Purchased

- Plumbing Hoses, Valves, Pressure Transducers
- Tanks for Hot and Cold Fire
- Thermocouples for Rocket Nozzle
- Rocket Motor Material: O Rings, Burst Discs, Safety Heads

Subsystem Break Down

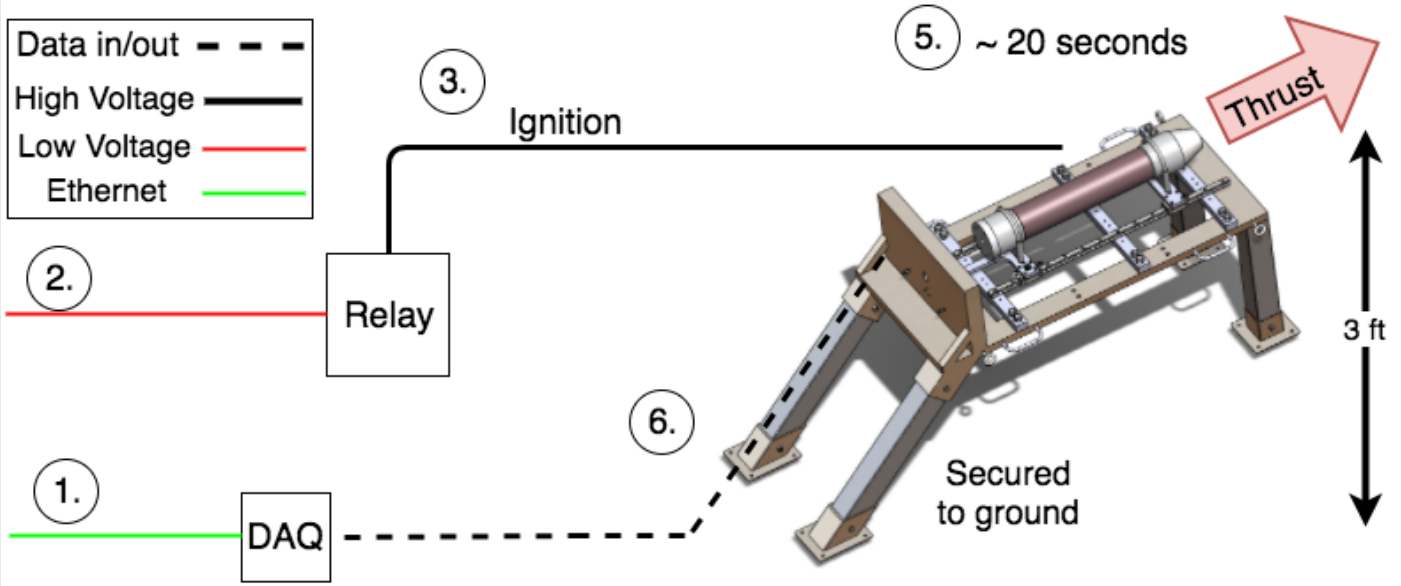
Subsystem	Total Spent
Plumbing	$0
Test Stand	$1,184.27
Rocket Motor	$1521.04
Data Acquisition	$204.08
Simulated Loads	$0
Shipping	$279.81
Total	$3,189.20
Remaining Funds	$2,810.80



Backup Slides

CONOPS

Hybrid-rocket **I**nformation-**C**ollection, **K**nowledgebase and **A**nalysis **M**odule (**HICKAM**)

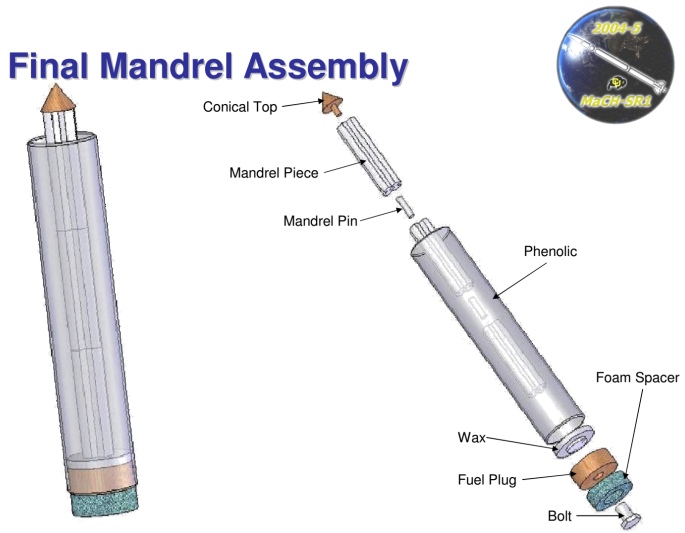


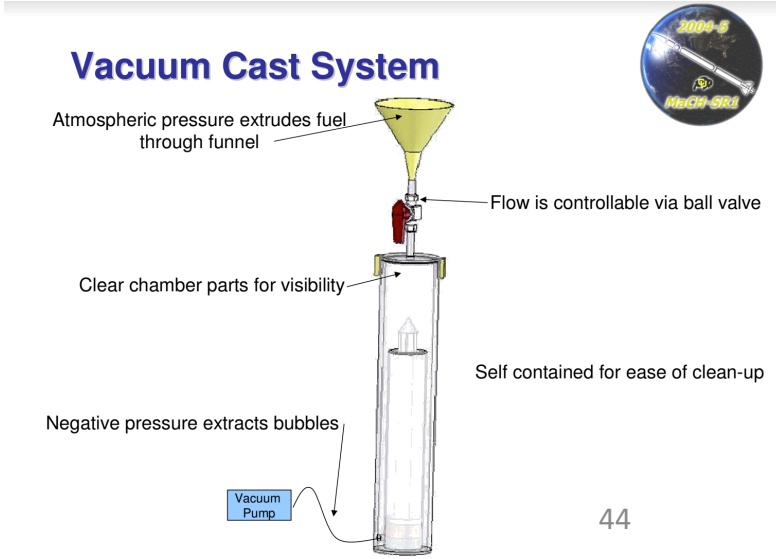
Step 1 - LabVIEW is engaged through ethernet cable
Step 2 - Low voltage engages relay
Step 3 - High voltage starts ignition
Step 4 - Safety: Check for ignition or start hang-fire/mis-fire procedure
Step 5 - Rocket burns for approximately 20 seconds
Step 6 - DAQ collects data from sensors and saves it to memory
Step 7 - Model is used to validate data and specifications for engine is created

Rocket Motor – Fuel Casting

- Teflon tube mandrel milled to shape of fuel port
- Conical top to ease pouring
- Vacuum Chamber with variable control flow. Allows bubbles to be extracted as it goes through lower pressure chamber
- Fuel mixture numbers from previous MaCH-SR1 Projects

Fuel Mixture		
Fuel Volume	0.09145 ft^3	
Fuel Density	57.54 lbm/ft^3	
Fuel Mass (With 5% extra margin)	5.52 lbm	
	Mass Ratios	Mass
HTPB	84.57%	4.67 lbm
IPDI	10.34%	0.571 lbm
Castor Oil	5.00%	0.276 lbm
Carbon Black	0.09%	0.005 lbm
Total	100%	5.52 lbm





Rocket Motor – Combustion Chamber

- Manufacture end caps
- Shape phenolic
- Attach end caps to phenolic
- Wrap the carbon fiber sheet around the chamber 6 times while spreading epoxy and applying pressure

From previous MaCH-SR1 projects

Rocket Motor – Nozzle and Injector Plate

Same process from MaCH-SR1 will be followed – Nozzle

- Drill the hole using the lathe with a 6-jaw chuck
- Bore the interior profile at speeds between 1100 & 1400 rpm
- Cut to length
- Cut the exterior profile using the lathe at speeds between 1100 & 1400 rpm

Same process from MaCH-SR1 will be followed – Injector Plate

- Drill holes in titanium injector plate
- Aluminum end fittings using CNC lathe
- Mold cerafiber into bottom aluminum fitting
- Drill instrument holes in cerafiber
- Heli-coil threads to injector fitting
- Cut graphite gasket to correct size

Thermocouple Verification

- Location: Senior Projects Shop
- Procedure:
  - Place thermocouples and thermometer within an ice bath
  - Check to see if thermocouples read values within 2 degrees of the thermometer
  - Repeat process but use boiling water bath instead of ice bath

Pressure Transducer Verification

- Location: TBD
  - Looking at Spacegrant, LASP, NIST
- Procedure:
  - Place pressure transducers in Bell Jar
  - Collect values from pressure transducers
  - Compare values of pressure transducer to that of pressure gauge on Bell Jar, ensure values are within 2 psi

Accelerometer Verification

- Location: Senior Projects Shop
- Procedure:
  - Tilt X-axis in the direction of Earth's gravity
  - Ensure the accelerometer measures approximately 1 G
  - Follow same steps for Y and Z-axes
  - Shake the accelerometer
  - Ensure accelerometer measures values greater than 1 G

Load Cell Verification

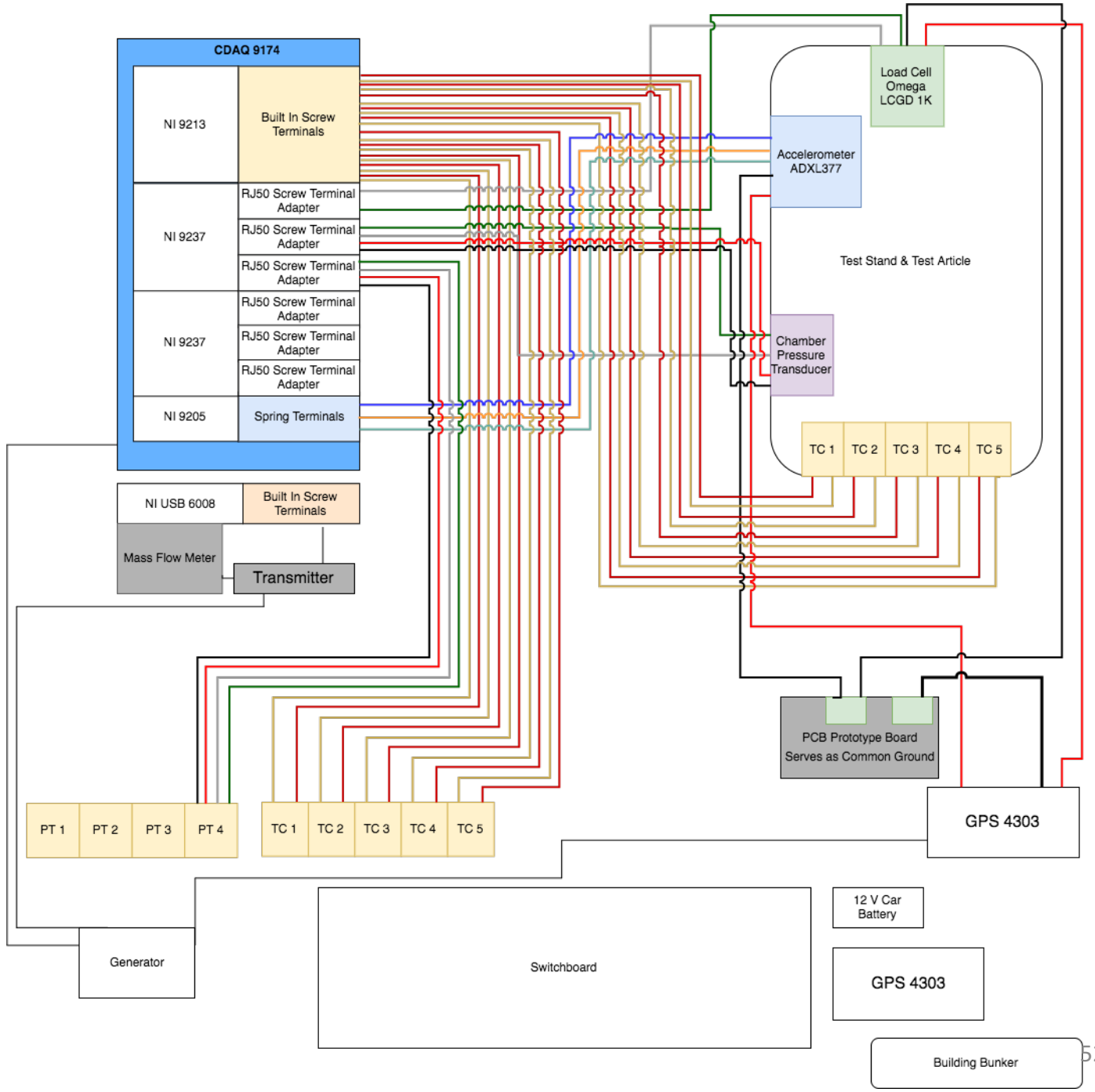
- Location: Senior Projects Shop
- Procedure:
  - Place weights in 5 lb increments on load cell
  - Ensure load cell measurements are accurate to within 1 lb of the mass placed
  - Stop placing weights at 50 lbs

Mass Flow Meter Verification

- Location: TBD
  - Contacting Emerson about field tech assistance in verification
- Procedure:
  - Measure and weigh 1 gallon of water
  - Pump water through mass flow meter
  - Integrate the results of the mass flow meter
  - Check if the result of the integration is within 1 lbm of the water pumped in through the mass flow meter

Wiring Diagram

Switchboard circuit not shown

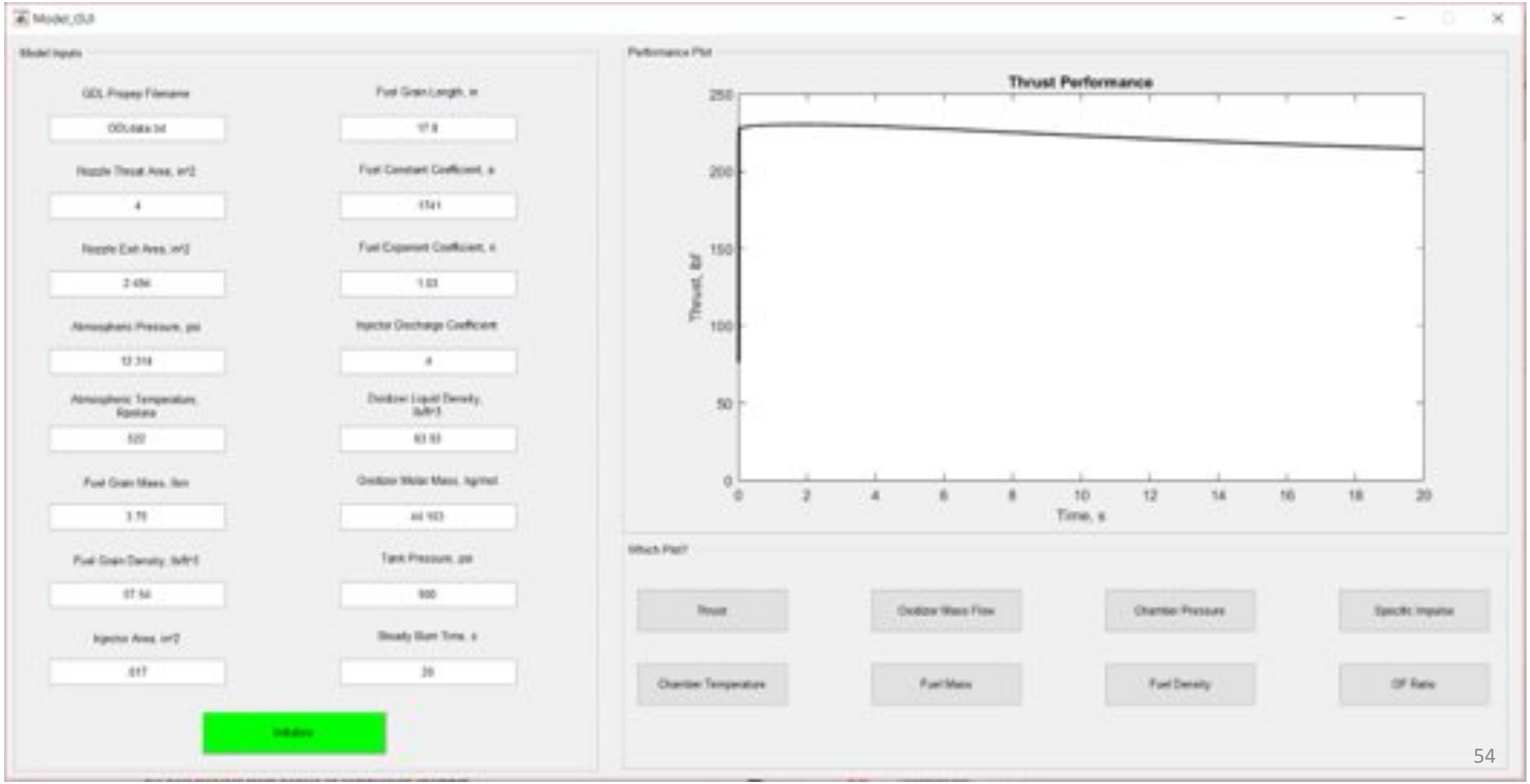


Software: Tasks

Task	Scheduled Finish Date	Status
Basic Main Code draft	January 22	Finished
Debug Given MFM Software	January 22	Finished
Add Times to File	January 28	Finished
Test software with hardware to ensure data rates	January 28	Finished
Output data to one file	February 11	Finished
Test MFM code with Hardware	February 11	In Progress
Test Main code with sensors to ensure it is reading correct values	February 11	Finished
Finish all Code	February 20	In Progress
Debugging of code if issues arise	April 1st	Ongoing

Manufacturing progress:

Model GUI


Model_GUI
Model Inputs
Performance Plot
Thrust Performance
Thrust, lbf
Time, s
0
50
100
150
200
250
0
2
4
6
8
10
12
14
16
18
20
Which Plot?
Thrust
Oxidizer Mass Flow
Chamber Pressure
Specific Impulse
Chamber Temperature
Fuel Mass
Fuel Density
OF Ratio

Switchboard Test Pictures