CETI | SHAMU

Cetacean **E**cholocation **T**ranslation **I**nitiative

Search and **H**elp **A**quatic **M**ammals **U**AS

Manufacturing Status Review

Team

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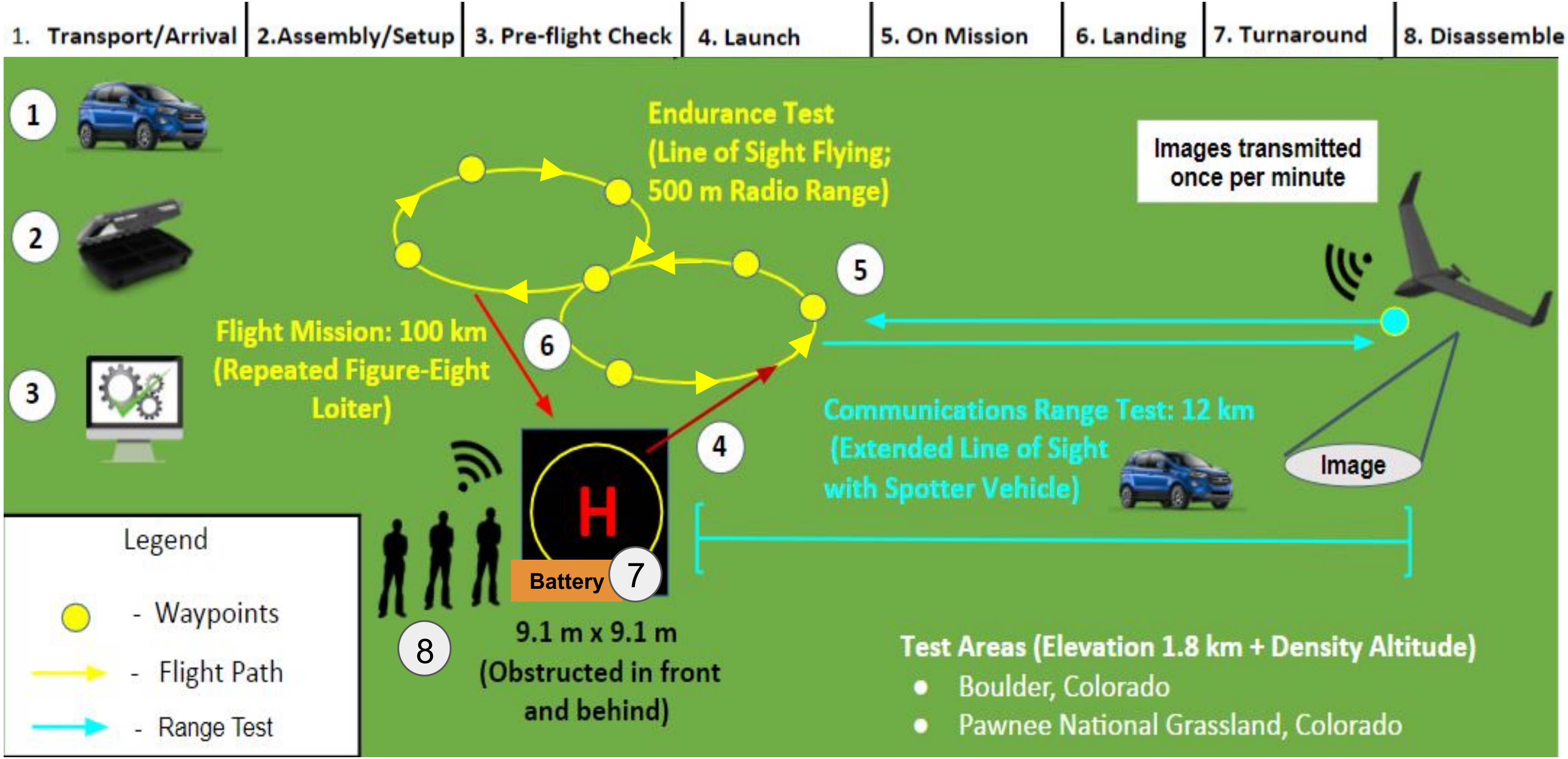
Project Description

Search and **H**elp **A**quatic **M**ammals **UAS**

will design an **unmanned aerial system** to carry a **future** instrument payload capable of **locating sperm whales in the ocean.** The future unmanned aerial vehicle will be **launched and recovered from a research vessel's helipad.**

SHAMU Test CONOPS



Levels of Success

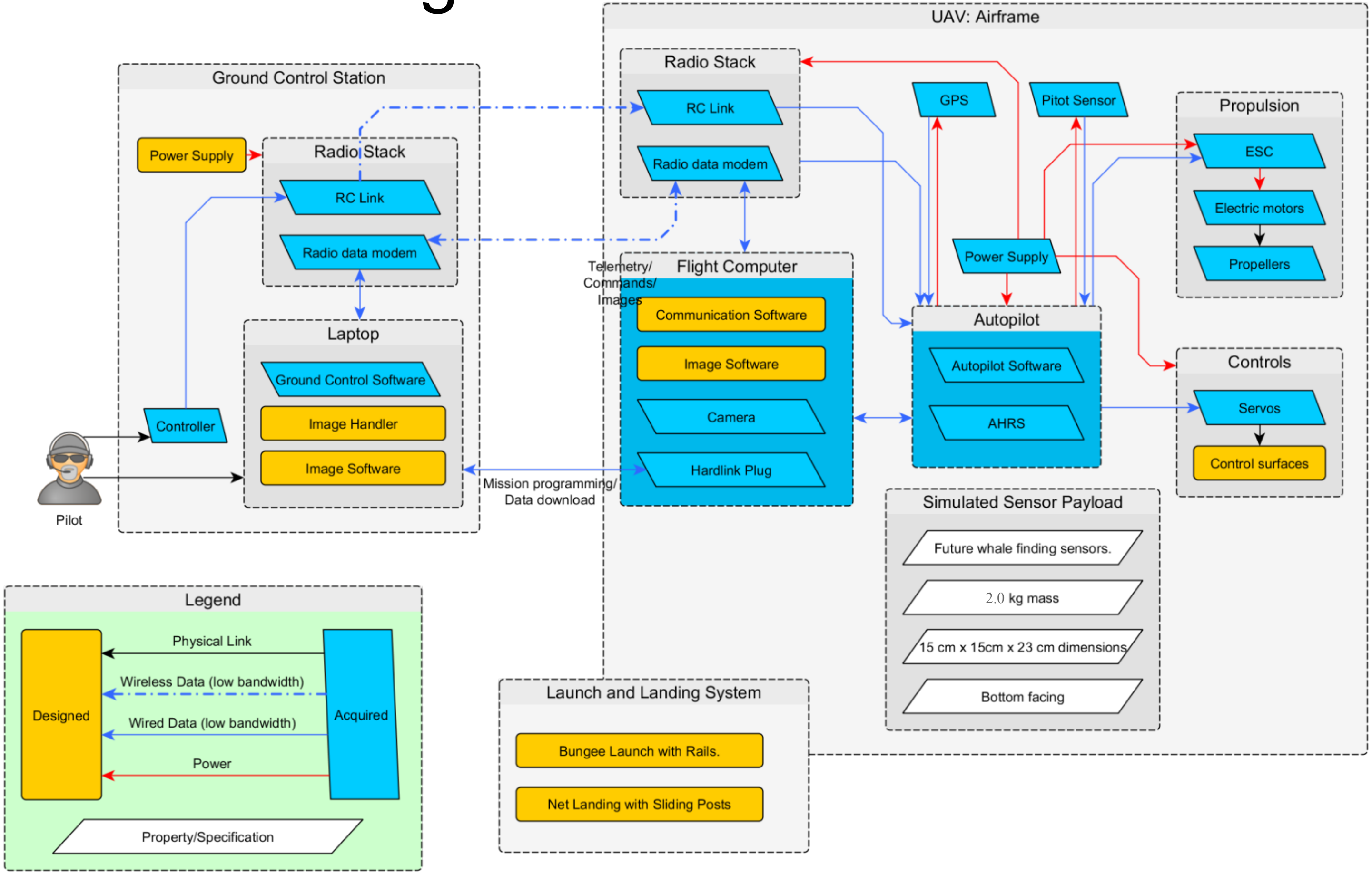
1. The **aircraft and associated systems pass ground tests**: Aircraft has **2 kg instrument payload** with **15 x 15 x 23 cm volume**; wing loading test of **5g**; aircraft mass below **22.7 kg**. Power source endures **1 hour** simulated flight mission. Locally **downlink telemetry**; **full manual control** over control surface servos.

1. The **aircraft is airworthy and proven to fly**: piloted **takeoff** and **landing**, **5 minutes** on mission, uplink **waypoints**, **telemetry** displayed to pilot.

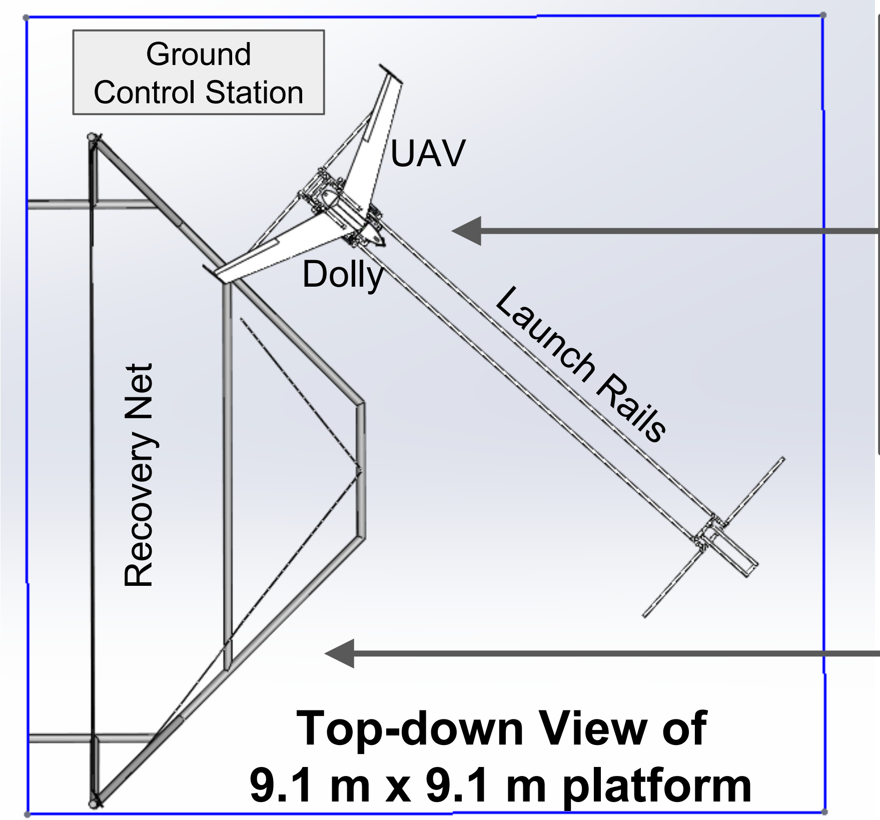
1. The **aircraft has improved flight performance**: **30 minutes** on mission, **full autonomy** at cruise, **500m** radio range, **images** are **saved onboard once per minute**.

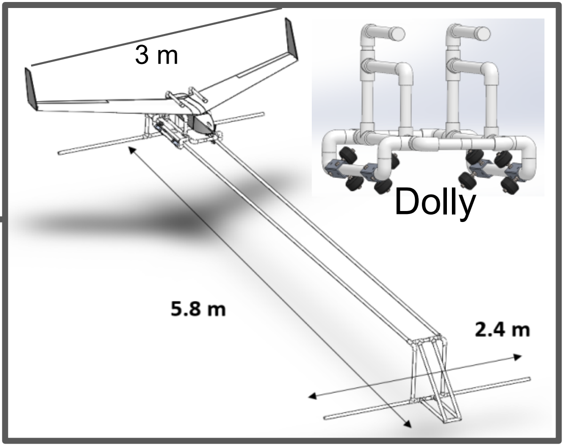
1. The **UAS meets all mission objectives**: **1.4 hours** on mission, **20 m/s cruise speed, 12km radio range, images transmitted once per minute.**

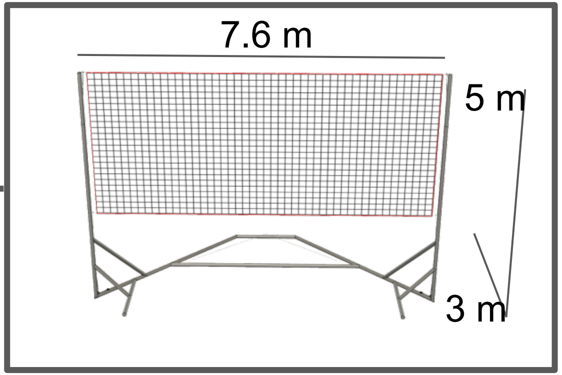
Functional Block Diagram



Review of Baseline Design







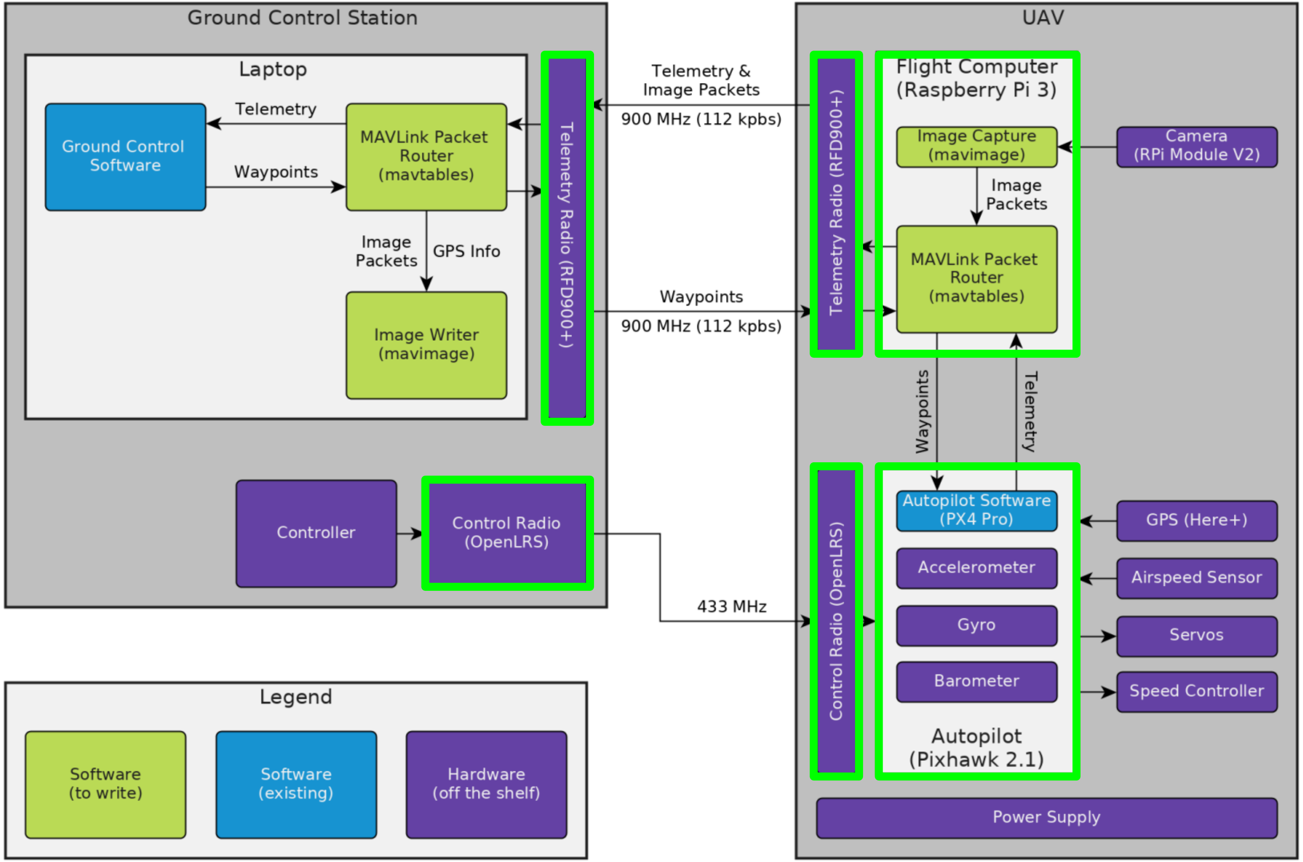
UAV on Launch Rails

- Dolley rides on rails
- UAV accelerated via dolley and bungees
- UAV ejected by sudden stop of dolley via restraining rope

Recovery Net

- Net extends
- Lines, pulleys, and bungees enable net extension
- Sailing cleat prevents rebound

Review of Navigation Hardware/Software Design



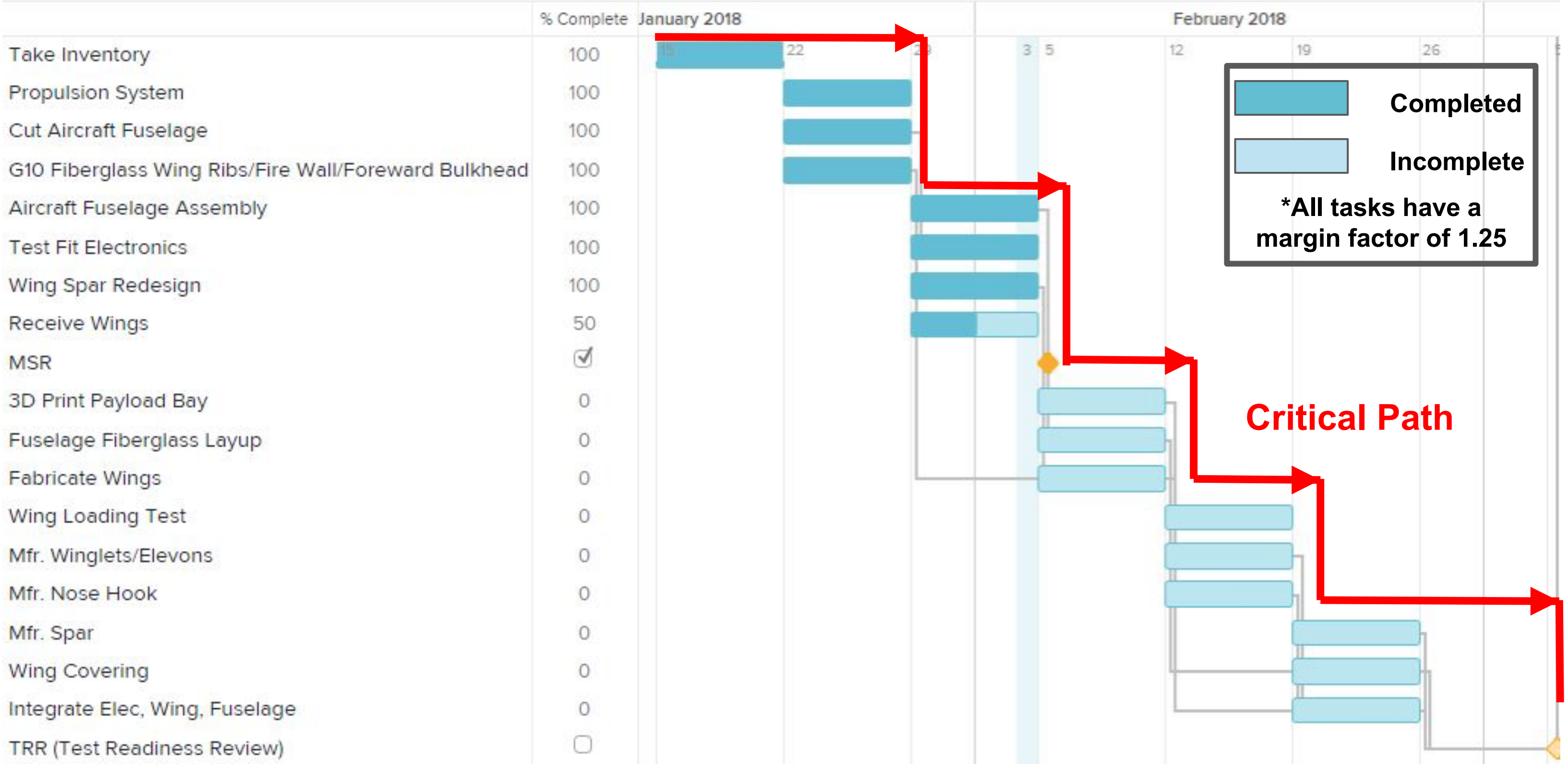
Critical Project Elements

CPE	Requirement Considerations
Aerial Vehicle	• **Stability and control** • **Future sensor payload** • **Tradeoff** between **maximizing lift-to-drag** ratio and **structural/manufacturing complexity**
Takeoff and Recovery	• Accelerate/decelerate aircraft under **maximum structural load** • Capability to transport and setup on **9.1m x 9.1m helipad**

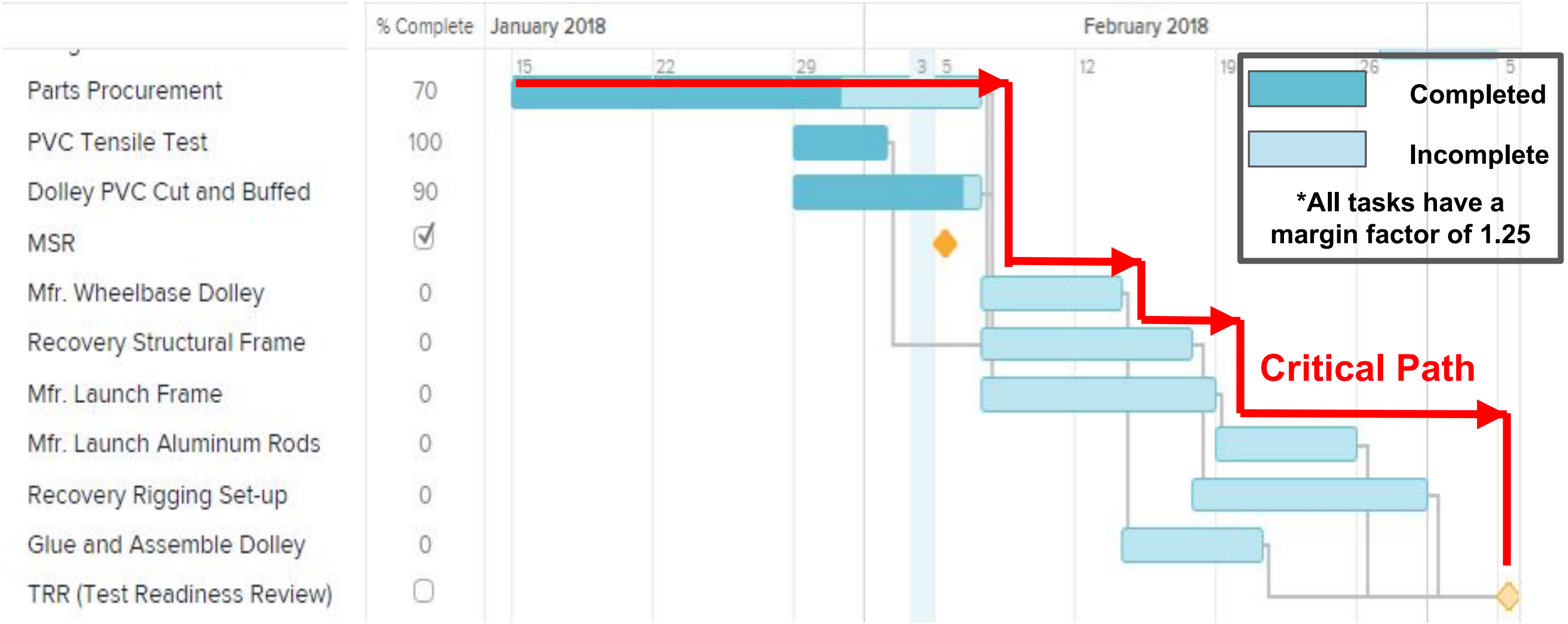
Critical Project Elements

CPE	Requirement Considerations
Communication with Ground Station	• **Communication range of 12 km** from ground station • Transmit images at **one per minute** • Piloted **manual control** • Transmit **updated flight waypoints** • Transmit **telemetry** to ground station
Flight Computer / Autopilot	• Collects **sensor data** for virtual cockpit • Autopilot keeps aircraft in **steady, level flight** • Accepts **flight waypoints** and **executes**

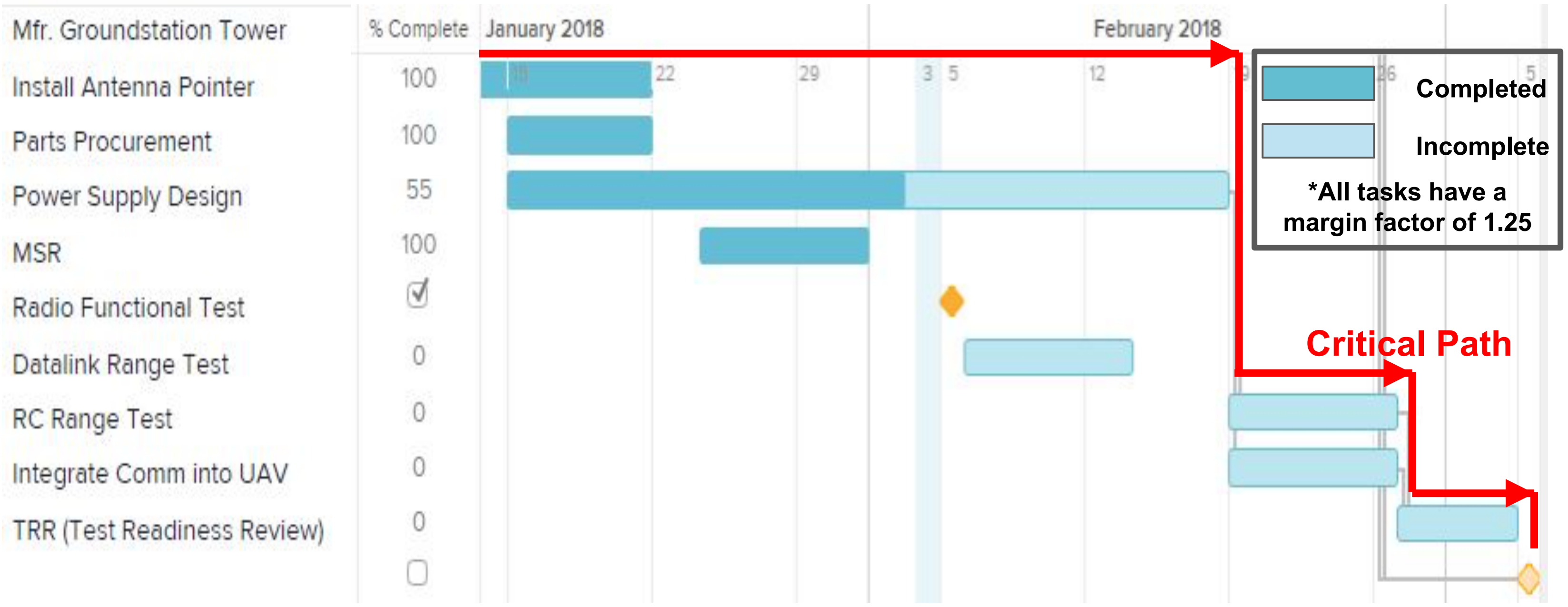
CPE: Aerial Vehicle Schedule



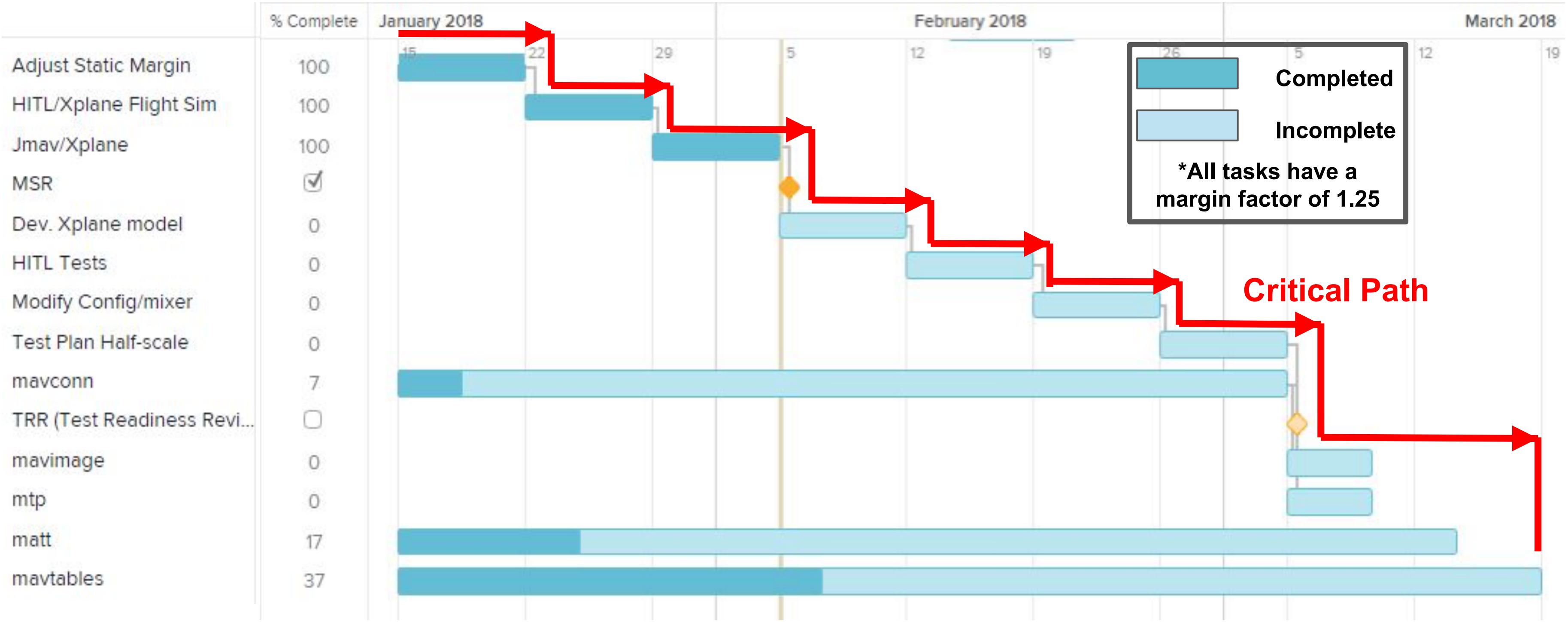
CPE: Takeoff/Recovery Schedule



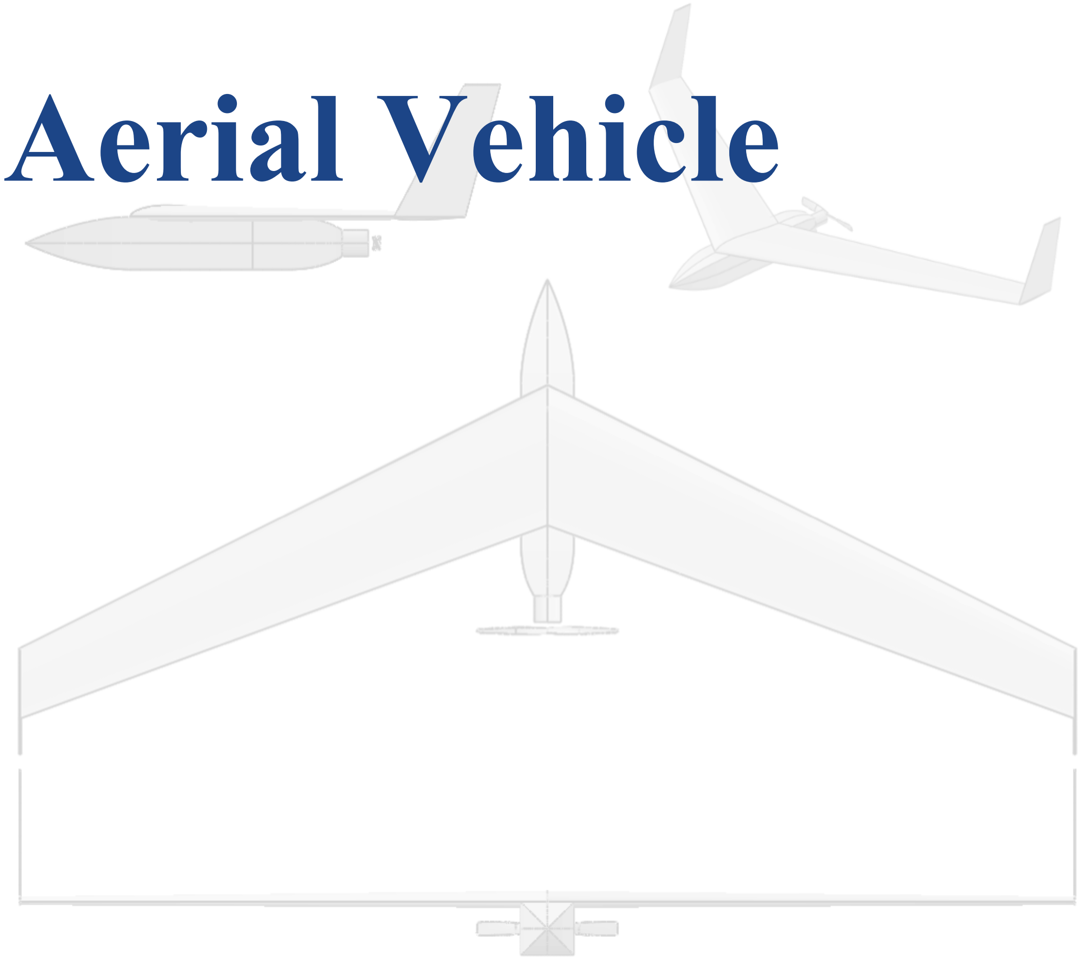
CPE: Communication Schedule



CPE: Flight Computer/Autopilot (Software) Schedule



CPE: Aerial Vehicle



Manufacturing Flow Chart

Completed | Behind schedule | Upcoming

Week	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/5 - 3/19
	Inventory	Propulsion System	Receive Wings	Fuselage fiberglass layup	Nose hook fabrication	Carry through spar fab.	Wing covering	Schedule margin
		Foam Fuselage Parts Fab.	Fuselage Assembly	Cut wing spars	Elevon cuts	Elevon rigging	Electronics Integration	
		G10 Parts Fab.	Test fit electronics	Cut wings for rib	Winglet fabrication		Wing/ fuselage mate	
				Glue spars/ribs in wing cores				

Challenges- Carry Through Spar

Issue:

Previous solution Aluminum 7075:

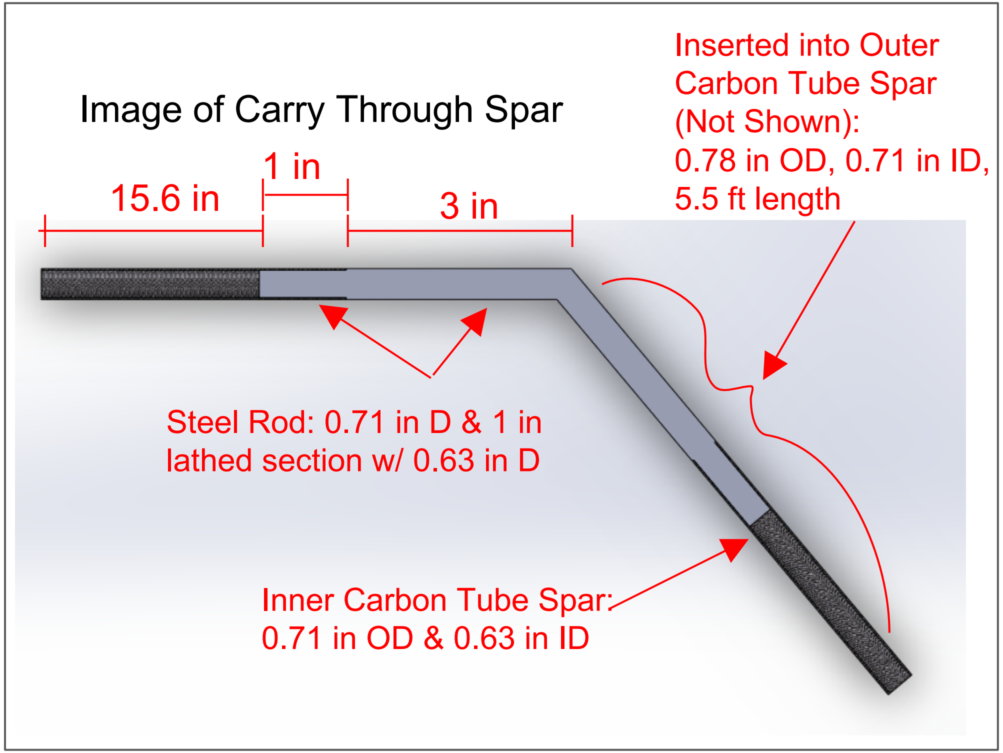
- Not weldable, thus cannot obtain “bend”
- No source for 0.71 in diameter rod

Mitigation:

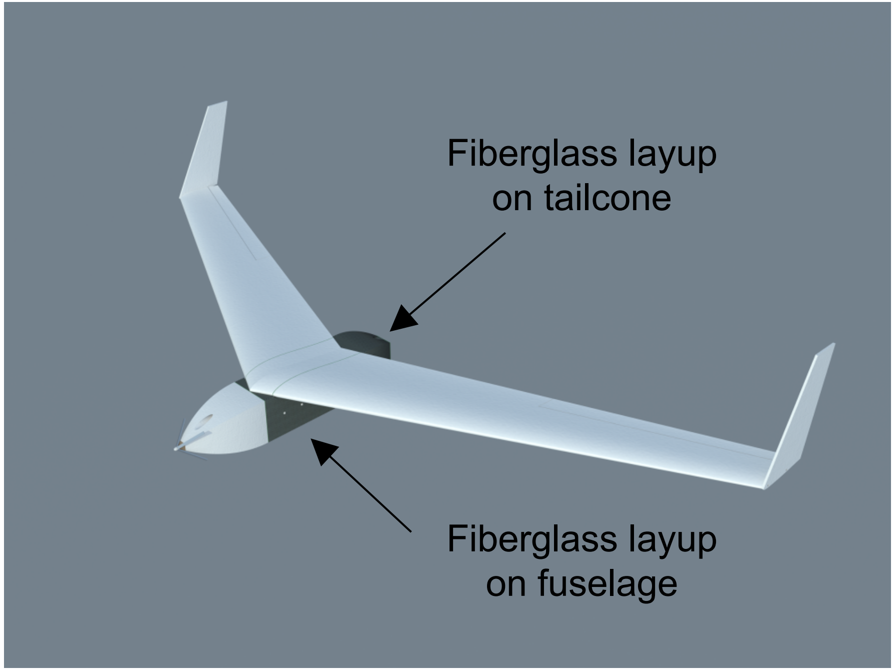
- Use 440c steel
- Shorten carry through spar (higher density)
- Reinforce wing’s Outer Carbon Tube Spars with Inner Carbon Tube Spar (together, create 0.78 in OD and 0.63 mm ID spar)

Process:

- Lathe steel rod ends (last 1 in) to fit within 0.63 in ID Inner Carbon Tube Spar.



Challenges- Fiberglass Layup



Issue:
- Attention to detail to prevent air pockets and wrinkles
- Lack of experience on team

Mitigation:
- Fuselage is designed without compound curves, which simplifies fiberglass layup

Solution:
- Get instruction from experts at RECUV
- Do a practice run with extra fiberglass and EPP

Challenges- Elevon Cuts

Issue:

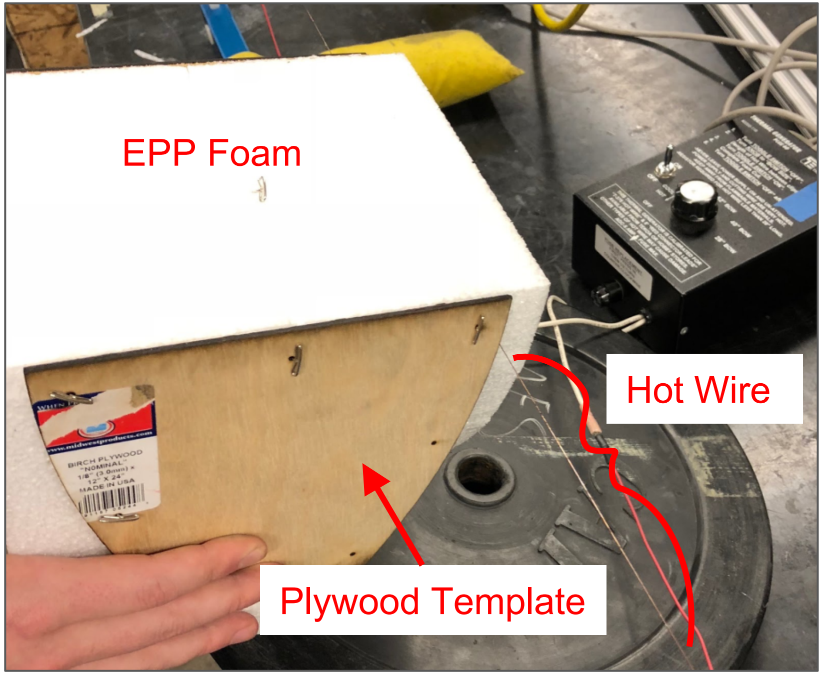
- To prevent wing damage, elevon cuts must be done to 1 mm precision
- Tolerance: 1 mm

Mitigation:

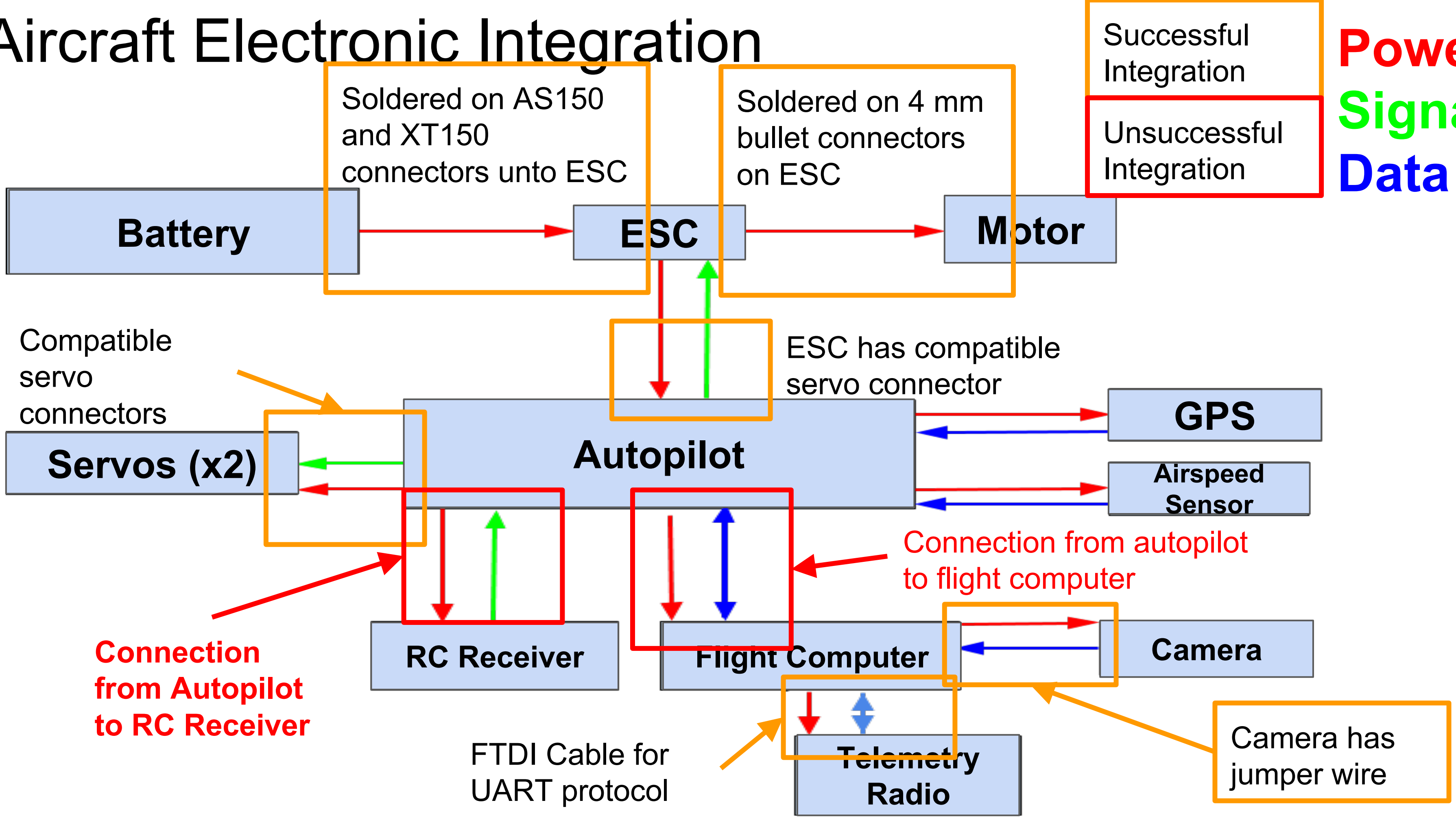
- Plan elevon hotwire cut late in schedule → group will have experience
- Practice on extra, unusable set of wings

Process:

- Laser cut ⅛ inch plywood templates
- Pin templates to wing (exterior sides on templates line up with wing planform)
- Cut foam by running hotwire cutter along templates

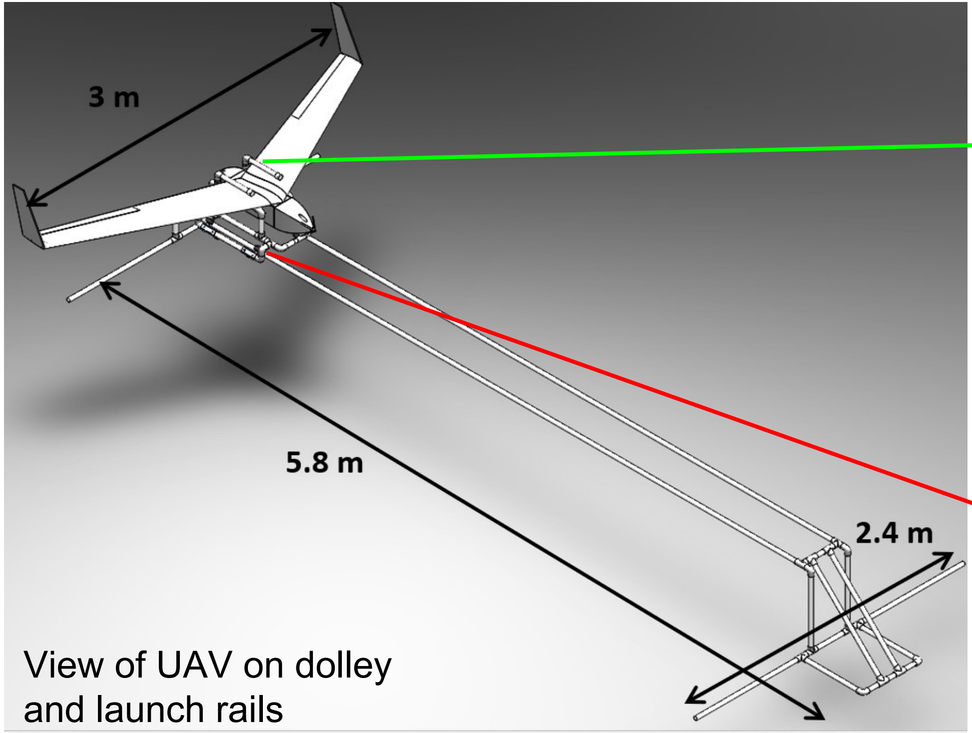


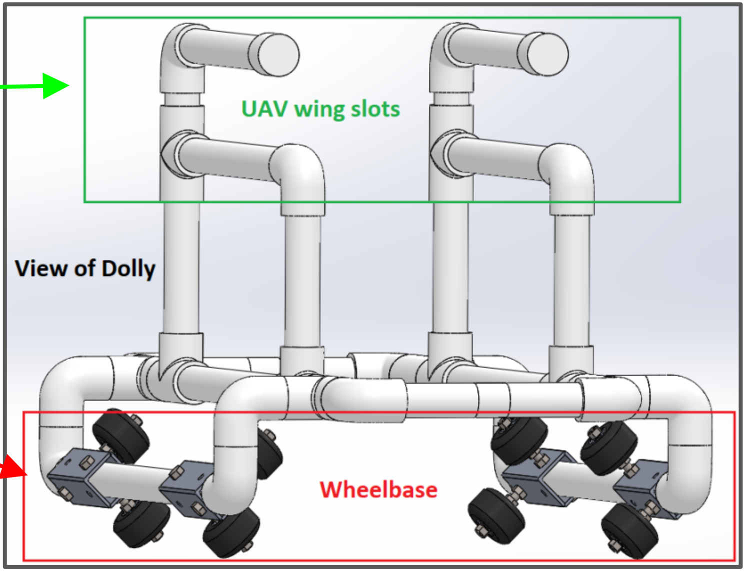
Aircraft Electronic Integration



CPE: Takeoff and Recovery

SHAMU Launch System





Launch System

Functionality	● **Dolly** will carry UAV down the rails up to speed ● **Rail Framing** will guide dolly for UAV takeoff
Challenges	● Wheelbase machining
Plan	● Pursue help from machine shop experts ● Perform tasks by February 14th

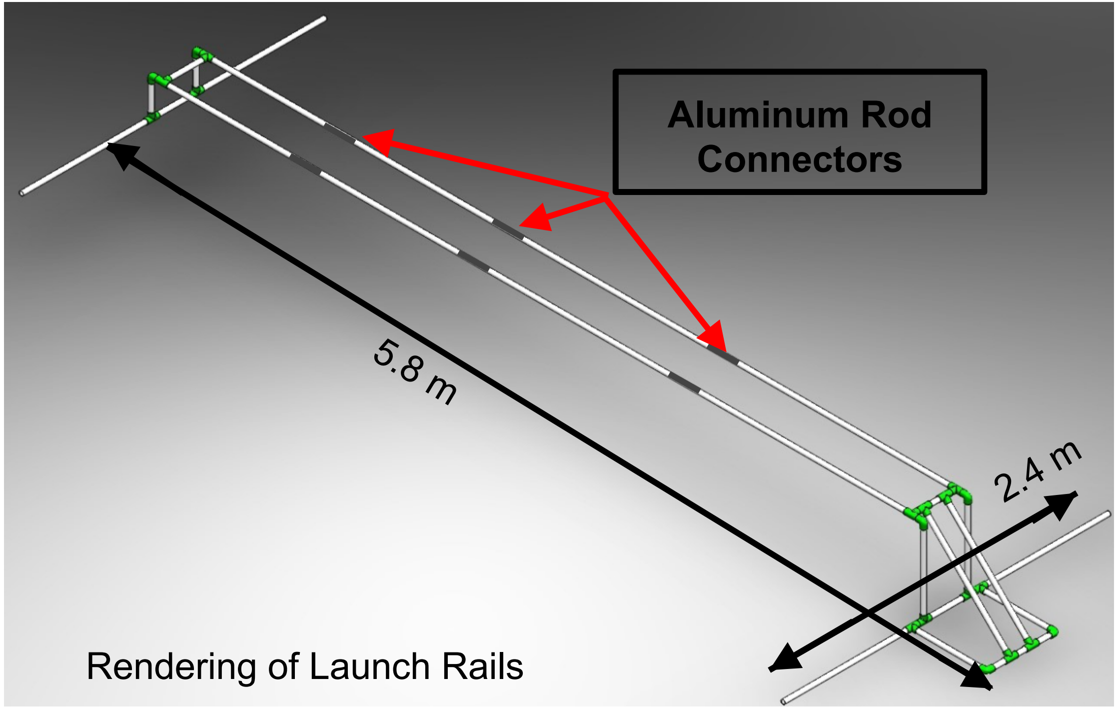
Rail System Status - 15% Complete

PVC (2 in. Sch 40)

- **Status:** PVC lengths marked
- **Next Steps:** Cutting the PVC with sawzall. Prepare for launch testing before TRR.

6061 Aluminum rods (6 in long)

- **Status:** Parts Acquired
- **Next Steps:** Drill 1 inch hole with drill press. Prepare for launch testing before TRR.



Rendering of Launch Rails

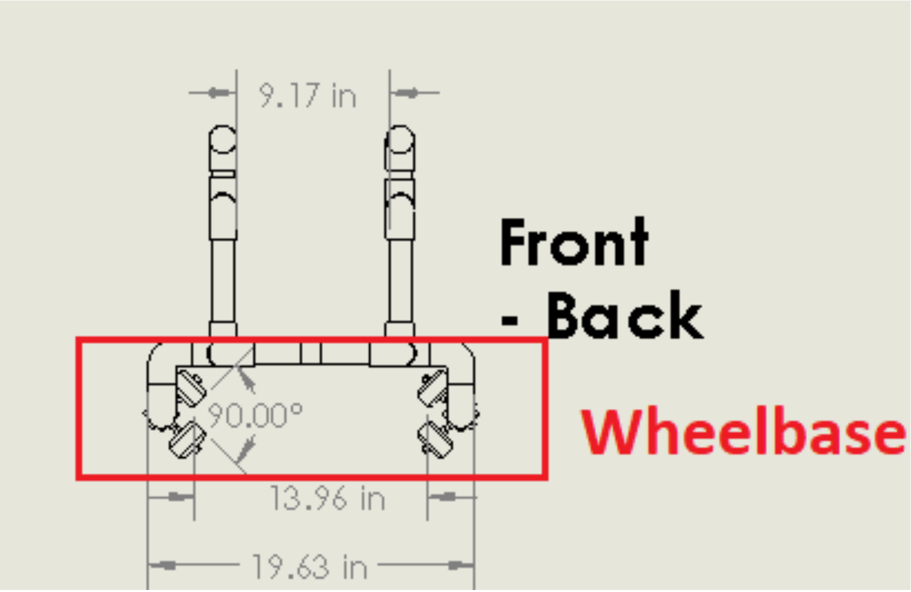
Dolly Status - 20% Complete

PVC (1 in. Sch 40)

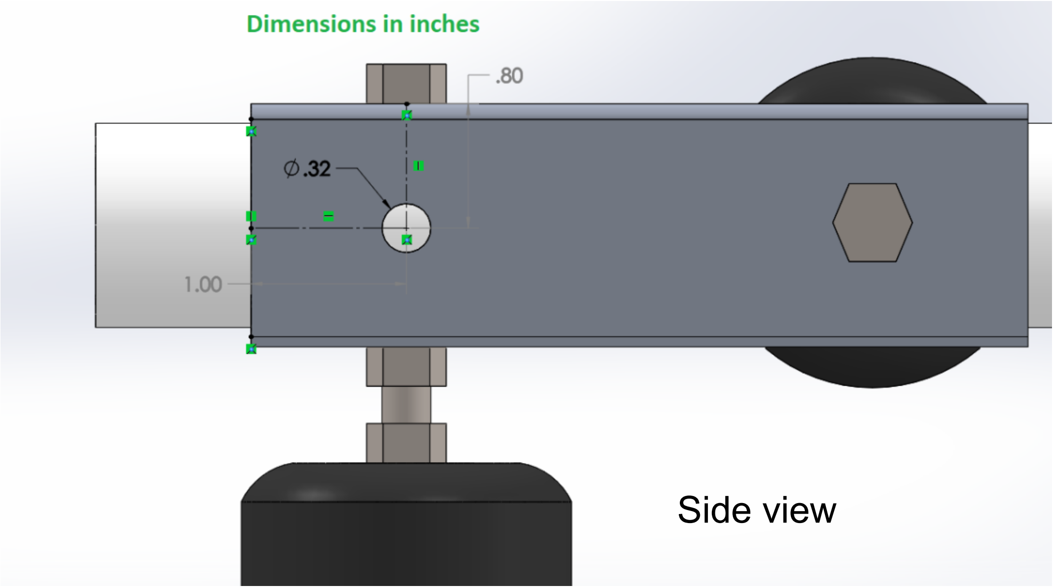
- **Status:** All segments cut
- **Next Steps:** Needs to be glued
- **Tools:** Sawzall, Sand, Buffer

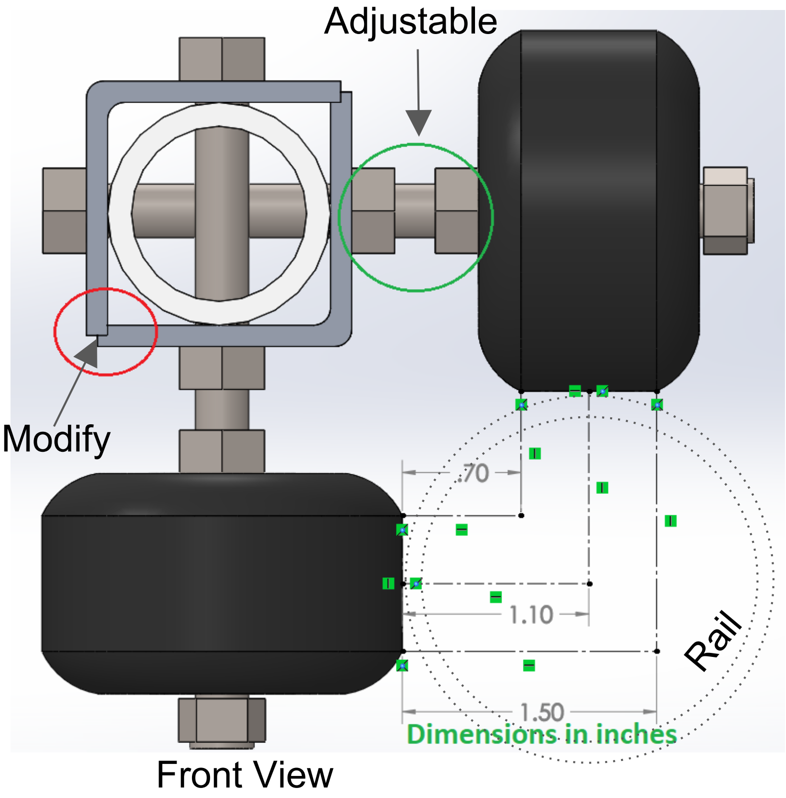
Wheelbase

- **Status:** Scheduled for manufacturing
- **Tools:** Saw, Sanding, Drill Press



Challenge - Wheelbase



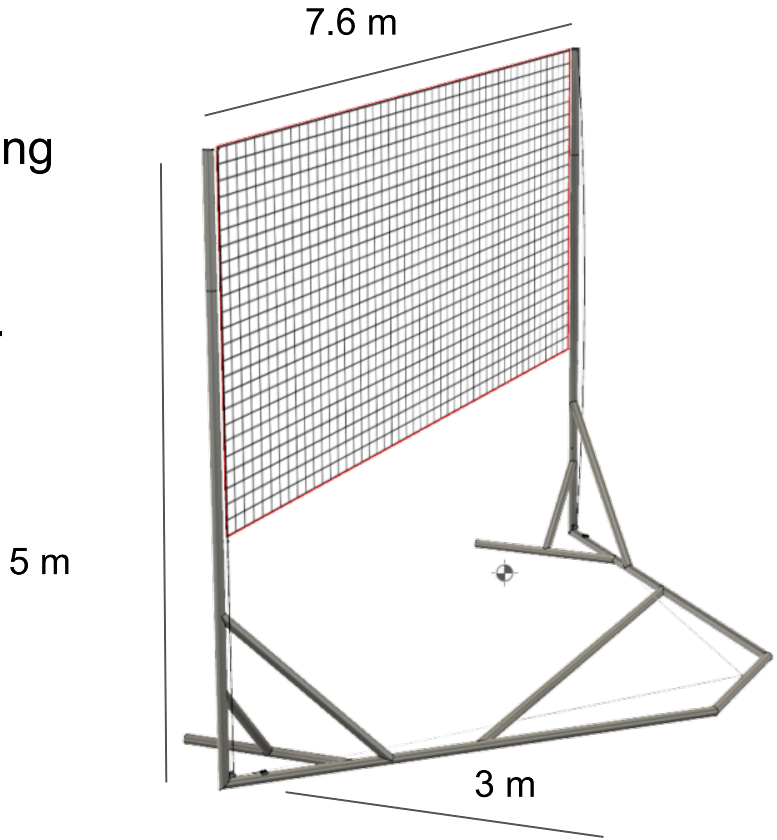


Recovery System

Functionality	• **PVC Structure** will support the recovery net • **Damping System** will slow the aircraft to a halt
Challenges	• System complexity • Rope/Pulley Interfacing/Tangling
Plan	• Complete PVC structure by Feb 18, 2018 • Use eyebolts to effectively guide rope

Recovery System Status

- Manufacturing delayed due to PVC Testing
- Dry Assembly - 10%
  - PVC testing completed Feb 3, 2018.
- Damping Setup - 10%
  - 50% of supplies acquired
- Despite delays, manufacturing scheduled to finish 1 week prior to TRR



Recovery Assembly

Structure

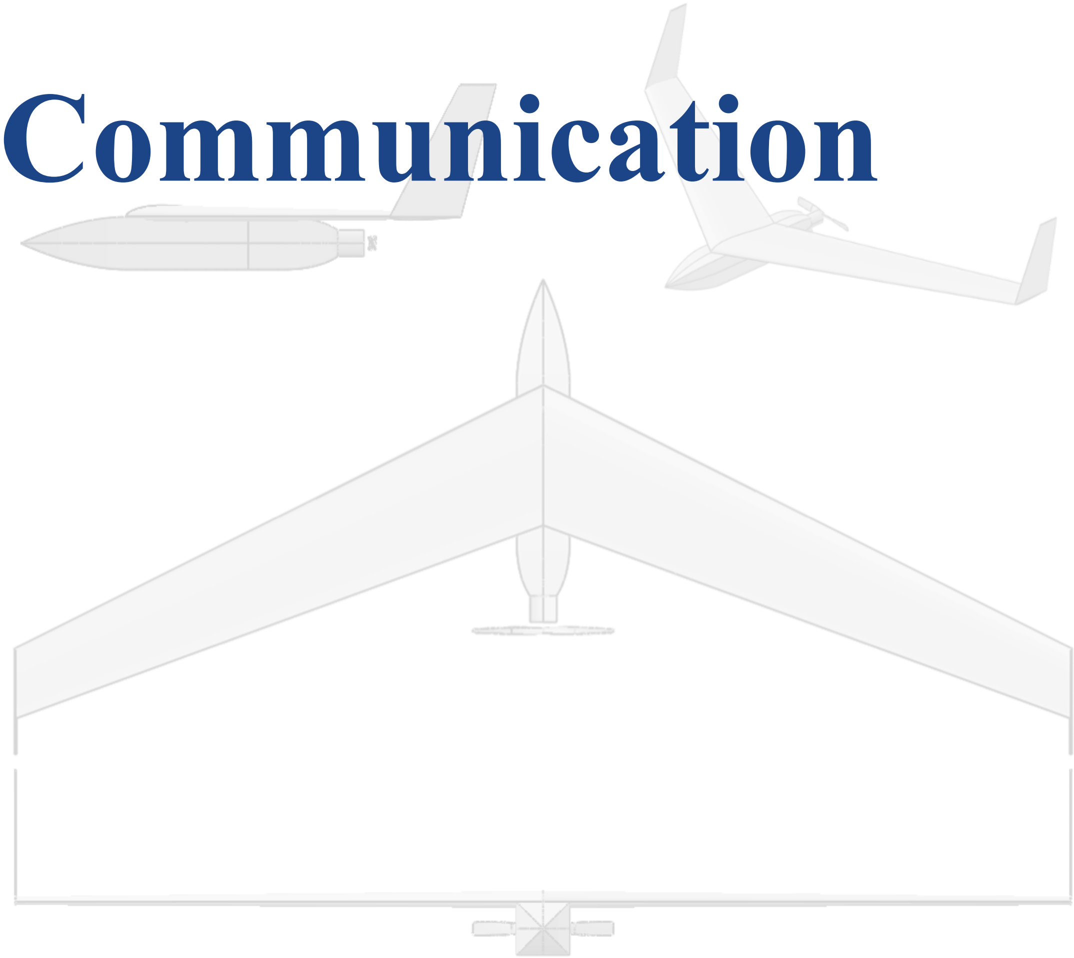
- Pipe sections secured to connectors with threaded adaptors
- Sections >6 feet long split and secured with couplings

Rigging/Net

- Eyebolts screw into pipe
- Eyebolt/Pulley every 1.5 ft on vertical section
- Pulleys/cleats screw through pipe and secured

Threaded Adapters

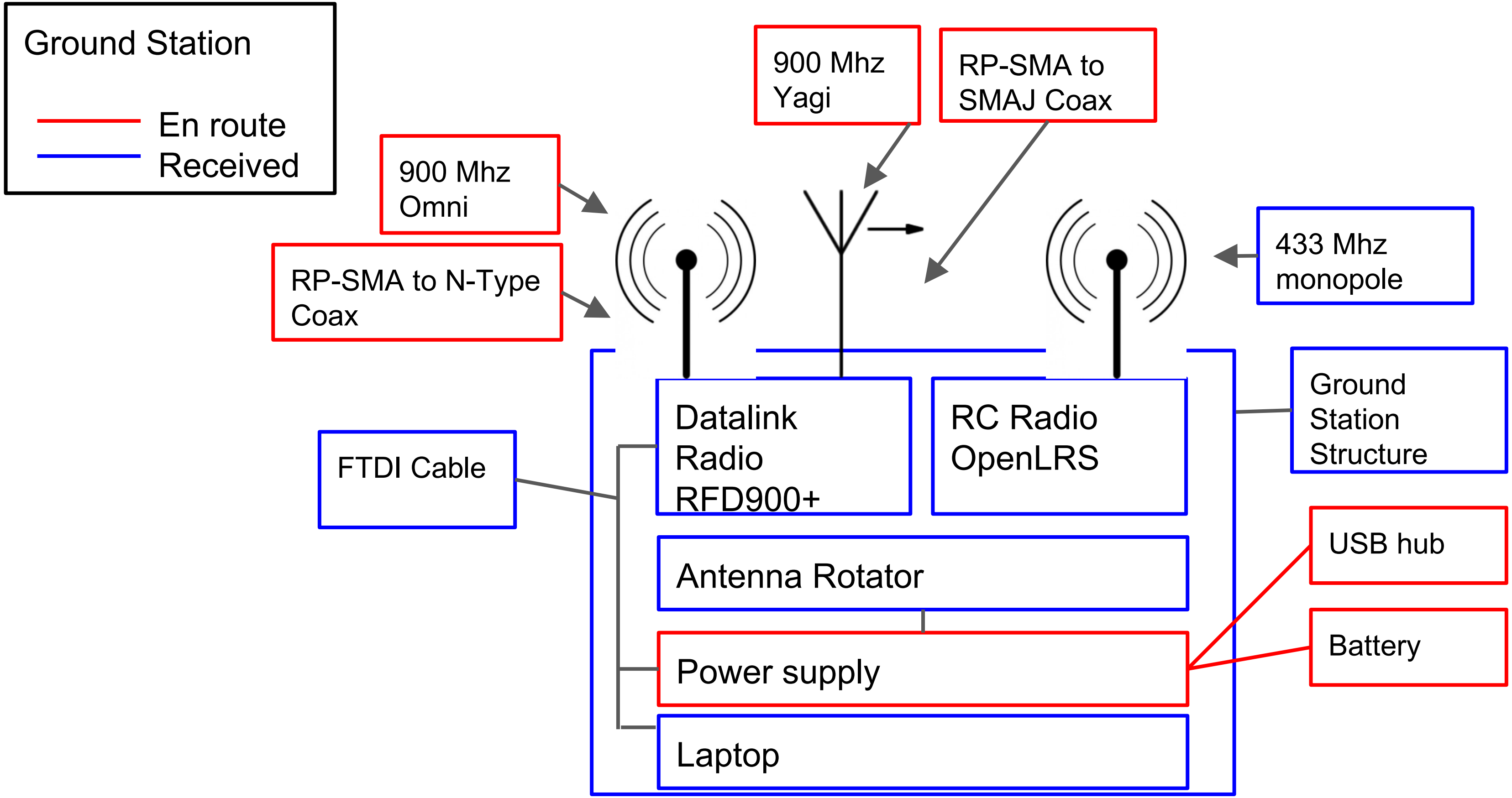
CPE: Communication



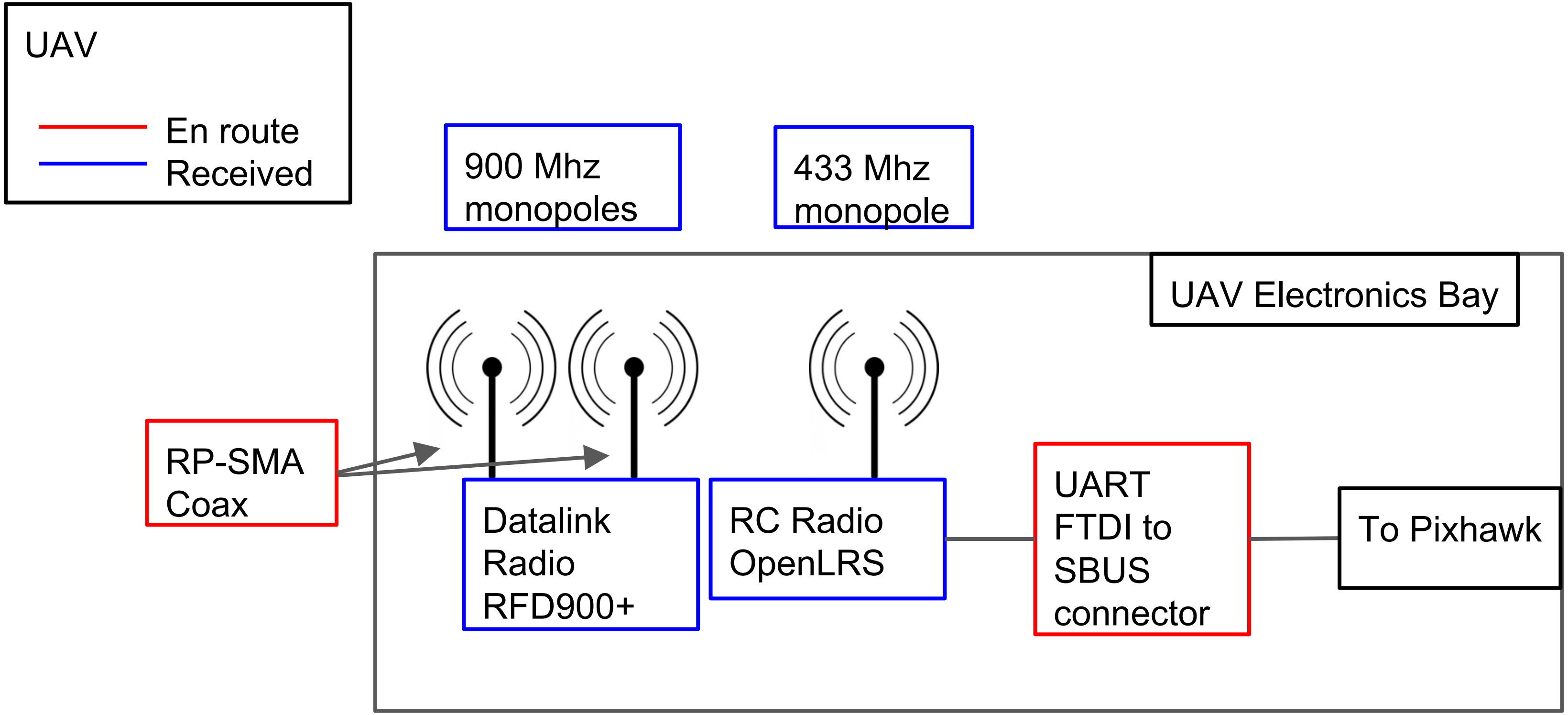
Communications

Functionality	• **RC and Datalink Communication range of 12 km** from ground station • Transmit **updated flight waypoints** • Transmit **telemetry & images** to ground station
Challenges	• Procurement of parts (long lead times) • Antenna pointing • RC channel performance (false specifications)
Plan	• Use an alternative supplier if parts do not arrive • Resort to use of omni-directional antenna or tracking system • More powerful backup system ordered (HawkEye OpenLRS)

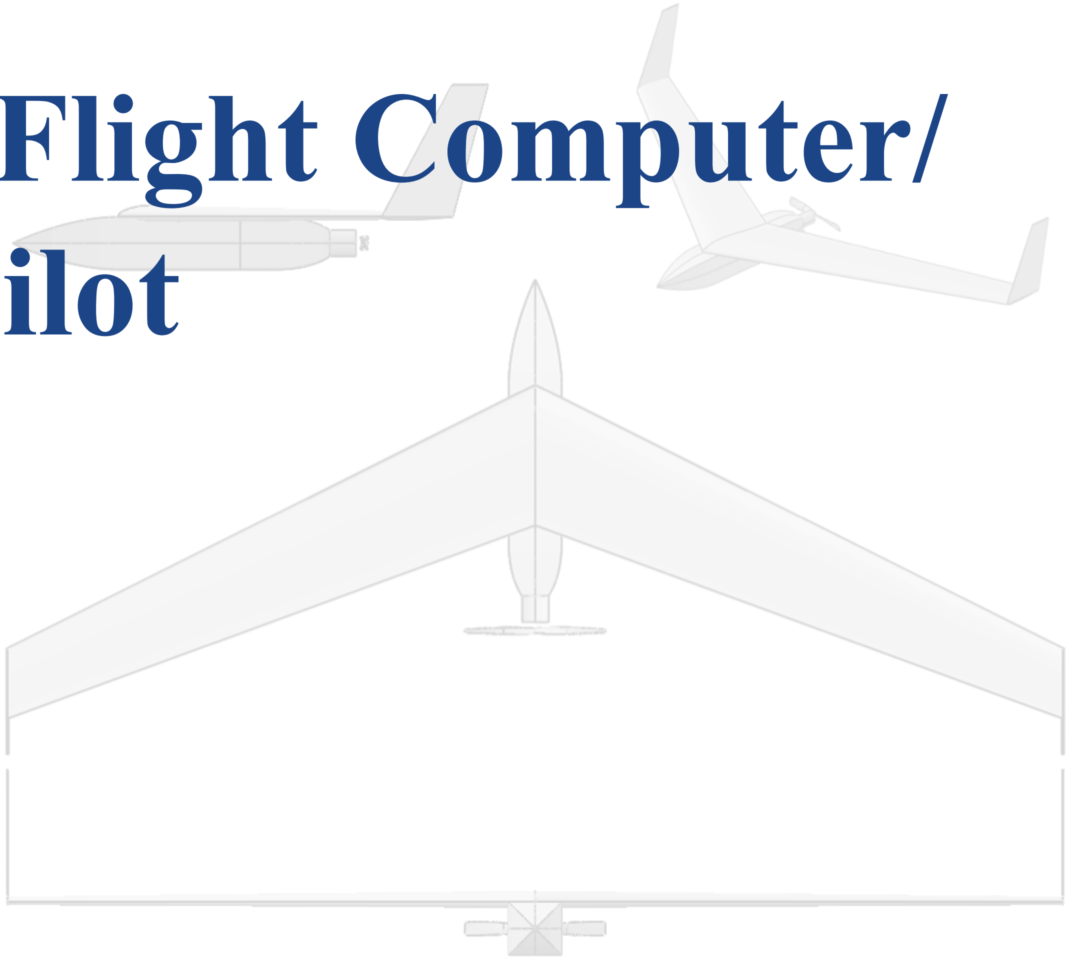
Communications System Status Diagram



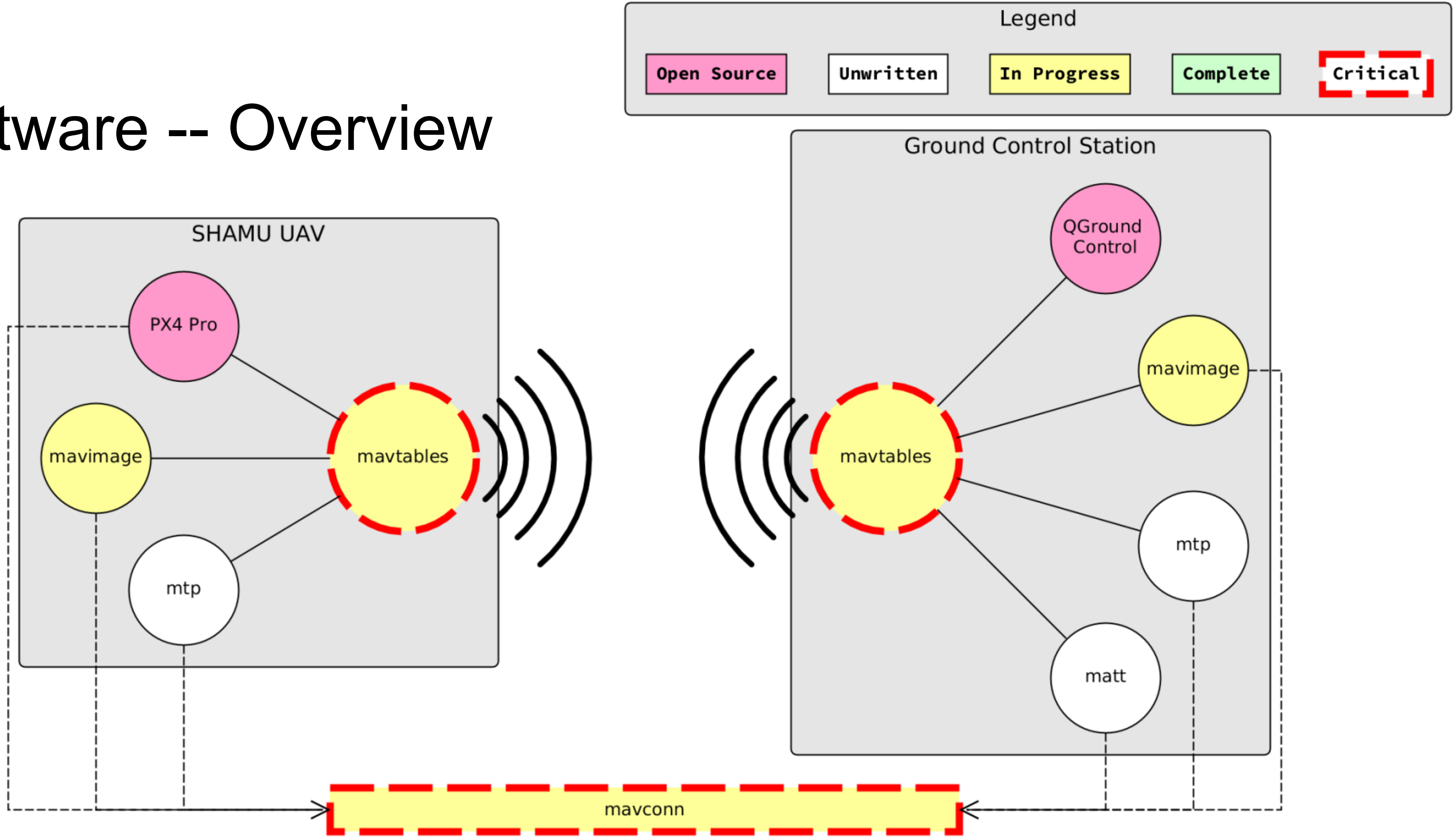
Communications System Status Diagram



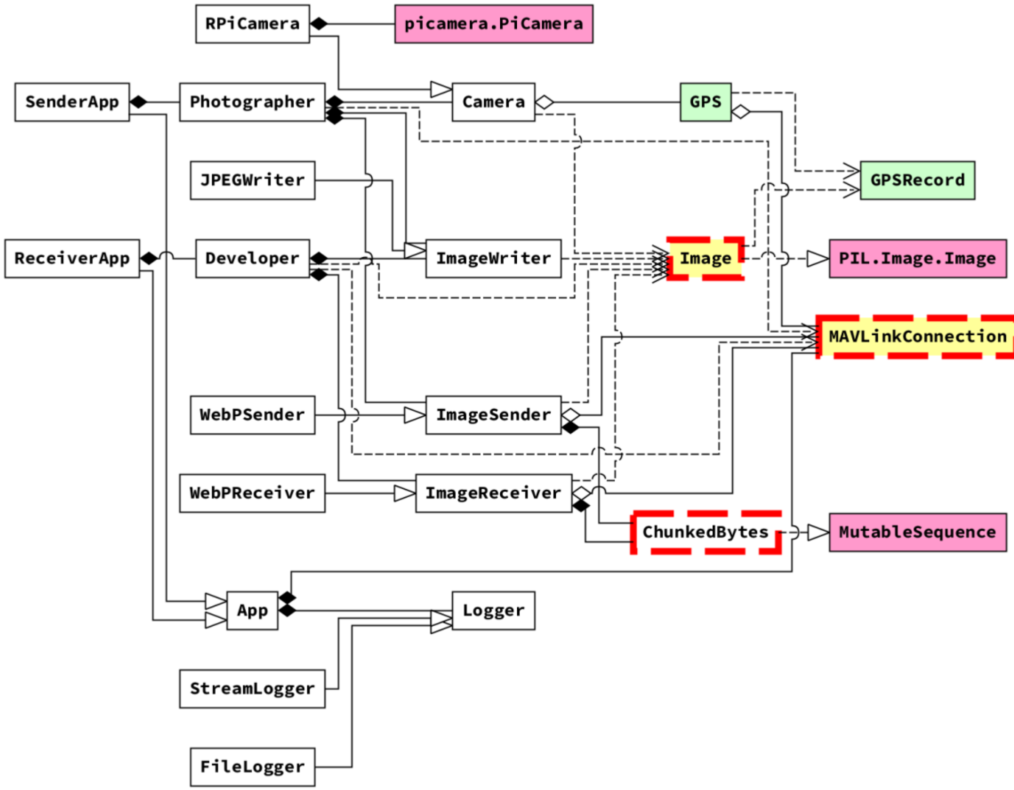
CPE: Flight Computer/ Autopilot

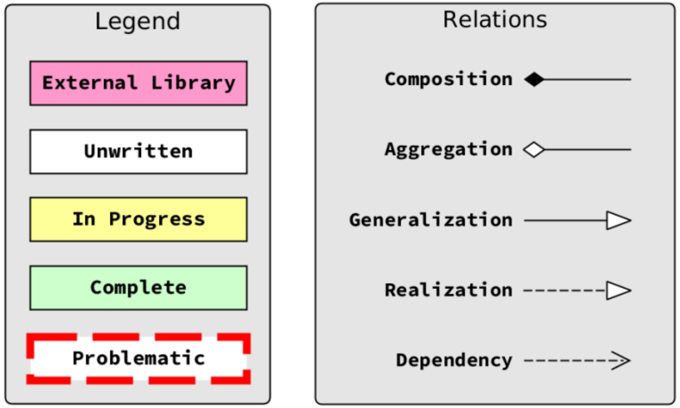


Software -- Overview



Software -- mavimage (12%)





Coverage report: 57%

Module ↓	*statements*	*missing*	*excluded*	*coverage*
Total	**68**	**29**	**0**	**57%**

coverage.py v4.4.2, created at 2018-02-03 22:01

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==================== 5 passed in 0.04 seconds ====================
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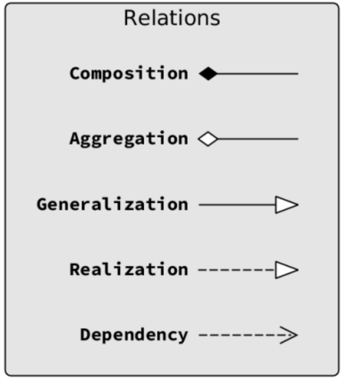
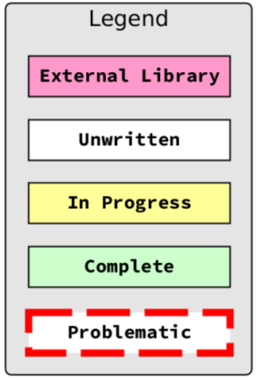
Software -- mavtables (37%)

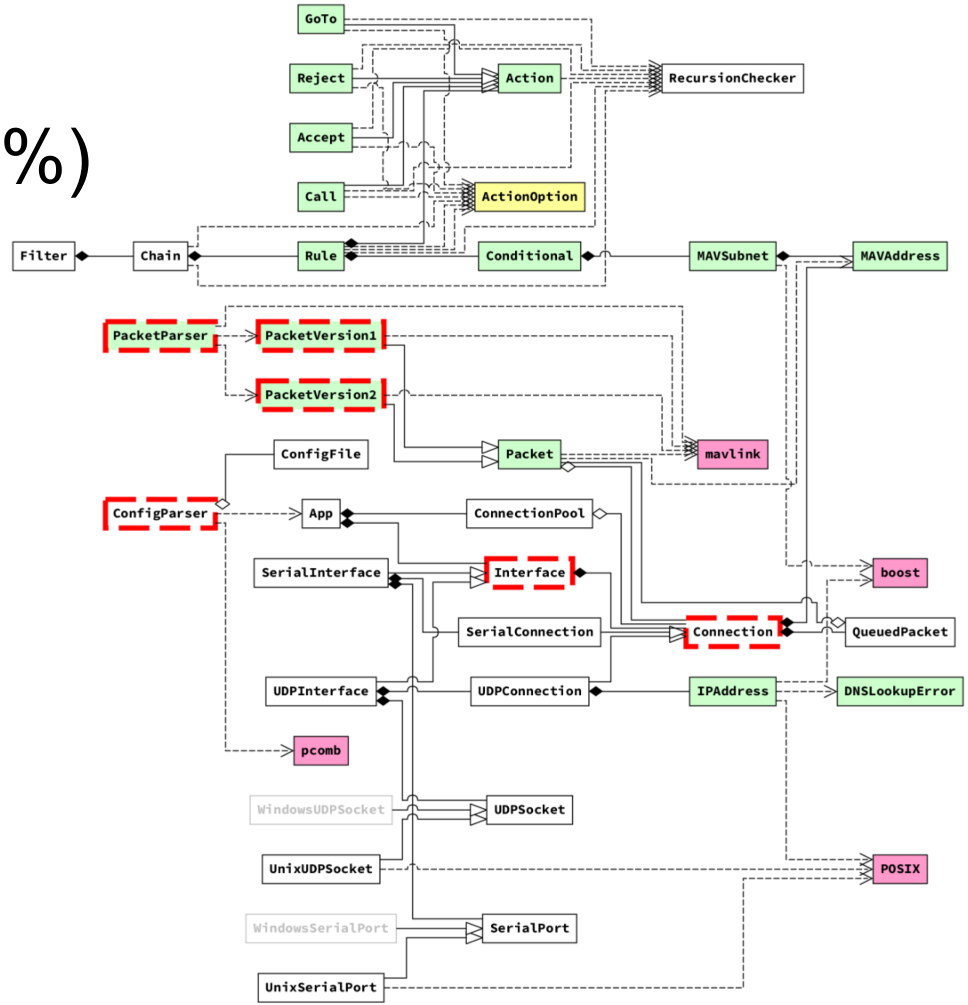
LCOV - code coverage report

			Hit	Total	Coverage
Current view:	top level - src				
Test:	mavtables - targets unit_tests mavtables	**Lines:**	709	712	99.6 %
Date:	2018-02-03 21:46:11	**Functions:**	180	183	98.4 %

`All tests passed (2425 assertions in 133 test cases)`



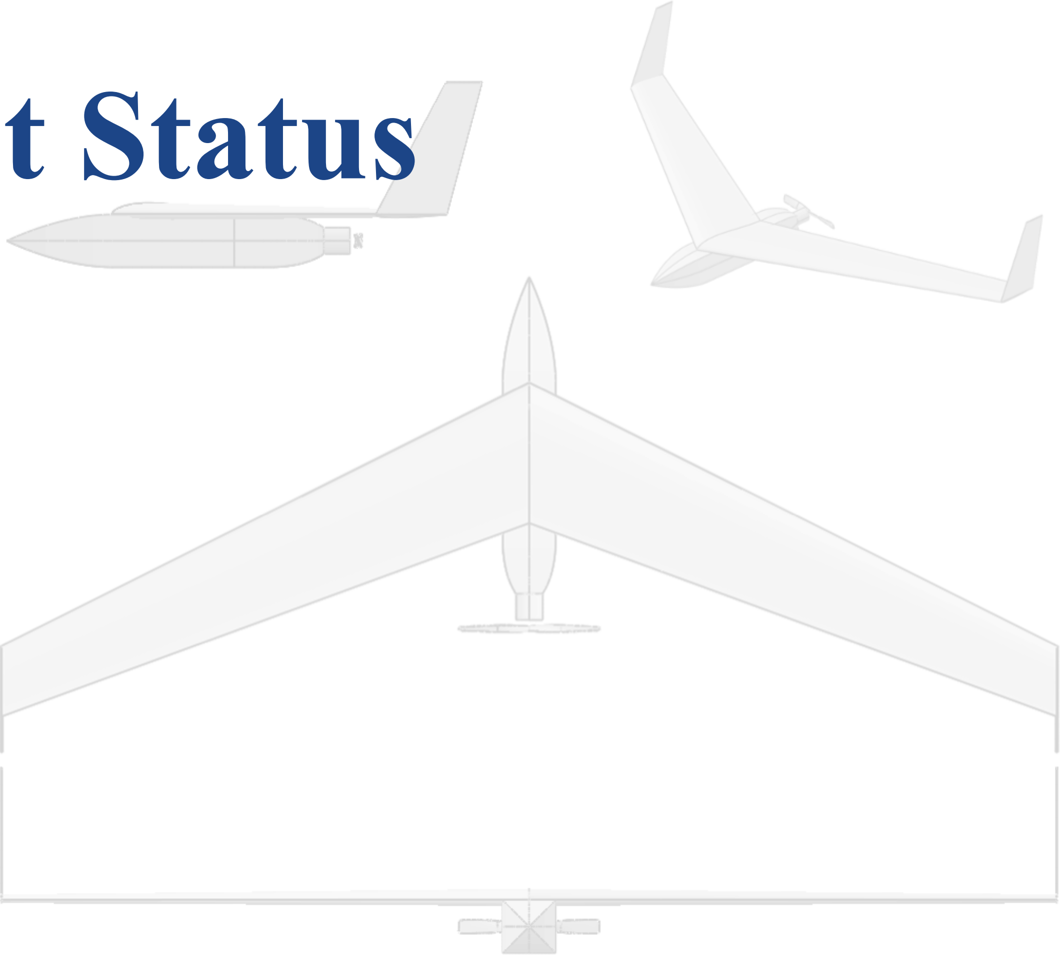




Adding New Airframe to Pixhawk 2.1

Functionality	• Enable autopilot to control aircraft • Provide aircraft parameters, i.e. PID gains
Procedure	• Develop configuration and mixer files • Hardware-in-the-loop (HITL) tests with Pixhawk 2.1 and X-Plane • Manual flights with maneuvers provided in PX4 Pro documentation
Challenges	• Incorrect gains lead to crash of aircraft
Plan	• Perform procedures with half-scale model: verifies method • Modify procedures if necessary • Perform procedures with full-scale aircraft

Budget Status



Budget Update

Airframe w/ motor:	$1230
Communications:	$530
Electronics:	$800
Launch system:	$295
Recovery system:	$510
Software:	$320

Fall Semester Estimate: $3,685

Airframe w/ motor:	$1229.00
Communications:	$771.62
Electronics:	$746.82
Launch system:	$340.83
Recovery system:	$207.16
Software:	$344.74

Budget Spent on Major **Parts**: $3,640.17*

*Shipping costs not included to provide cost of system components only.

Note: 95% of parts have been purchased

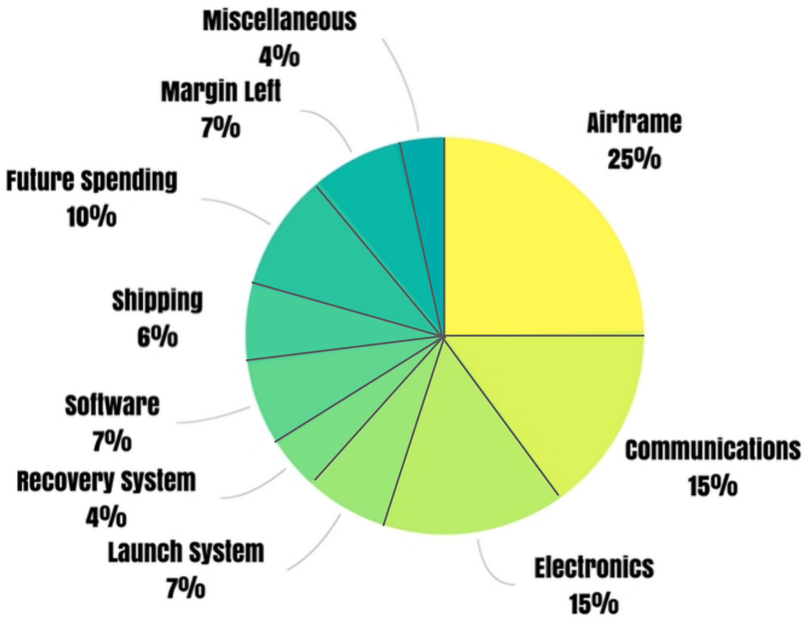
SHAMU Spending

As of 2/5/18, 95% of critical parts have been ordered and are being manufactured with the exception of the recovery PVC.

Total Spent as of 2/5/2018: **$4,154.21**

Remaining Purchases
Recovery PVC: ~ $200
Printing SFR and poster: ~$200
Miscellaneous remaining items: ~ $100

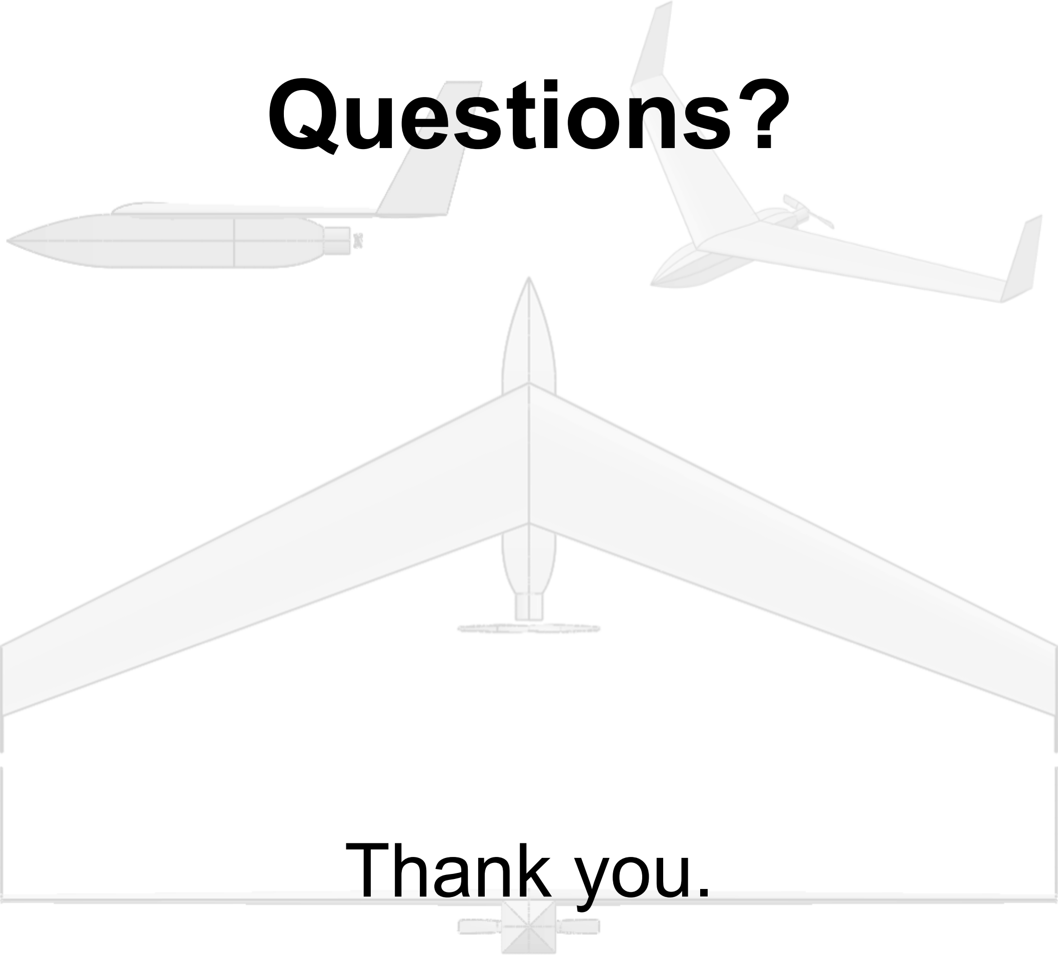
Estimated Margin Remaining: **$345.79**



Acknowledgements

The SHAMU team would like to thank Dr. Gerren, Dr. Koster, Dr. Lawrence, Trudy Schwartz, Bobby Hodgkinson, Matt Rhode, PAB, Tim Kiley, Lee Huynh, Trimble Inc., James Nestor, and David Gruber.

Questions?



Thank you.

Backup Slides

References

- Cooper-Harper scale: https://skybrary.aero/bookshelf/books/1962.pdf (retrieved 12/3/17)
- Pixhawk 2.1 Assembly Guide: http://www.hex.aero/wp-content/uploads/2016/09/PIXHAWK2-Assembly-Guide.pdf (retrieved 12/3/17)
- Pixhawk 2.1 Feature Overview: http://www.proficnc.com/index.php?controller=attachment&id_attachment=5 (retrieved 12/3/17)
- PX4 Pro: http://px4.io/ (retrieved 12/3/17)
- QGroundControl: http://qgroundcontrol.com/ (retrieved 12/3/17)
- Model Aircraft Propellers: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&cad=rja&uact=8&ved=0ahUKEwjO8MLoh-_XAhVD6oMKHduWDCsQFghrMAU&url=http%3A%2F%2Fdc-rc.org%2Fpdf%2FModel%2520Propellers%2520Article.pdf&usg=AOvVaw1CxfDyyhN4K5DlHAanXPPt (retrieved 12/3/17)
- OrangeRx Open LRS Transmitter: https://hobbyking.com/en_us/orangerx-open-lrs-433mhz-transmitter-1w-jr-turnigy-compatible.html (retrieved 12/3/17)
- OrangeRx Open LRS Receiver: https://hobbyking.com/en_us/orangerx-open-lrs-433mhz-9ch-receiver.html (retrieved 12/13/17)
- UIAA climbing rope: http://www.theuiaa.org/safety-standards/
- Solidworks: http://www.solidworks.com/
- PVC porperties: https://www.engineeringtoolbox.com/physical-properties-thermoplastics-d_808.html
- PVC pressure ratings: https://www.engineeringtoolbox.com/pvc-cpvc-pipes-pressures-d_796.html

Software Repositories

- https://github.com/shamuproject/mavtables
- https://github.com/shamuproject/mavimage
- https://github.com/shamuproject/mavlogger
- https://github.com/shamuproject/mavconn

Functional Requirements

1.	Operate in **manually piloted** mode throughout **all phases of flight** with **autonomous mode capability at cruise altitude**.
2.	**Takeoff and land** from/to a **stationary 9.1 m x 9.1 m platform** obstructed fore (represents ship superstructure) and aft (represents ship crane).
3.	**12 km communication range** for telemetry, images, and RC control **from ground control station**.

Functional Requirements

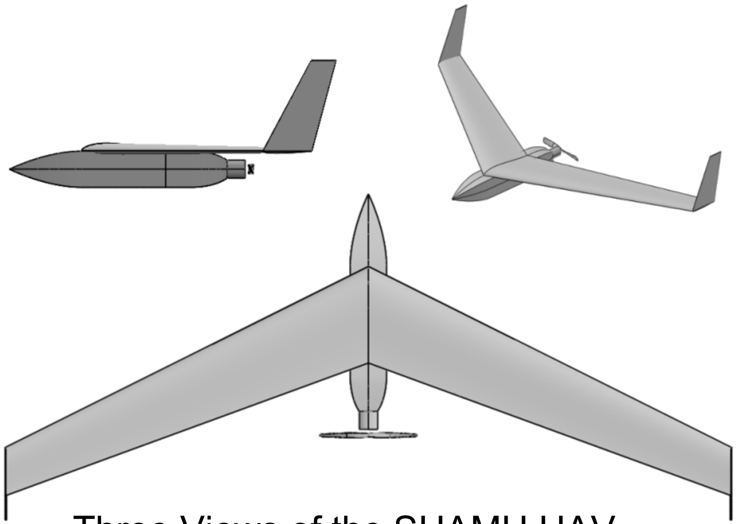
4.	Aircraft shall support **downward-facing 2.0 kg simulated instrument payload** with 15 cm x 15 cm x 23 cm dimensions.
5.	Aircraft shall be **operable and recoverable** onto stationary platform in **winds up to 10 m/s.**
6.	Aircraft shall have **100 km ground track range endurance.**

Design Solution

Aircraft	Takeoff	Recovery	Autopilot	Flight Computer	RF Comm.
Design and Validate Airframe	Bungee Launch with Rail	Net with Extending Lines	PX4 Pro with Pixhawk 2.1	Raspberry Pi 3 Model B	RFD900+ Datalink OpenLRS RC

Aircraft Design: Specifications

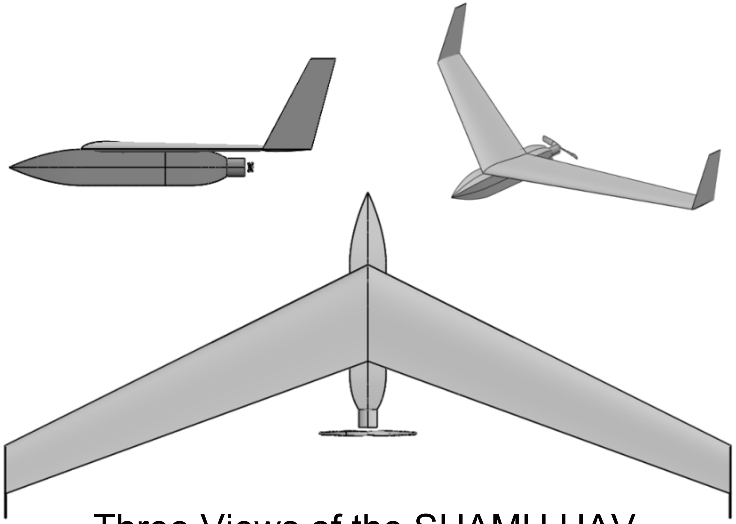
Wing Span	3.0 m (10 ft)
Length	1.4 m (4.5 ft)
Height	0.53 m (1.8 ft)
Wing Area	0.93 m^2 (10 ft^2)
Wing Aspect Ratio	10
Empty Weight	4.5 kg (10 lbs)
Payload Weight	2.0 kg (4.4 lbs)
Gross Weight	8.45 kg (19 lbs)
Motor Power	1300 W (1.74 hp)



Three Views of the SHAMU UAV

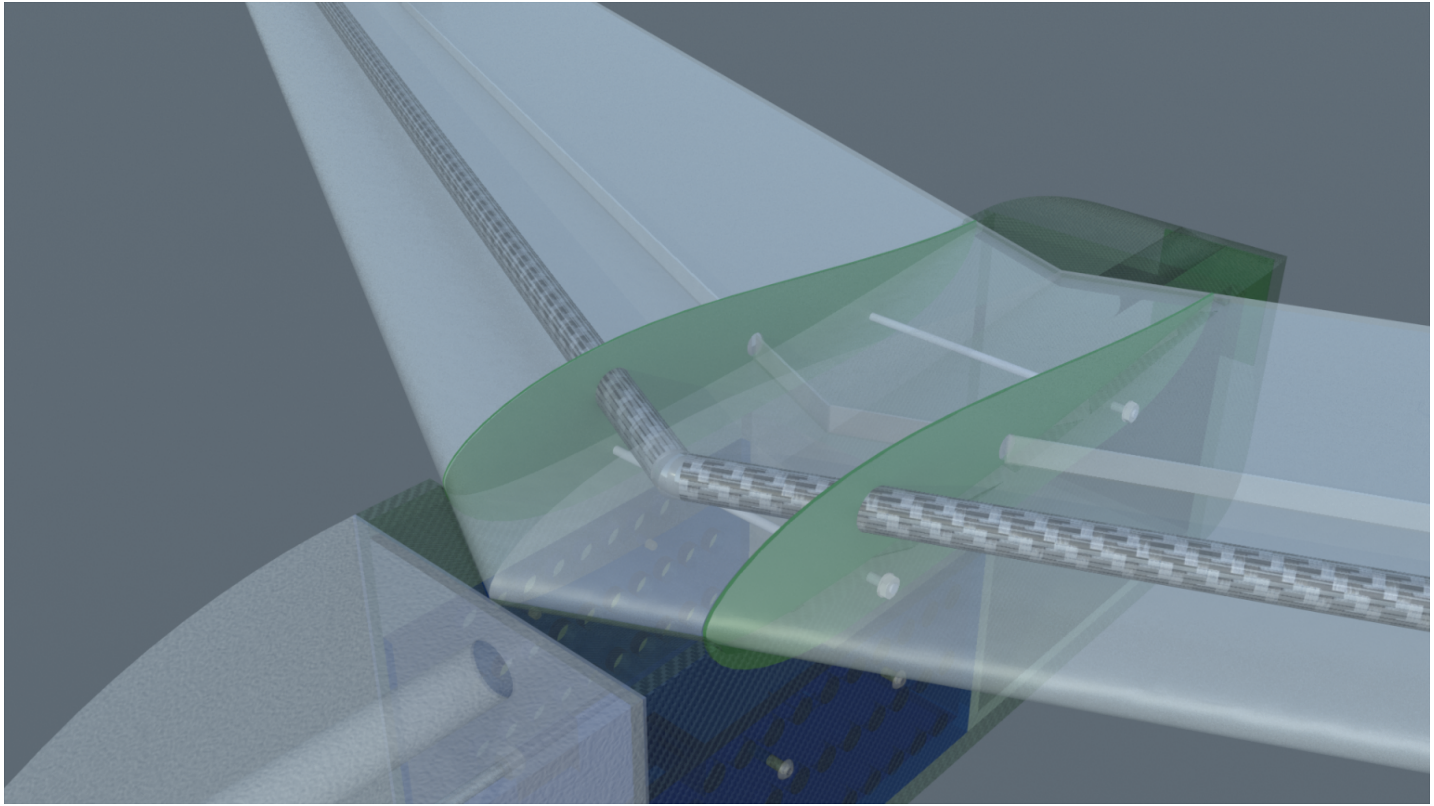
Aircraft Design: Performance

Cruise Speed	20 m/s (38 kts)
Stall Speed	11 m/s (20 kts)
Range	100 km (62 mi)
Climb Rate	>5.1 m/s (>1000 ft/min)
Cruise L/D	12 - 16.2
Wing Loading	9.8 kg/m^2 (2.0 lbs/ft^2)



Three Views of the SHAMU UAV

Carry through spar interface



Challenges- Logistics Delays

- Issue
  - Incorrect wings were shipped. Redesign required purchase of new carry through spar materials and materials to test wing spar

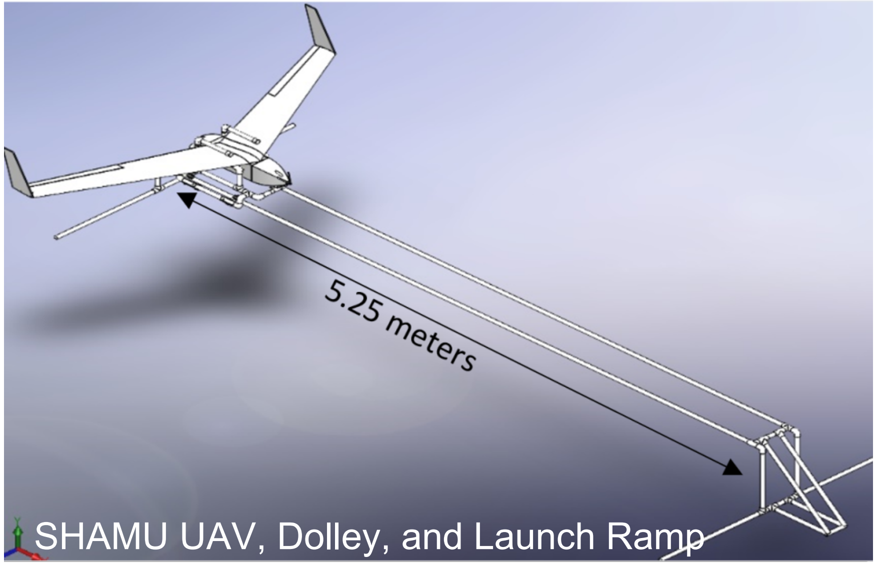
- Solution
  - All previously mentioned parts have been ordered. Incorrect set of wings will be used for practice and testing purposes

Design Solution

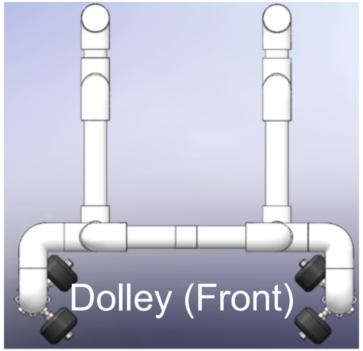
Aircraft	Takeoff	Recovery	Autopilot	Flight Computer	RF Comm.
Design and Validate Airframe	Bungee Launch with Rail	Net with Extending Lines	PX4 Pro with Pixhawk 2.1	Raspberry Pi 3 Model B	RFD900+ Datalink OpenLRS RC

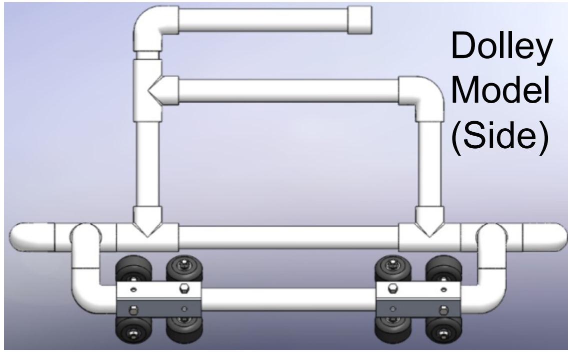
Takeoff Design Overview

Bungees	5
Initial length of Bungee	1.99 m
Spring Constant	86 N/m
Tension Force	343.33 N
Final Velocity	13.2 m/s
Rail Length	5.25 m
PVC Diameter	2”
Takeoff Angle	5 degrees
Max Deflection of Rails	3.86 mm
Time	0.69 s



SHAMU UAV, Dolley, and Launch Ramp

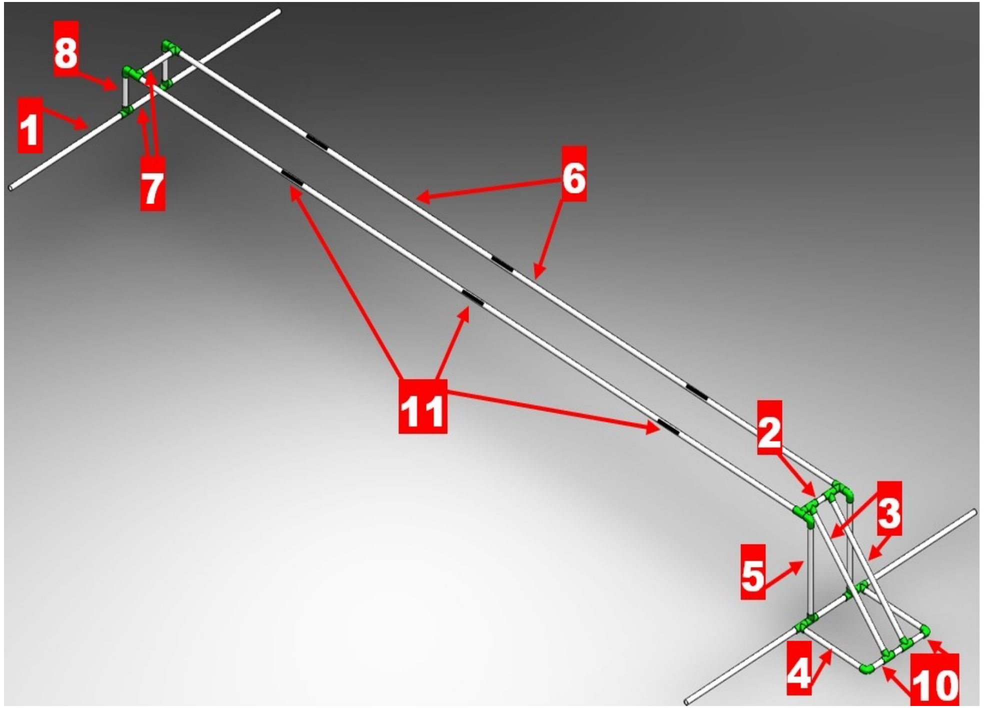

Dolley (Front)


Dolley Model (Side)

Rail Framing Status

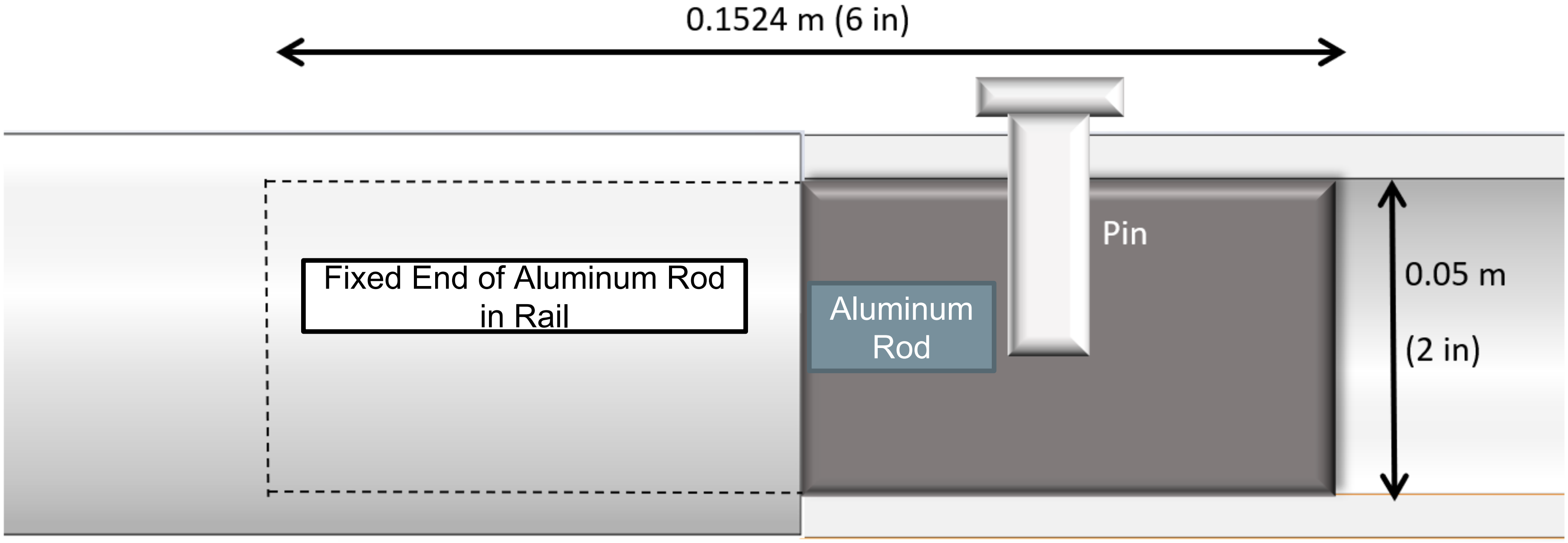
PVC (2 in. Sch 40)
Lengths:

1	4 x 29.37	7	3 x 14.15 in
2	2 x 6.83 i	8	2 x 11.84 in
3	2 x 38.45	9	8 x 40 in
4	2 x 23.65	10	2 x 5.50 in
5	2 x 26.78	11	Internal Connectors
6	8 x 51.57 in		

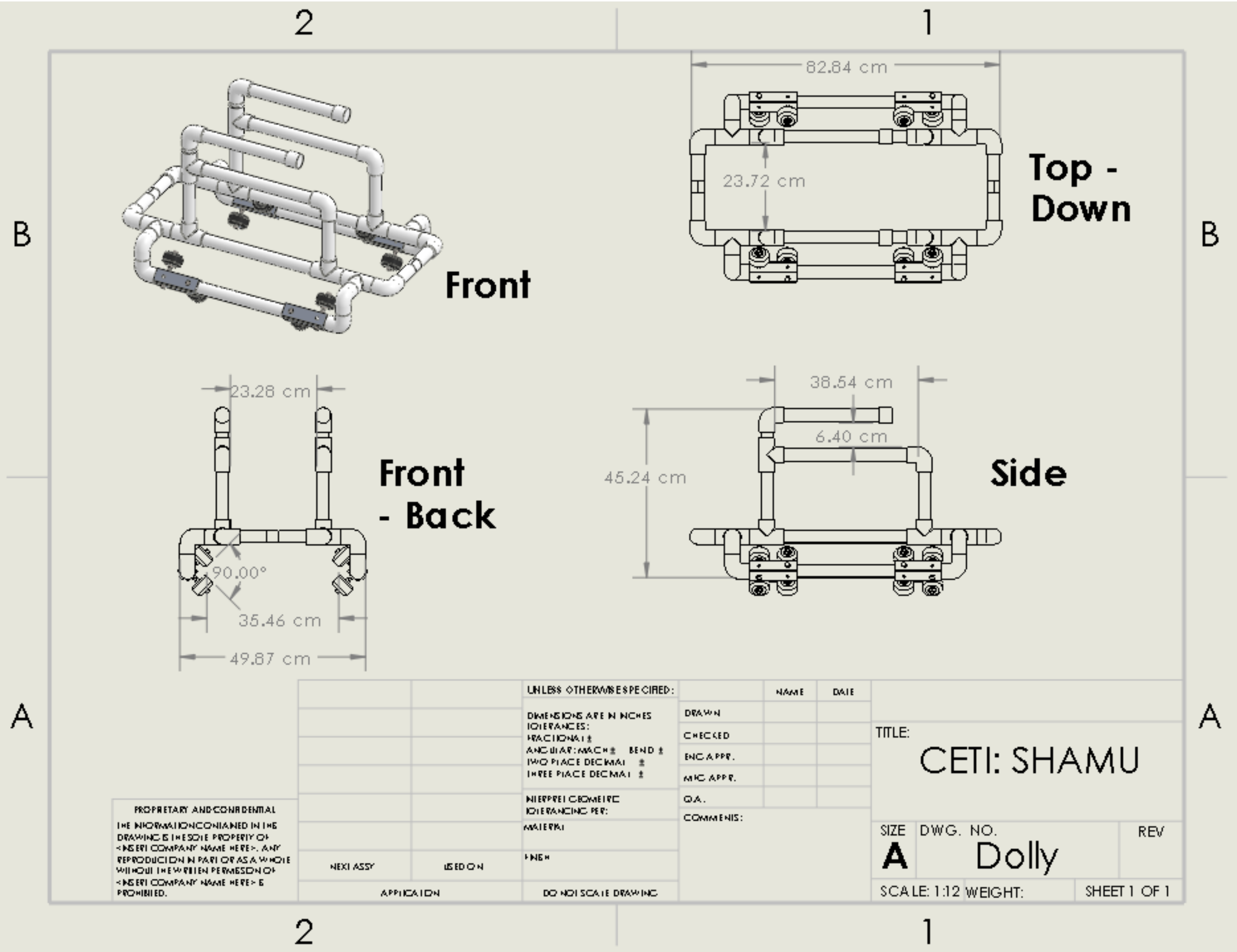


Elbows: 6 **T-Connectors: 14**

Internal Connectors

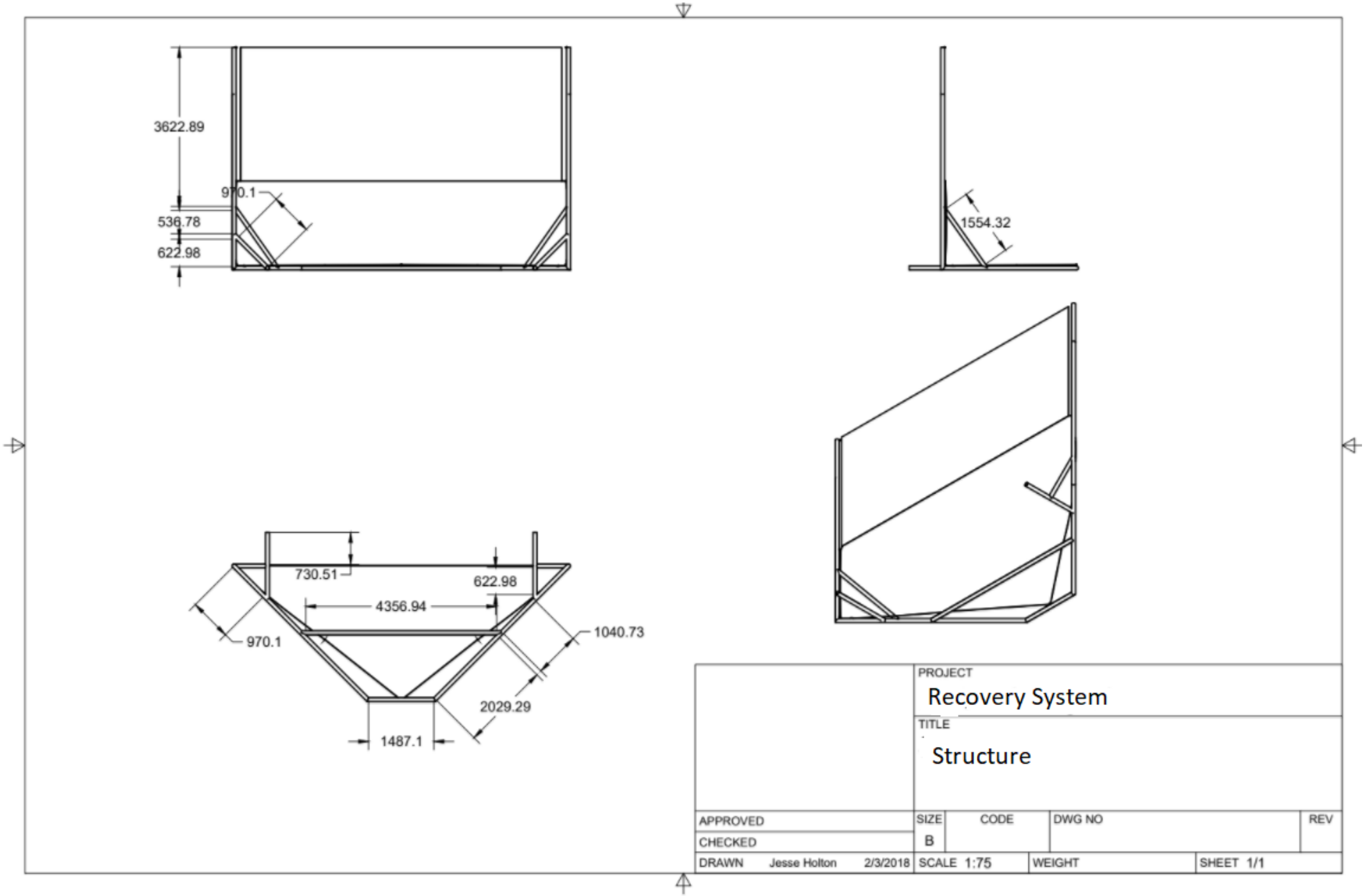


Dolley Dimensions



Recovery Dimensions

- Structure
  - Width: 7.6m
  - Height: 4.6m
- Net
  - Width: 7.3m
  - Height: 3m



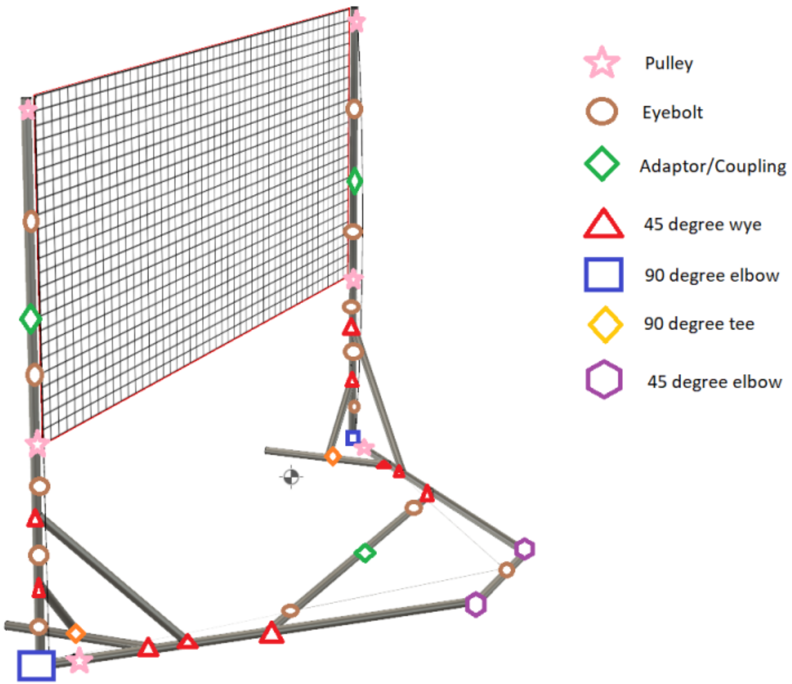
Recovery Major Tasks

- Dry Assembly (1.5 Weeks)
  - Cutting PVC to size (2-3 Days)
  - Gluing Adaptors/Tees (3-4 Days)
  - Structure Assembly (3-4 Days)
- Rigging Setup (1.5 Weeks)
  - Structure Markup (1 Day)
  - Drilling/Component Addition (2-3 Days)
  - Rigging (1-2 Days)
  - Full Assembly(2-3 Days)

Communications Tasks

Task	**Remaining Steps**
Parts procurement	Awaiting antennas and cables
Ground Station Assembly	Antenna/Radio/Power supply attachments
Functional Test	Firmware Update
Datalink Range Test	Awaiting Antennas & coax connections
RC Range Test	Awaiting OpenLRS cables

Recovery System Complexity

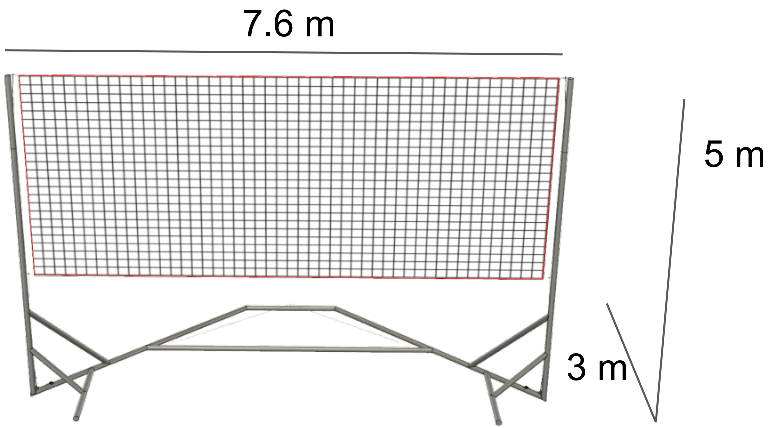


Design Solution

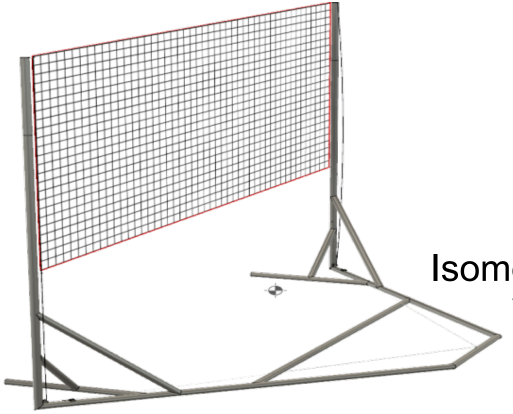
Aircraft	Takeoff	Recovery	Autopilot	Flight Computer	RF Comm.
Design and Validate Airframe	Bungee Launch with Rail	Net with Extending Lines	PX4 Pro with Pixhawk 2.1	Raspberry Pi 3 Model B	RFD900+ Datalink OpenLRS RC

Recovery System

- **Net** suspended between two poles
- **Pulley connections to extend upon impact**
- **Extension** of net **reduces forces** upon landing and **closes the net** to **capture aircraft**
- **Impact forces** are **damped** by a **bungee** attached to the pulley line
- **Sailing Cleat** prevents line from rebounding
- **Hook on nose** of aircraft will **catch** the net to **prevent impact** with **ground**



Net Front View



Isometric Back View

Work Breakdown Chart

SHAMU

Aircraft	Launch/Recovery	Manufacturing/ Development	Testing	Deliverables	Crowdfunding
Control and Stability Model	Dimension Components	Overview Plan	Overview Plan	Project Definition	Project Outline
Wing Design	Stress/Deflection Analysis	Determine Components	Hook Concept	Conceptual Design	Storyboard
Fuselage Design	Launch Energy Model	Order Components	Launch Velocity	Preliminary Design	Website Page
Material Selection	Recovery Energy Model	Construct Launch System	Net Recovery	Critical Design	Film/Edit Video
Structural Load Analysis	Material Selection	Construct Landing System	Communication Range Test	Fall Final Report	
CAD Model	Reaction Force Analysis	Aircraft Composites	Wing Loading	Manufacturing Status	
Modularity	Dolley Tipping Analysis	Construct Aircraft Structures	Power Endurance	Test Readiness	
Electronics Design	CAD Model	Software	Aircraft Stability	Spring Final Review	
		Communications System	Software	Project Final Report	
			Hardware Integration		

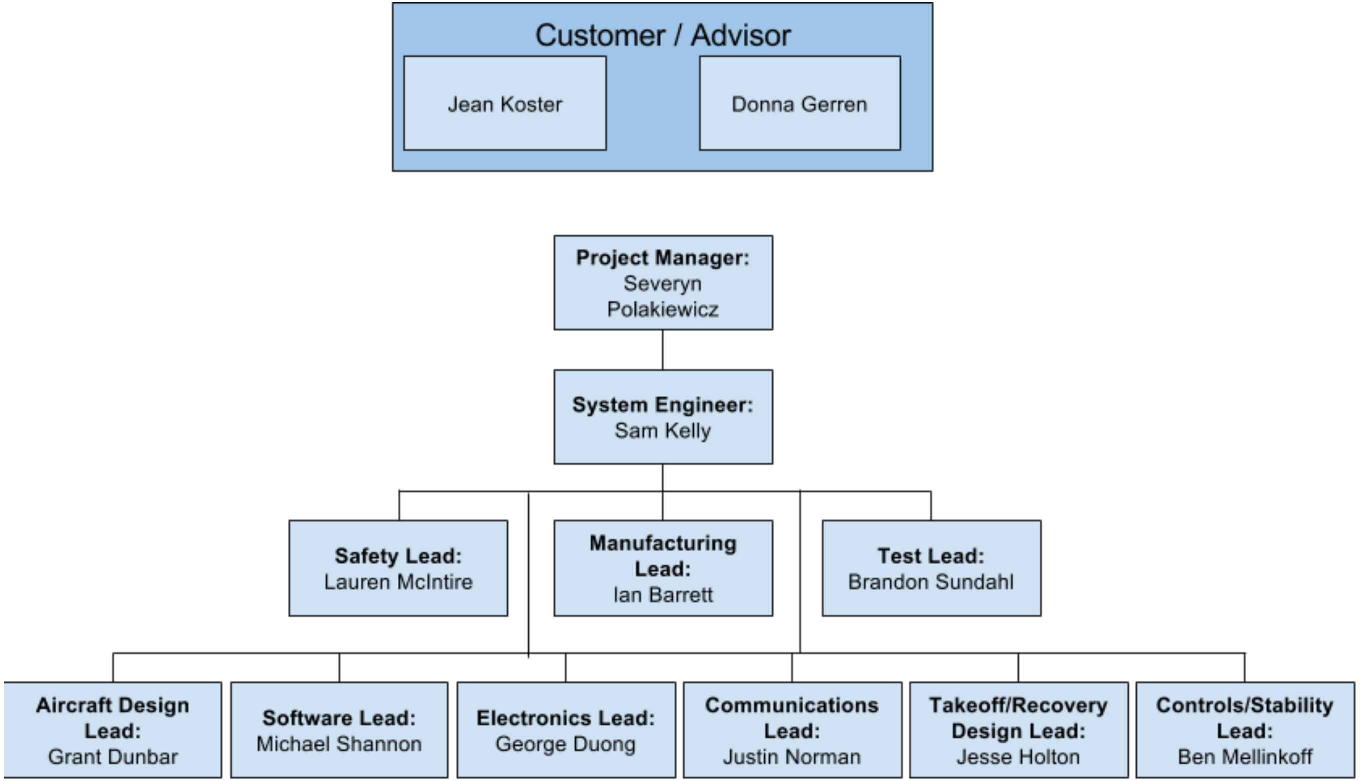
Completed

To Be Completed

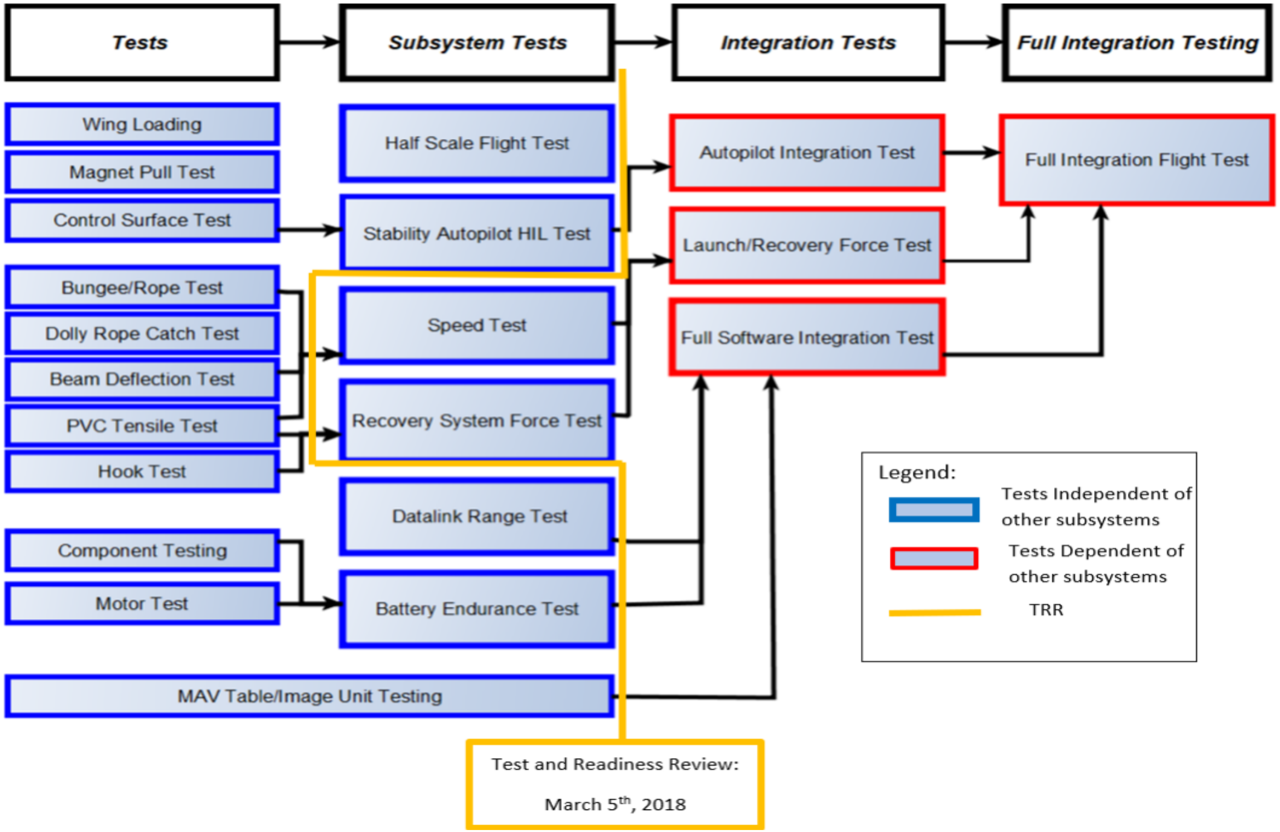
Design Solution

Aircraft	Takeoff	Recovery	Autopilot	Flight Computer	RF Comm.
Design and Validate Airframe	Bungee Launch with Rail	Net with Extending Lines	Pixhawk 2.1 with PX4-Pro	Raspberry Pi 3 Model B	RFD900+ Datalink OpenLRS RC

Organizational Chart

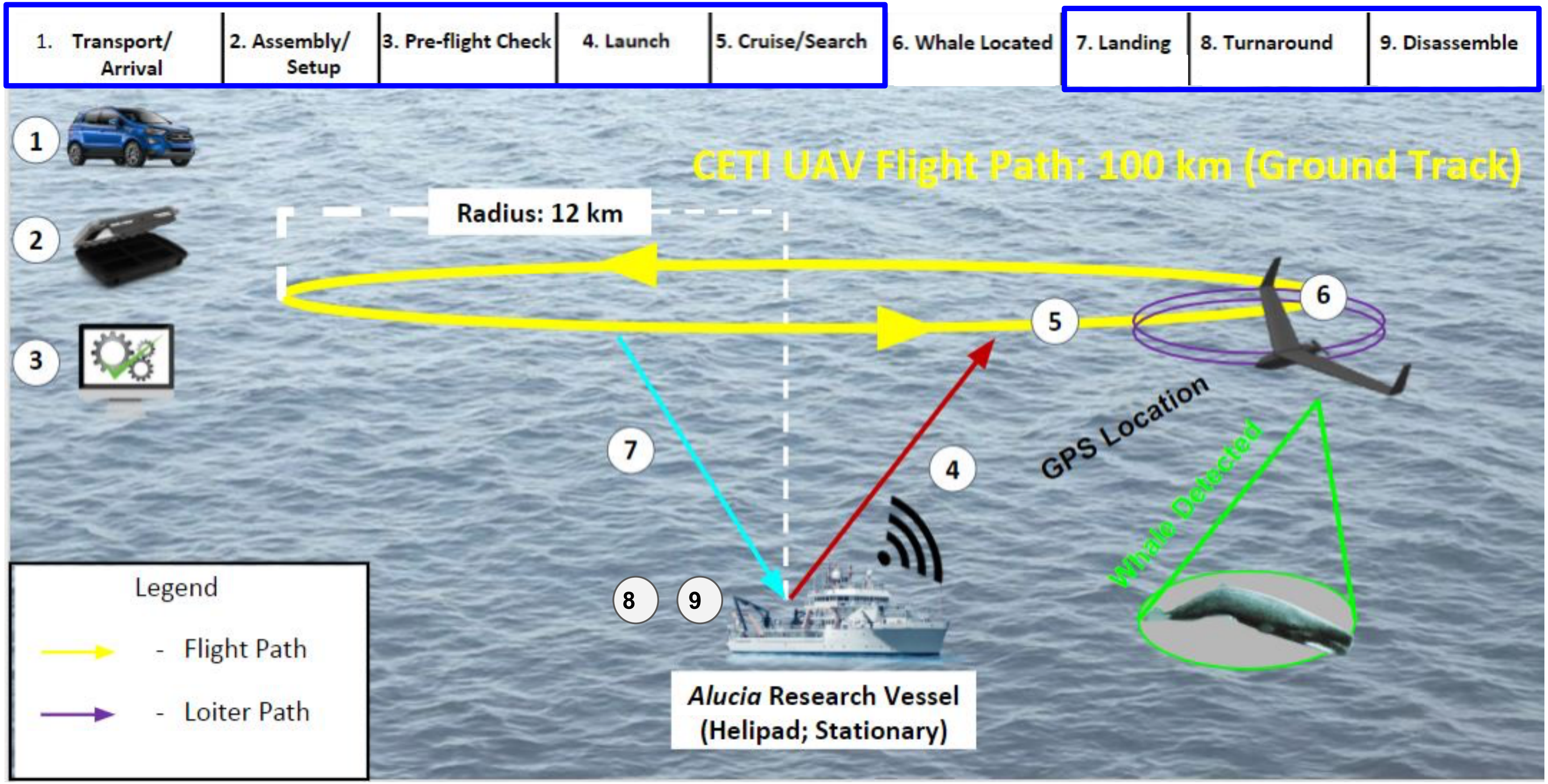


Test Plan

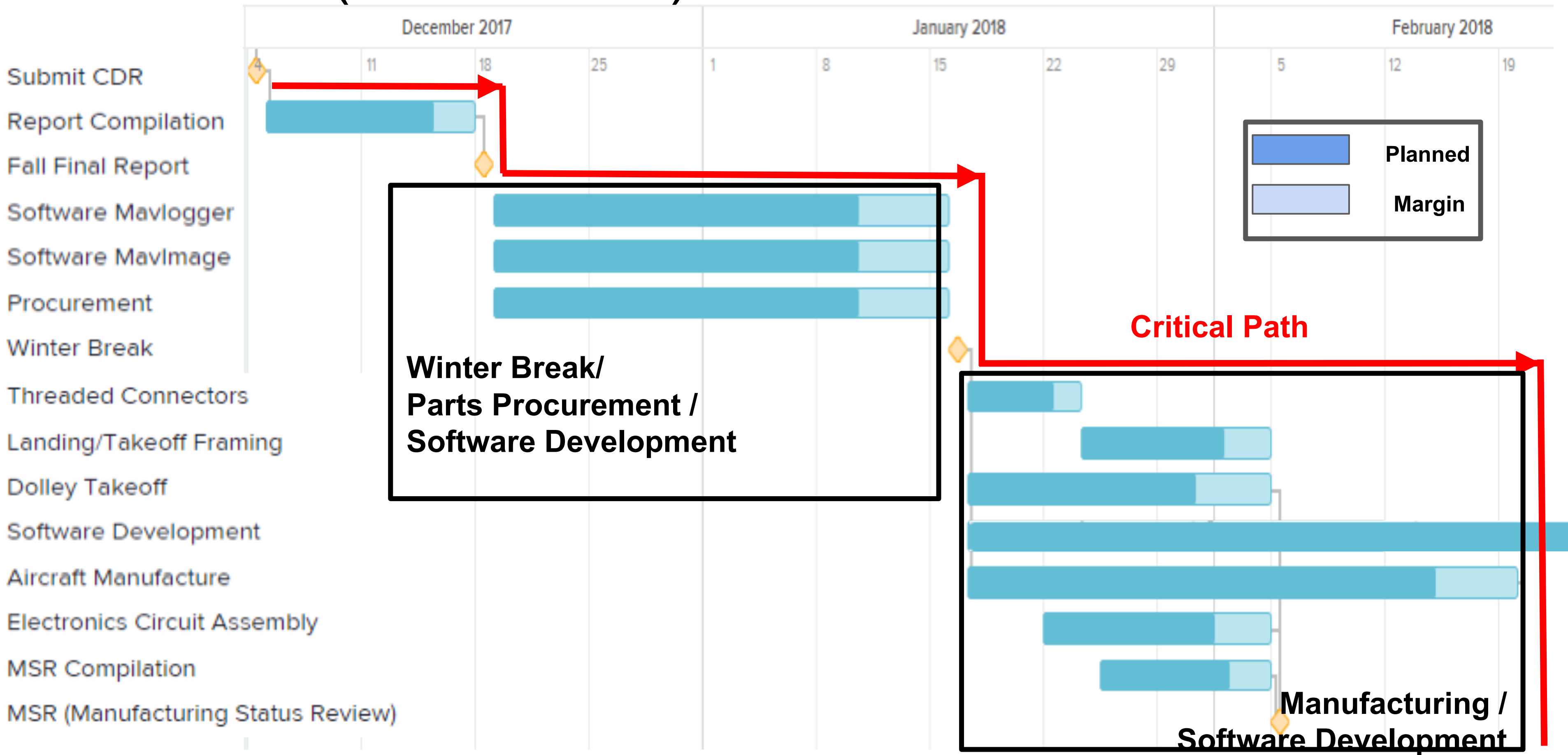


Tests
Subsystem Tests
Integration Tests
Full Integration Testing
Wing Loading
Magnet Pull Test
Control Surface Test
Bungee/Rope Test
Dolly Rope Catch Test
Beam Deflection Test
PVC Tensile Test
Hook Test
Component Testing
Motor Test
MAV Table/Image Unit Testing
Half Scale Flight Test
Stability Autopilot HIL Test
Speed Test
Recovery System Force Test
Datalink Range Test
Battery Endurance Test
Autopilot Integration Test
Launch/Recovery Force Test
Full Software Integration Test
Full Integration Flight Test
Legend:
Tests Independent of other subsystems
Tests Dependent of other subsystems
TRR
Test and Readiness Review:
March 5th, 2018

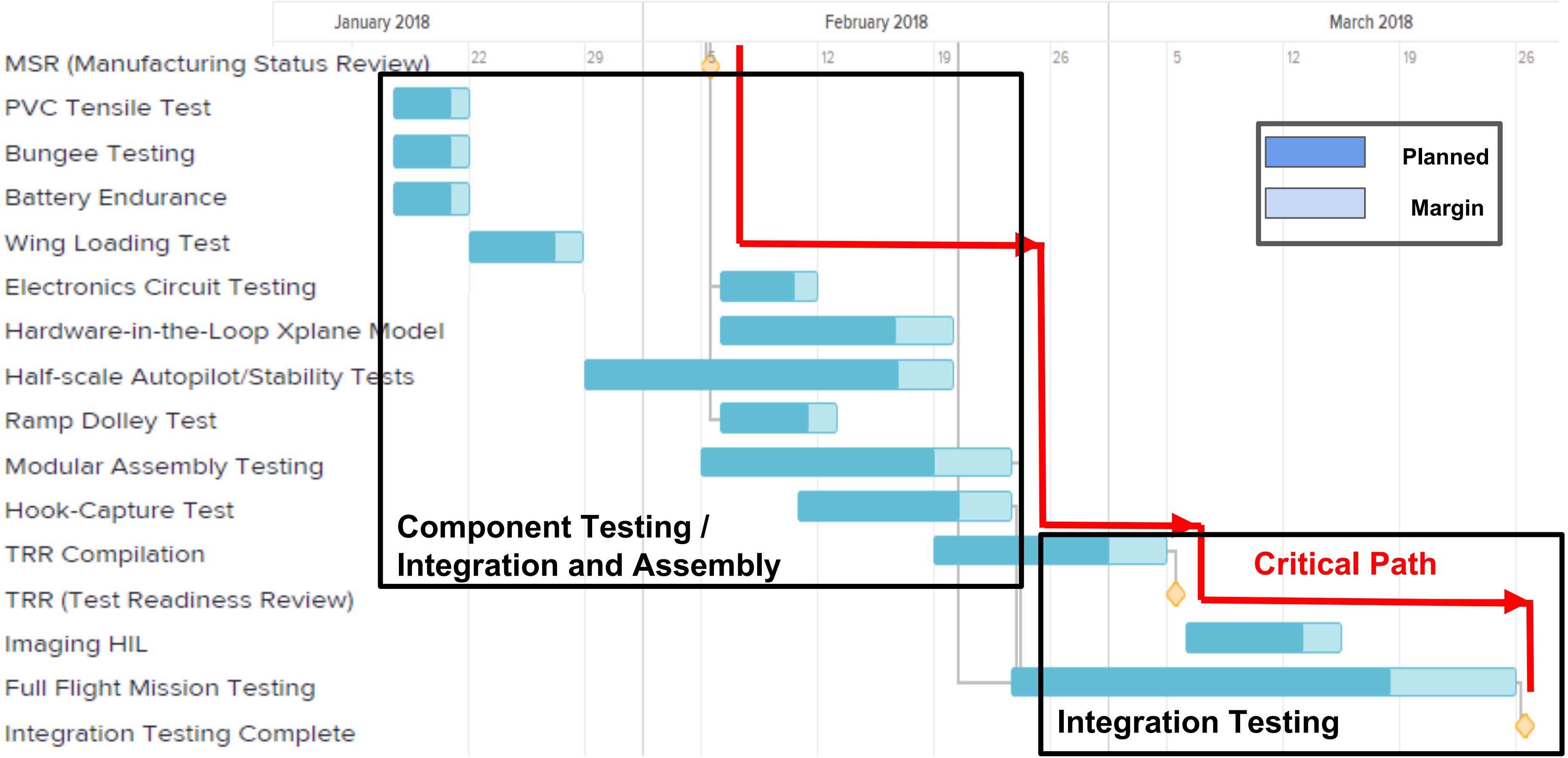
Multi-Year User CONOPS



Work Plan (Gantt Chart)

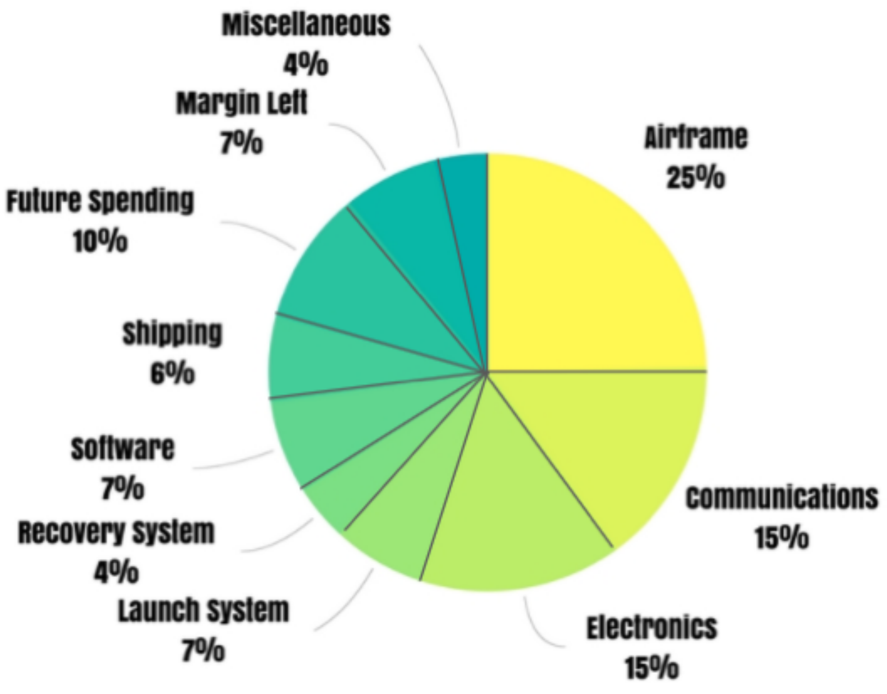


Work Plan (Gantt Chart Continued)



Back up Budget

Label	Value
Airframe	1229
Communications	771.62
Electronics	746.82
Launch System	340.83
Recovery System	207.16
Software	344.74
Shipping	316.41
Future Spending	500
Margin Left	345.79
Miscellaneous	197.63



DO NOT REMOVE SLIDE - USE FOR REFERENCE

- What design components are most challenging/time consuming
- Describe the scope of manufacturing - What? Where? How?
- Address Critical Project Elements - Prioritize.
- Plan detailing integration of systems into project.
- CAD models, diagrams, schematics, flowcharts wrt manufacturing
- DIMENSIONS AND TOLERANCES (do tolerances stack up?)

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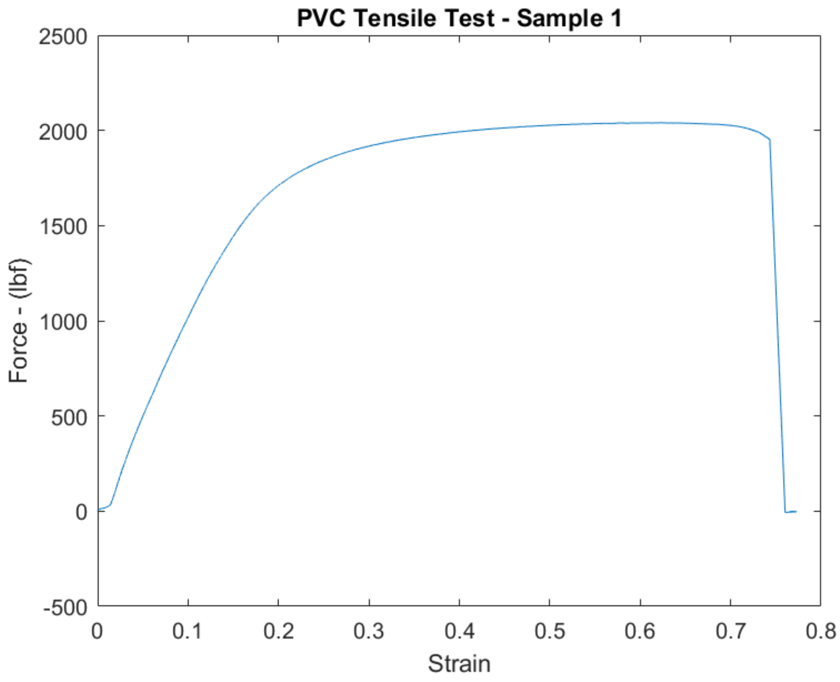
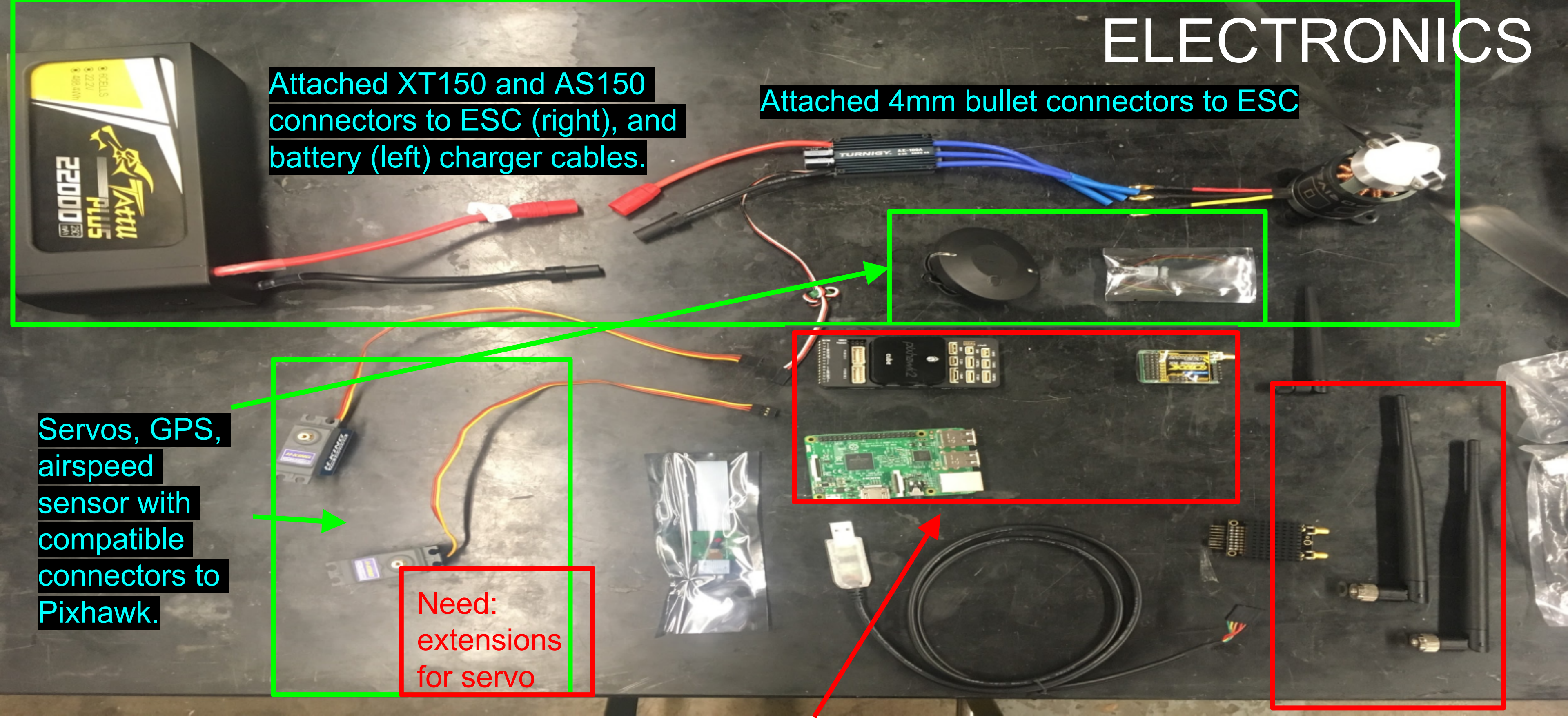
- CAD models, diagrams, schematics, flowcharts wrt manufacturing
- DIMENSIONS AND TOLERANCES (do tolerances stack up?)

PVC Tensile Strength Results

- Design Point - 2x + Safety Factor
- Expected Bending Stress - 2100 psi
- Mean Failure Stress Tested - 6800 psi
- Factor of Safety - 3.25



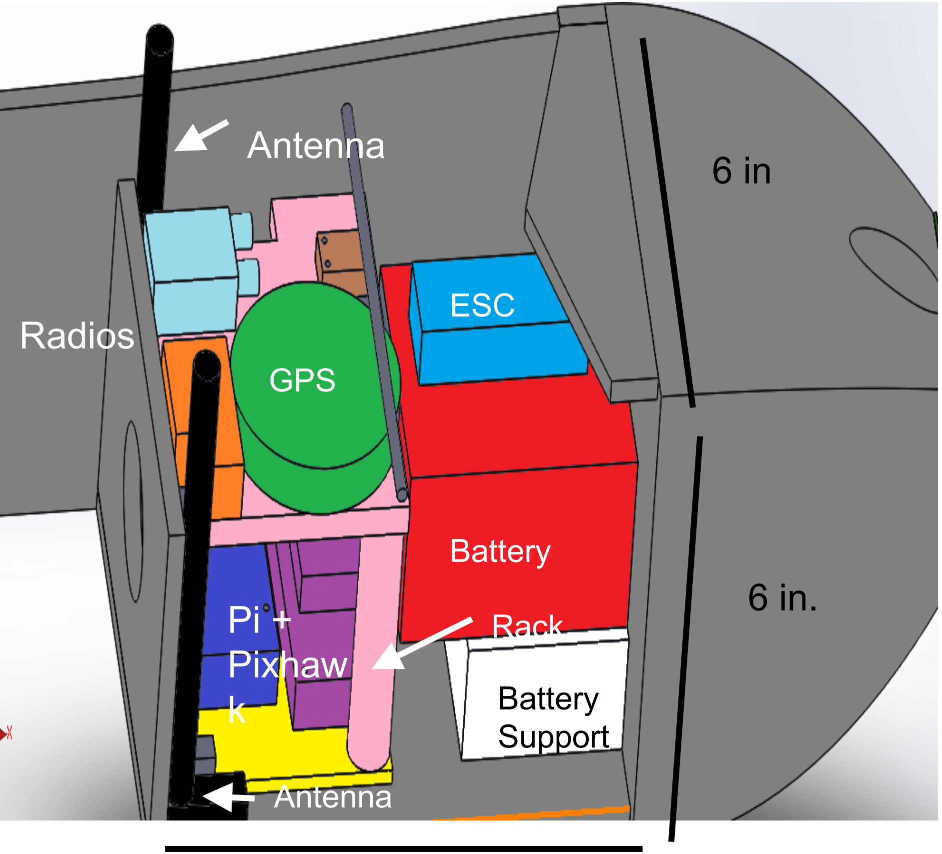
ELECTRONICS



Connection from Pixhawk to Raspberry Pi, Connection from Pixhawk to OpenLRS Receiver

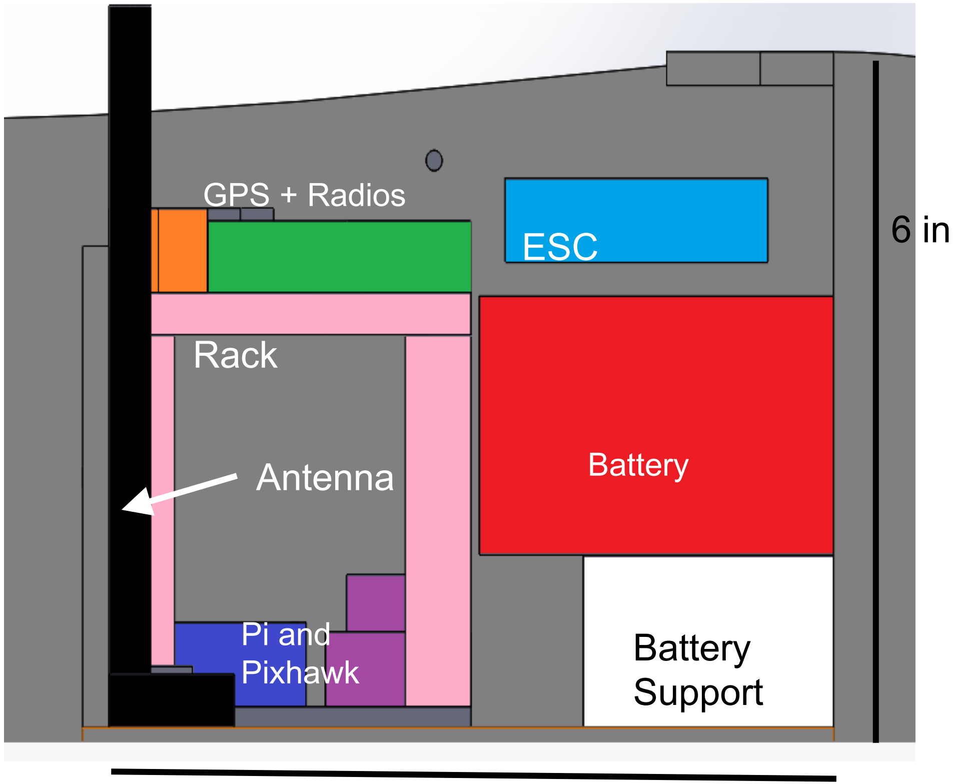
Need Coaxial Cables

Electronic Bay CAD Colored



6 in

Isometric View of Electronics Bay

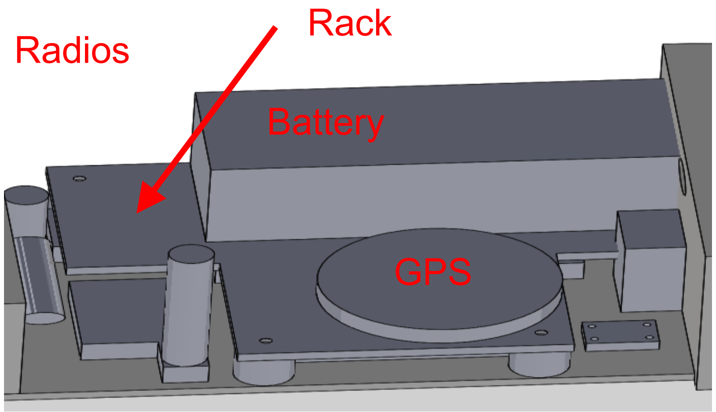


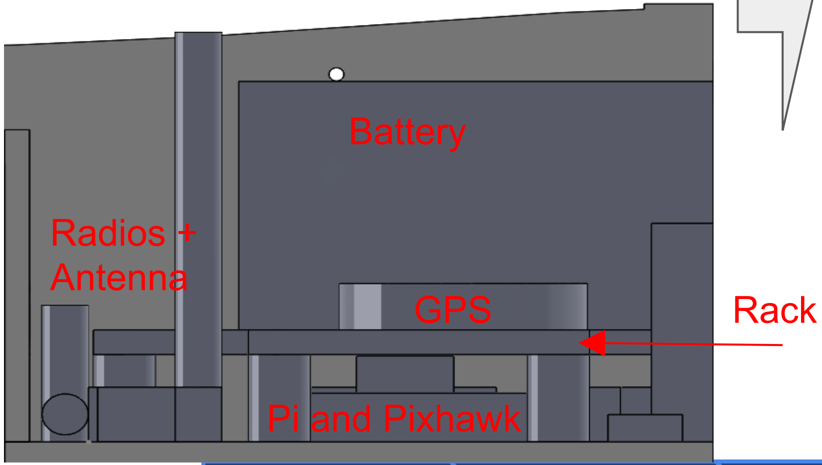
6 in

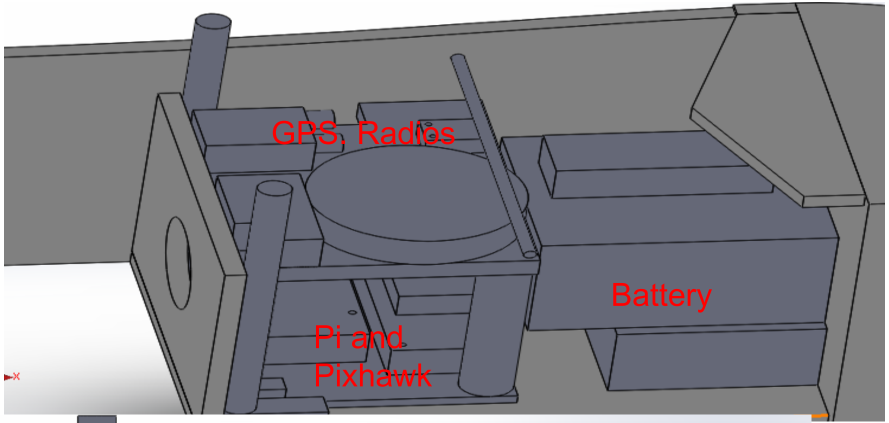
Side View of the Electronics Bay

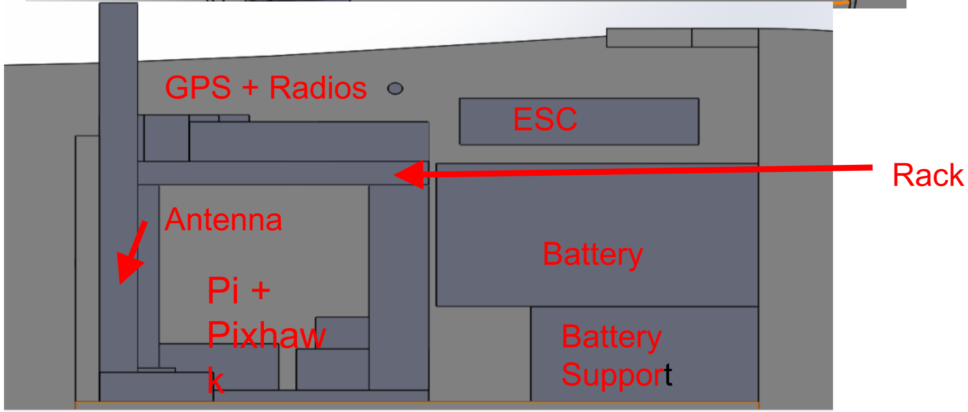
Electronic Bay CAD

-Bottom layer will be 3D printed (Nylon) to allow mounting holes for rack, airspeed sensor and Raspberry Pi.
-Layout has changed from FFR: coaxial extensions for RFD900's, and OpenLRS Receiver



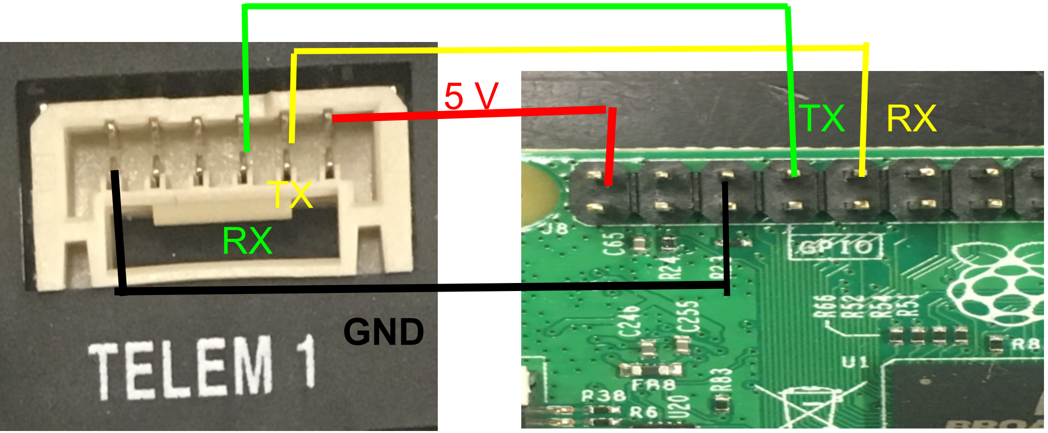






Plans for Electronic Challenges

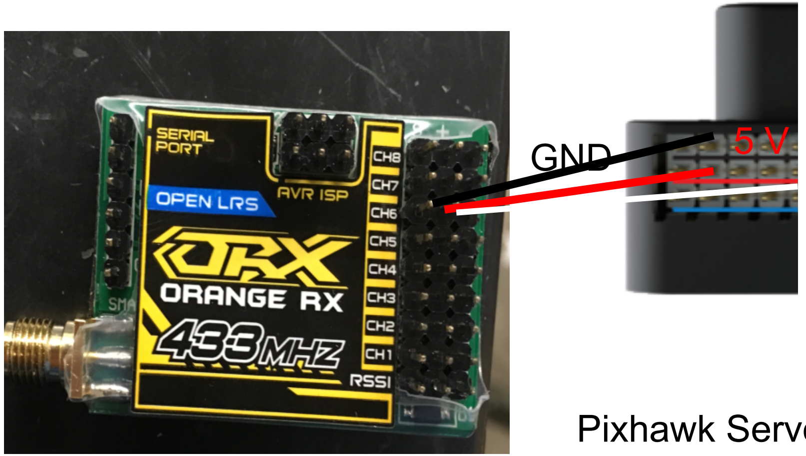
For Pixhawk to Raspberry Pi Connection:
Use only RX, TX, +5V, and GND pins



Pixhawk
Telem Pins

Raspberry Pi Pins

For Pixhawk to OpenLRS Receiver:
Use only GND, 3.3V, Signal pins



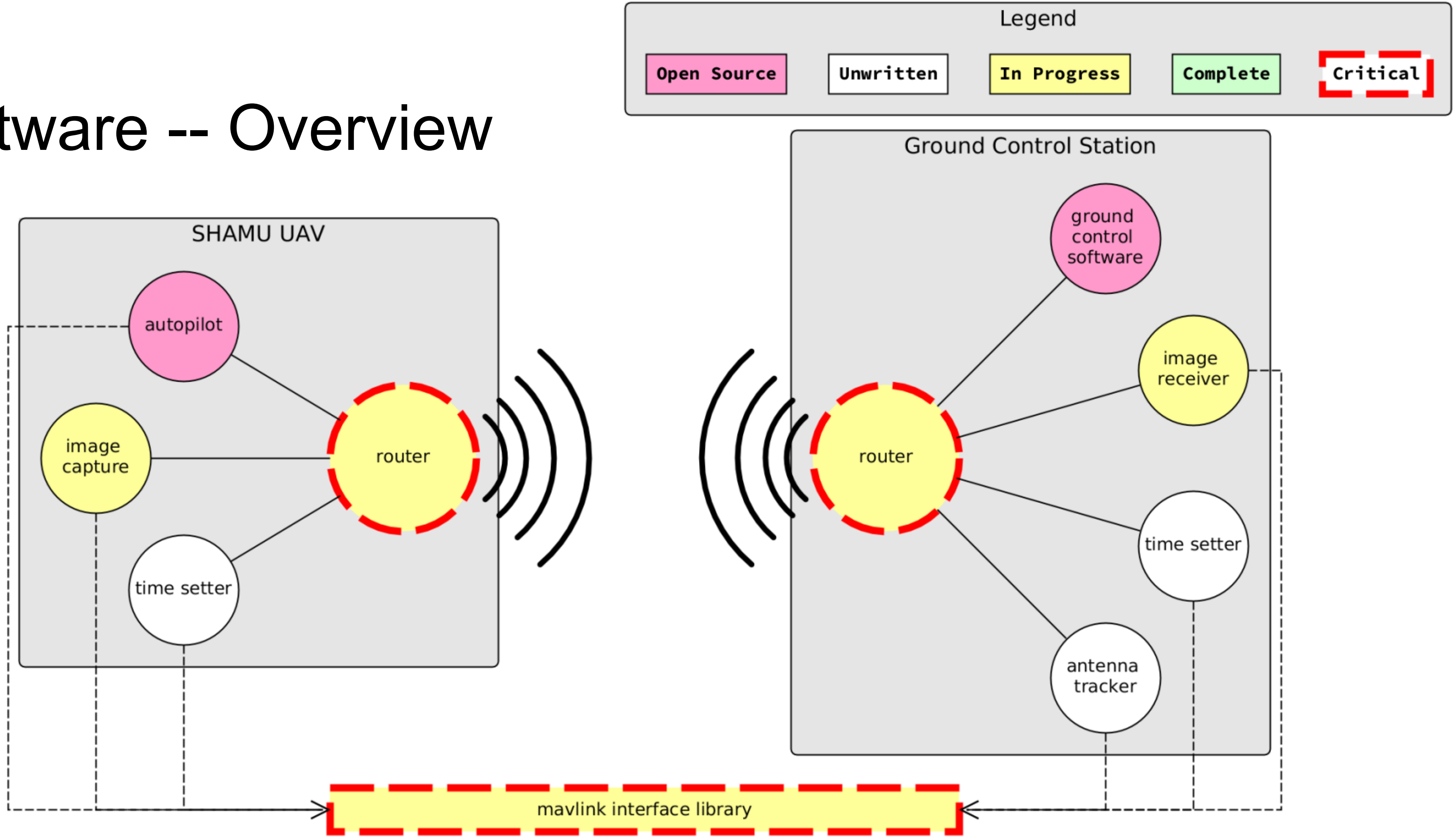
Pixhawk Servo
Pins

For Coaxial Cables:
Estimate needed length from CAD Model, order cables

Functionality

Without Flight Computer	• Remotely piloted and autonomous aircraft. • Possibly reduced (below 12 km) communication range.
With Flight Computer	• Image capture and transmission to ground station. • Antenna tracking to support full 12 km communication range.

Software -- Overview



Software -- mavimage

Functionality	• Capture images from the Raspberry Pi Camera • Tag the WebP image with the GPS coordinates • Send and receive the image over MAVLink from the flight computer to the ground station
Procedure	• Write classes starting with dependencies • Unit test each class until 90% coverage, 100% passing
Challenges	• Time constraints and roadblocks in challenging classes

Software -- mavtables

Functionality	• Route MAVLink packets between components. • Prioritize safety critical packets.
Procedure	• Write classes starting with dependencies • Unit test each class until 90% coverage, 100% passing
Challenges	• Time constraints, large amount of software to write.

Software -- Plan

Plan	• Increase individual lines written per week
	• Meet 4 hours per week for problem solving
	• Off ramp: By February 12th, if software development meetings fail to produce a net gain they will be replaced with individual work time and remote help
	• Off ramp: By February 26th, if mavconn proves too complex for current team member it will be reassigned to the software lead

mavimage (17%)

mavconn (6%)