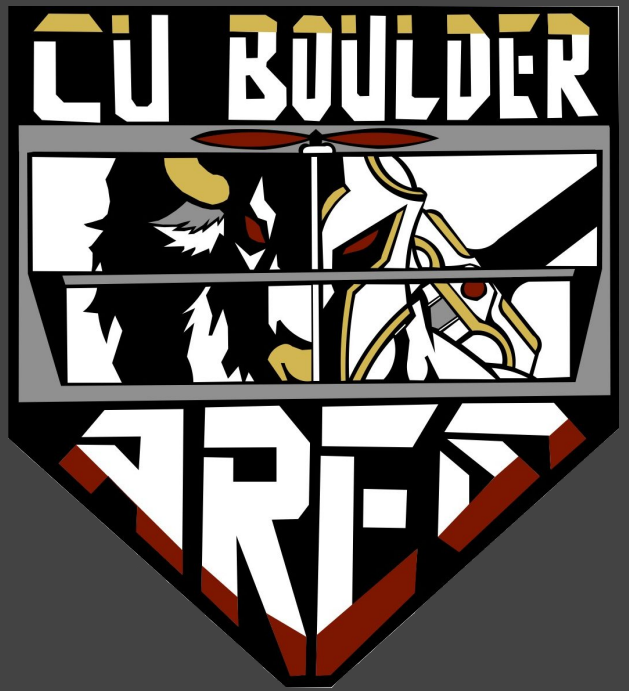


ASPECT-RATIO REDESIGN OF EAGLE OWL FOR STORMCHASING

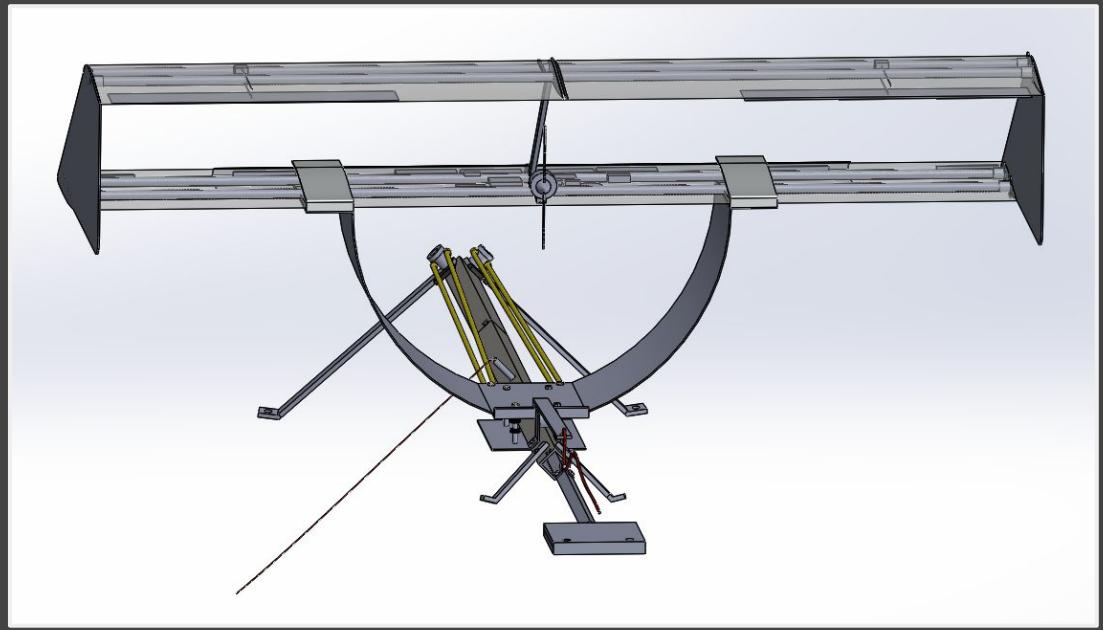
TEAM Matt Alexander, Carson Brumley, Will Butler, Alejandro Corral, Elliott Davis, Ryan Davis, Cody Goldman, Thomas Kisylia, Connor Myers, Erika Polhamus, Alec Stiller, Yuma Yagi

ADVISOR Dr. Donna Gerren

SPONSOR Dr. Brian Argrow

Agenda

- Project Overview
- Executive Summary
- Scheduling
- Airframe Status
- Avionics Status
- Takeoff Status
- Project Budget
- Backup Slides



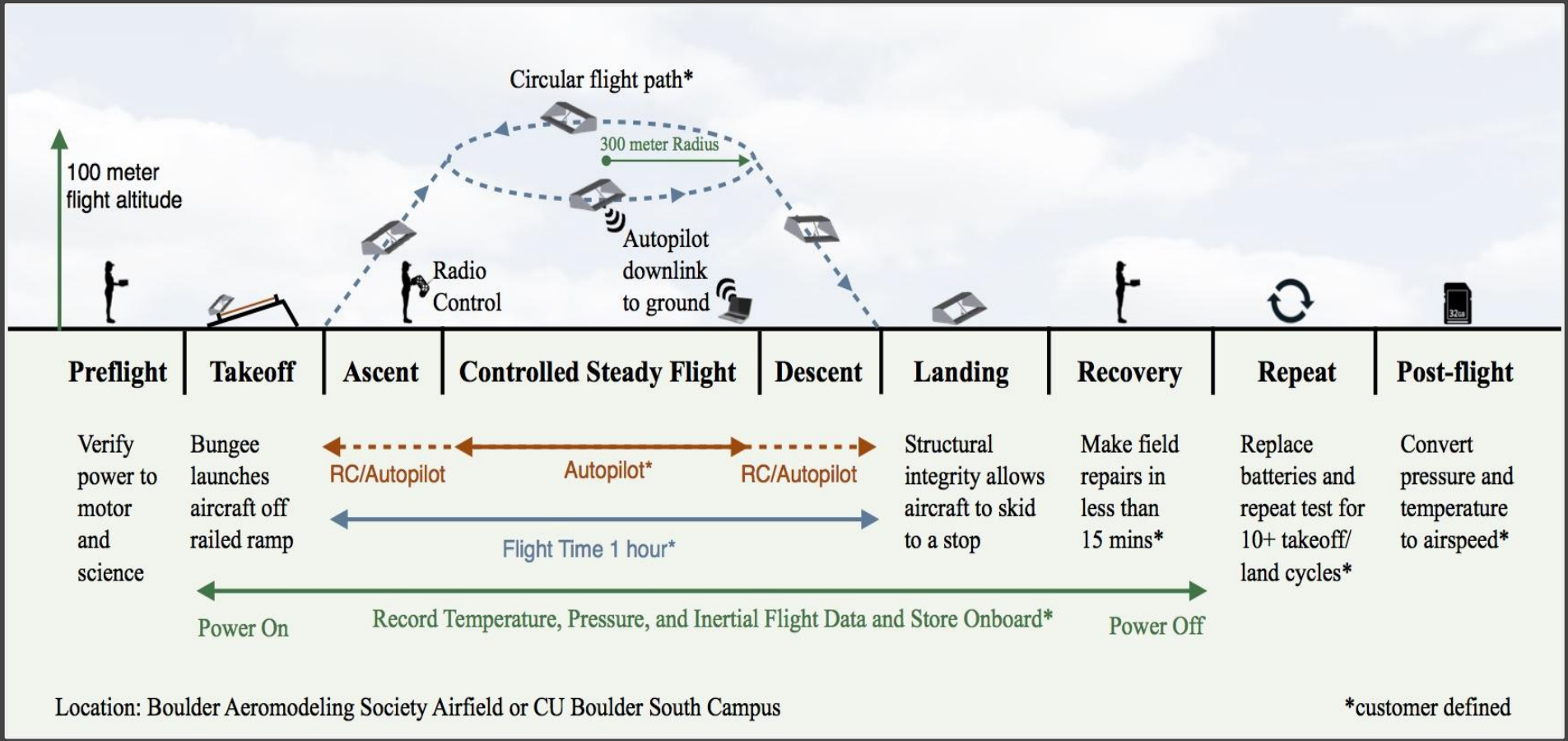
PROJECT OVERVIEW

PROJECT OBJECTIVES

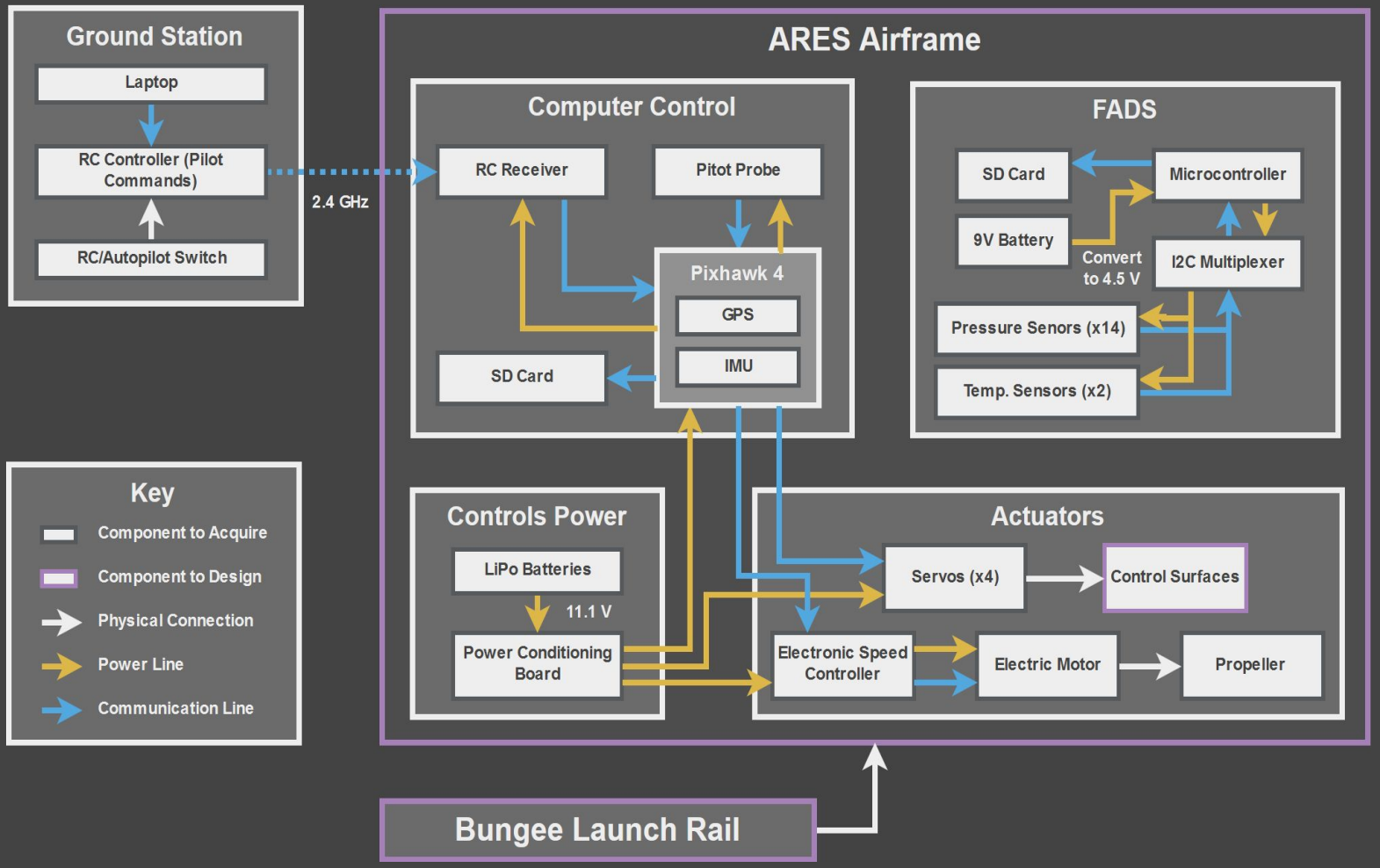
- **Aspect-ratio Redesign of Eagle-owl for Stormchasing (ARES)** will build upon the previous Eagle Owl project by designing, building, and testing a box-wing unmanned aircraft with a flush airdata sensing system (FADS) to measure relative wind velocity with the objective of creating a high endurance system that can eventually fly into extreme weather conditions.

- The ARES rendition of Eagle Owl will increase the aspect ratio, add an hour of endurance, integrate an autopilot, pressure sensors, and a temperature sensor which are incorporated in the FADS system, all within the wings of the aircraft.

CONOPS

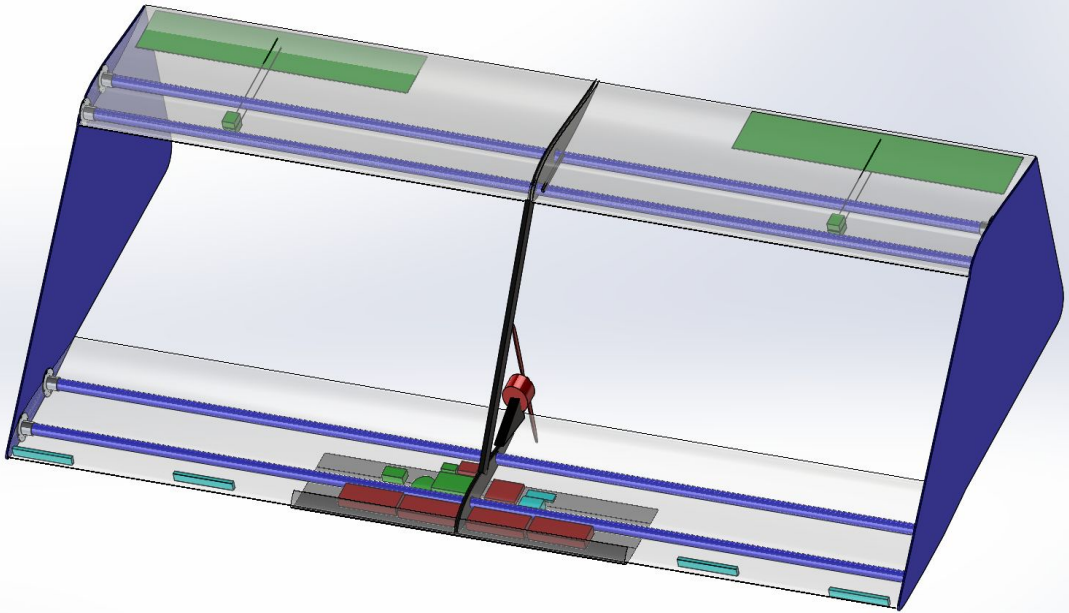

Circular flight path*
300 meter Radius
100 meter
flight altitude
Autopilot
downlink
to ground
Radio
Control
Preflight
Takeoff
Ascent
Controlled Steady Flight
Descent
Landing
Recovery
Repeat
Post-flight
Verify power to motor and science
Bungee launches aircraft off railed ramp
RC/Autopilot
Autopilot*
RC/Autopilot
Flight Time 1 hour*
Structural integrity allows aircraft to skid to a stop
Make field repairs in less than 15 mins*
Replace batteries and repeat test for 10+ takeoff/ land cycles*
Convert pressure and temperature to airspeed*
Power On
Record Temperature, Pressure, and Inertial Flight Data and Store Onboard*
Power Off
Location: Boulder Aeromodeling Society Airfield or CU Boulder South Campus
*customer defined

FUNCTIONAL BLOCK DIAGRAM



BASELINE DESIGN REVIEW

Coefficient	Value
$(L/D)_{cruise}$	13.8
$C_{L,max}$	0.809
α_{cruise}	5.20 deg
V_{cruise}	11.1 m/s
α_{stall}	13.9 deg
V_{stall}	8.36 m/s
Endurance	80 min
Mass	4 kg



Structure **Control** **Propulsion** **Science**

LEVELS OF SUCCESS

	Data Capture	Landing	Navigation & Control	Flight
Level 1	FADS system integrated and recording continuous pressure data while powered. Record continuous local temperature and inertial measurements to onboard storage while powered	Airframe can survive a simulated landing cycle outside of flight test	Control surfaces are actuated in response to RC input and autopilot feedback look; autopilot verified by feeding in test data on ground	Provide flight models and simulations to show that the design can complete design objectives
Level 2	Level 2 objectives are the same as Level 1 objectives	Landing method allows for consecutive takeoff and landing cycles with only power replacement/recharge	Autopilot achieved with ability to maneuver the aircraft in a 600m diameter circle while staying within visual sight	Takeoff with no damage to sensors, structure, or operators. Achieve steady, level flight with no more than 3m divergences
Level 3	Calibrate FADS system such that if the data is converted to aircraft-relative wind velocity it will be to within 1 m/s and 1° of accuracy	Consecutive takeoff and landing cycles occur a minimum of 10 times	Full flight with takeoff and landing achieved with autopilot	Flight endurance is 1 or more hours with all systems powered

CRITICAL PROJECT ELEMENTS

CPE	Description
Aircraft Manufacturing	Construction of the aircraft is integral to the project's success. With no aircraft, nearly all project objectives are not met.
Avionics and Science	ARES must have an avionics system on board to achieve its power needs for all other CPEs. The FADS system must be integrated into this system as well to measure and record data.
Autopilot and Control	The autopilot and control CPE is driven by the need to maintain stability and must achieve an automated, large diameter circular flight.
Propulsion	To maintain flight, the ARES aircraft must have an on board propulsion system. This must be able to provide enough thrust efficiently enough to achieve a 1 hour flight time.
Takeoff	The aircraft must be able to take off successfully in order to achieve any of its other top level successes. Without this, the project risks not meeting several requirements.

EXECUTIVE SUMMARY

	Status	Hours	Comment
Airframe	On Schedule (After Adjustments)	17/269	- Ship & Lead times delayed schedule - Adjustments kept us on track
Avionics	On Schedule	107/241	- Software production, board production, and initial testing in progress
Takeoff	Ahead of Schedule	70/133	- Entire system nearly complete - Allows for more time to test

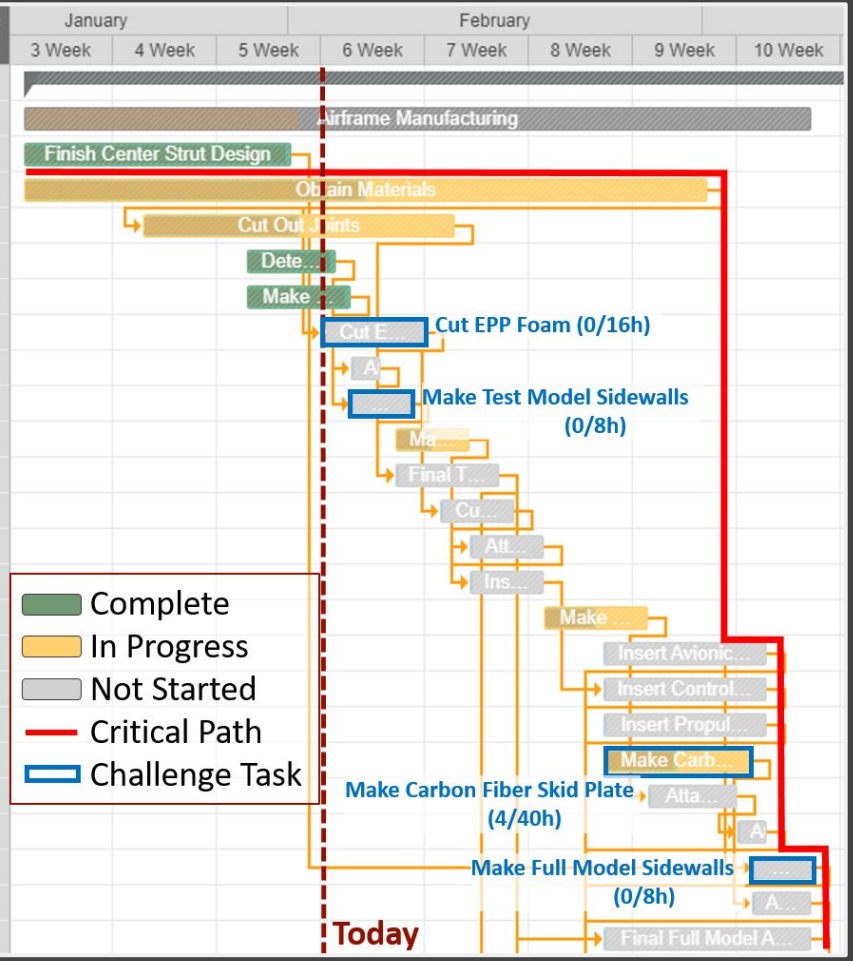
Budget

- We bought enough material for **3 airframes**
- We have **$575** left
- Applying for money from College of Engineering & Aero dept for AIAA travel

SCHEDULING

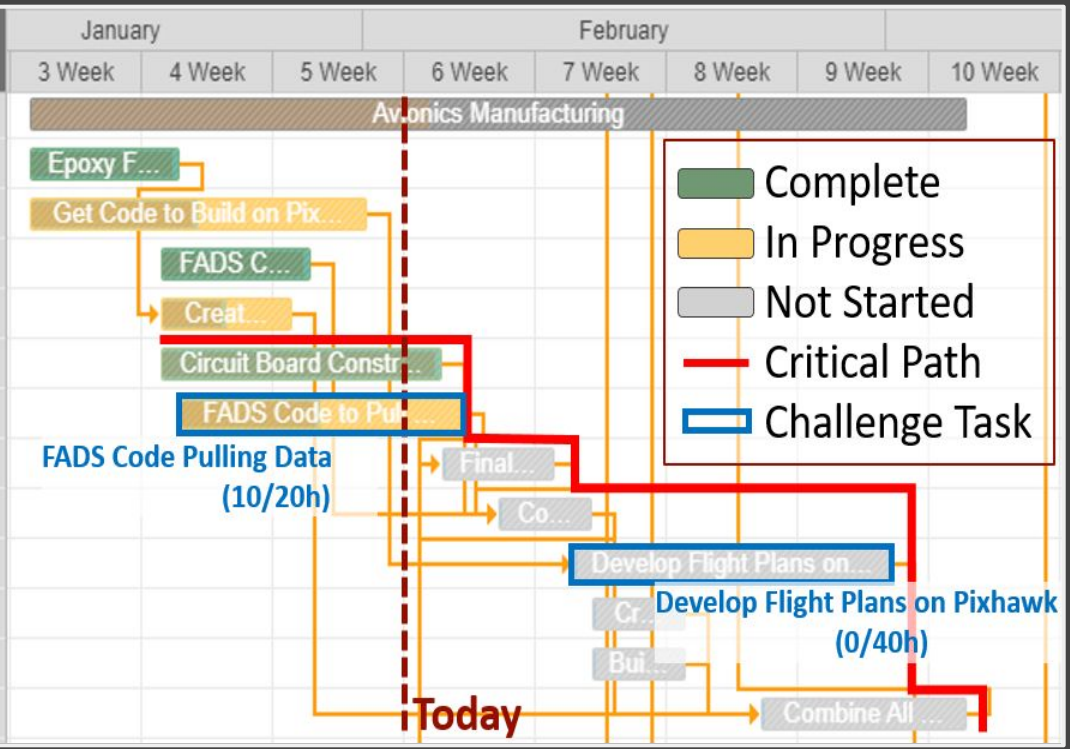
AIRFRAME SCHEDULE

Task name	Start da	End dat
Total estimate	01/14/...	05/06/...
Airframe Manufacturing	01/14/...	03/08/...
Finish Center Strut Design	01/14/...	02/01/...
Obtain Materials	01/14/...	03/01/...
Cut Out Joints	01/22/...	02/12/...
Determine Material for Sidewalls (Test Model)	01/29/...	02/04/...
Make Plastic Inserts for Joints	01/29/...	02/05/...
Cut EPP Foam for Wings (Both Models)	02/03/...	02/10/...
Attach Inserts to Rods	02/05/...	02/07/...
Cut Out Sidewalls (Test Model)	02/05/...	02/09/...
Make Control Surfaces (Full Model)	02/08/...	02/13/...
Final Test Model Assembly	02/08/...	02/15/...
Cut out Electronics Locations in Airfoil (Full M...	02/11/...	02/16/...
Attach Control Surfaces (Full Model)	02/13/...	02/18/...
Insert Servos / Piano Wire (Full Model)	02/13/...	02/18/...
Make Prop Motor Mount	02/18/...	02/25/...
Insert Avionics Components (Full Model)	02/22/...	03/05/...
Insert Controls Components (Full Model)	02/22/...	03/05/...
Insert Propulsion Components (Full Model)	02/22/...	03/05/...
Make Carbon Fiber Plate	02/22/...	03/04/...
Attach Motor Mount (Full Model)	02/25/...	03/03/...
Attach Motor/Spinner/Prop to Mount (Full Mod...	03/03/...	03/05/...
Cut Out Sidewalls and Strut (Full Model)	03/04/...	03/08/...
Attach Carbon Fiber Plate (Full Model)	03/04/...	03/08/...
Final Full Model Assembly	02/22/...	03/08/...



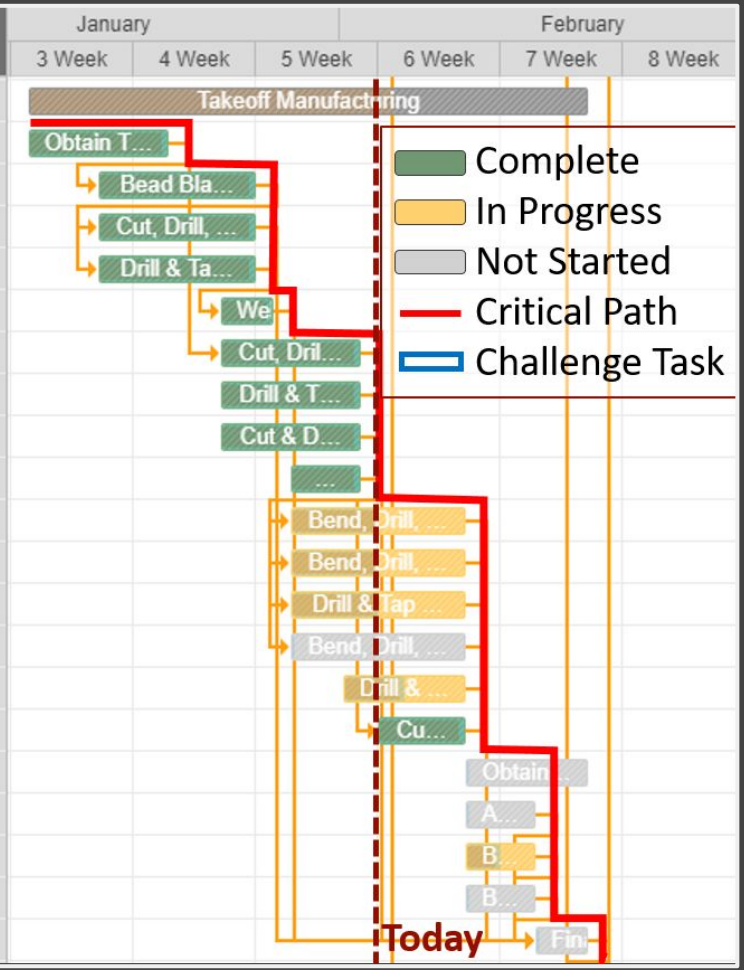
AVIONICS SCHEDULE

Task name	Start da	End dat
Avionics Manufacturing	01/14/...	03/05/...
Epoxy FADS Boards and Add Tubing	01/14/...	01/22/...
Get Code to Build on Pixhawk4	01/14/...	02/01/...
FADS Code to Write to SD	01/21/...	01/29/...
Create Teensy / 9V Power Circuit	01/21/...	01/28/...
Circuit Board Construction	01/21/...	02/05/...
FADS Code to Pull Data	01/22/...	02/06/...
Finalize FADS Code	02/05/...	02/11/...
Compile FADS Code on Teensy	02/08/...	02/13/...
Develop Flight Plans on Pixhawk4	02/12/...	03/01/...
Create Propulsion Power Circuit	02/13/...	02/18/...
Build Servo Connections	02/13/...	02/18/...
Combine All Components and Prep for DITL	02/22/...	03/05/...

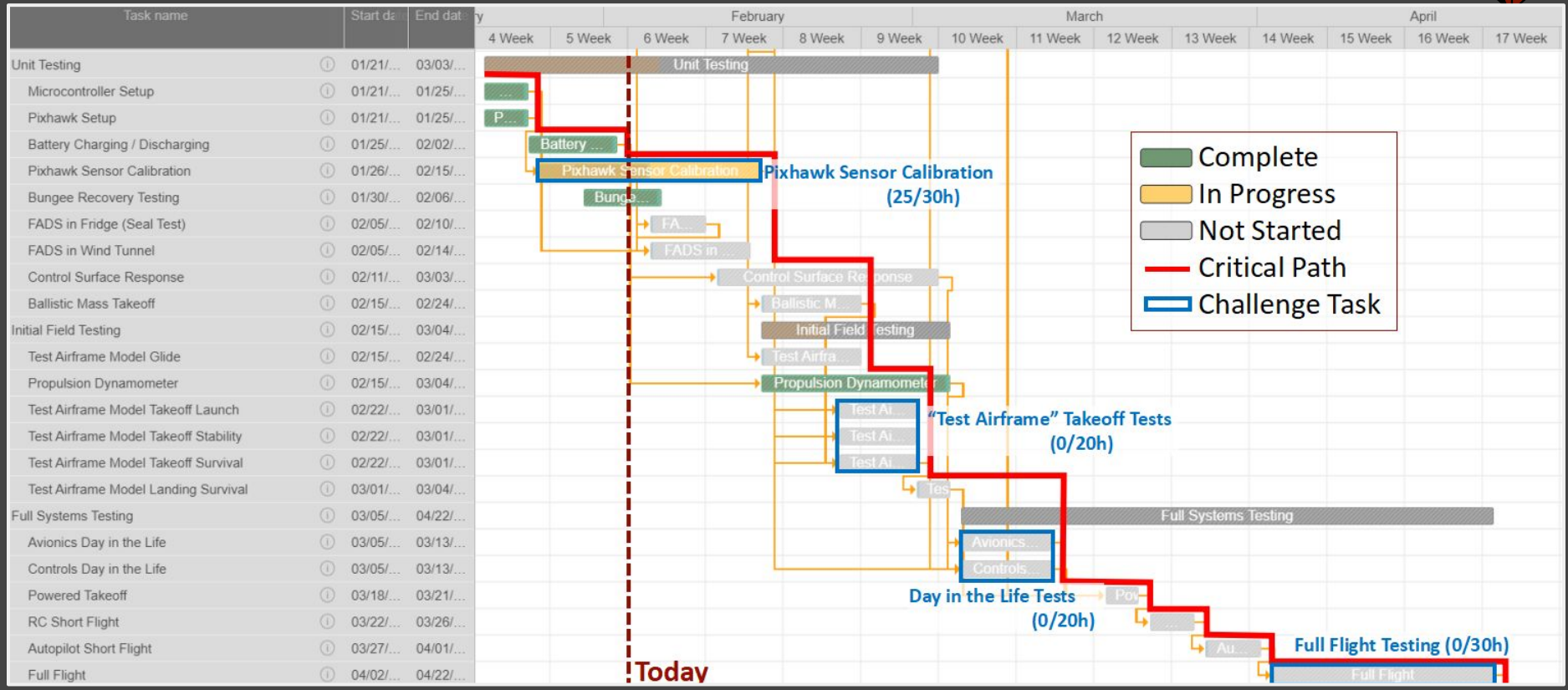


TAKEOFF SCHEDULE

Task name	Start date	End date
Takeoff Manufacturing	01/14/...	02/15/...
Obtain Takeoff Materials	01/14/...	01/22/...
Bead Blast, Drill, & Tap Center Rail	01/18/...	01/27/...
Cut, Drill, & Tap Center Support Rods	01/18/...	01/27/...
Drill & Tap Holes for Center Rail Clips	01/18/...	01/27/...
Weld Center Rail Clips	01/25/...	01/28/...
Cut, Drill, & Tap Legs	01/25/...	02/02/...
Drill & Tap Tail Post	01/25/...	02/02/...
Cut & Drill Rubber Stoppers	01/25/...	02/02/...
Obtain Scrap Metal for Release	01/29/...	02/02/...
Bend, Drill, & Tap Plate Metal for Release	01/29/...	02/08/...
Bend, Drill, & Tap Lever Arm	01/29/...	02/08/...
Drill & Tap Tube for Release	01/29/...	02/08/...
Bend, Drill, & Tap Carriage Clip for Release	01/29/...	02/08/...
Drill & Ream Standoffs	02/01/...	02/08/...
Cut, Drill, & Tap Carriage Plate Metal	02/03/...	02/08/...
Obtain Additional Takeoff Materials	02/08/...	02/15/...
Attach Carriage Clip for Release	02/08/...	02/12/...
Bend, Drill, & Tap Sheet Metal for Carriage U	02/08/...	02/12/...
Bend, Drill & Tap Sheet Metal for Carriage Clips	02/08/...	02/12/...
Final Takeoff Assembly	02/12/...	02/15/...



TESTING SCHEDULE



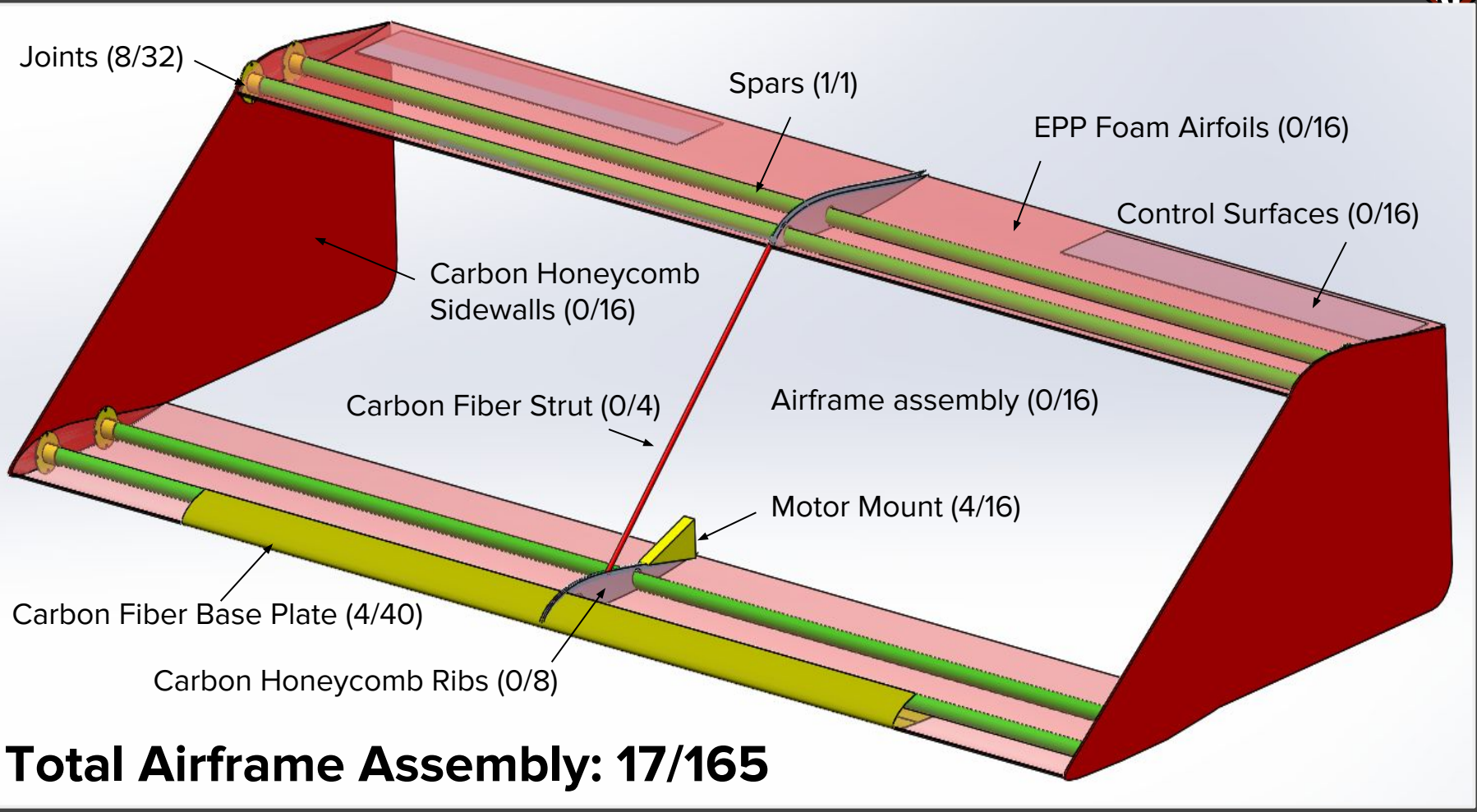
AIRFRAME STATUS

Legend

- Complete
- In Progress
- Has not been started (but still on schedule)

AIRFRAME OVERVIEW

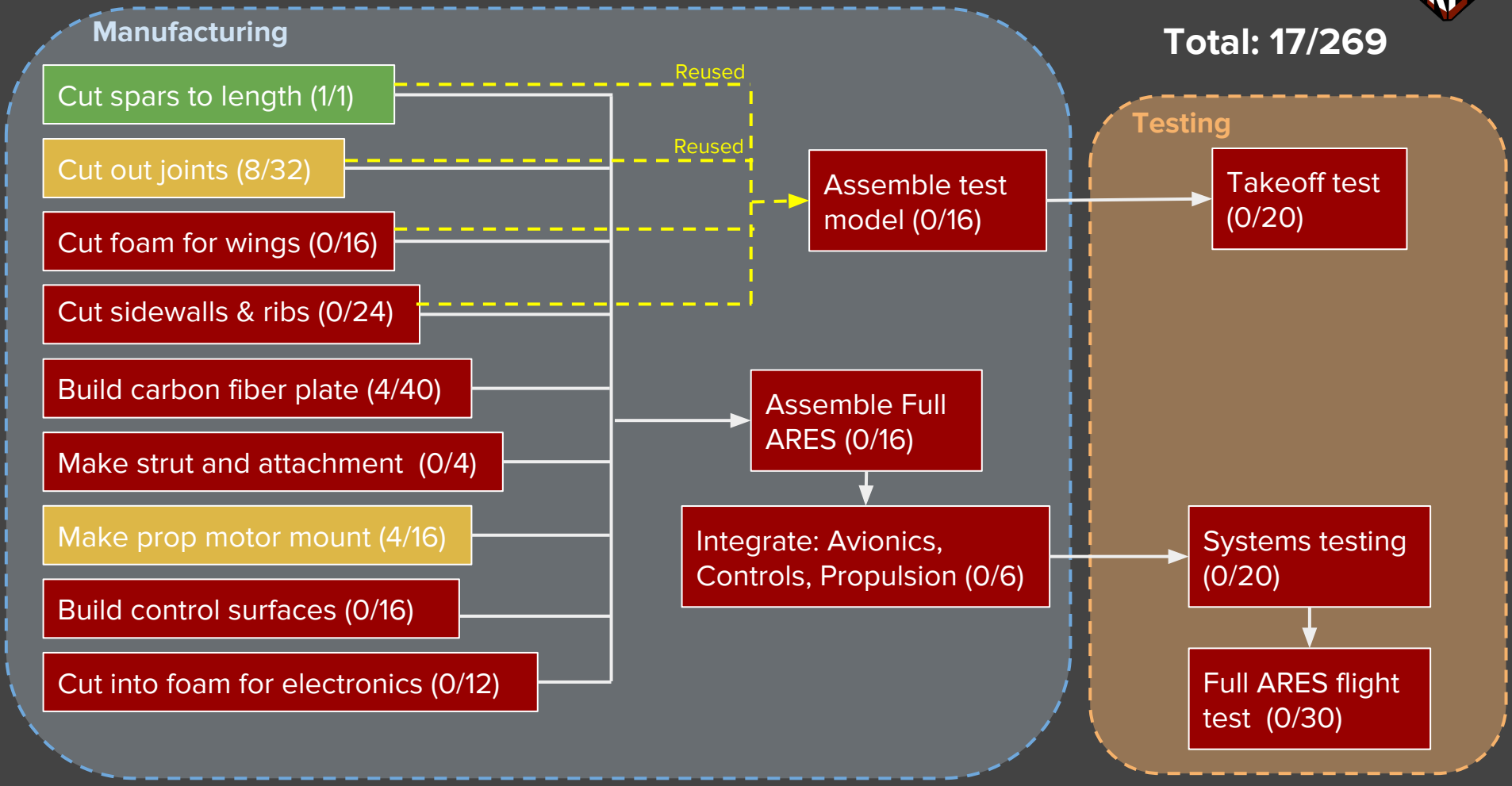
*MAN-HOURS
(Complete/Total)



Total Airframe Assembly: 17/165

AIRFRAME FLOWCHART

*MAN-HOURS
(Complete/Total)



AIRFRAME CHALLENGES

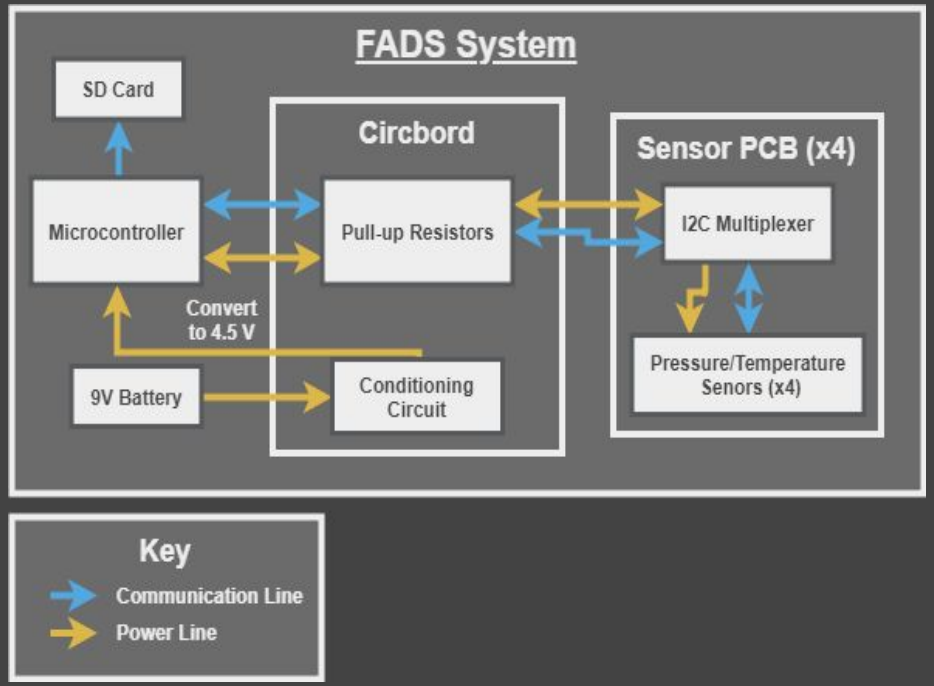
- Carbon Honeycomb
  - Honeycomb on back order from US company so had to order from China
  - Happy Chinese New Year! Business shuts down production for 2 weeks - delayed honeycomb shipment
  - Expected delivery by 3/1
- Off-ramp: Use alternate material (corrugated plastic) for takeoff testing
- EPP Foam
  - Tracking number puts it in New York
  - Expected delivery by 2/8
- Back up: Borrow from Dr. Lawrence until delivery (trade foam for foam)

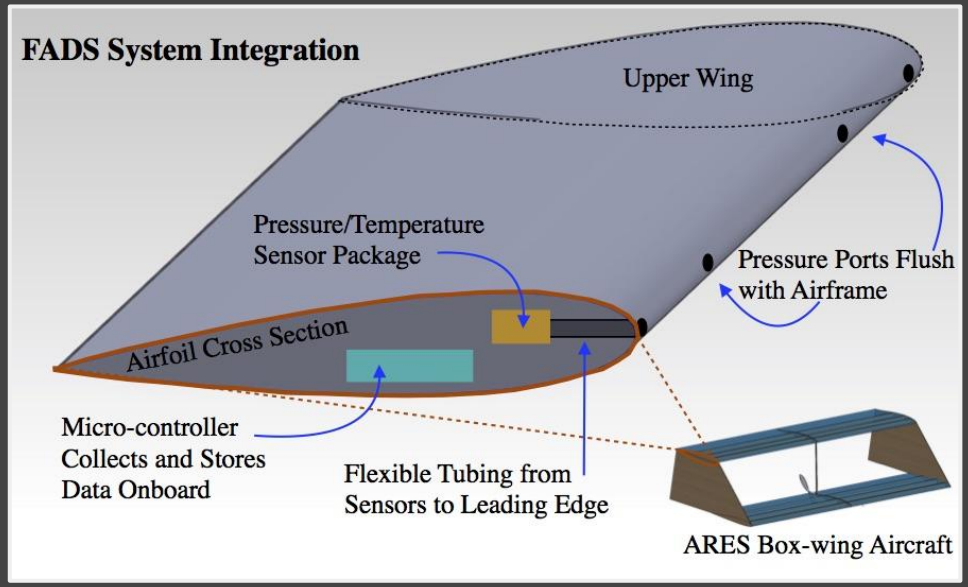
AVIONICS STATUS

Legend

- Complete
- In Progress
- Has not been started (but still on schedule)

FADS SCHEMATIC





FADS FLOWCHART

*MAN-HOURS
(Complete/Total)

Total: 52/93

Manufacturing

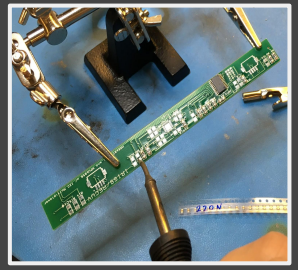
Solder 4 Sensor PCBs (10/10) → Seal the Sensors (28/28)

Design Circuit Board (4/4) → Solder Circbord (6/6) → Integrate Circbord/Microcontroller/Sensor PCBs (1/2)

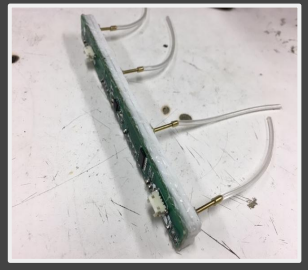
Software

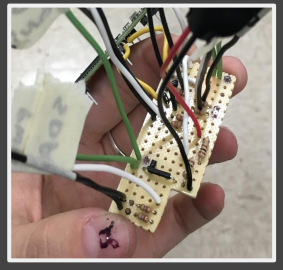
Build and Compile (4/4) → Pull Data from Sensors (10/20) → Postprocess to get Velocity (1/8)

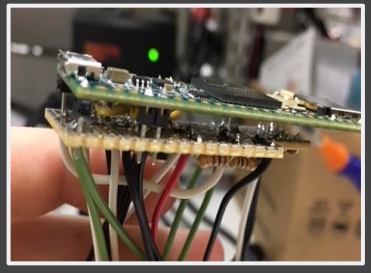
Test Sensors (0/8) → Integrate into Airframe Wing (0/3)


Solder Sensor PCB


Seal the Sensors


Sensor PCB


Circbord

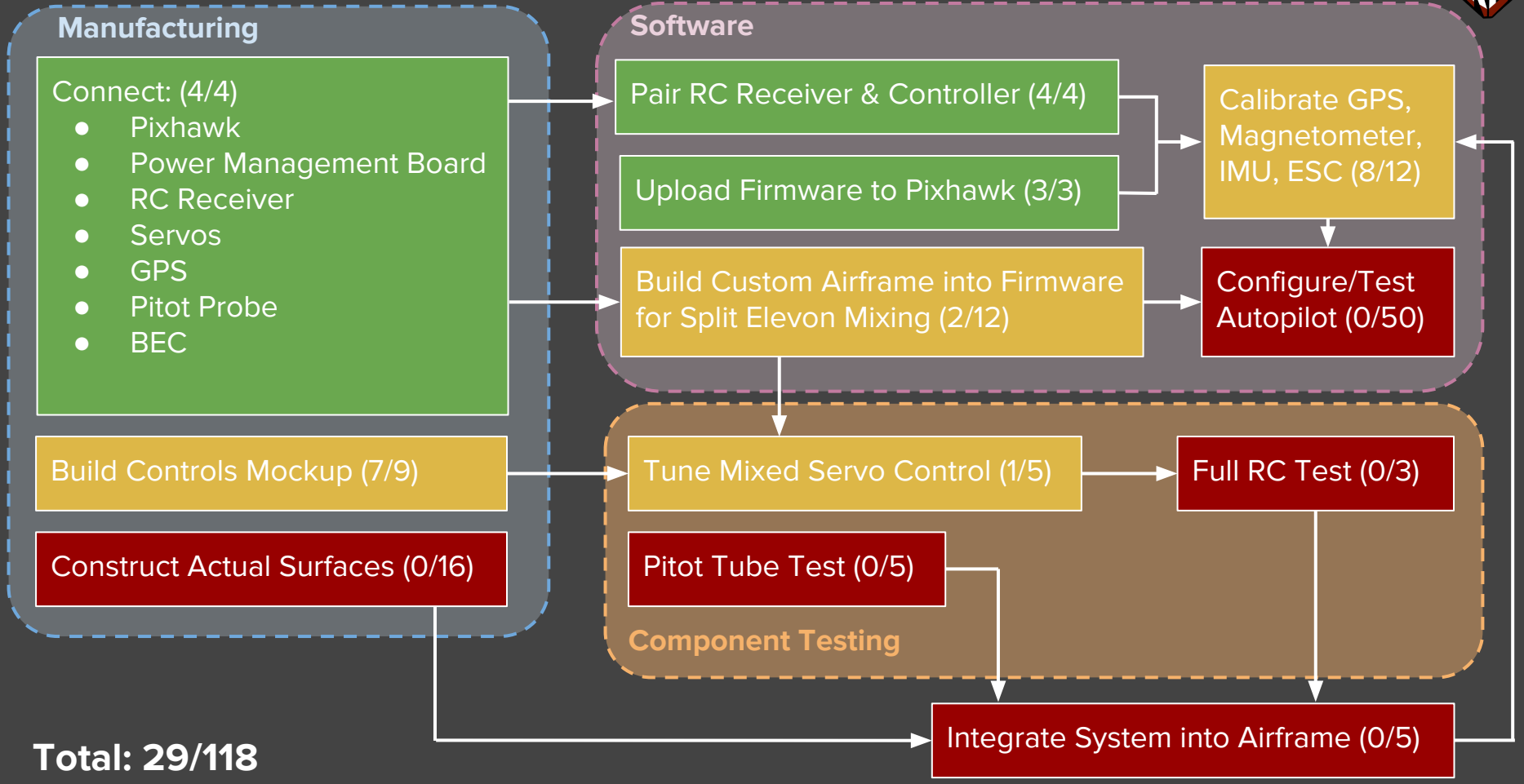

Circbord/Microcontroller

FADS CHALLENGES

- Design of new FADS Circbord
  - Change was made due to required pull-up resistors
  - Forced Circbord design for connections
  - Additional 10 man-hours
  - No additional budget cost
- FADS data challenges
  - Pulling data has proved harder than we expected
  - Expecting 10 hours longer than prior expectations
  - No additional budget cost

CONTROLS FLOWCHART

*MAN-HOURS
(Complete/Total)



Total: 29/118

CONTROLS CHALLENGES

- Software
  - Calibration of compass took longer than expected; issue now resolved
    - Added 6 hours
  - No additional budget cost
- Manufacturing
  - Trailing edge very thin, gets hard to cut with foam cutter
  - Multiple practice cuts completed to try different parameters
    - Increased kerf buffer distance on certain sections
    - Going to turn off heated wire on backtracking sections
    - Balsa sandwiching
  - Servo push rods acquired were too flimsy, purchased stronger ones
- None of the above items have pushed our schedule back

PROPULSION FLOWCHART

*MAN-HOURS
(Complete/Total)

Manufacturing

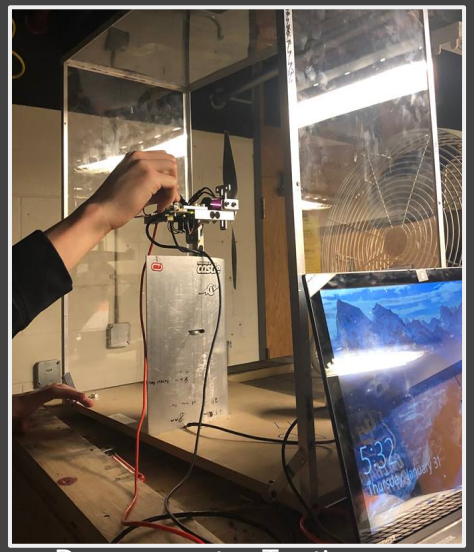
- Connect Propeller, Spinner and Motor (2/2)
- Connect 4 Batteries in Parallel (1/1)
- Integrate with Electronic Speed Controller and Batteries (5/5)

Component Testing

- Motor Dynamometer Test (10/10)
- Battery Test (8/8)

- Integrate with Airframe Mount (0/2)

Total: 26/28



Dynamometer Testing

Propeller/Spinner/Motor

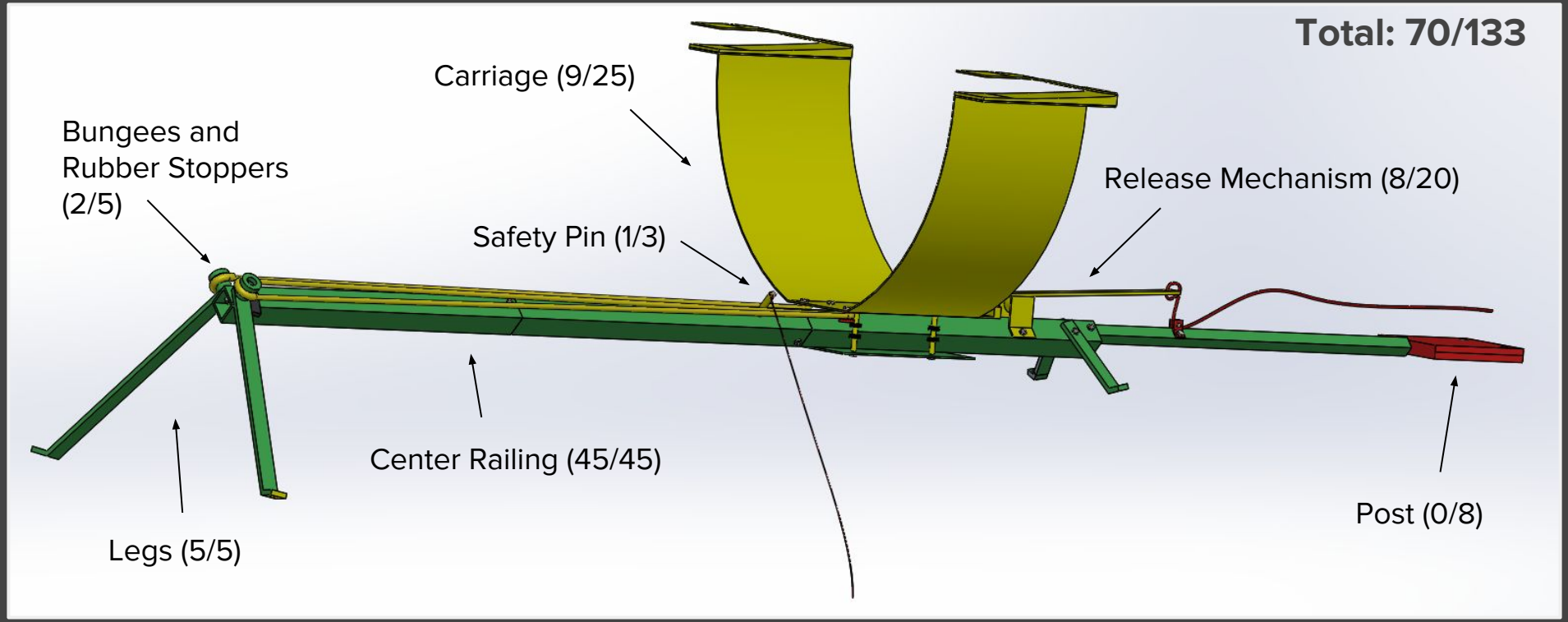
TAKEOFF STATUS

Legend

- Complete
- In Progress
- Has not been started (but still on schedule)

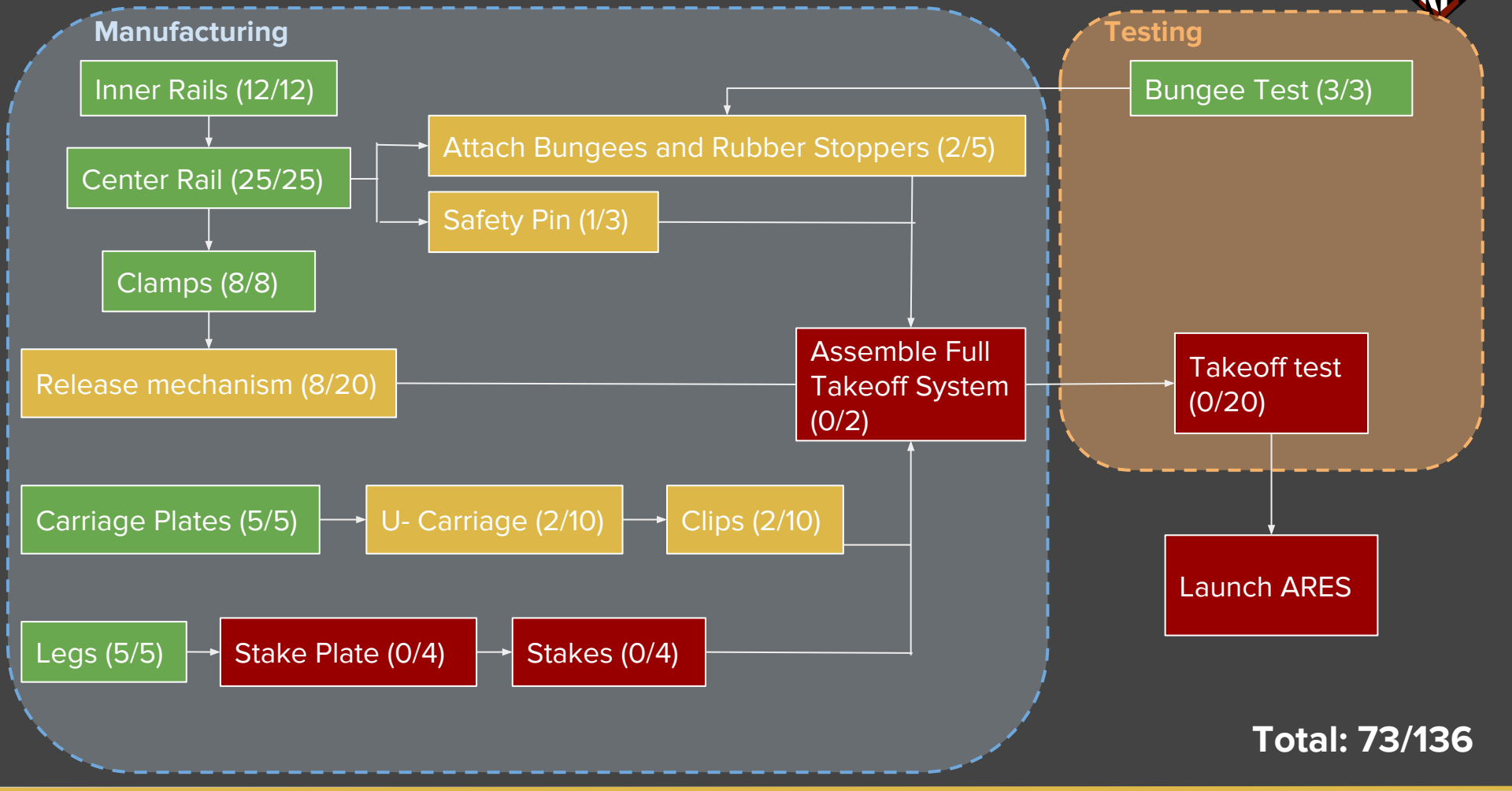
TAKEOFF SCHEMATIC

*MAN-HOURS
(Complete/Total)



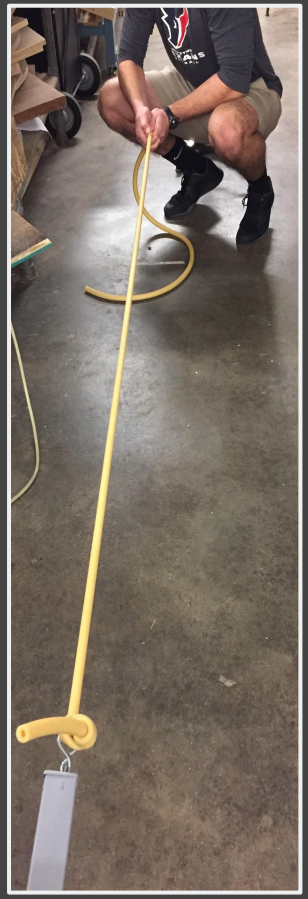
TAKEOFF FLOWCHART

*MAN-HOURS
(Complete/Total)



TAKEOFF CHALLENGES

- Bungees
  - Current design: 4 segments of silicon tubing (budget/size decision)
    - Change from KBand Victory Ropes
    - Required displacement of 2m and force of 400 N still met
    - Heritage on X8 Skywalker Launcher
    - Load testing performed; no degradation in bungees after 100 tests



PROJECT BUDGET

ORDERS AND DELIVERIES

Company	Subsystem	Cost	Delivery Status
Sparkfun	Avionics	$62.42	Delivered
Venom	Propulsion	$383.92	Delivered
Hacker/Graupner	Propulsion	$270.12	Delivered
Amazon	All	$190.03	Delivered
Drotek	Controls	$124.50	Delivered
Horizon/Holybro/F3a	Controls	$493.91	Delivered
McMaster Carr	Takeoff	$617.68	Delivered
Rockwest/ACP	Airframe	$660.80	Delivered
Tower Foam	Airframe	$306.10	Shipped
CA Composites	Airframe	$1000	In Production

*All parts have been ordered.

*We bought enough material for 3 airframes

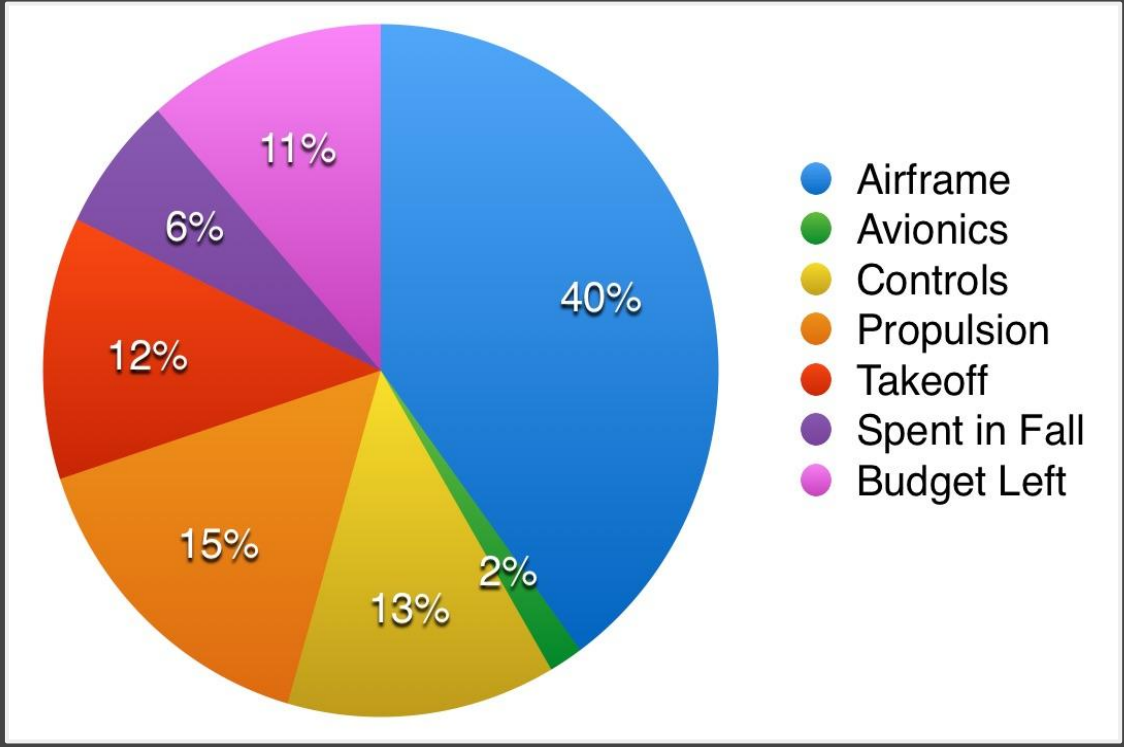
Tower Foam
- Scheduled for delivery on 2/8/19

CA Composites
-Expected delivery 3/5/19
-Back-up: Use alternate material (foam board) for the launch test

BUDGET

Subsystem	Spent
Airframe	$1996.90
Avionics	$81.42
Controls	$643.41
Propulsion	$774.04
Takeoff	$612.68
Spent in Fall	$316.41
Total	**$4424.47**

Left: $575.53



***Note: During manufacturing we discovered we needed a few more parts so we have spent $156.56 more than we predicted last semester.**

ACKNOWLEDGEMENTS

- Dr. Brian Argrow
- Dr. Donna Gerren
- Dr. Jelliffe Jackson
- Dr. Dale Lawrence
- Matt Rhode
- Bobby Hodgkinson
- Adrian Stang
- Trudy Schwartz
- Ian Cooke
- Christine Reilly
- Dan Hesselius
- Ken Jochim
- Murray Lull
- Christopher Choate

REFERENCES

“High Performance 6 - Axis MEMS MotionTracking™ Device in 4x4 Mm Package.” *TDK*, 14 Mar. 2018.

“Small, Versatile 6DoF Sensor Module.” *BOSCH*, 24 July 2014.

https://www.hacker-motor-shop.com/Hacker-eCalc-Setup-calculator.htm?shop=hacker_e&SessionId=&a=catalog&p=7334

Hantae Kang, Nicola Genco, and Aaron Altman. "Gap and Stagger Effects on Biplanes with End Plates: Part I", 47th AIAA Aerospace Sciences Meeting including The New Horizons Forum and Aerospace Exposition, Aerospace Sciences Meetings.

Lance W. Traub. "Range and Endurance Estimates for Battery-Powered Aircraft", Journal of Aircraft, Vol. 48, No. 2 (2011), pp. 703-707.

“Horizon Hobby.” Horizon Hobby, 11 Oct. 2018, https://www.horizonhobby.com/content/e-flite-rc

“Venom Power.” Venom Power, 7.12, 12 Oct. 2018, https://www.venompower.com.

“XFLR5.” XFLR5, 6.43, 10 Oct. 2018, www.xflr5.com/xflr5.htm.

Dimitriadis, G. “Flight Dynamics and Control Lecture 4: Lateral Stability Derivatives.” University of Liege, www.ltas-aea.ulg.ac.be/cms/uploads/FlightDynamics04.pdf.

Mueller, Markus. “ECalc Hacker Motor.” ECalc - PropCalc - the Most Reliable Propeller Calculator on the Web, ecalc.ch/motorcalc.php?usahacker.

“Hacker Motor USA Brushless Motors and Servos for RC and Industry!” Hacker Motor USA, hackermotorusa.com/.

Raymer, D.P., Aircraft Design: A Conceptual Approach American Institute for Aeronautics and Astronautics. Print

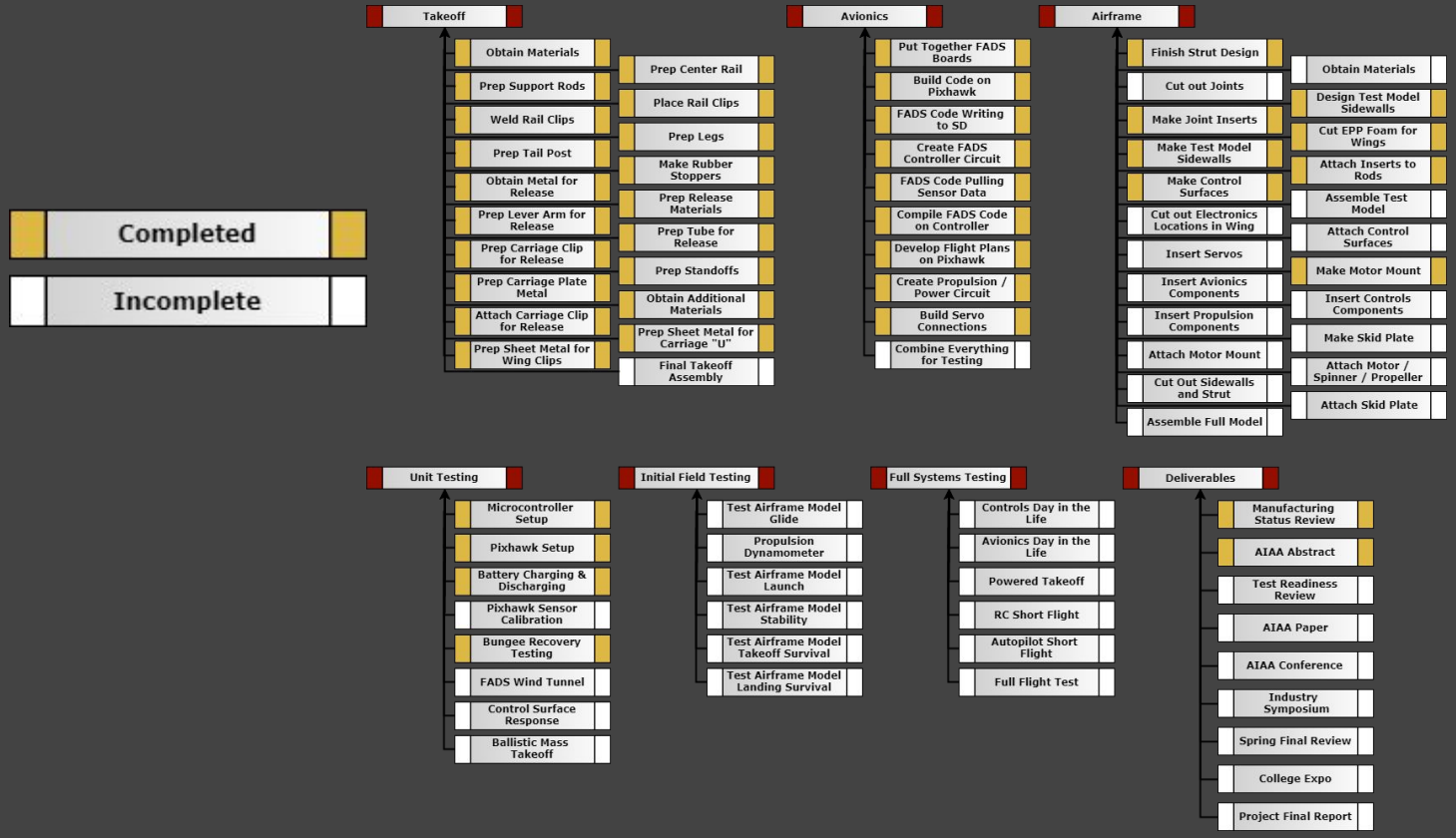
PHOENIX EDGE LITE 75 AMP ESC, 8S / 33.6V WITH 5 AMP BEC, www.castlecreations.com/en/phoenix-edge-lite-75-esc-010-0112-00.

Staples, Gabriel. “Propeller Static & Dynamic Thrust Calculation - Part 2 of 2 - How Did I Come Up With This Equation?” ElectricRCAircraftGuy.com--RC, Arduino, Programming, & Electronics, 1 Jan. 1970, www.electricrcaircraftguy.com/2014/04/propeller-static-dynamic-thrust-equation-background.html.

QUESTIONS?

BACKUP SLIDES

WORK BREAKDOWN STRUCTURE



Challenges (So Far and Forseen)

- Airframe
  - Delay on Foam delivery
  - Delay on Honeycomb delivery
- Avionics:
  - Pull-up resistor requirements
    - Forced 4 day delay on microcontroller testing
  - Battery discharging and charging tests
  - Embedded software communication
- Takeoff
  - Bungee Performance
  - Release Mechanism

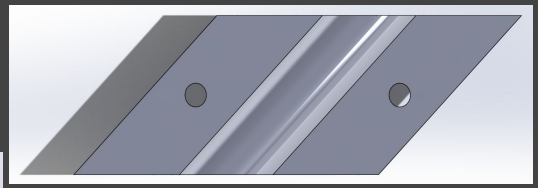
AIRFRAME BACKUP

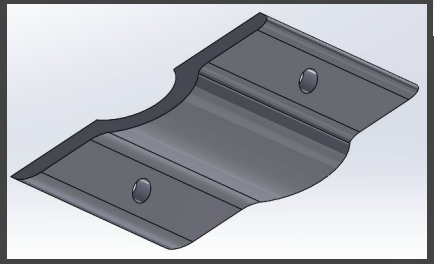
Legend

- Complete
- In Progress
- Has not been started (but still on schedule)

FRAMES (Spars, Joints, Strut)

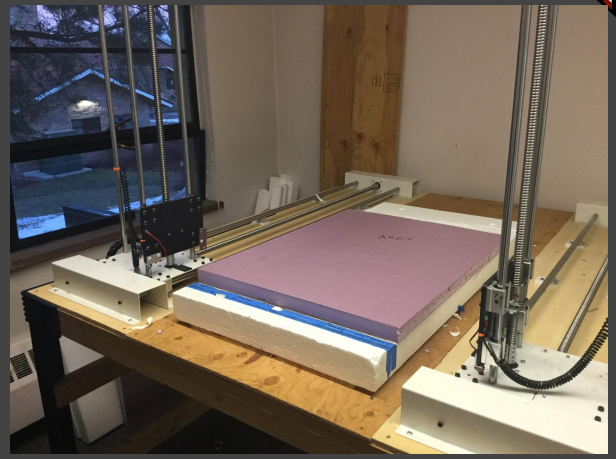
- Spars
  - Arrived
  - Cut to length
- Joints
  - Material procured
  - In process of manufacturing
- Carbon fiber rod
  - Bracket attachment
    - Carbon Fiber 3D Print
- Assembly
  - Nuts, bolts
  - EPP foam wings

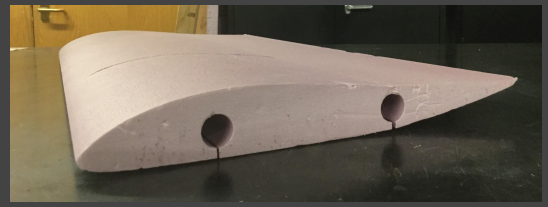


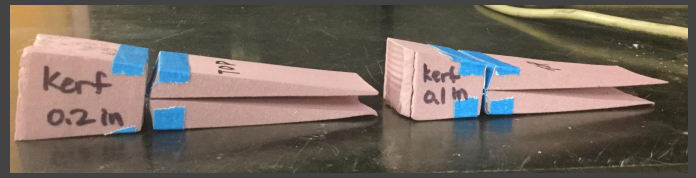


4-AXIS FOAM CUTTER

- Foam Cutting Practice
  - Learned how to use the foam cutter
- Prototype: Aerodynamic Model
  - Use Pink foam to build an aerodynamic model (No avionics mounted)
- Control Surface Design
  - Manufacturability constraint on the foam cutter (Hinge design is done)
- EPP Foam Cutting
  - EPP foam not yet arrived (on a ship)

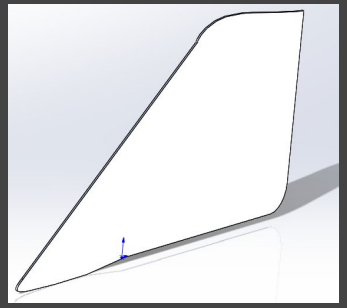


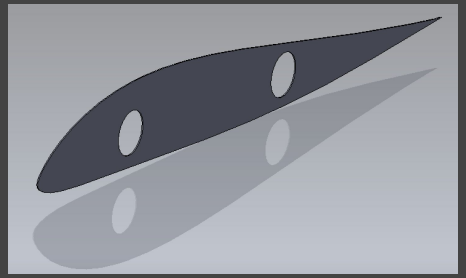




SIDE PANELS/RIBS

- Carbon Honeycomb not shipped - (Not Yet Arrived)
  - expected arrival on March 1st (happy Chinese New Year!)
  - Plan: Use alternate material (corrugated plastic panels, poster board) as approximation for launch/ aerodynamic testing
  - Cannibalize SCUA for ribs
  - Off ramp - use alternate material (aluminium, foam core composite) on final project

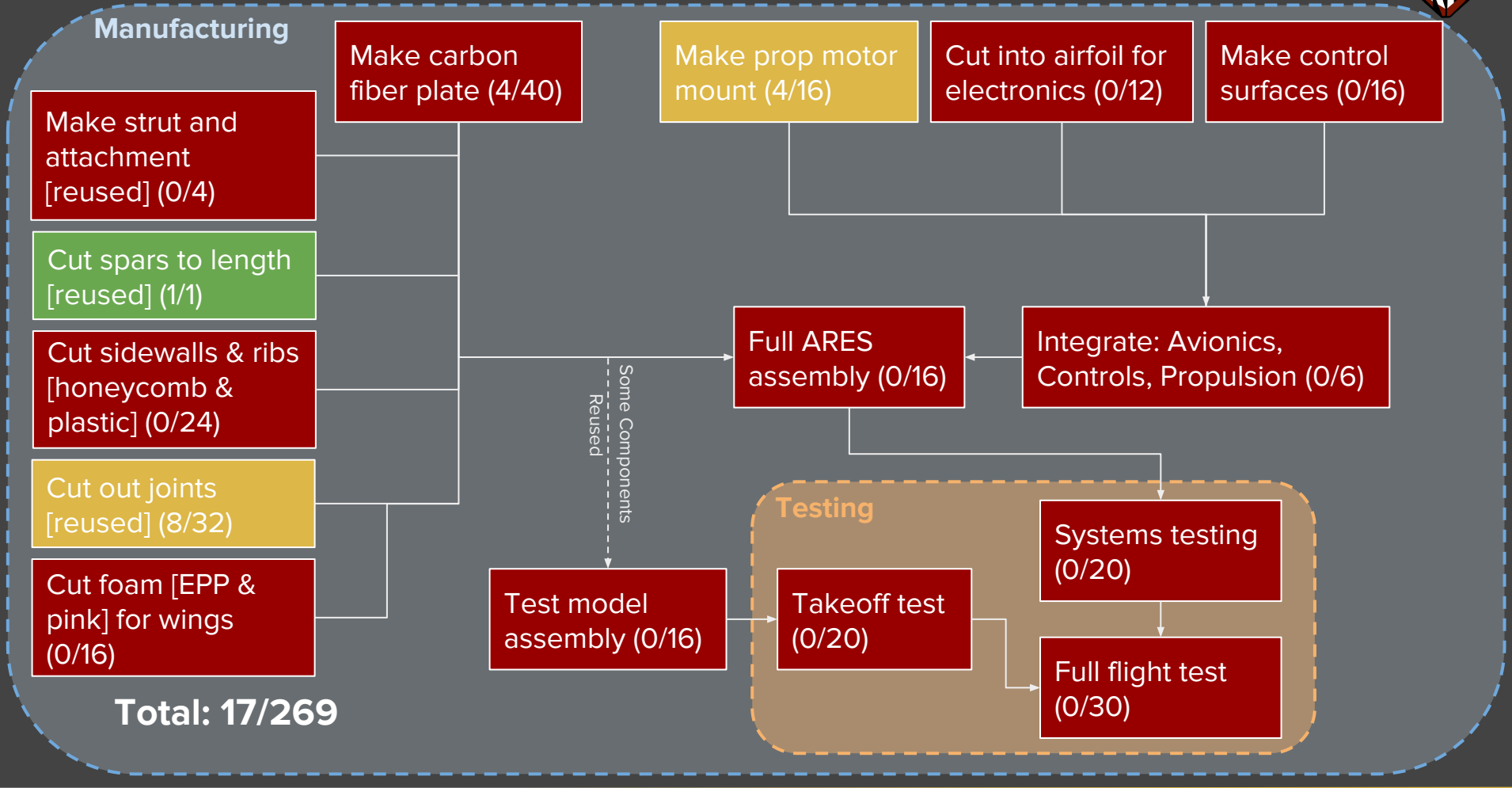




Material Sample

AIRFRAME FLOWCHART

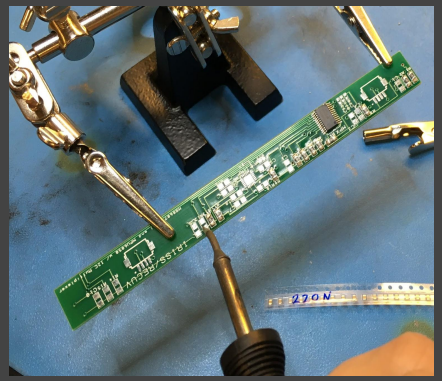
*MAN-HOURS
(Complete/Total)

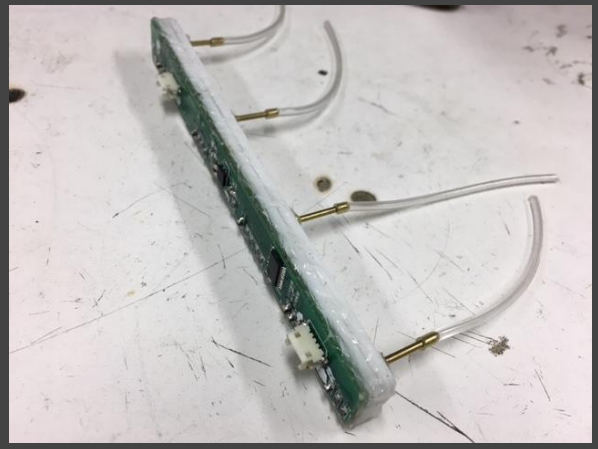


AVIONICS BACKUP

FADS BOARD DESIGN

- Surface mount FADS PCBs
  - Capacitors and resistors
  - Multiplexers and headers
- Epoxy PCBs
  - Acrylic layers
  - PCB to acrylic
- Create brass/tubing/board connection
  - Cut brass tubing to length
  - Glue brass fittings to acrylic
  - Cut and insert tubing to brass
- Test voltages to assure connections

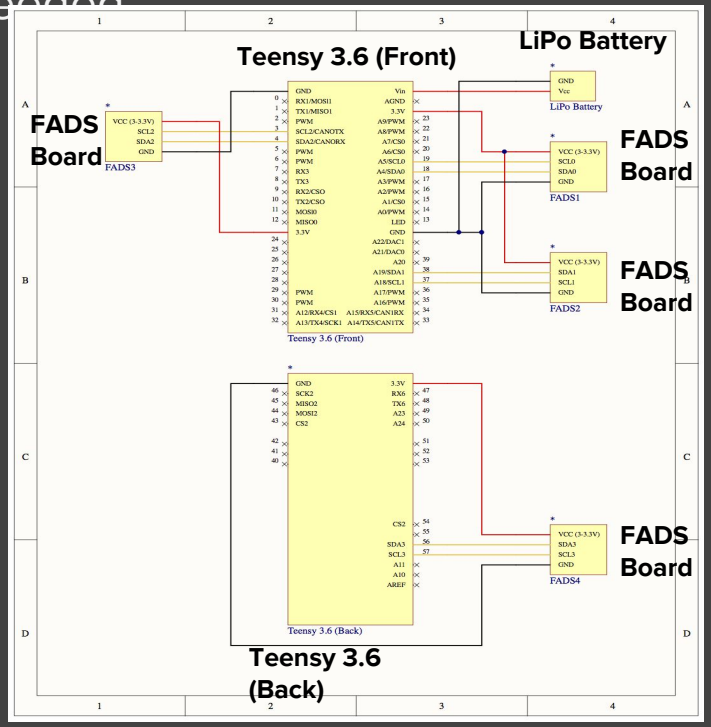


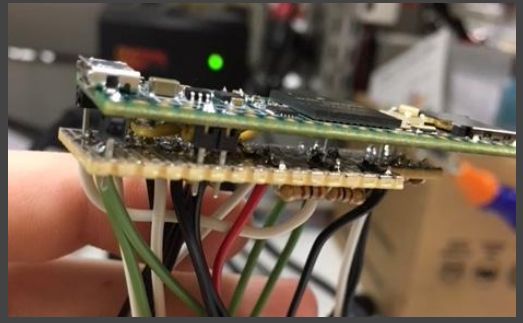


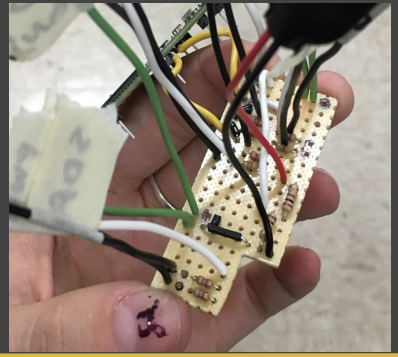
TEENSY/FADS CIRCUIT BOARD

Design Change: learned that pull-up resistors were needed

- Design new circuit board
- Procure vector board, resistors, and wire
  - Cut circuit board to size
- Solder components
- Test power conditioning circuit
- Solder microcontroller headers to board

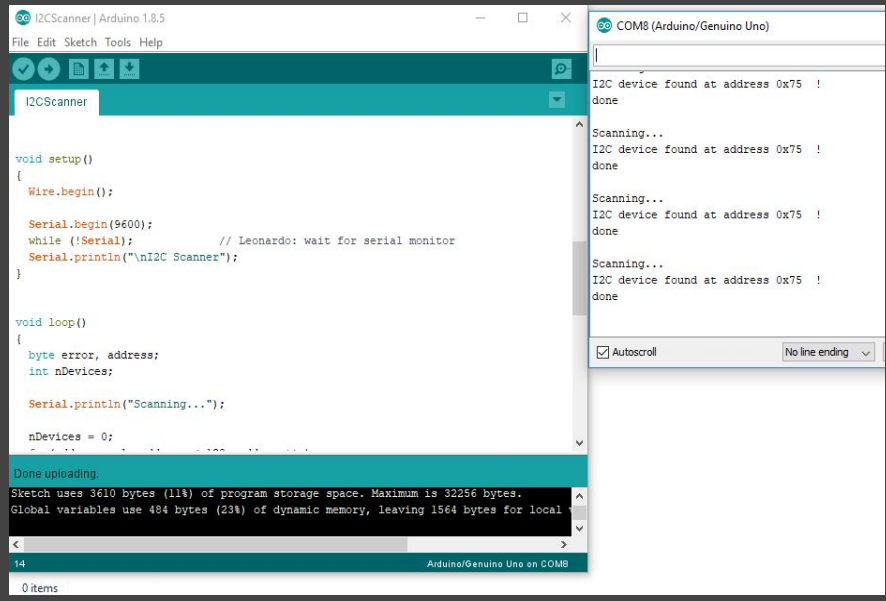






FADS EMBEDDED SOFTWARE

- Build integrated development environment (IDE)
- Build and compile code on microcontroller
  - Blink program
- Scan for I2c address
  - Multiplexer and P/T sensors
- Send command register for P/T
  - Decimal values (Challenge step)
- Write data to SD card
  - P/T and real time clock (RTC) data
- Reproduce code for 4 boards



FADS POST-PROCESSING

- Calculate velocity from pressure function
- Convert decimal to P/T function
  - Pressure in Pa, Temperature in Kelvin
- Parse output file from embedded software
  - Read in data from SD
  - Iterate through above functions
- Compare pitot probe to FADS output
  - Read in pitot probe data
  - Compare with a mean square error
- Create pressure as a function of α and β curve
  - Fit measured α and β values

```
% This function takes in stagnation and static pressure, mean sea level
% density and boulder density, and temperature. It gives the indicated
% airspeed, the true airspeed and the associated error.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [P_stag, P_static, rho, rho_0, T] = ARES_CalcTAS(TAS,IAS)
R = 287; % J/KgK
IAS = sqrt(2*(P_stag - P_static)/rho_0);
TAS = IAS*sqrt((rho_0*P_stag)/(R*T));
error = TAS*.003;
end
```

Vary alpha and beta in wind tunnel, measure pressure

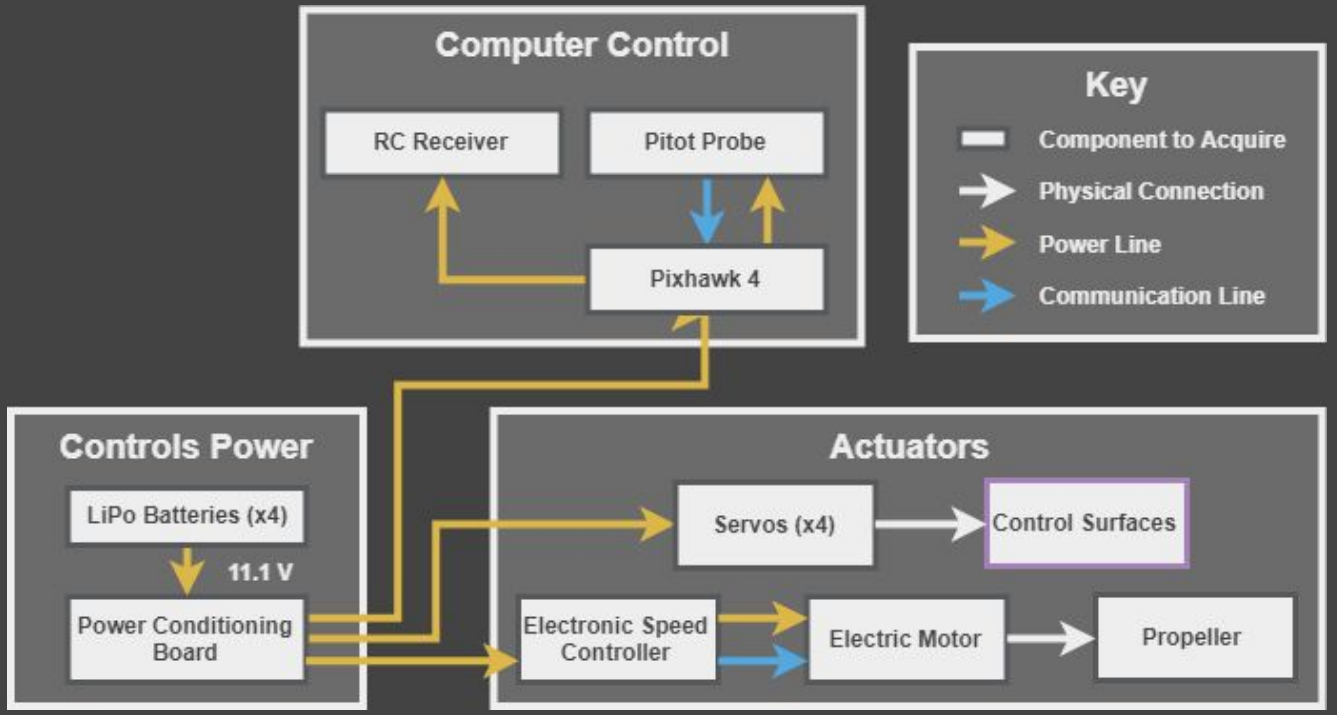
↓

MATLAB least squares fit

↓

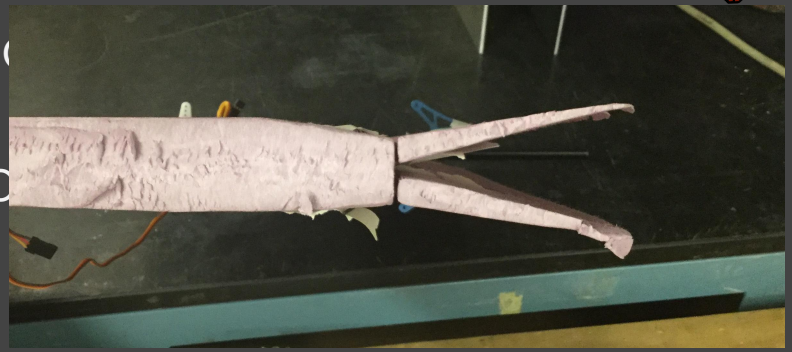
P = f (α,β)

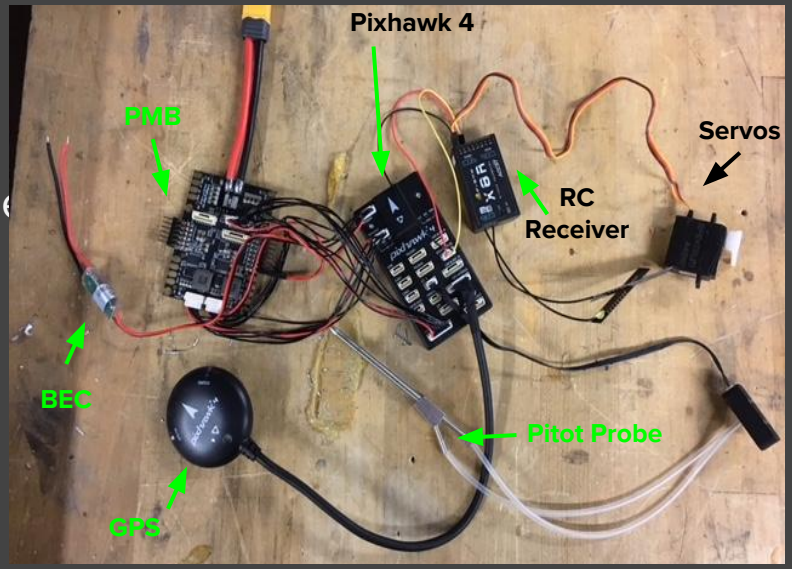
CONTROLS/PROPULSION SCHEMATIC



CONTROLS AVIONICS

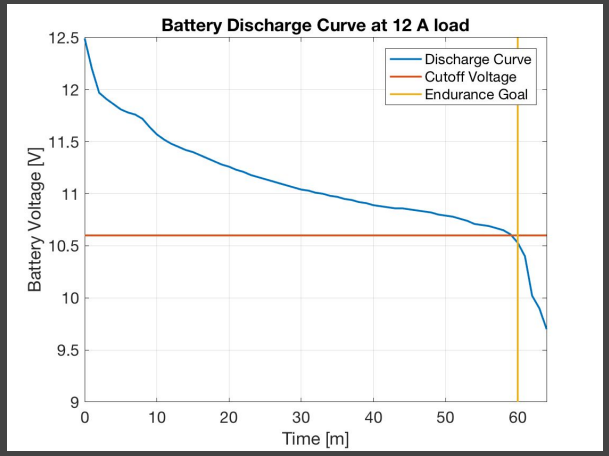
- Firmware uploading to Pixhawk board from
- Pixhawk wiring mostly complete
- Successful pairing between receiver and RC
- Sensor calibration almost done
- Powered with LiPo battery connection
- Post-flight log files received
- Wind tunnel test for pitot tube
- Integrate ESC/Motor
- Custom airframe built into firmware for split e
-
-
-





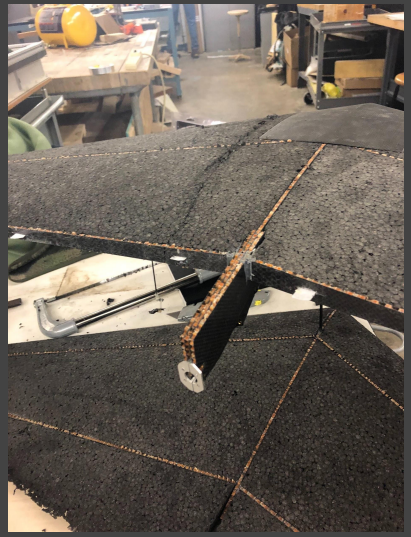
Testing

- Data recording and storage
- Fridge testing (sensor accuracy)
- Wind tunnel testing
  - Pressure data comparison
  - Pressure-velocity comparison
- Battery discharging and charging
- Dynamometer testing
- Servo perturbation testing



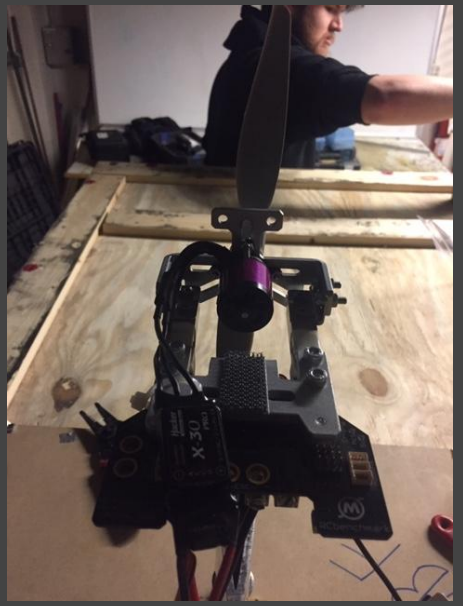
Propulsion Status

- Propulsion mounting structure will be recycled from heritage design (SCUA)
  - Already manufactured
  - Will be cut out from SCUA and simply glued to ARES' center ribbing
  - Current mount doesn't fit our motor - will make aluminum adapter



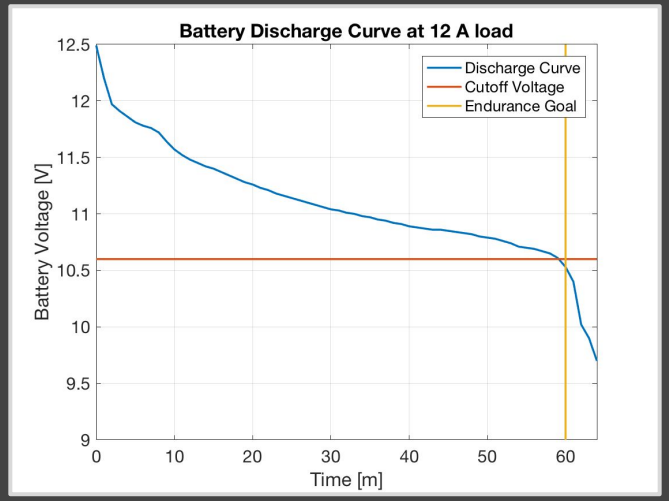
Propulsion Status

- Propulsion system has been completely configured and tested
  - Motor is compatible with ESC, batteries, wiring, etc.
- No further manufacturing required for propulsion - in very good standing
- DR 1.2.1 has been met



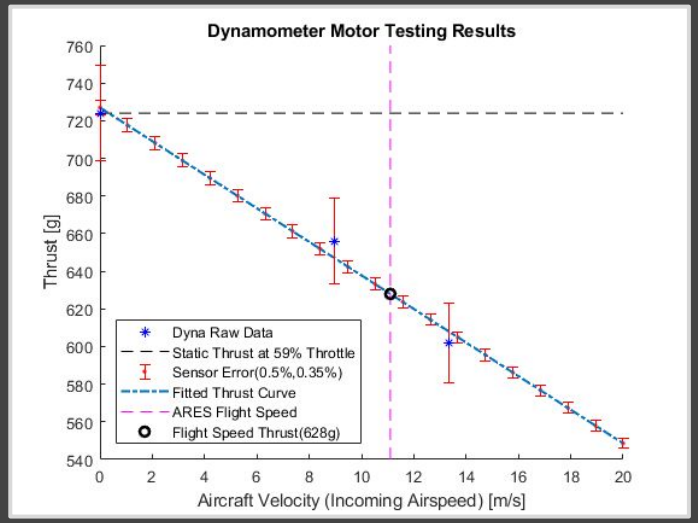
Battery Discharge Testing

- Ran test with charged batteries to ensure endurance requirement (V_i = 4.24v)
- Prop ran for over an hour successfully with 550-720g thrust range
- At the hour mark, changed the thrust output to see its effect on the battery
- FR 1.0 has been met
- Level 1 success criteria conditionally is met



Dynamometer Testing

- Used DBF Dynamometer (0.5% Error)
  - Tested motor for:
    - max thrust output
    - Expected flight thrust output
    - Startup throttle system response
    - Response to incoming wind at varying speeds

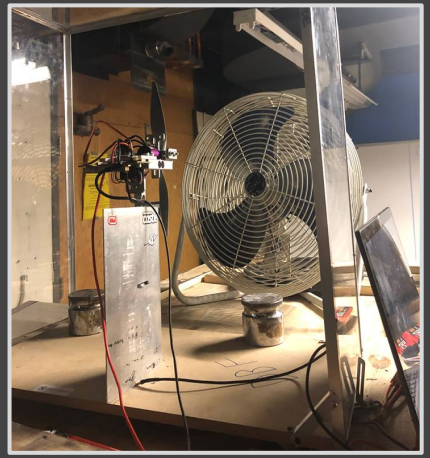


Throttle Effects on Thrust

Throttle	Thrust	RPM
100%	1140g	9234
59%	724g	7941
9%	32g	294

Incoming Wind Speed Effects on Thrust at 59% Throttle

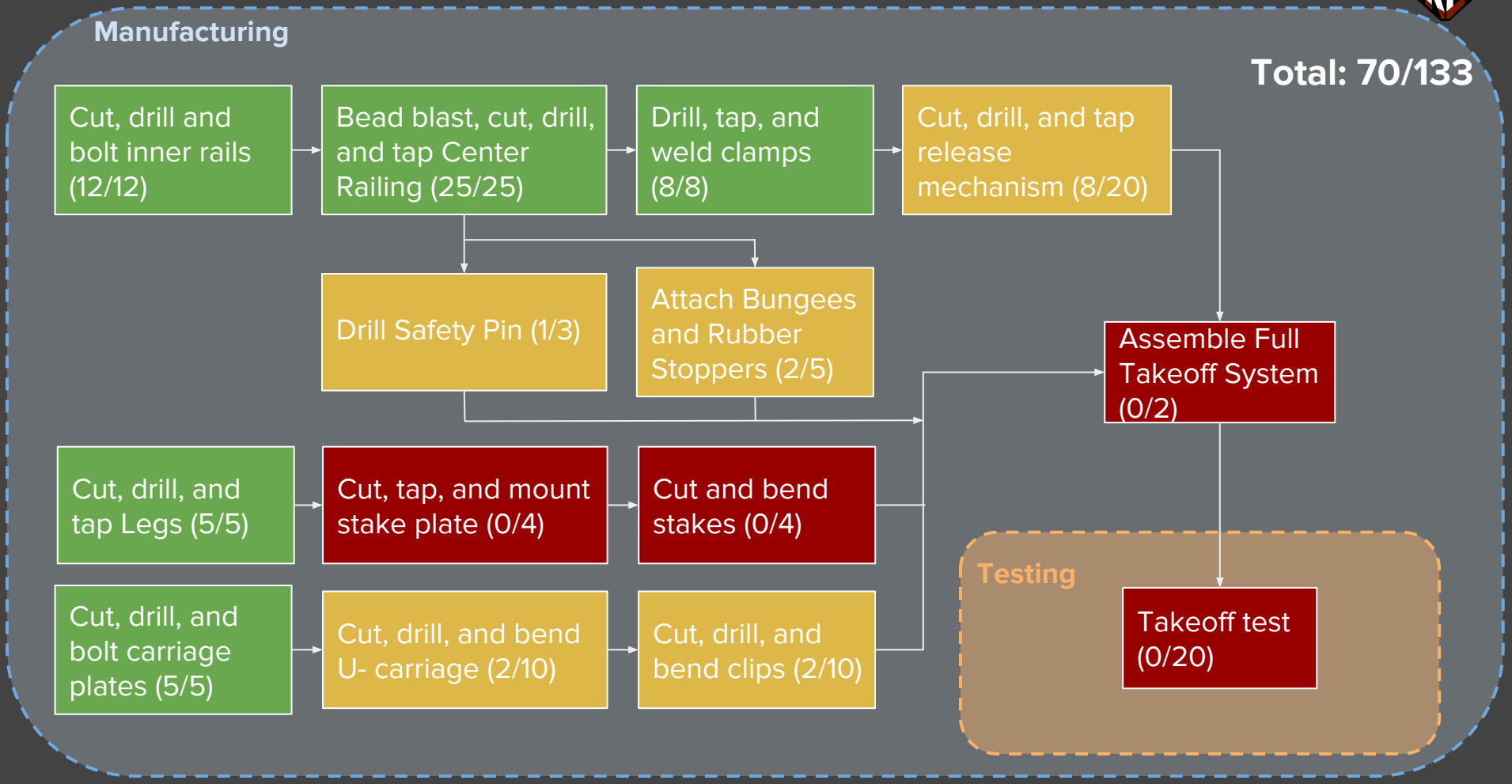
Wind Speed	Thrust	RPM
0m/s	724g	7941
8.98m/s	656g	7483
13.32m/s	602g	7096



TAKEOFF BACKUP

TAKEOFF FLOWCHART

*MAN-HOURS
(Complete/Total)



TAKEOFF SYSTEM

Center Rail Status

- Bead blast steel beams
- Drill holes for legs, support rods, clips, tail post
- Weld center rail clips
- Cut and drill legs
- Drill and tap tail post
- Cut and drill rubber stoppers
- Drill Safety Pin Hole
- Drill Release mechanism holes

TAKEOFF SYSTEM

Carriage Status

- Cut and drill carriage plate metal
- Attach carriage clip for release mechanism
- Cut and drill spacers
- Cut metal for carriage U
- Cut metal for carriage clips
- Bend/roll U and clips
- Cut all - thread

TAKEOFF SYSTEM

Release Mechanism Status:

- Obtain material for release mechanism
- Drill and tap L - brackets (if needed)
- Drill and tap lever arm
- Drill and tap tube for release

TAKEOFF SYSTEM

Bungee Status:

- KBand Victory Ropes have been replaced
- Current design is using silicon tubing (budget/size decision)
  - Required displacement of 2m and force of 400 N still met
  - Heritage on X8 Skywalker Launcher
  - Load testing???

To - Do Material Procurement:

- Rebar
- Flight string
- Screws/bolts (to reimburse machine shop)
- L - brackets

TAKEOFF SYSTEM

Summary:

- Center rail
- Legs and Posts
- Release Mechanism
- Carriage
- Safety Pin

Current Challenges

- Bungee performance
- Release mechanism

To-Do:

- Material procurement
  - Rebar
  - Flight string
  - Screws/bolts (to reimburse machine shop)
  - L - brackets
- Finish ‘in progress’ components