ASPECT-RATIO REDESIGN OF EAGLE OWL FOR STORMCHASING

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SPONSOR	Dr. Brian Argrow

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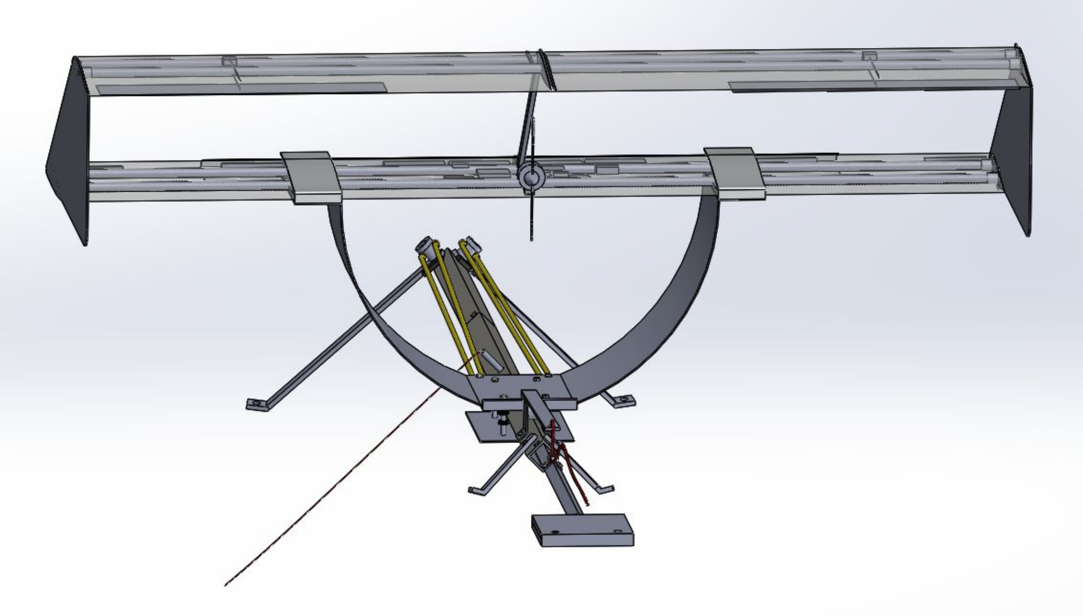


PURPOSE & OBJECTIVES

PROJECT OBJECTIVES

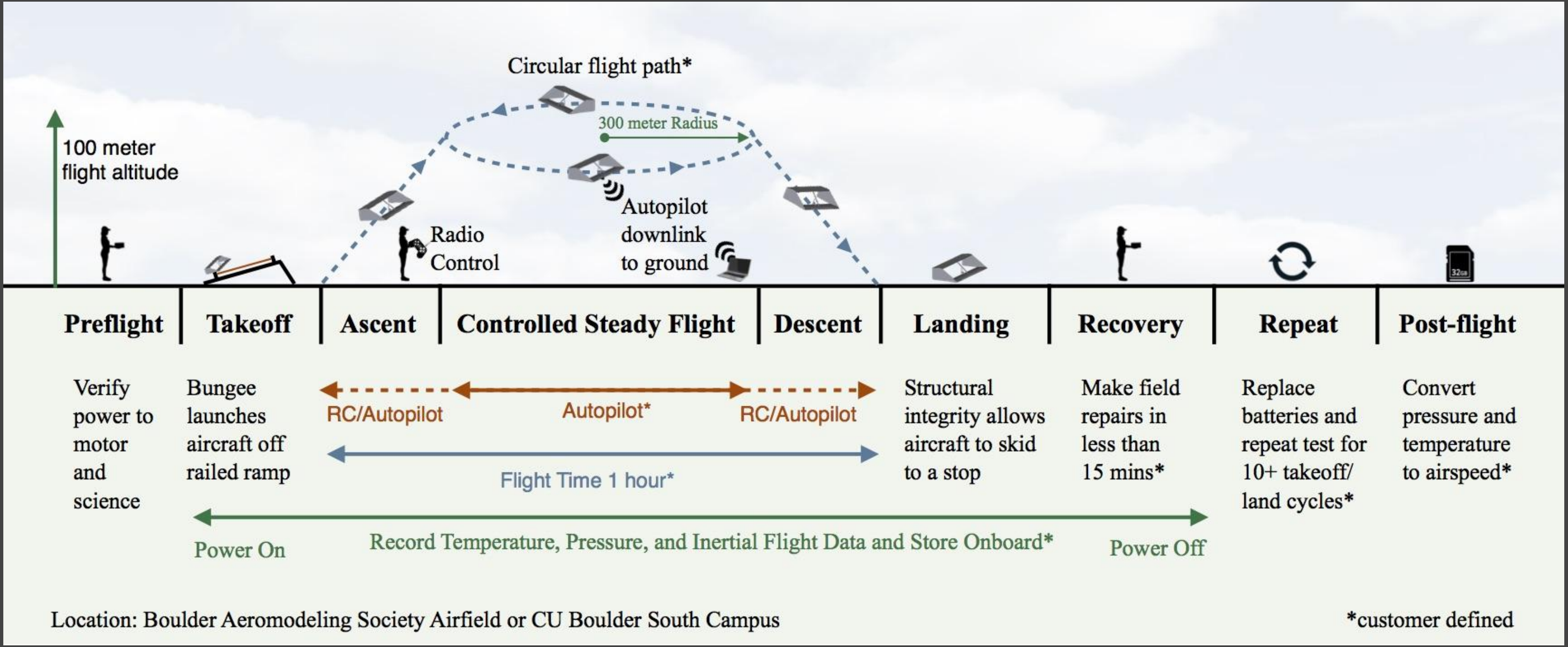
- **Aspect-ratio Redesign of Eagle-owl for Stormchasing (ARES)** will build upon the previous Eagle Owl project by designing, building, and testing a box-wing unmanned aircraft with a flush airdata sensing system (FADS) to measure relative wind velocity with the objective of creating a high endurance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

FUNCTIONAL REQUIREMENTS

FR 1.0	The aircraft shall have a total flight endurance of at least 1 hour while maintaining visual sight with the operator.
FR 2.0	The system shall be an aircraft with a box wing configuration with a span no larger than 72 inches; the effects of increasing aspect ratio from the previous version to increase endurance will be investigated.
FR 3.0	The aircraft shall demonstrate a controlled takeoff.
FR 4.0	The aircraft shall be piloted by an autopilot during the steady flight regime of the mission.
FR 5.0	The aircraft shall simultaneously measure external temperature, inertial flight data, and pressure on the airframe surface at multiple points with a flush airdata sensing (FADS) system.
FR 6.0	The aircraft shall land in a manner such that the aircraft is capable of completing at least 10 takeoff and landing cycles with only 15 minutes on the ground between landing and takeoff.

CONOPS



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	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*

Flight Time 1 hour*

Power On — Record Temperature, Pressure, and Inertial Flight Data and Store Onboard* — Power Off

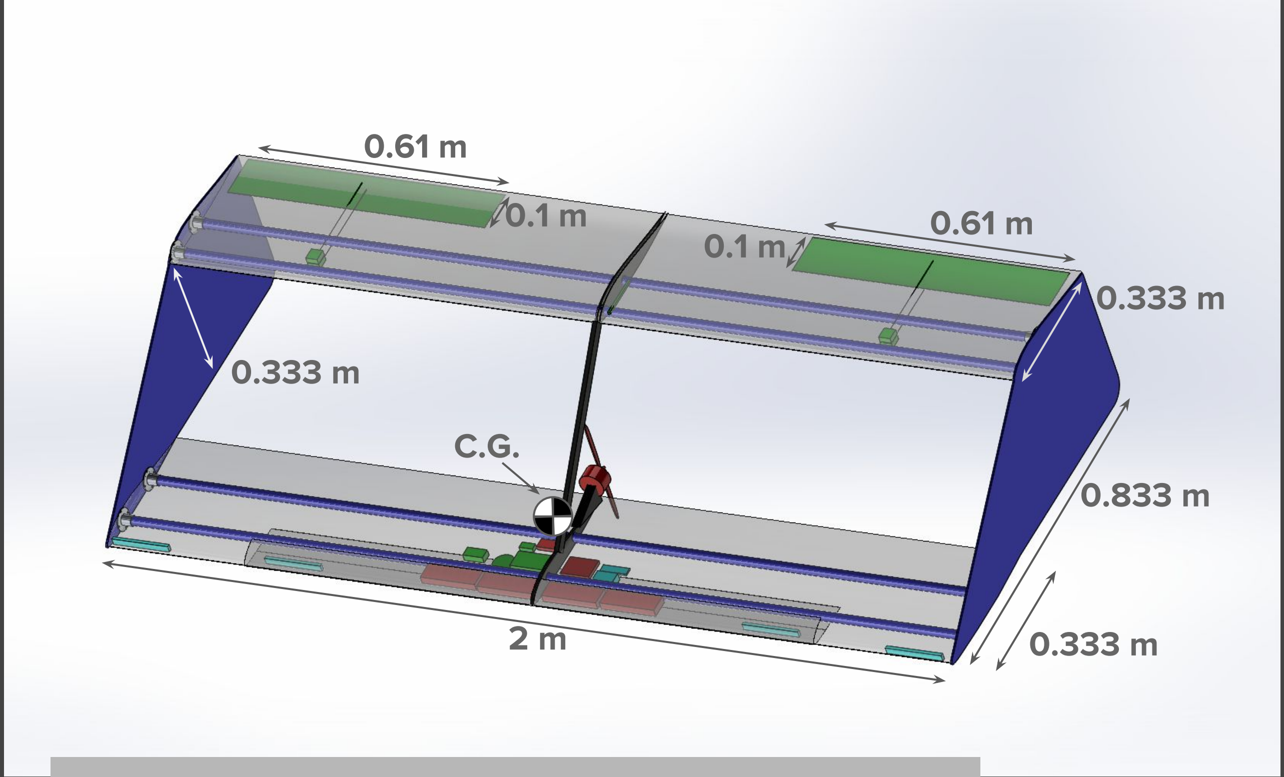
Location: Boulder Aeromodeling Society Airfield or CU Boulder South Campus

*customer defined

DESIGN SOLUTION

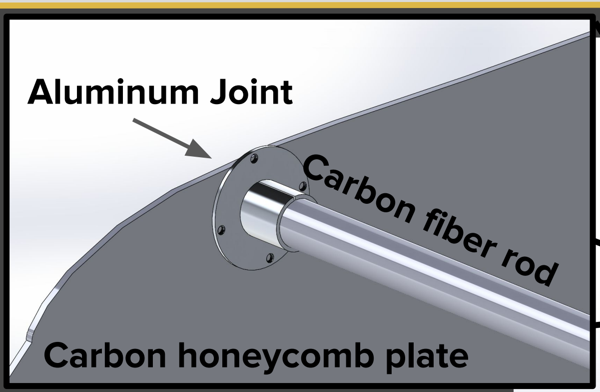
FULL AIRCRAFT DESIGN

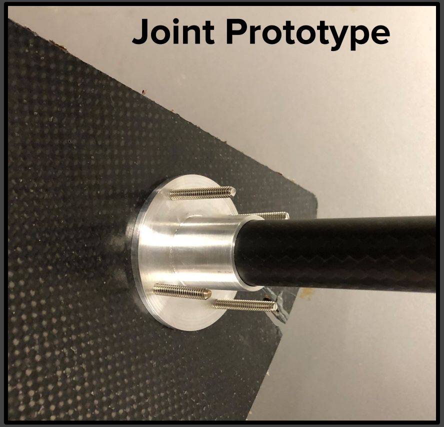
Coefficient	Value
$(L/D)_{cruise}$	13.8
$C_{L,max}$	0.809
α_{cruise}	5.20 deg
V_{cruise}	11.1 m/s
α_{stall}	13.9 deg
V_{stall}	8.36 m/s
Endurance	80 min
Mass	4 kg

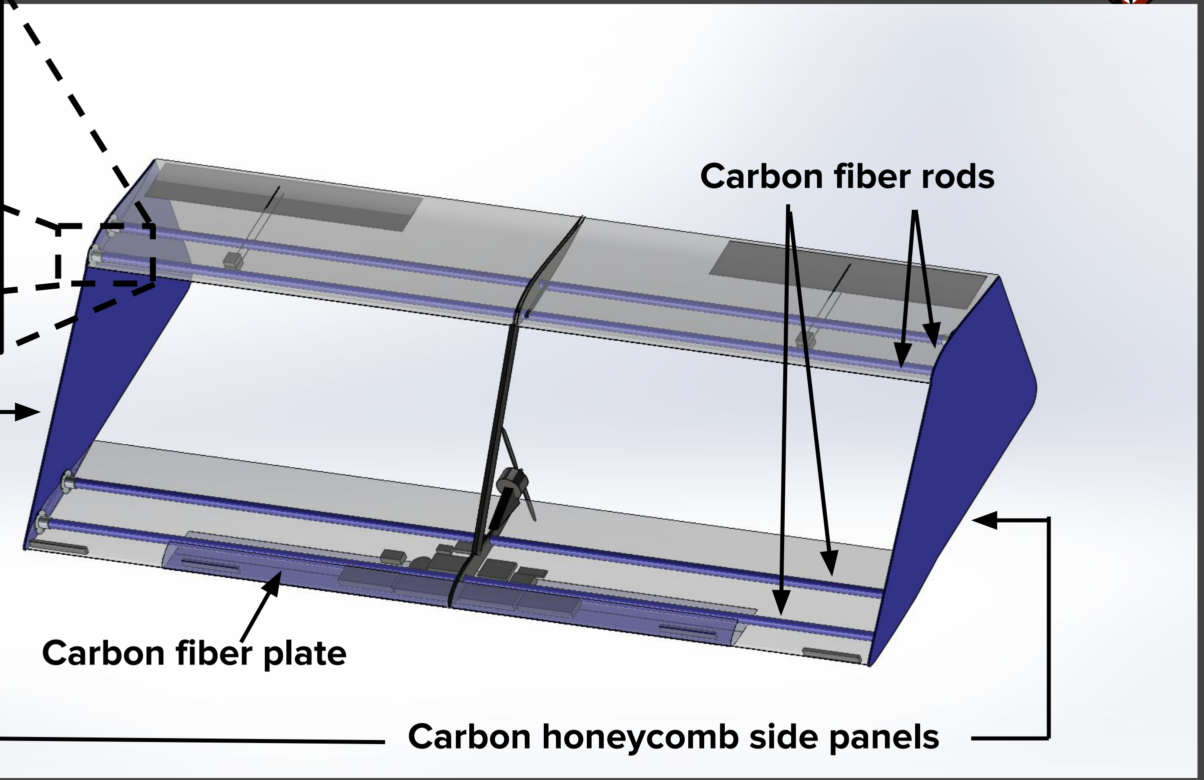


Structure Control Propulsion Science

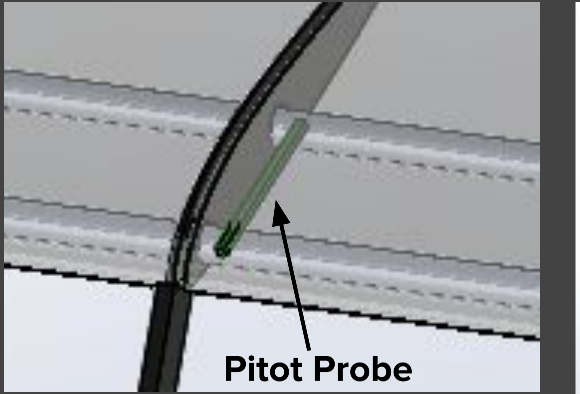
AIRCRAFT STRUCTURE

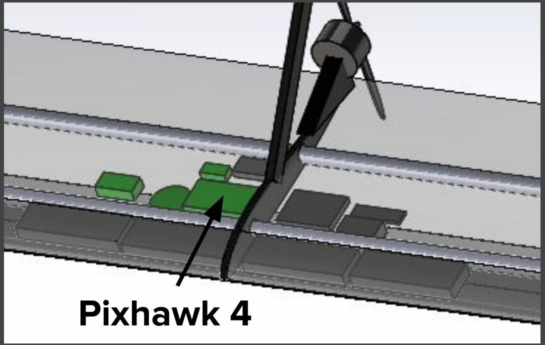


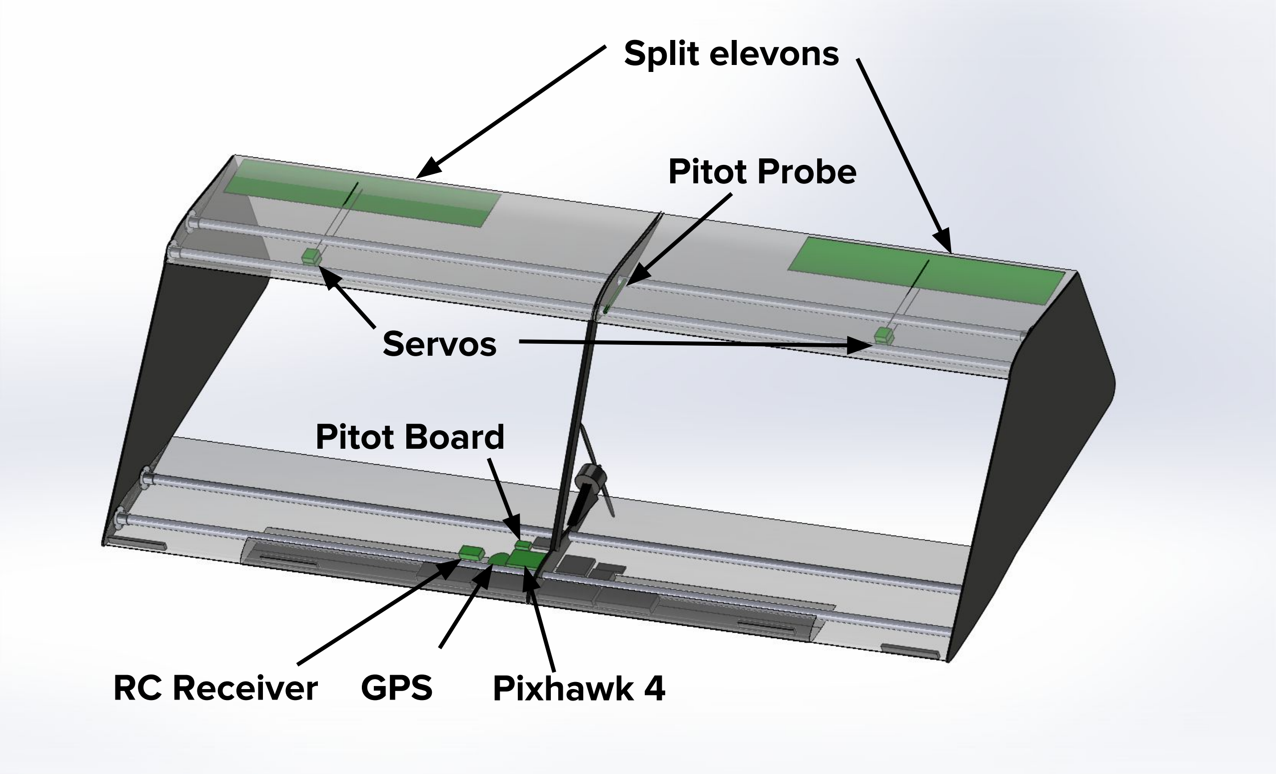




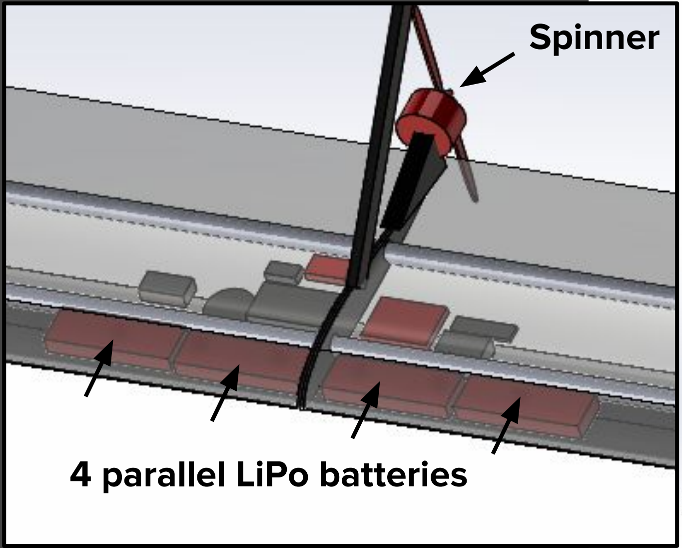
AIRCRAFT CONTROL

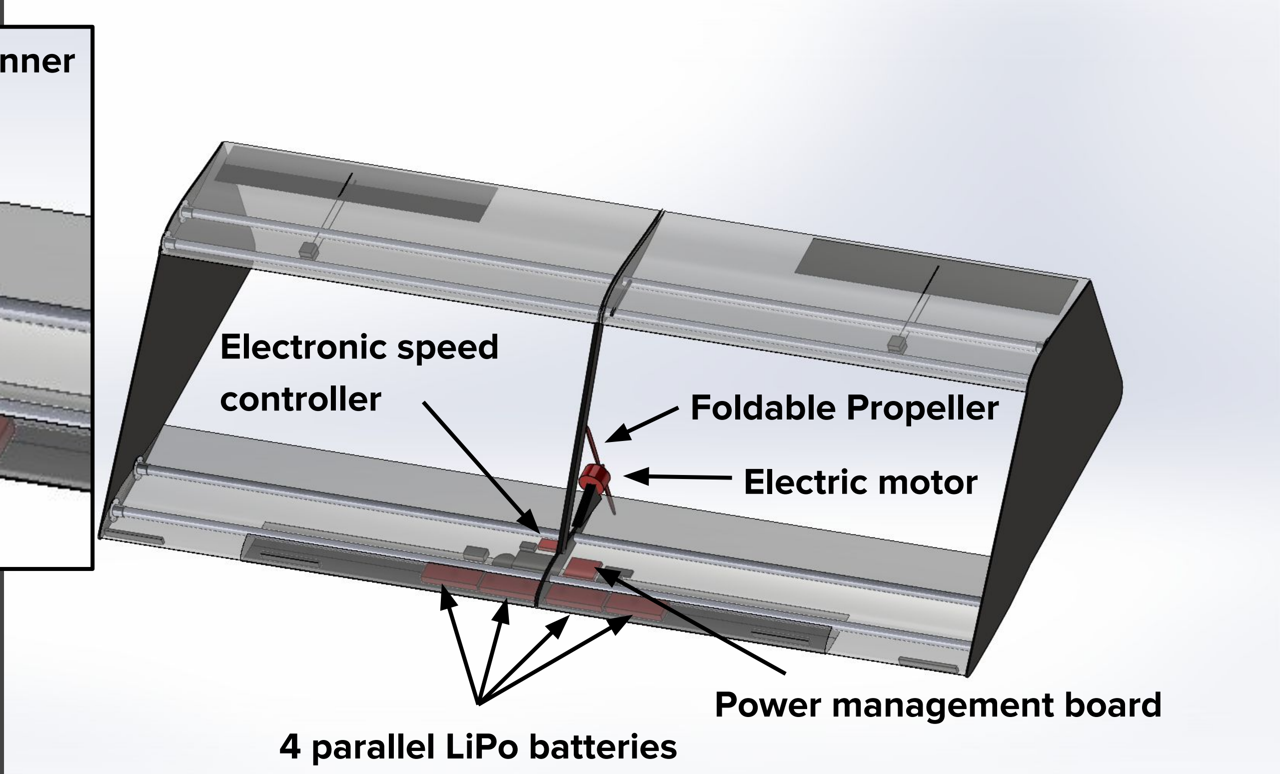




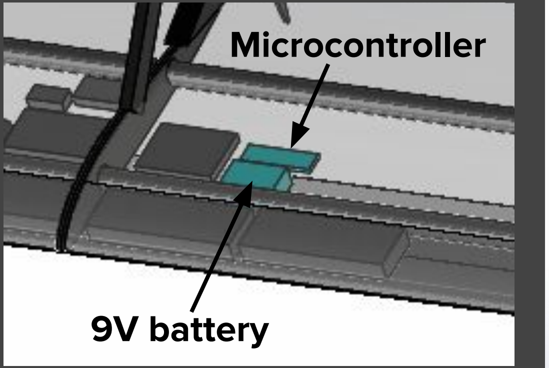


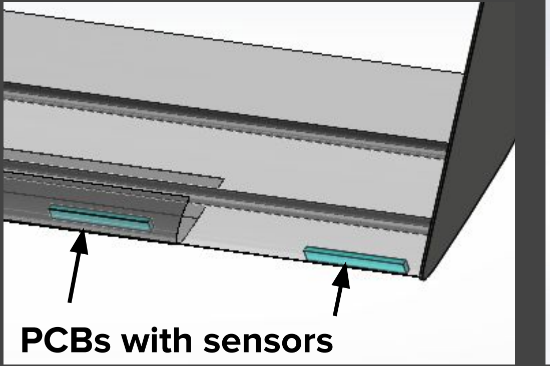
AIRCRAFT PROPULSION

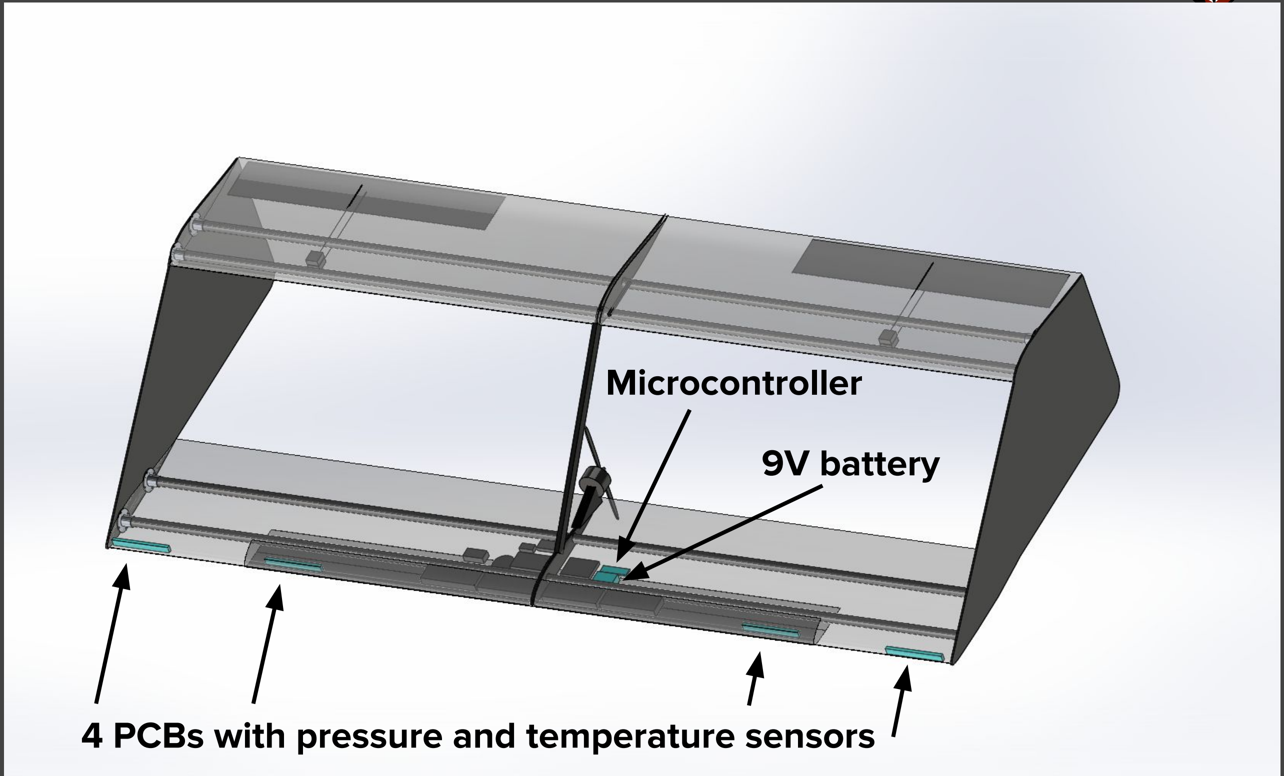




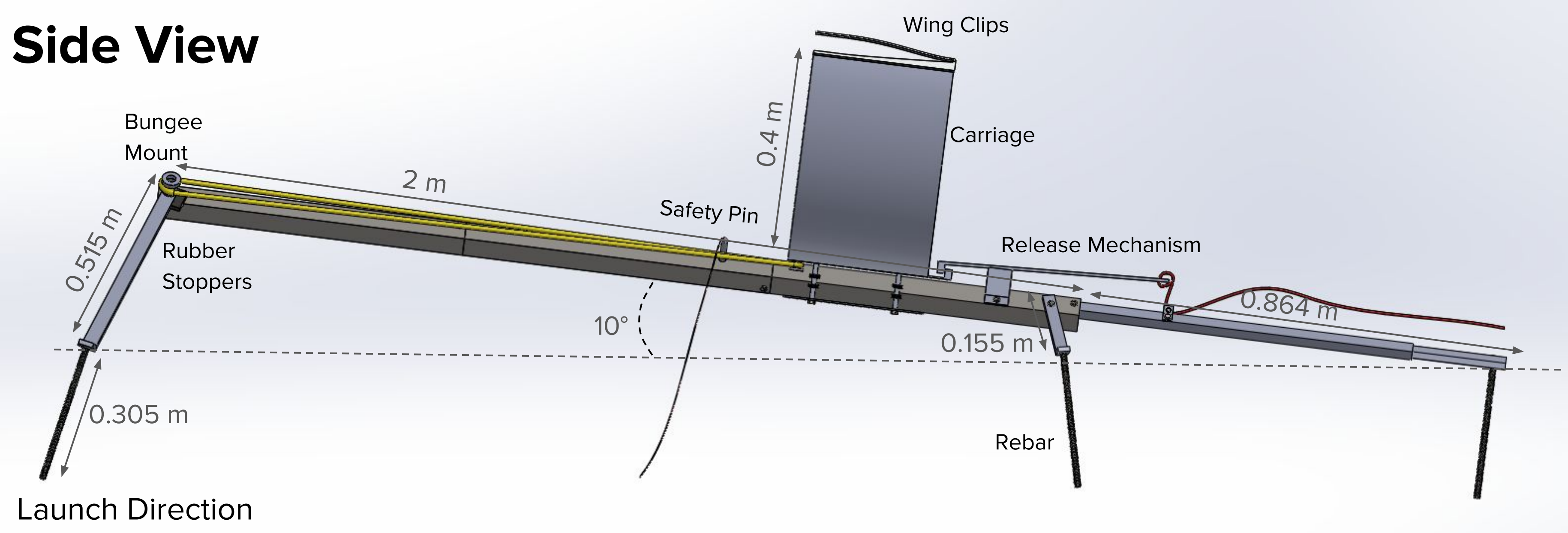
AIRCRAFT SCIENCE





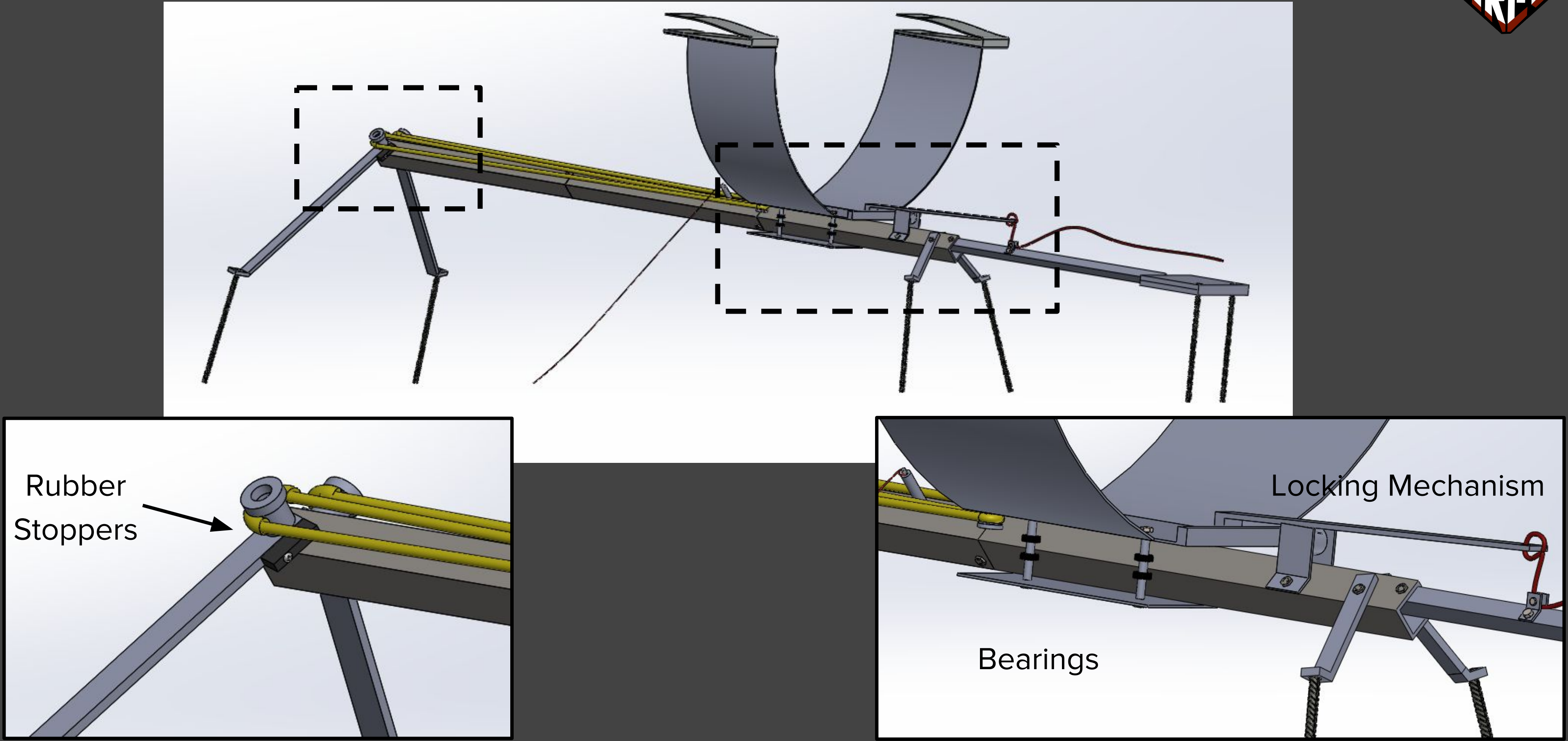


FULL TAKEOFF DESIGN

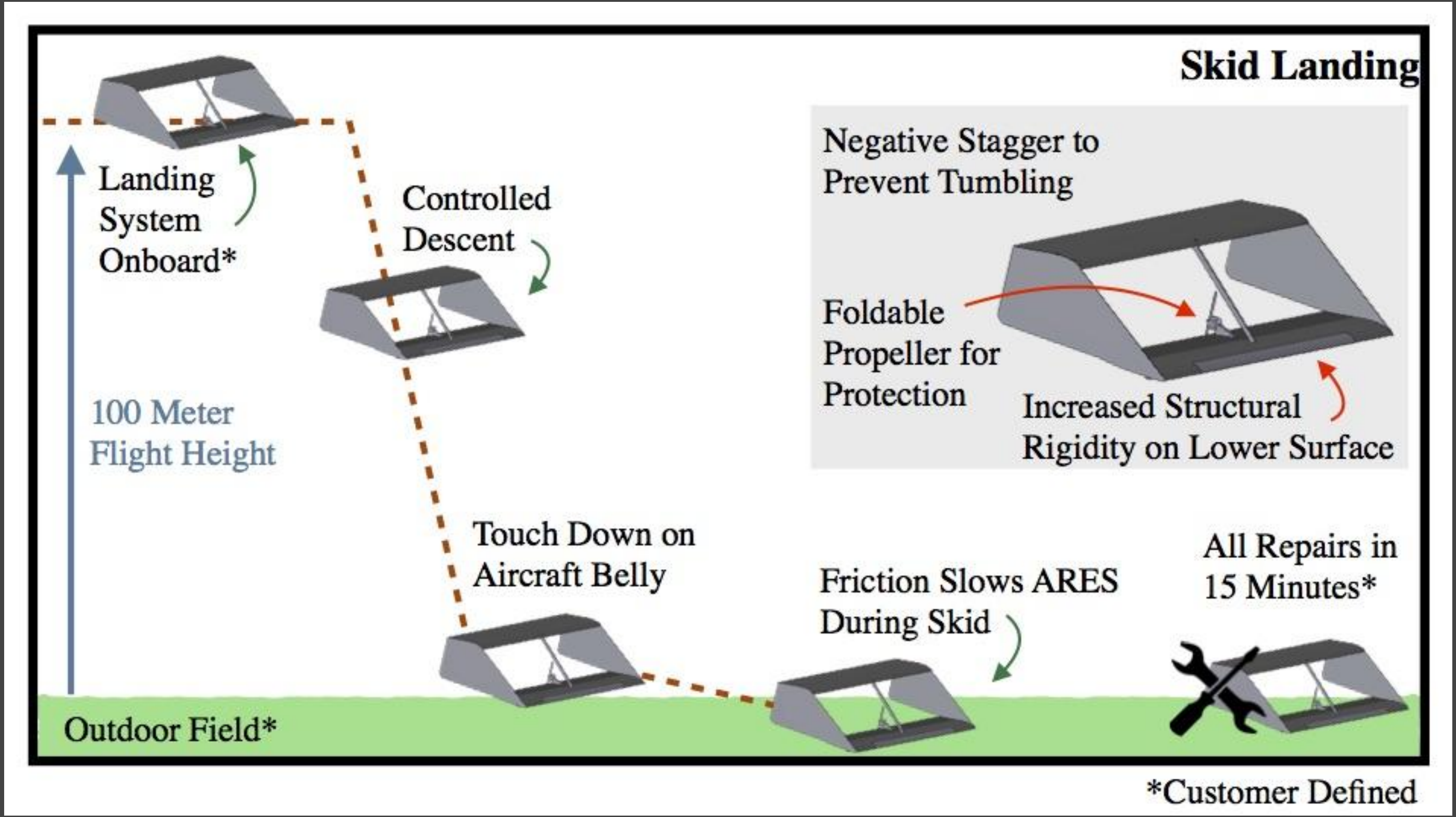


- Takeoff System based on a system with heritage: X8 Catapult.
- Consists of an aluminum carriage riding on a steel bar with bearings
- Kband Victory Ropes used for bungees

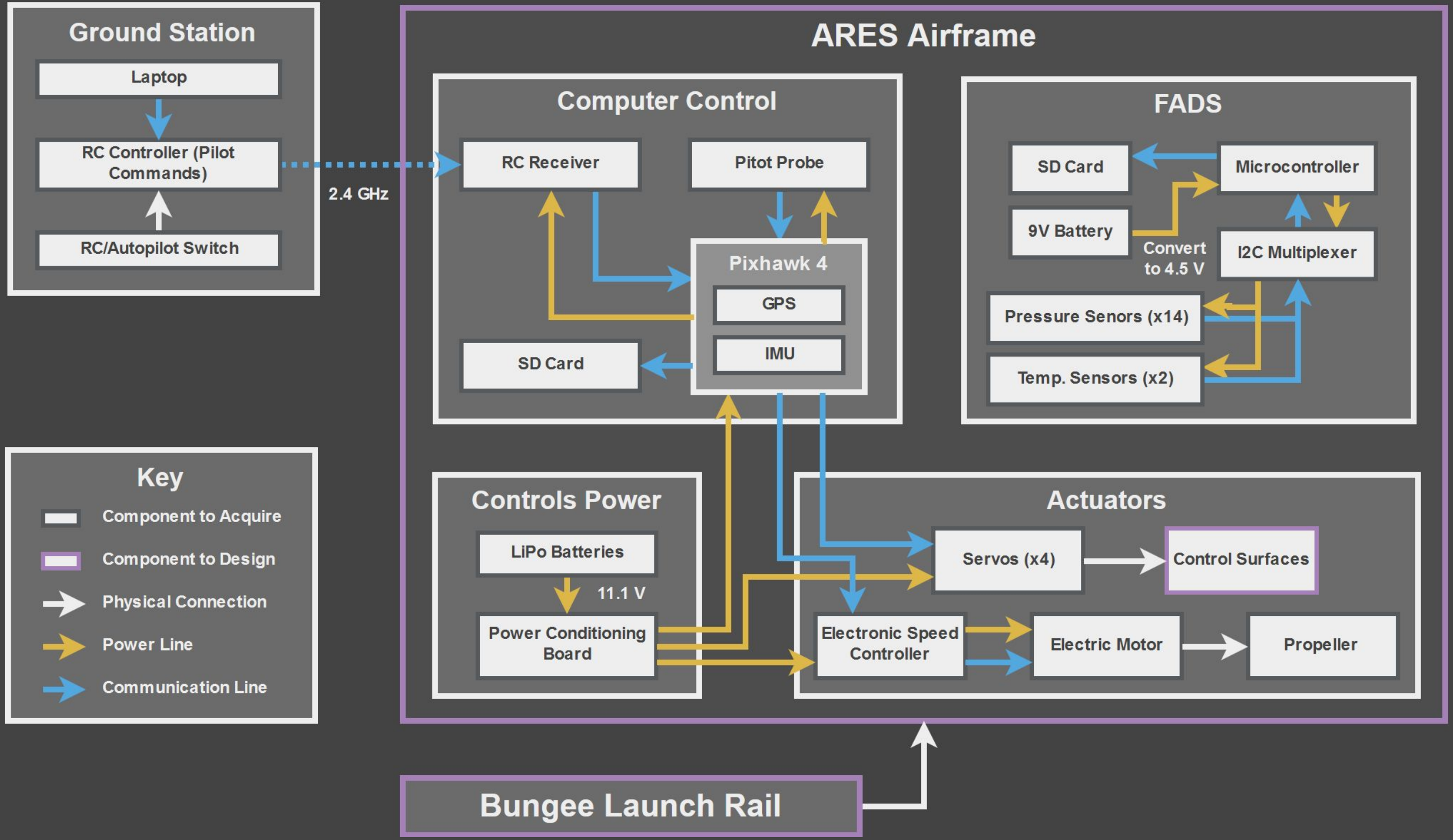
TAKEOFF DESIGN - LOCKED



LANDING DESIGN



FUNCTIONAL BLOCK DIAGRAM



Ground Station

Laptop

RC Controller (Pilot Commands)

RC/Autopilot Switch

2.4 GHz

ARES Airframe

Computer Control

RC Receiver

Pitot Probe

Pixhawk 4

GPS

IMU

SD Card

FADS

SD Card

Microcontroller

9V Battery

Convert to 4.5 V

I2C Multiplexer

Pressure Senors (x14)

Temp. Sensors (x2)

Controls Power

LiPo Batteries

11.1 V

Power Conditioning Board

Actuators

Servos (x4)

Control Surfaces

Electronic Speed Controller

Electric Motor

Propeller

Key

- ▭ Component to Acquire
- ▭ Component to Design
- → Physical Connection
- → Power Line
- → Communication Line

Bungee Launch Rail

CRITICAL PROJECT ELEMENTS (CPEs)

CRITICAL PROJECT ELEMENTS

CPE	Description
Wing Design	To achieve a 1 hour flight successfully, the box wing aircraft must be stable and have an airframe that is efficient.
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.
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.
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.
Landing	To be a full success, ARES must be able to withstand 10 takeoff and landing cycles and be able to takeoff within 15 minutes of landing.

DESIGN REQUIREMENTS & SATISFACTION

WING DESIGN

Driving Requirements

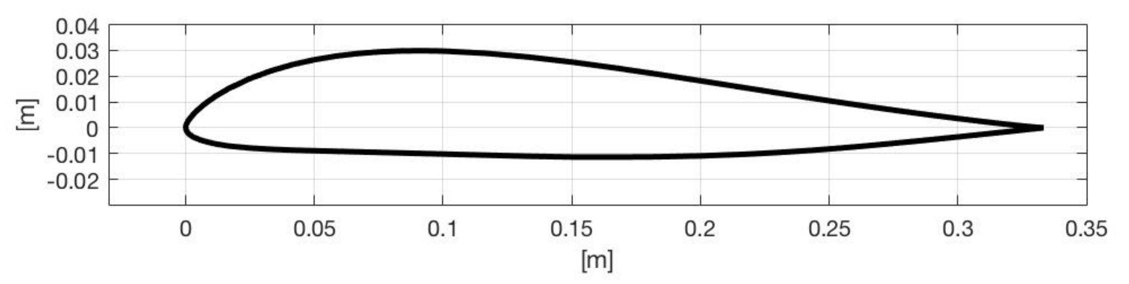
FR 2.0: The system shall be an aircraft with a box wing configuration with a span no larger than 2.0 m.

DR 2.1: The aircraft's structure shall only consist of two lifting surfaces connected by struts in the middle and walls on the outside such that it appears in a rectangular ”box” shape when viewed from the front and rear.

DR 2.2: The aircraft shall have a Lift-to-Drag ratio greater than that of previous designs from the Eagle Owl lineage (12).

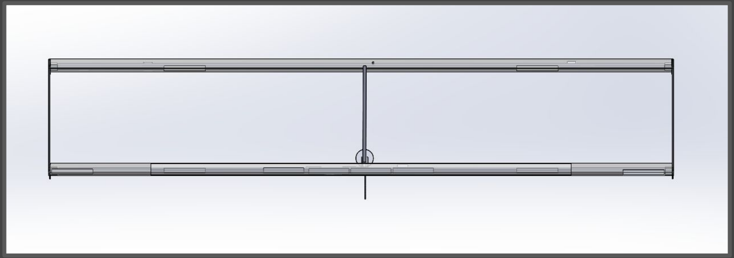
AIRFOIL: EH 3.0/12

- Reflexed
  - Helps stabilization for flying wings/aircraft without cantilevered tail system
- For RC Aircraft
  - Operates at lower Reynolds numbers
- Size
  - Thick enough for components
  - Light enough for flight
- Lift
  - High $C_{L,\,max} = 1.30$
- Dimensions - driven by AR
  - Span: 2.0 m
  - Chord: 0.333 m



AIRFRAME CONFIGURATION

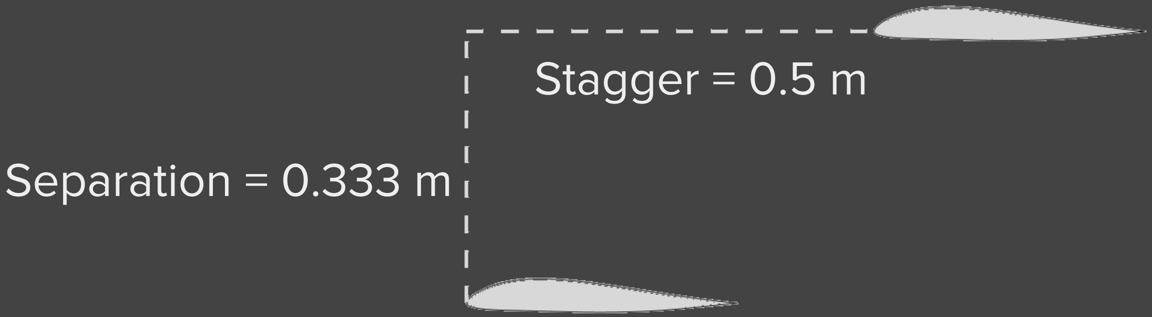
- Stagger
  - Stability
  - Weight
- Separation
  - Flow Interference
  - Weight
- Wing Characteristics
  - Wing Area = 1.33 m^2
  - Span = 2 m
  - Aspect Ratio = 3



ARES Front View

FR 2.0: Box shape, span ≤ 2m ✓

DR 2.1: Box-Wing Structure ✓

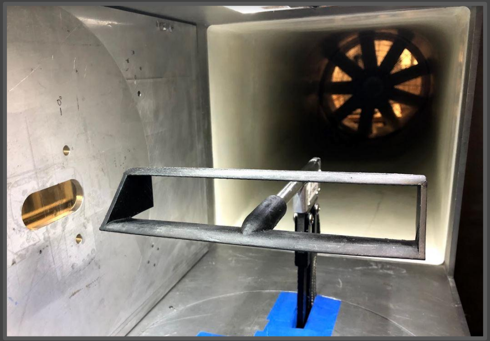


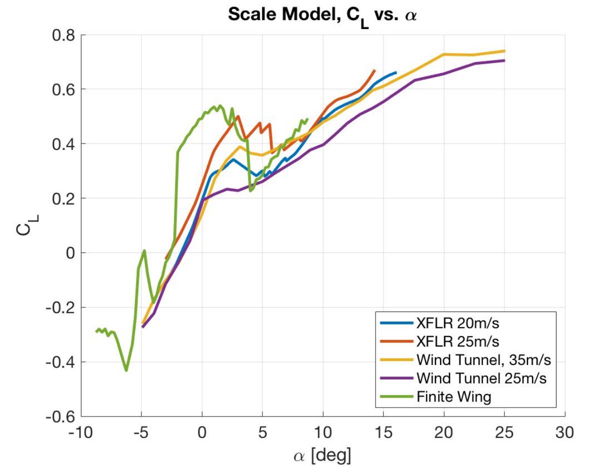
Stagger = 0.5 m

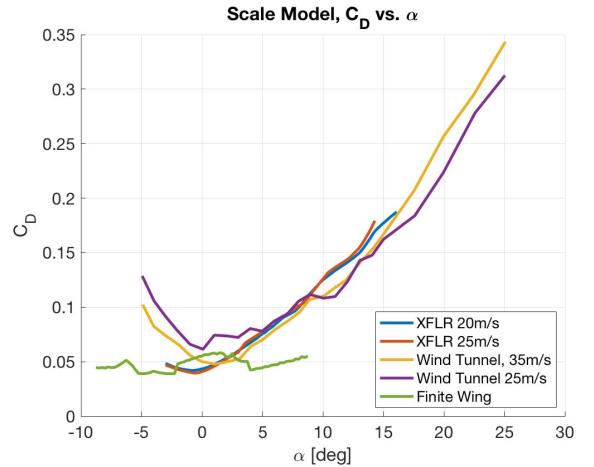
Separation = 0.333 m

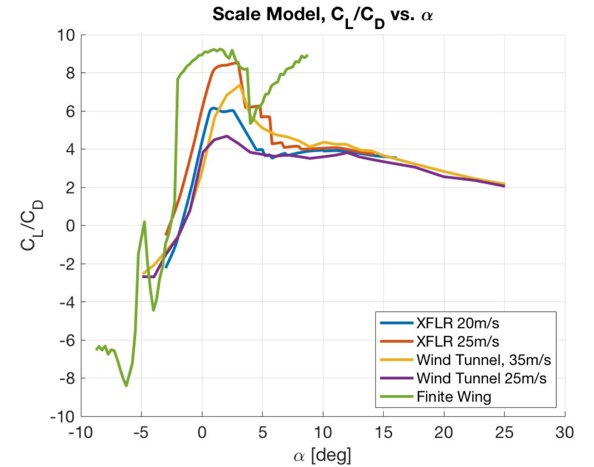
AIRFOIL MODELING VERIFICATION

- XFLR5 - Use to find C_L, C_D
  - Need to confirm theoretical results
- Wind Tunnel Test
  - EPPLER 339 Airfoil (previous design choice)



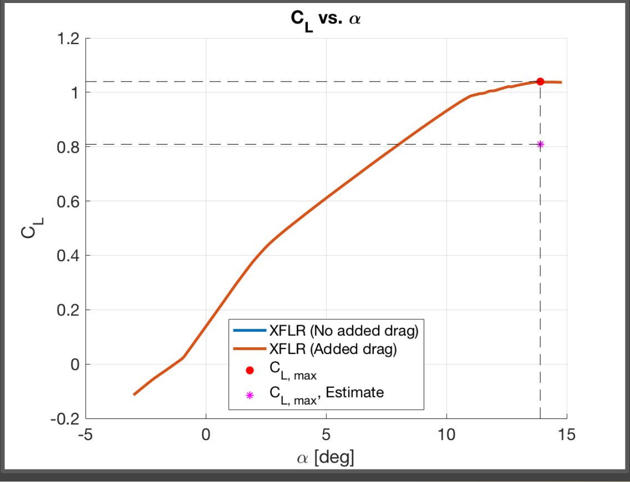

Scale Model, C_L vs. α

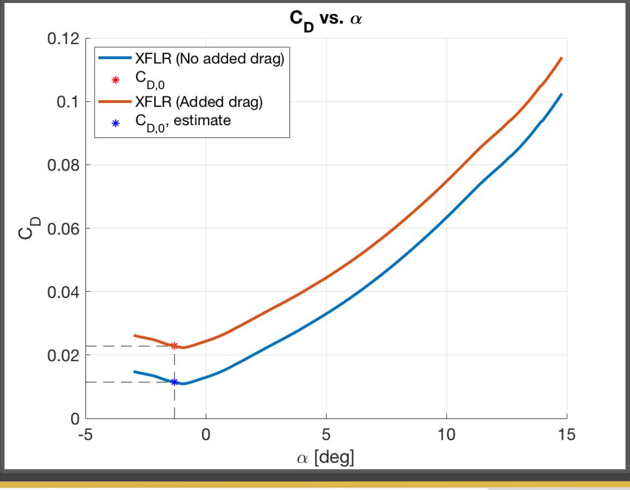

Scale Model, C_D vs. α

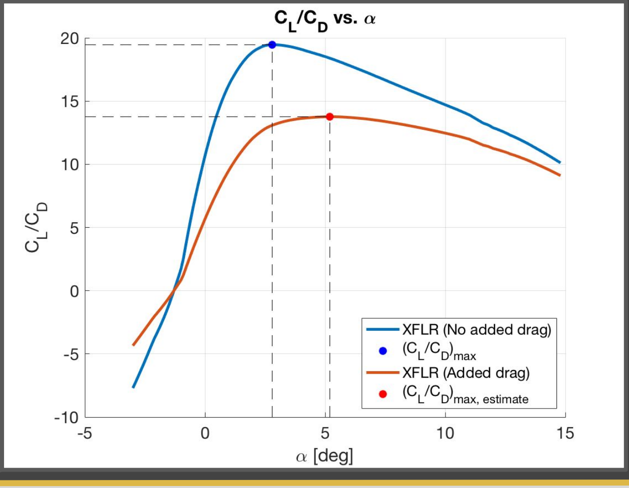

Scale Model, C_L/C_D vs. α

FLIGHT CHARACTERISTICS

- XFLR5
  - $C_{L,\ max} = 1.04$
  - $C_{D,0} = 0.0228$
- MATLAB Calculations
  - $V_{stall} = 8.36$ m/s
  - $\alpha_{stall} = 13.9$ deg
  - $V_{cruise} = 11.1$ m/s
  - $\alpha_{cruise} = 5.20$



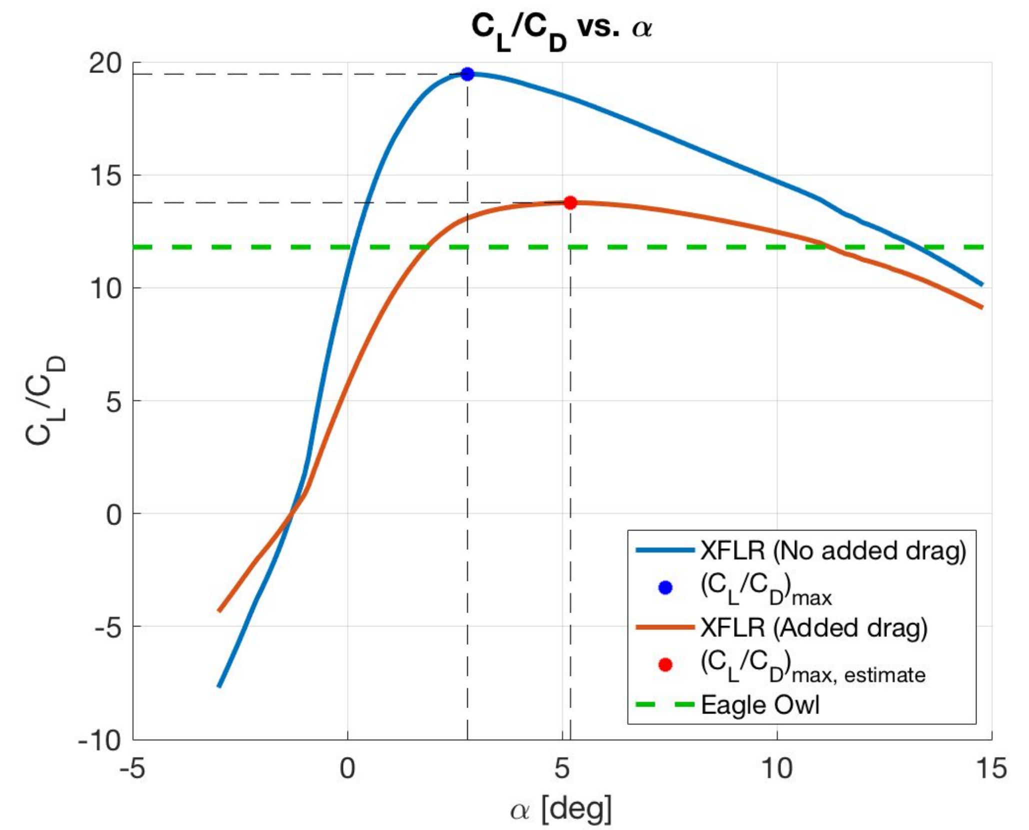




L/D CRITERION

- Eagle Owl
  - $L/D_{max} = 11.8$
- ARES
  - $L/D_{max,\ XFLR} = 19.5$
  - $L/D_{max,\ estimate} = 13.8$

DR 2.2:
L/D > 12 ✓

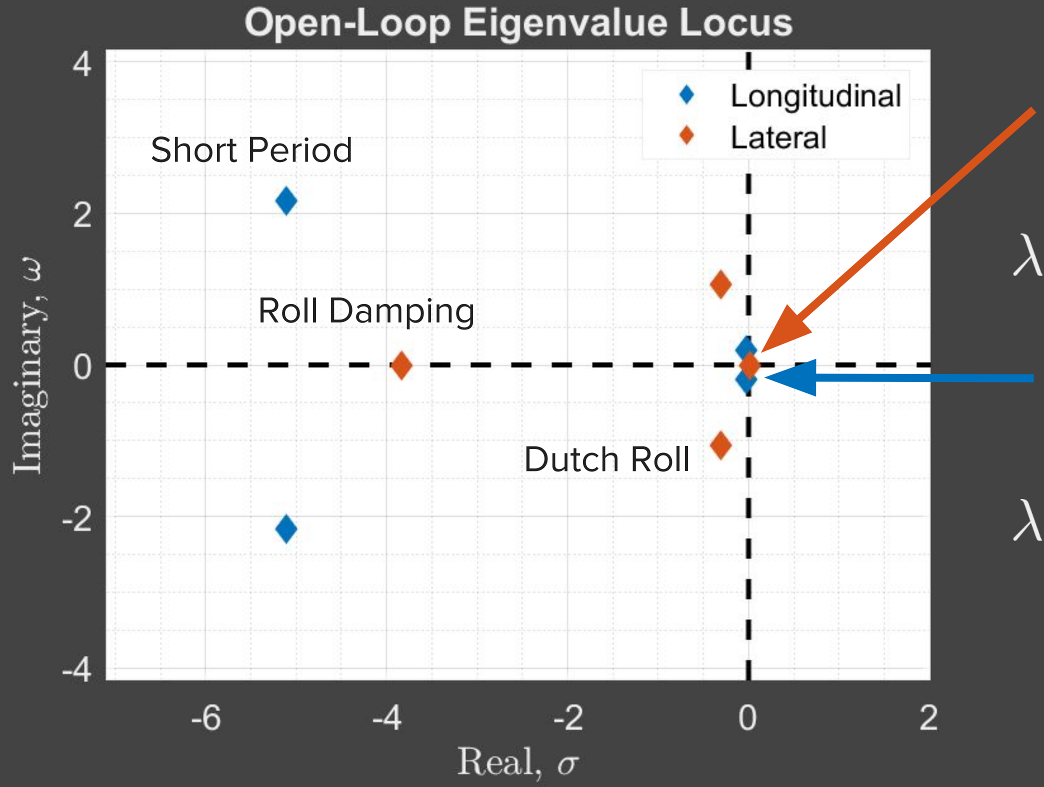


AUTOPILOT & CONTROL SYSTEM

Driving Requirements
DR 4.1: The aircraft's autopilot shall demonstrate steady level flight for at least 2 minutes by ensuring that the altitude disturbance does not exceed 3 meters.
DR 4.6: The autopilot shall be able to control the aircraft such that it performs a circular path.
DR 4.7: The autopilot system shall be able to send commands to actuators and the propulsion system to move control surfaces and make speed adjustments.

OPEN LOOP STABILITY

Athena Vortex Lattice (AVL) used to obtain aerodynamic state matrix.



Spiral mode is unstable due to lack of weathercock stability.

$$\lambda_{Spiral} = 0.0101$$

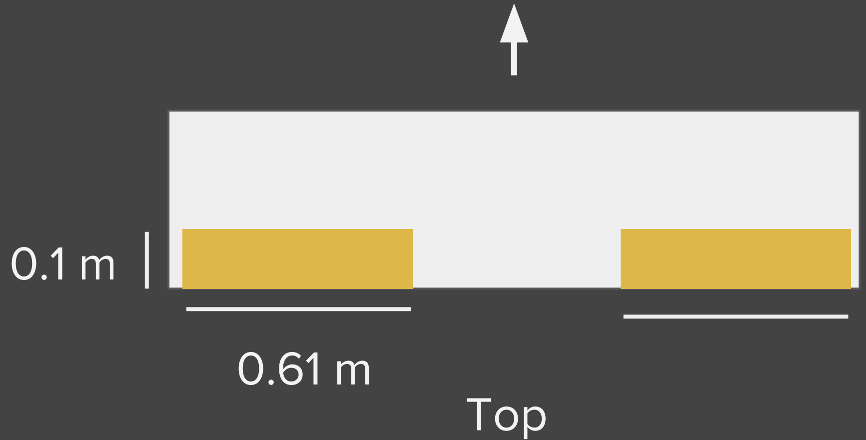
Phugoid mode is stable but has a very low time-constant.

$$\lambda_{Phugoid} = -0.0207 + 0.2004j$$

CONTROL SURFACES: ELEVONS

Pitch and roll stability given by elevons; typical delta wing setup. Elevons placed on the upper wing:

- Control surfaces farther from c.g. to create a larger moment arm
- Less interference with propeller airflow disruptions
- Safer landing



DR 4.6
Circular Path ✓

YAW CONTROL: SPLIT ELEVONS

Lack of sweep or vertical tail aft of c.g. requires active control of yawing motion to stabilize spiral mode.

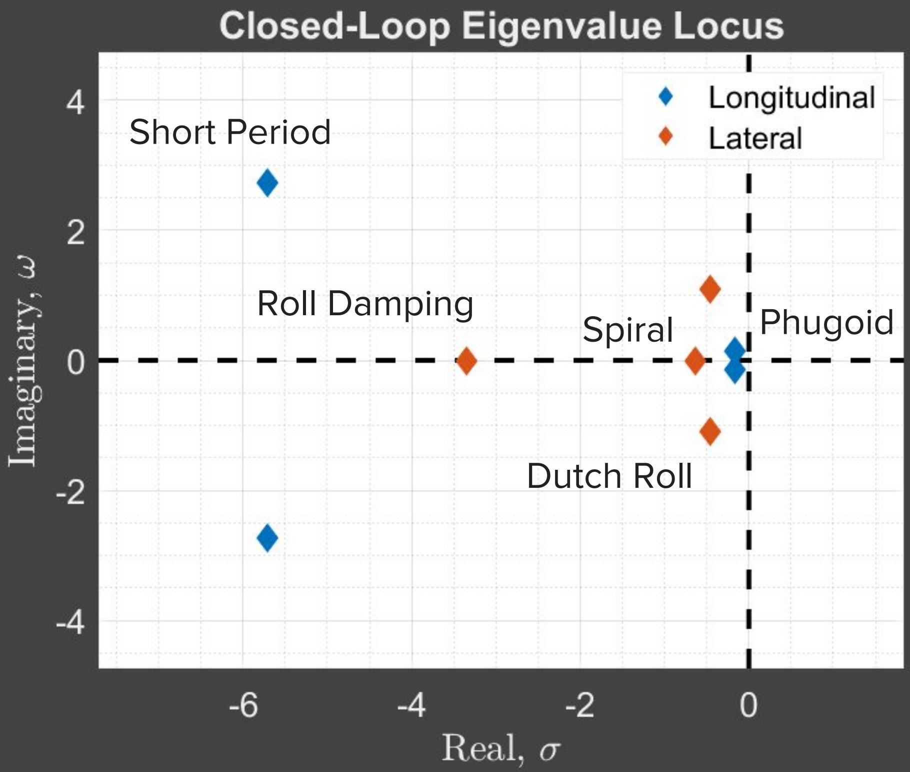
- Control each side separately. Increasing drag by splitting the elevons on one side produces yawing moment.

B2 stealth bomber

DR 4.7
Actuators move ✓

CLOSED LOOP STABILITY

With PD control, spiral is stabilized and Phugoid becomes more stable



DR 4.1
Steady level flight ✓

FLIGHT VIDEOS

- Half-scale model glide test
- Approximate reflexed airfoil shape used

PROPULSION SYSTEM

Driving Requirements

FR 1.0: The aircraft shall have a total flight endurance of at least 1 hour while maintaining visual sight with the operator.

DR 1.2.1: The propulsion system shall be capable of producing enough thrust for the aircraft to reach a flight speed between 10-30 m/s.

PROPULSION: PART SELECTION

Chose motor and propeller using online calculator eCalc: recommended by IRISS/RECUV propulsion experts

System Constraints:

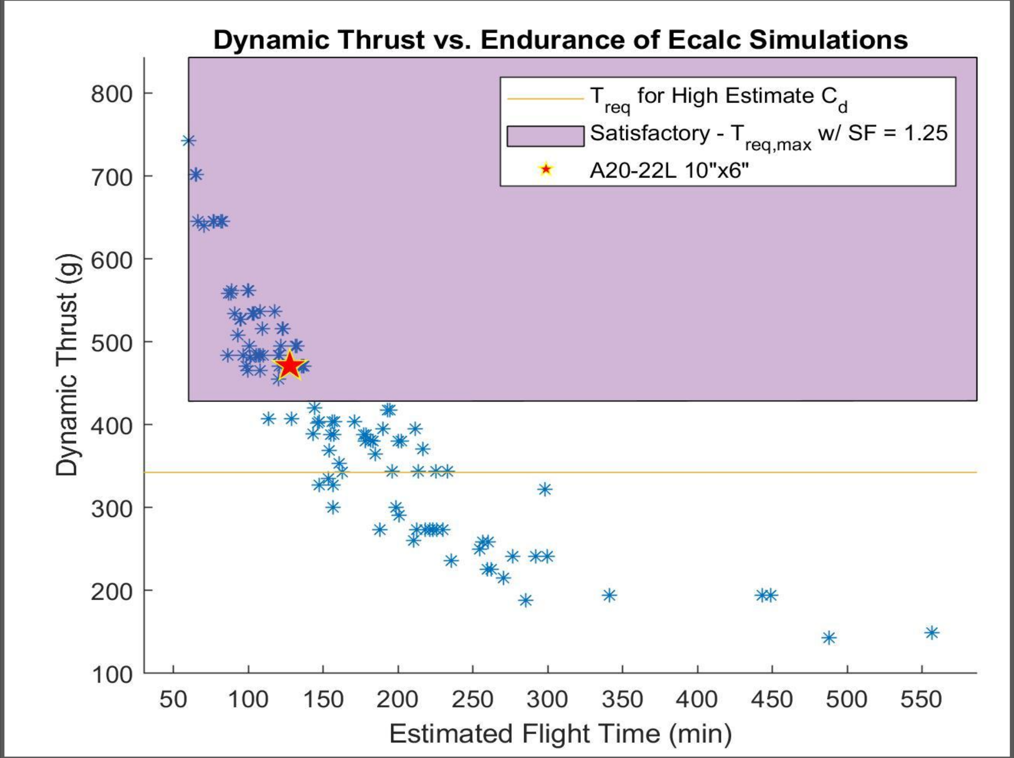
- $T_{req} = D = 428\ g = 4.20\ N$
- $V_{cruise} = 11.1\ m/s$
- $C_{d,max} = 0.051$

Hacker A20-22L EVO motor with 10”x 6” propeller

- Best weight, cost, ability
- Dynamic thrust at cruise: 488 g = 4.79 N
- Estimated endurance: 80-90 min
- Shimmed by 12.6° to counter CG offset

FR 1.0:
1 hr endurance ✓

DR 1.2.1:
V > 10 m/s ✓



FADS SYSTEM

Driving Requirements
FR 5.0: The recorded data shall be stored onboard and converted to relative wind speed after flight.
DR 5.1: An array of pressure sensors shall be integrated flush to the exterior of the airframe.
DR 5.5: An on-board computer shall be integrated with the pressure and temperature sensors.

FADS ANALYSIS

Airspeed can be calculated from static and stagnation pressure measured by the FADS system.

Airspeed Derivation:

Dynamic Pressure

$$q = P_t - P$$

Ideal Gas Law

$$\rho = P_t / RT$$

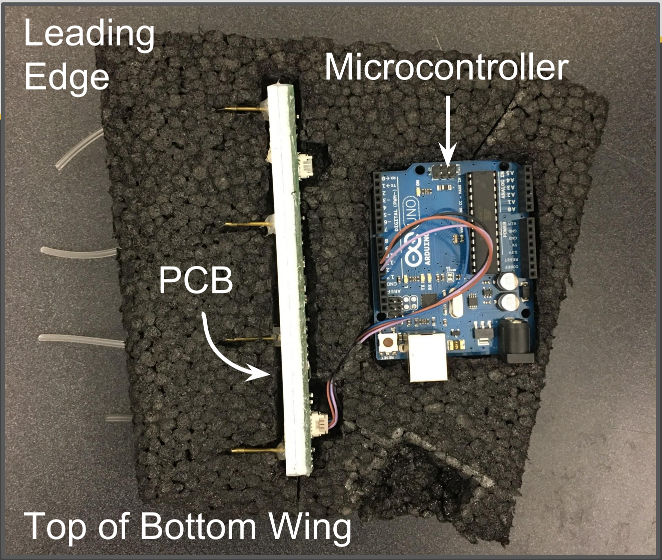
Airspeed

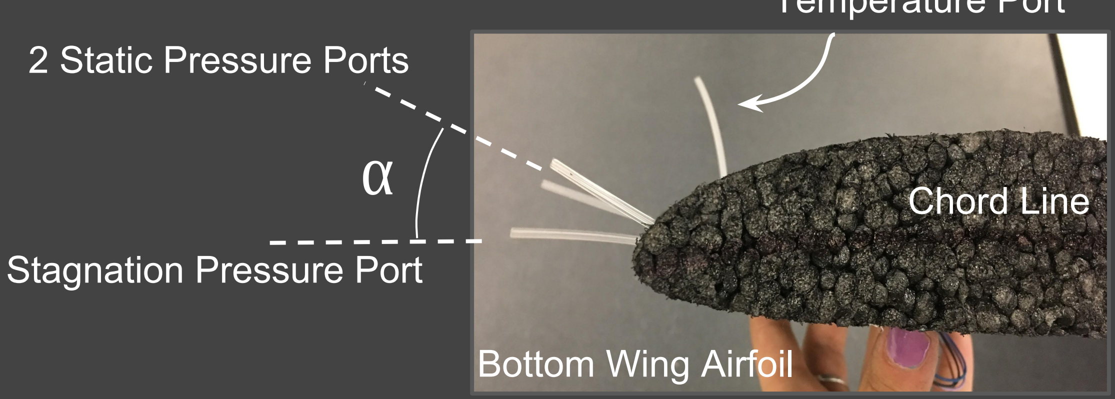
$$AS = \sqrt{2P_t(P_t - P)/RT}$$

DR 5.1:
Data converted to airspeed ✓

Integration:

DR 5.1:
Sensors flush with airframe ✓





AVIONICS SYSTEM

Driving Requirements
DR 1.1.1: The power system shall provide power to the propulsion system, autopilot, GPS, radio controller, and flight computer.
DR 1.1.2: The power system shall be rechargeable or replaceable between flights.

AVIONICS: BATTERY CHOICE

Controls

- 4x 3S LiPo batteries: 11.1 V, 30C, 3200 mAh
- Connected in parallel to increase capacity
- Requirement: 121 W and 11200 mAh
- Design: 142 W and 12800 mAh
- Safety Factor: 1.2

FADS

- Traditional 9 V Alkaline battery
- Converted down to 4.5 V to power Teensy
- Teensy powers I2C multiplexer and different sensors

DR 1.1.1:
Provide power for subsystems ✓

DR 1.1.2:
Replaceable / rechargeable ✓

Safety Precautions:

- Batteries will be charged and discharged as a set
- Will discharge at 1.56 C during steady flight (well below max rate of 30 C)

TAKEOFF SYSTEM

Driving Requirements
DR 3.2: The takeoff system shall be able to bring the aircraft to its desired initial velocity before it leaves the takeoff system.
DR 3.3: The takeoff system shall be capable of a minimum of 10 consecutive takeoffs.
DR 3.4: The aircraft shall not require repairs, due to takeoff, that last longer than 15 minutes after a full flight cycle (terminating with landing) has been completed.

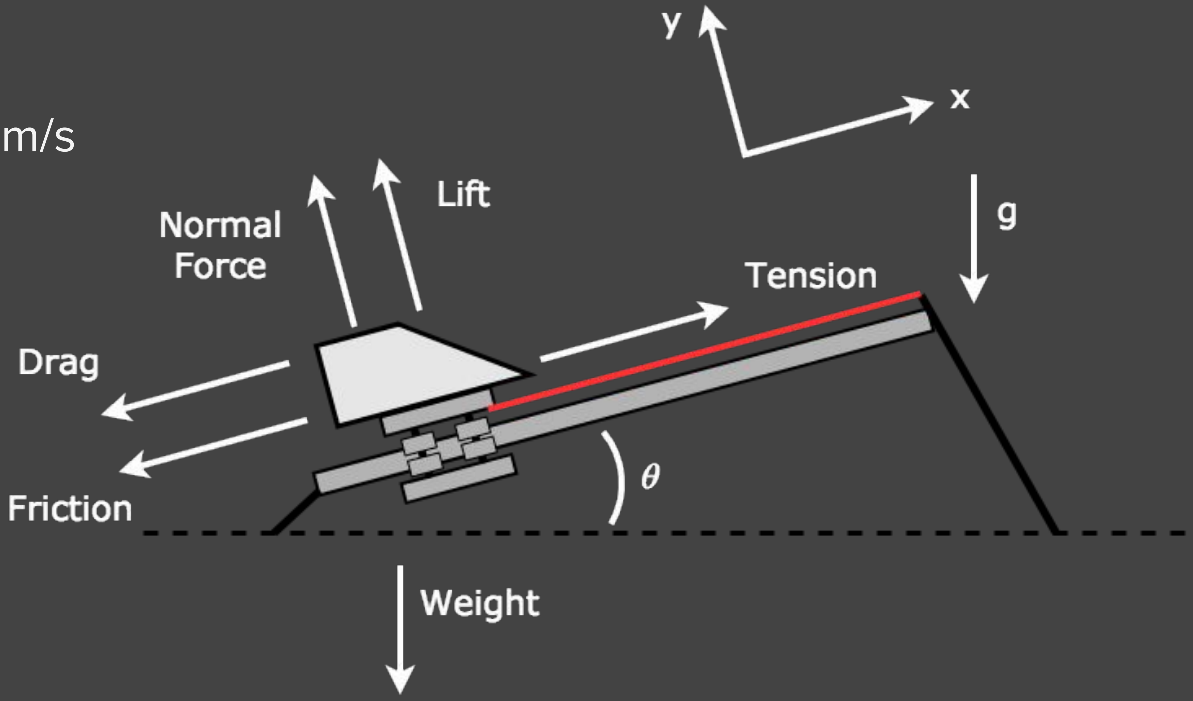
TAKEOFF SYSTEM

Model Input:

- V_{TO} (Takeoff Velocity) = 11.1 m/s
- ARES cruise speed

Model Output:

- Rail length
- Bungee force
- Forces on aircraft

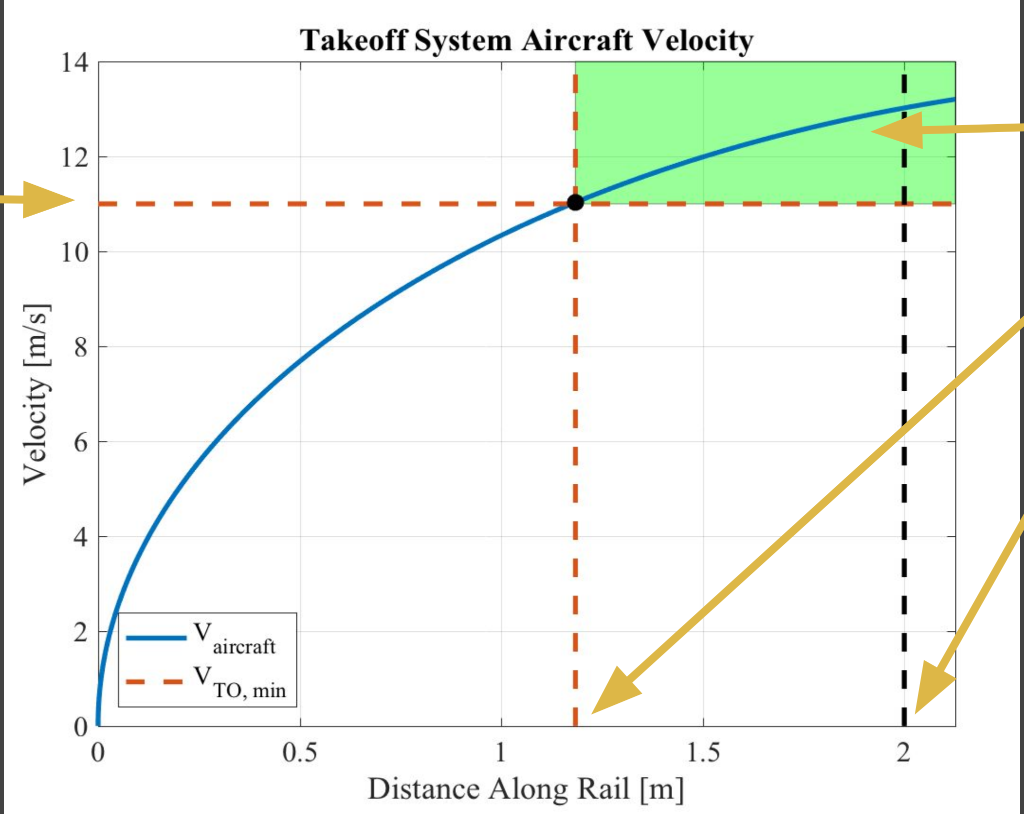


TAKEOFF SYSTEM

$V_{\text{TO, minimum}}$ = 11.1 m/s

Outputs:

Rail = 2 m
F_{bungee} = 399 N



Design Space

Min rail length: 1.18 m

Design rail length: 2.00 m

<u>Bungee Selection:</u>

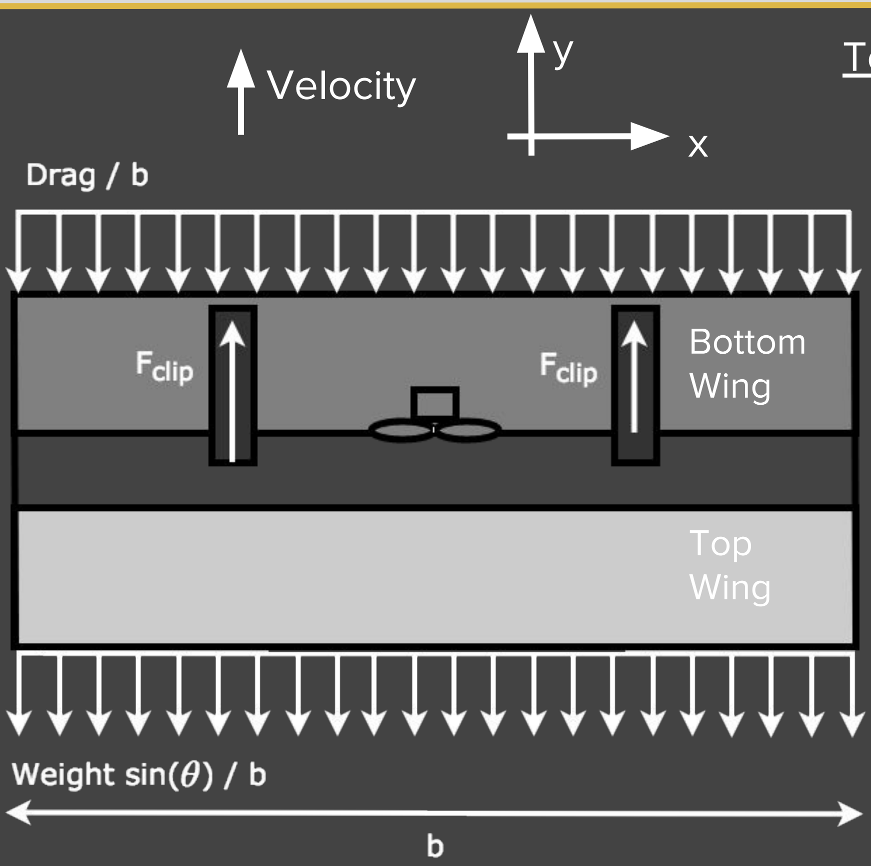
Kband Victory Ropes

534 N (max load)

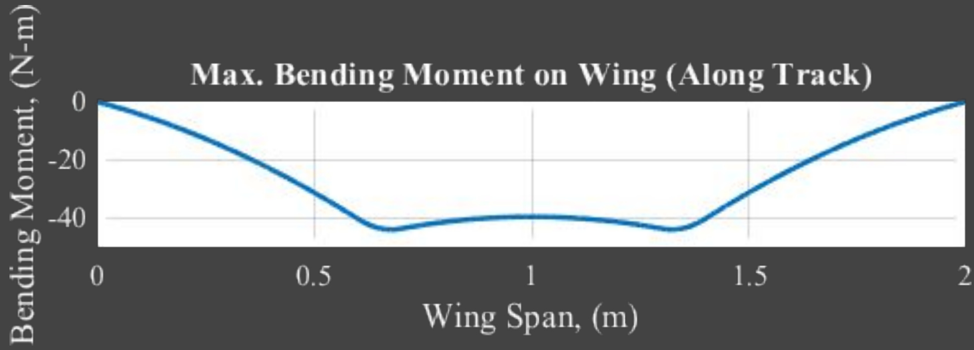
F.O.S. = 5.4

DR 3.2: Initial Velocity ✓

TAKEOFF SYSTEM



Top View

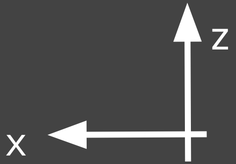


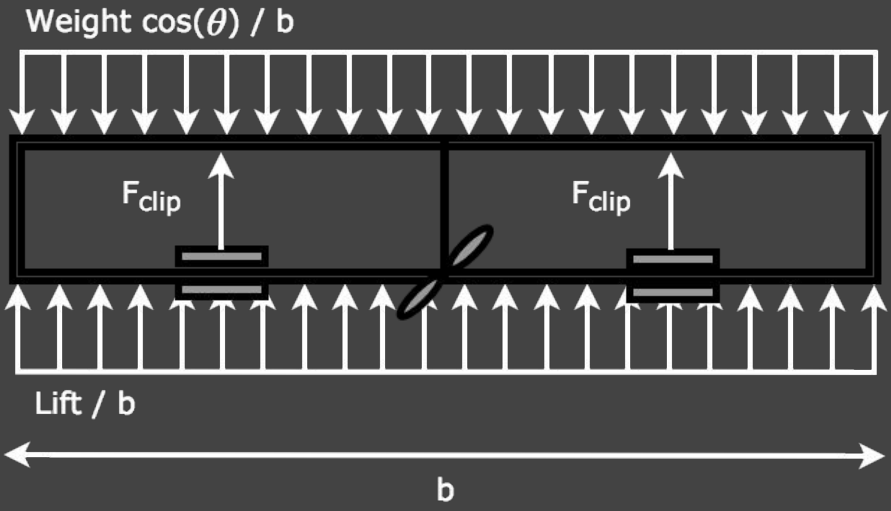
10.9 kPa < 290 kPa (EPP foam max shear)

F.O.S = 26

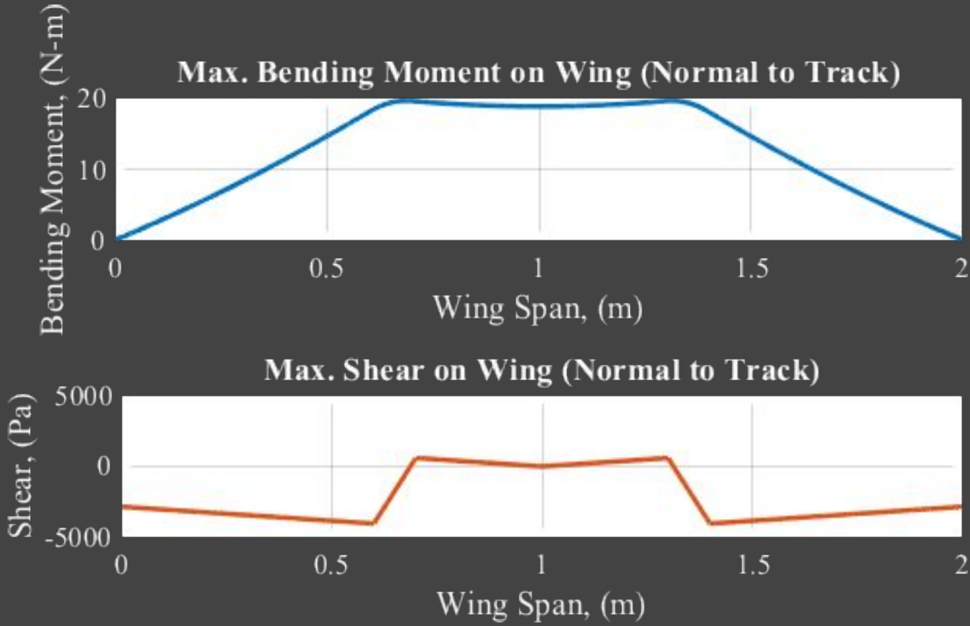
TAKEOFF SYSTEM

Velocity - out of page





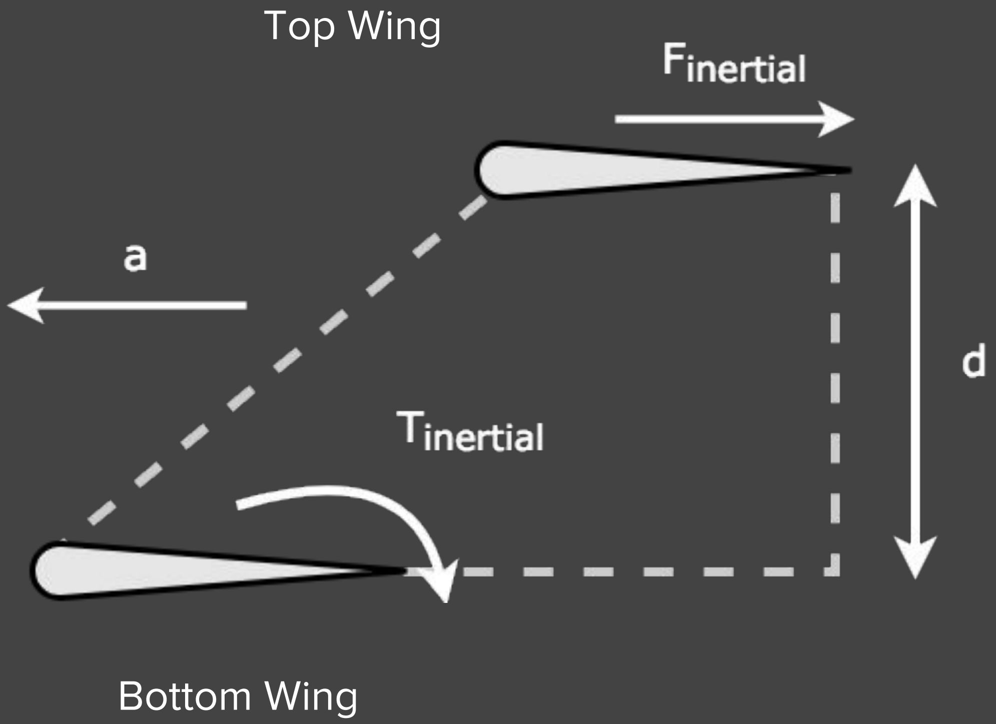
Front View



4.08 kPa < 290 kPa (EPP foam max shear)

F.O.S = 71

TAKEOFF SYSTEM



Torsion on bottom wing joints due to force required to accelerate top wing

$$F_{inertial} = m_{top\ wing}\ a$$

$$T_{inertial} = F_{inertial}\ d$$

$m_{top\ wing} = 0.622$ kg

$a_{max} = 63.9\ m/s^2$

$d = 0.330$ m

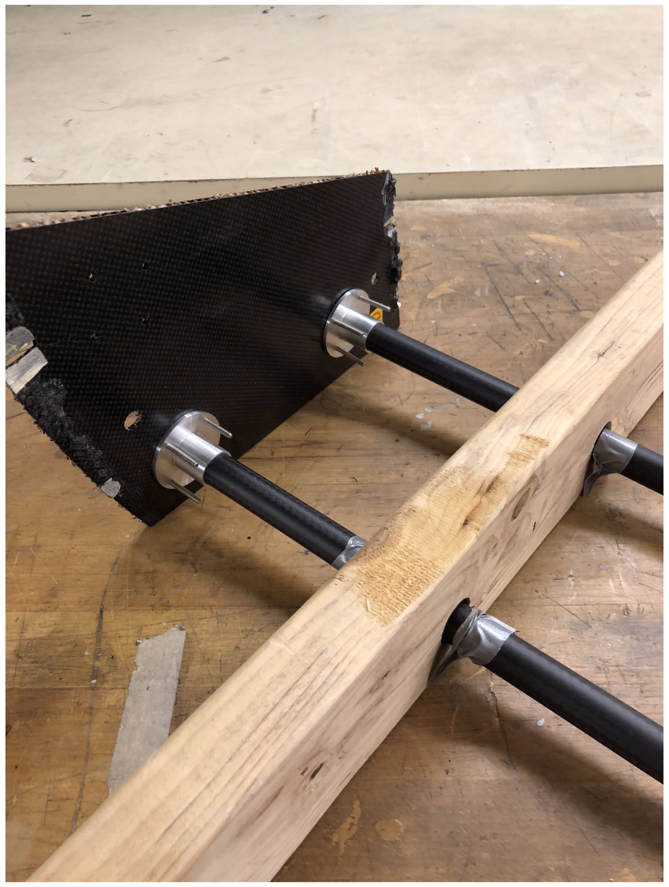
$T_{inertial} = 13.1$ N-m

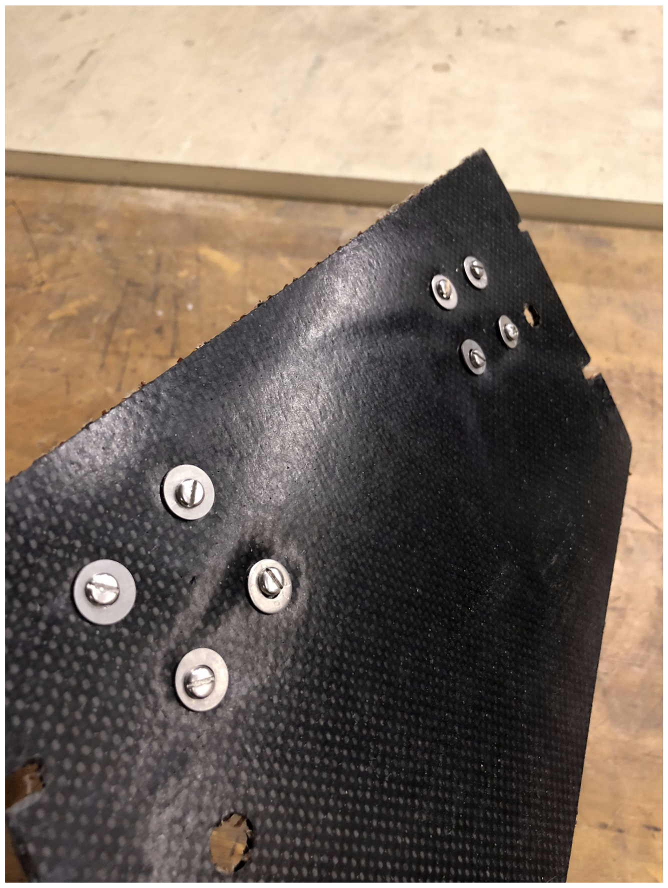
TAKEOFF SYSTEM

Torsion Test

- Failure at 67.8 N-m (50 ft-lbs)
- Inertial torque (modeled) of 13.1 N-m
- F.O.S. = 5.2

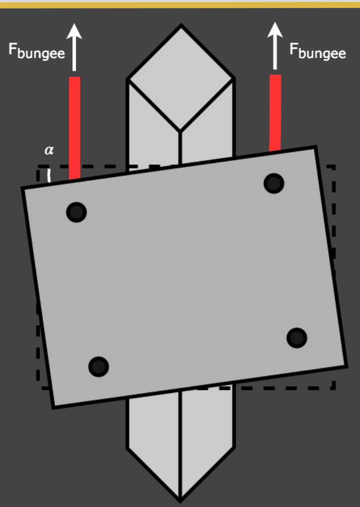
DR 3.4:
No damage from takeoff ✓



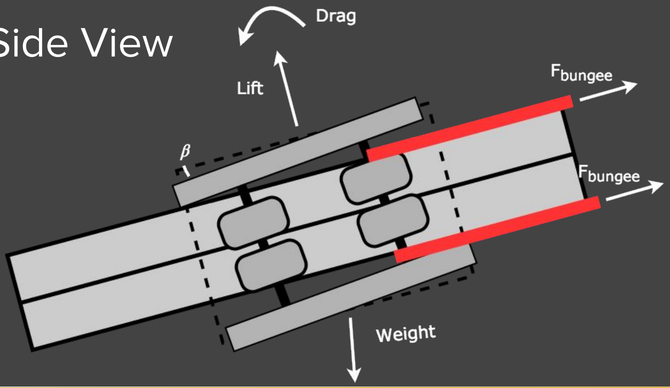


TAKEOFF SYSTEM

Top View



Side View



Carriage Binding

DR 3.3:
Able to take off 10 times ✓

LANDING SYSTEM

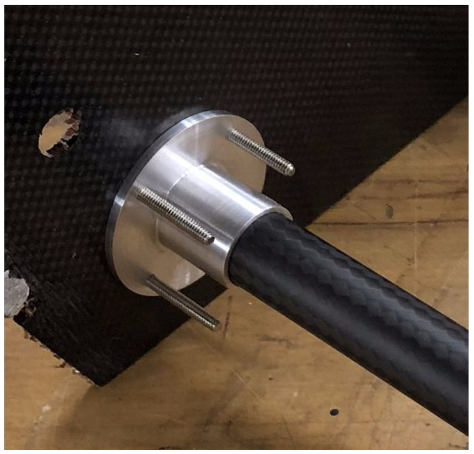
Driving Requirements
DR 6.1 The aircraft shall land such that it can takeoff again within 15 minutes.
DR 6.3 The aircraft shall be able to land in an outdoor field.

LANDING SYSTEM ANALYSIS

Concern: Joint Strength

Testing Results:

- Max torque = 67.8 Nm
- No failure in joint or carbon fiber rod
- Failure mode = carbon honeycomb



*Detailed FBDs & Equations in Backups

Structural Failure Contingency:

Component	Action	Time to Fix
Carbon Honeycomb	4 screws per joint	3 minutes
Center Strut	2 nuts and screws	5 minutes
Propeller	Remove spinner (1 screw)	2 minutes
Batteries	Remove tape, plug in new set	3 minutes

DR 6.1:
Takeoff again < 15 minutes ✓

*Repairs can be made at the same time

VERIFICATION & VALIDATION

VERIFICATION TESTS SUMMARY

Test	Driving Req.	Date	Method	Location/ Facility	Level of Success
W.D. - Flight Test	DR 2.3.1	02/15/19	Testing	CU South Campus	Flight 2
T.O. - Launch Velocity	DR 3.2 & DR 3.3	02/15/19	Testing	Elliott's Backyard 20x6m	-
T.O. - Stable Takeoff/Wing Deflection	DR 3.0 & DR 3.1	02/22/19	Testing	CU South Campus	Flight 2
Avionics - Charging/Discharging	DR 1.1.1 & DR 1.1.2	01/21/19	Testing	ASEN Senior Projects Lab	-
Avionics - FADS Calibration/Validation	DR 5.0, DR 5.1, DR 5.1.1, DR 5.2.1, DR 5.5.1, DR 5.5.3, DR 5.6.1	01/26/19	Testing	ITLL Wind Tunnel	Science 1 & 3
Prop. - Dynamometer	DR 1.2 & DR 1.2.1	02/15/19	Testing	CU ASEN Composites Lab	-

VERIFICATION TESTS SUMMARY

Test	Driving Req.	Date	Method	Location/ Facility	Level of Success
A.P. - AutoPilot Power	DR 4.3	01/21/19	Testing	ASEN Electronics Lab	-
A.P. - Pitot Tube Calibration	DR 4.7	01/26/19	Testing	ITLL Wind Tunnel	-
A.P. - RC Transmitter	DR 4.5 & DR 4.4 & DR 4.7	01/26/19	Testing	ASEN Senior Projects Room	Navigation/Control 1
A.P. - Control Surface	DR 4.5 & DR 4.7	02/11/19	Testing	ASEN Senior Projects Room	Navigation/Control 1
Landing - Dur. & Rep.	DR 6.3 & DR 6.7	03/01/19	Testing	CU South Campus	Landing 2 & 3
ARES Full System Flight Test	ALL Design Requirements	04/02/19	Testing	CU South Campus	All Success Criteria 2 & 3

VERIFICATION TESTS SUMMARY

Test	Driving Req.	Date	Method	Location/ Facility	Level of Success
Takeoff Observational	DR 3.3.1, DR 3.7, DR 3.7.1, DR 3.7.2	-	Visual/Mathematical	ASEN Senior Projects Room	-
Wing Design Observational	DR 2.1, DR 2.1.1, DR 2.1.2, DR 2.1.4, DR 2.2	-	Visual/Mathematical	ASEN Senior Projects Room	-
Avionics Observational	DR 1.1.3, DR 5.1.1, DR 5.1.2, DR 5.2, DR 5.3.1, DR 5.4, DR 5.5, DR 5.5.1, DR 5.5.2, DR 5.5.3, DR 5.6.1	-	Visual/Mathematical	ASEN Senior Projects Room	-
Propulsions Observational	DR 1.2.2	-	Visual/Mathematical	ASEN Senior Projects Room	-
Autopilot Observational	DR 4.4.1 & DR 4.6	-	Visual/Mathematical	ASEN Senior Projects Room	-
Landing Observational	DR 6.2, DR 6.2.1, DR 6.2.2, DR 6.4	-	Visual/Mathematical	ASEN Senior Projects Room	-

WING DESIGN FLIGHT TEST

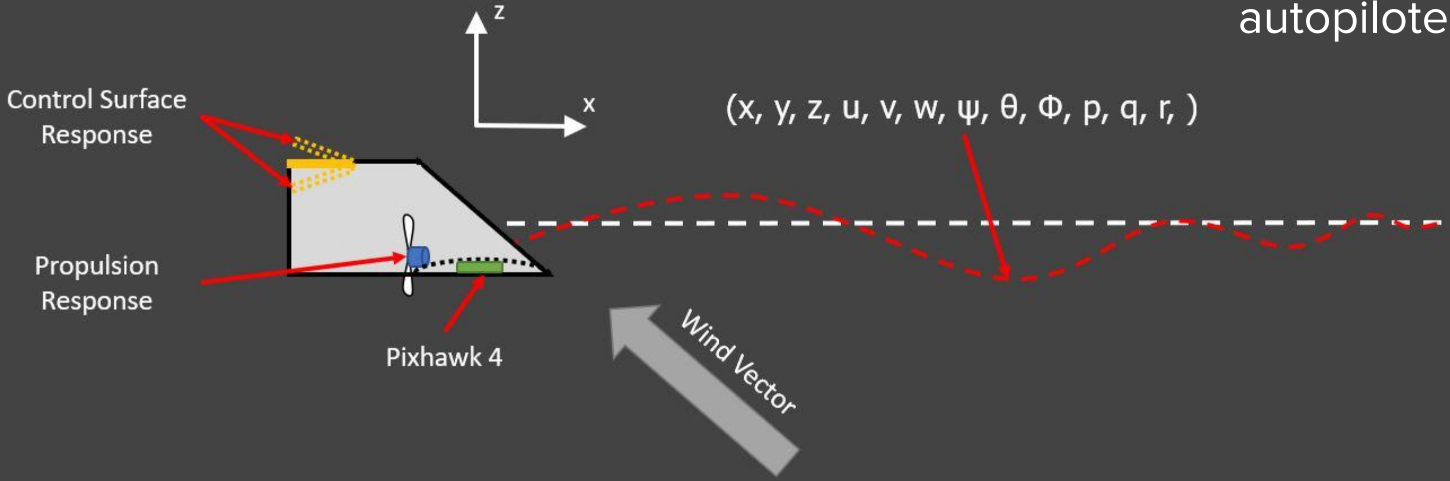
Driving Requirements

DR 2.1.3: The air frame shall be able to fly without a tail boom or any cantilever type structures attached to increase stability.

DR 4.1: The aircraft’s autopilot shall demonstrate steady level flight for at least 2 minutes by ensuring that the altitude disturbance is does not exceed 3 meters.

Objective:

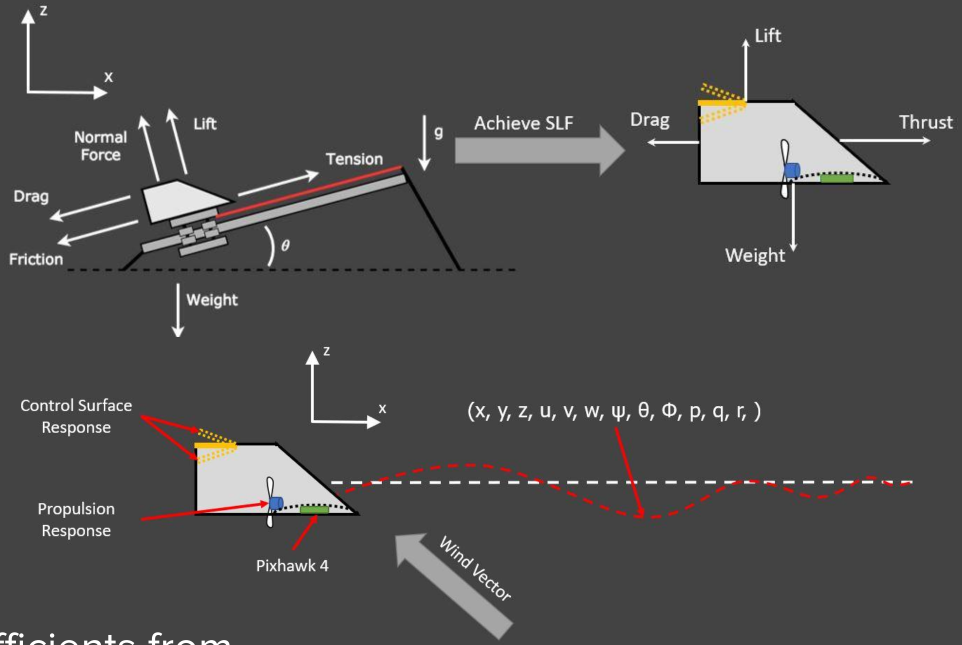
- Validate the modeled airframe response to wind disturbances in a both piloted and autopiloted mode



WING DESIGN FLIGHT TEST

Components:

- Takeoff Stand
- Bungees
- Rebar
- ARES Airframe Test Model
  - Motor
  - Speed controller
  - Receiver
  - **Pixhawk 4 (IMU & GPS)**
  - 4 Servos
  - Control Surfaces
  - 4 LiPo Batteries



- **Calculate:** Calculate Stability Coefficients from Flight Data to prove ARES stability without tail
- **Compare:** To ARES Flight Dynamics Models

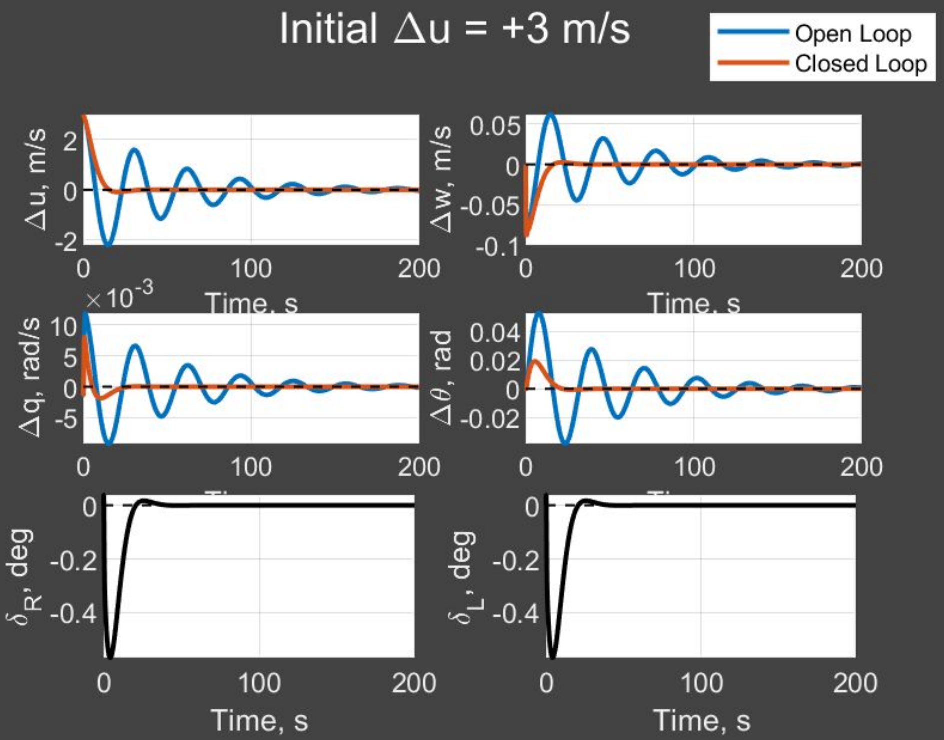
Device	Measurement	Accuracy
Pixhawk 4 ICM-20689 BMI055	x, y, z, ψ, θ, Φ u, v, w, p, q, r	± 2% ,± 0.04g's ± 1%, ± 0.164 °/s

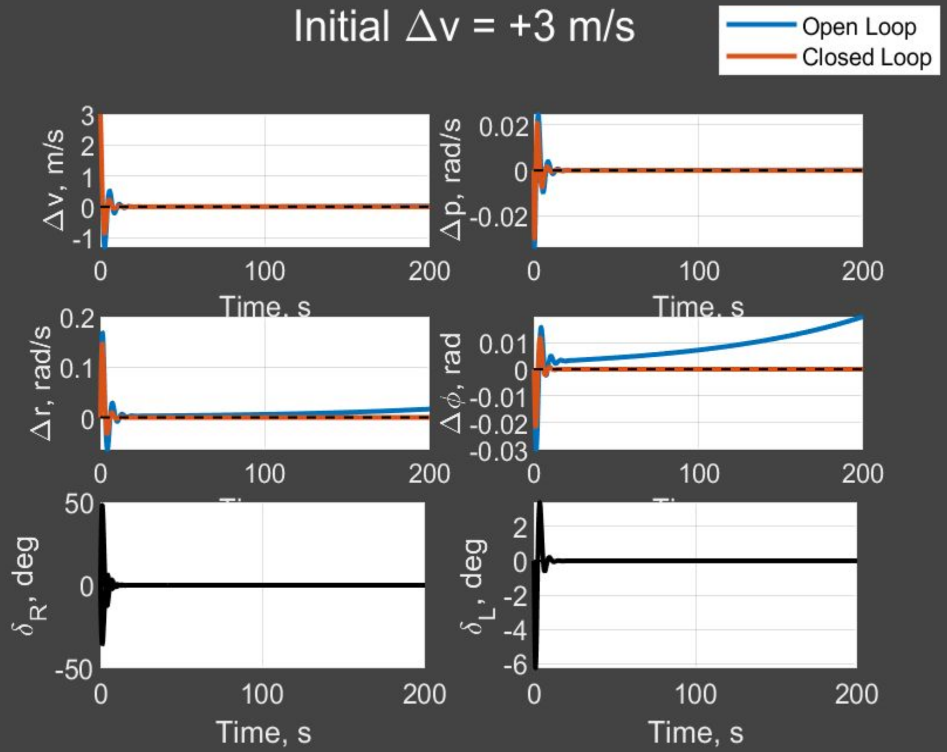
* ICM-20689: Accel/Gyro

* BMI055: Accel/Gyro

WING DESIGN FLIGHT TEST

ARES Flight Models

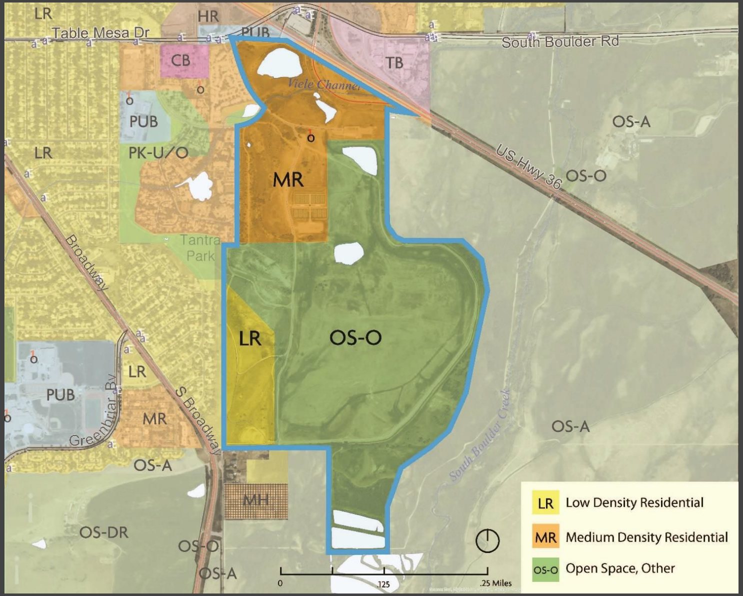




FLIGHT TEST LOCATION

CU Boulder South Campus - Open Space

- Flight access requirements:
  - AMA card of pilot
  - FAA registration number of drone
  - Dan Hesselius’ permission to fly



LAUNCH VELOCITY TEST

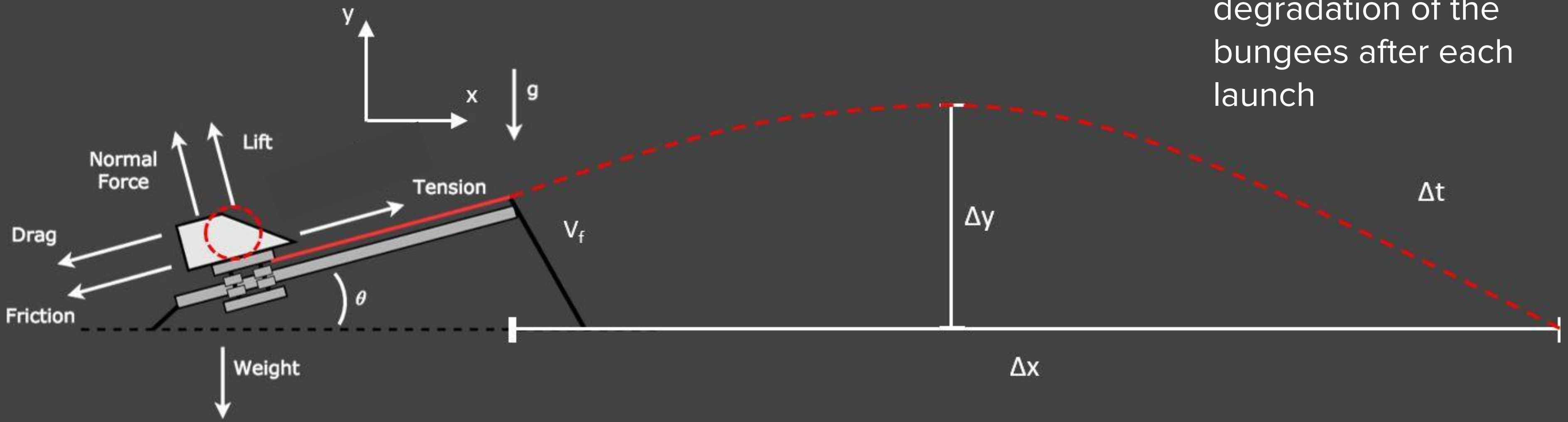
Driving Requirements

DR 3.2: The takeoff system shall be able to bring the aircraft to its desired initial velocity before it leaves the takeoff system.

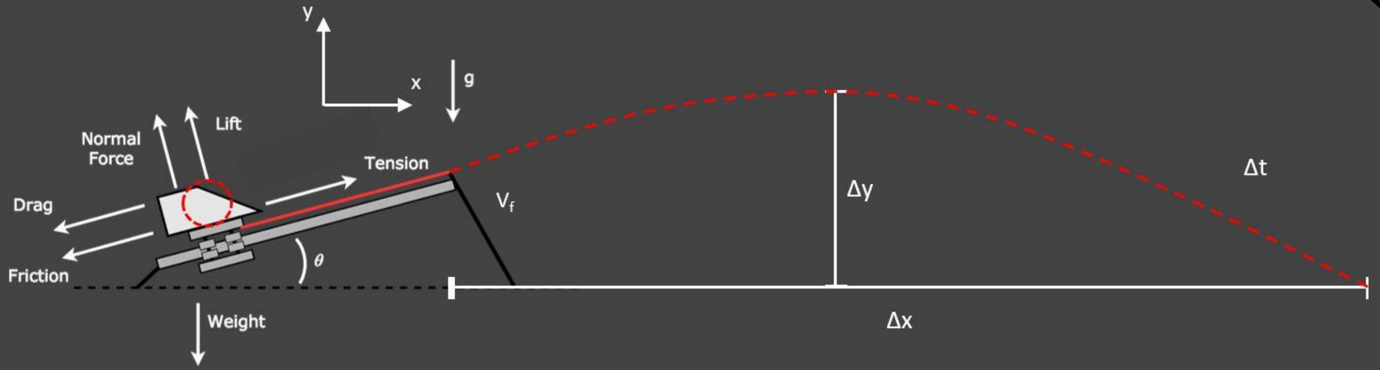
D.R 3.3: The takeoff system shall be capable of a minimum of 10 consecutive takeoffs.

Objective:

- Validate the Launch System's ability to provide the required $V_{Launch} = 11.1\text{m/s}$
- Validate the degradation of the bungees after each launch



LAUNCH VELOCITY TEST



Components:

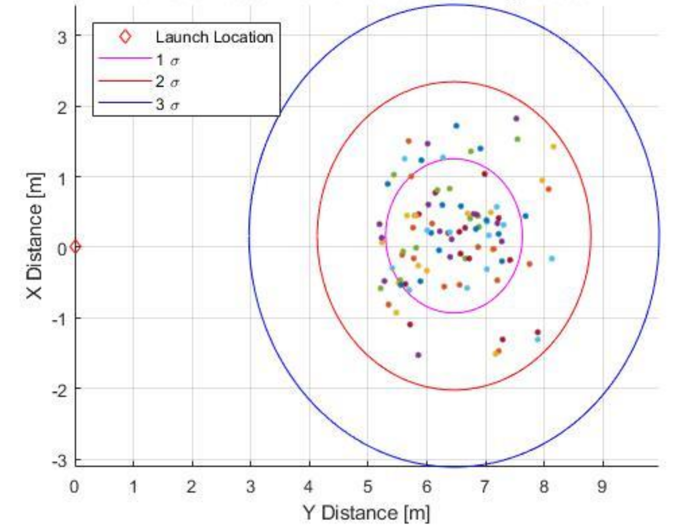
- Launch System
  - Bungees
  - Rebar
  - Ballistic Mass (Sandbag)
  - ARES Airframe Test Model

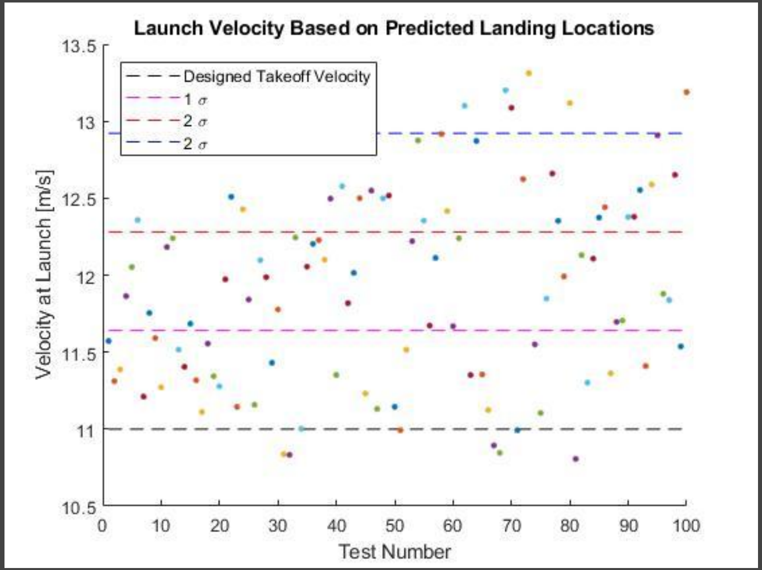
- **Location:** Team Member’s Backyard (20x6m)
- **Record:** the launch distance (Δx), launch height (Δy), launch time (Δt), and film each launch
- **Calculate:** Launch Velocity (V_f), Launch Force (F), and degradation of bungee force applied (F_{app}).
- **Compare:** Ballistic Models to data recorded

Device	Measurement	Accuracy
Measuring Tape	Distance [m]	± 1mm
iPhone 10 Camera	Height [m]	± 6.1%

LAUNCH VELOCITY TEST

Ballistic Modeling for Comparison



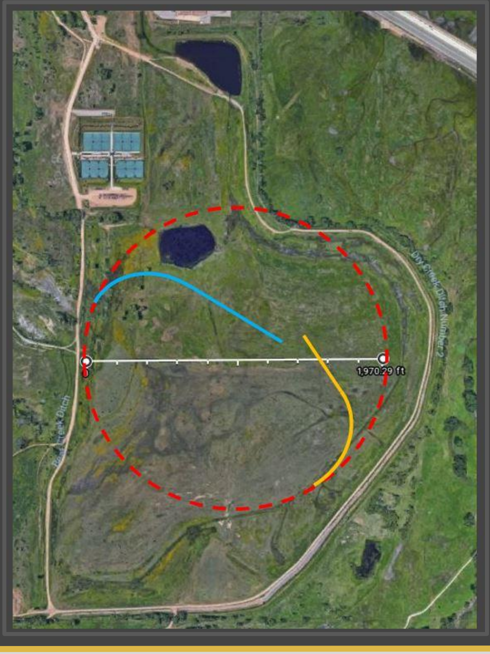


FULL SYSTEM FLIGHT TEST

Driving Requirements
All Functional Requirements and Design Requirements

- Test Description (follows ConOps process):
  - Power on ARES Aircraft
    - Being recording temperature and pressure data
    - Confirm RC connection by actuating surfaces & powering motor
  - Launch ARES from Takeoff Launch System at **CU South Campus**
  - Fly up to 100m altitude, allow autopilot to fly 300m radius circle
  - Continue flight for > 1 hour, descend, and land
  - **Validate:** All levels of success

🟦 - Takeoff/Ascent Path
🟥 - 1 hour Flight Circle
🟧 - Landing/Descent Path



RISK ANALYSIS

RISKS

Risk	Mitigation Plan	Post Mitigation: Likelihood	Post Mitigation: Impact
1) Accidentally reaching stall due to inaccuracy in estimated stall speed	• Factor of safety introduced to V_{Cruise} • Additional stall testing planned	2	5
2) AVL and XFLR inaccuracy to actual aircraft behavior	• Scale model testing to validate results	3	3
3) Lack of control authority during complex maneuvers	• Use X-Plane hardware in the loop simulator • Max T/W above T/W required for cruise	3	3
4) Carbon honeycomb side panels fail during landing	• Manufacture extra side panels to replace any broken components	3	2
5) Battery combustion while charging / after puncture	• Shield batteries with carbon fiber plate • Charge and discharge together • Replace if discharged below 15%	1	5

1 = lowest likelihood/ severity

5 = highest likelihood/ severity

PRE-MITIGATION RISK MATRIX

		Severity				
		NEGLIGIBLE	MARGINAL	MODERATE	CRITICAL	CATASTROPHIC
Probability	Very Unlikely	🟩	🟩	🟩	🟨	🟨
	Low Likelihood	🟩	🟩	🟨	🟨	🟥 5
	Likely	🟩	🟨	🟨	🟥 3 4	🟥 1
	Extremely Likely	🟨	🟨	🟥	🟥 2	🟥

POST-MITIGATION RISK MATRIX

		Severity				
		NEGLIGIBLE	MARGINAL	MODERATE	CRITICAL	CATASTROPHIC
Probability	Very Unlikely	🟩	🟩	🟩	🟨	🟨 5
	Low Likelihood	🟩	🟩	🟨	🟨	🟥 1
	Likely	🟩	🟨 4	🟨 2 3	🟥	🟥
	Extremely Likely	🟨	🟨	🟥	🟥	🟥

MAJOR RISK ANALYSIS

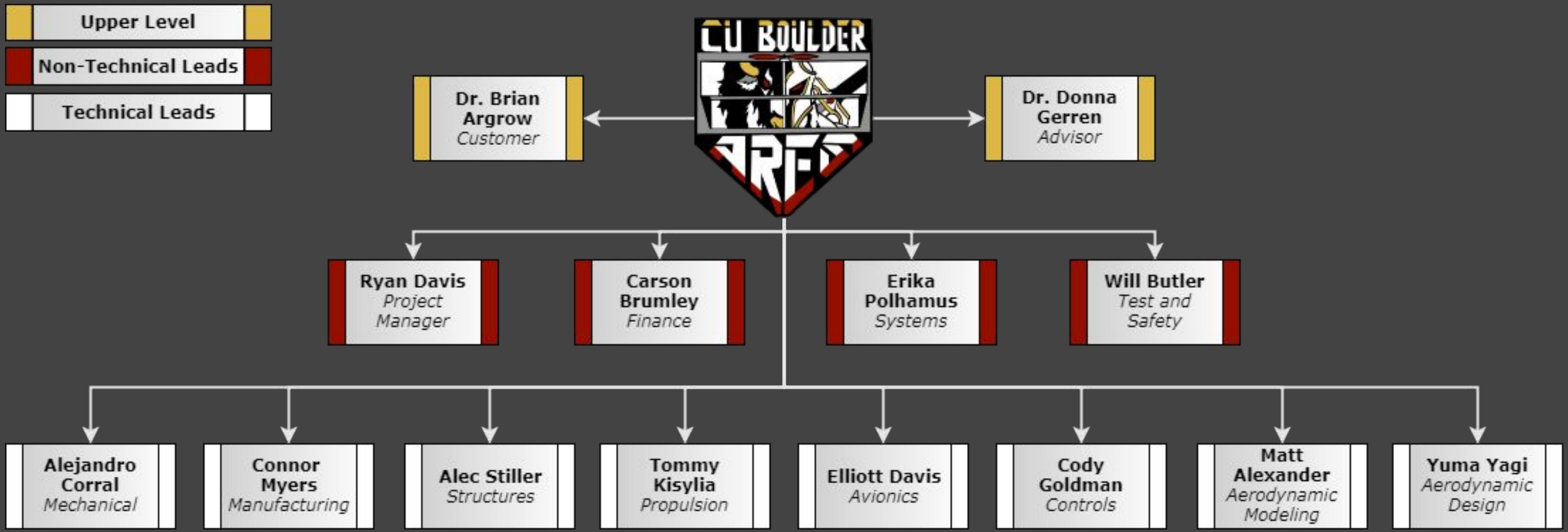
Risk 1:

Description: Inaccuracy and uncertainty in modeling gives an unreliable stall speed. At a high altitude and mid flight, this can end in a crash that destroys the aircraft

- Pre Mitigation
    - Likelihood: 3
    - Impact: 5
- Post Mitigation
    - Likelihood: 2
    - Impact: 5
- Mitigated by adding in a factor of safety to increase cruise speed and real world testing planned to achieve better estimations ✓

PROJECT SUMMARY

TEAM ORGANIZATION



🟨 Upper Level
🟥 Non-Technical Leads
⬜ Technical Leads

Dr. Brian Argrow *Customer*

Dr. Donna Gerren *Advisor*

Ryan Davis *Project Manager*

Carson Brumley *Finance*

Erika Polhamus *Systems*

Will Butler *Test and Safety*

Alejandro Corral *Mechanical*

Connor Myers *Manufacturing*

Alec Stiller *Structures*

Tommy Kisylia *Propulsion*

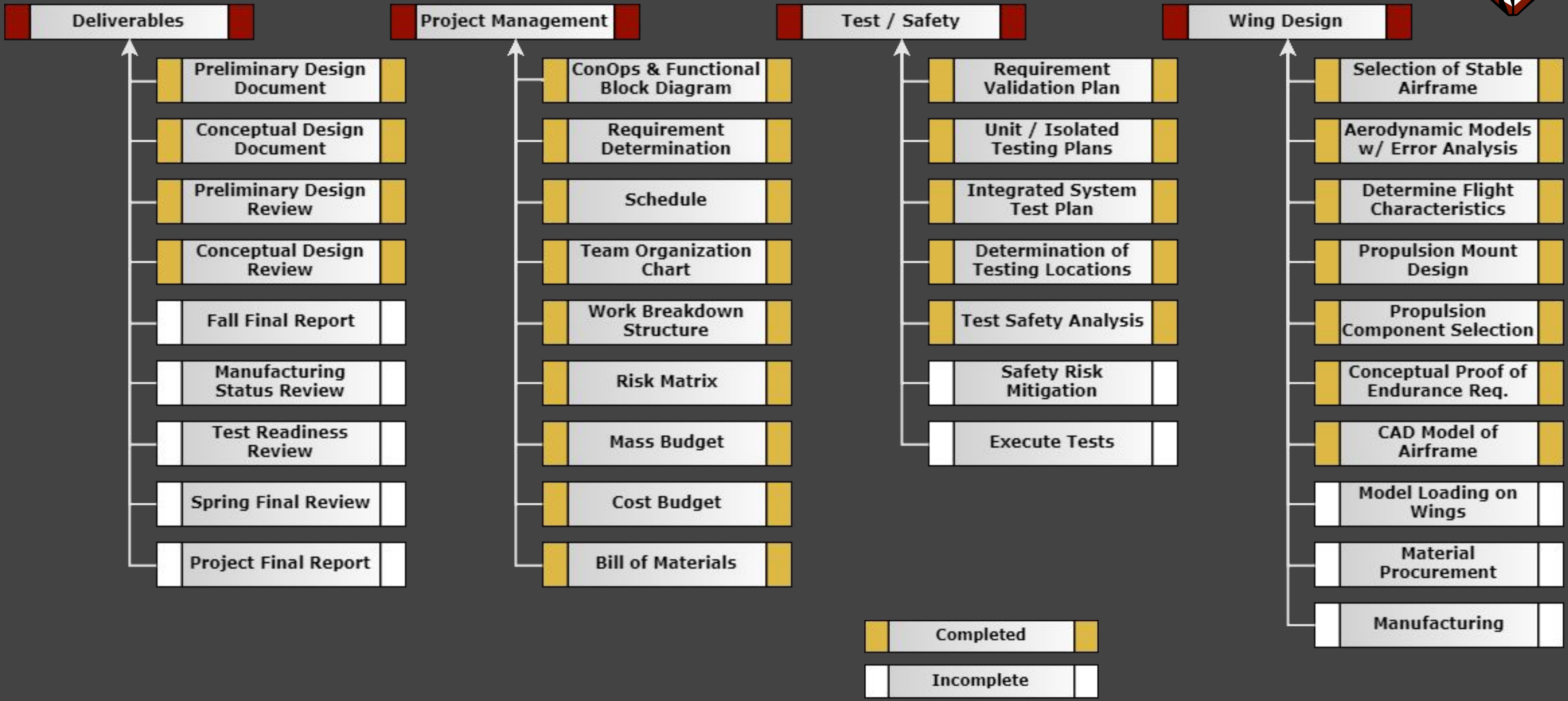
Elliott Davis *Avionics*

Cody Goldman *Controls*

Matt Alexander *Aerodynamic Modeling*

Yuma Yagi *Aerodynamic Design*

WORK BREAKDOWN STRUCTURE



Deliverables
- 🟨 Preliminary Design Document
- 🟨 Conceptual Design Document
- 🟨 Preliminary Design Review
- 🟨 Conceptual Design Review
- ⬜ Fall Final Report
- ⬜ Manufacturing Status Review
- ⬜ Test Readiness Review
- ⬜ Spring Final Review
- ⬜ Project Final Report

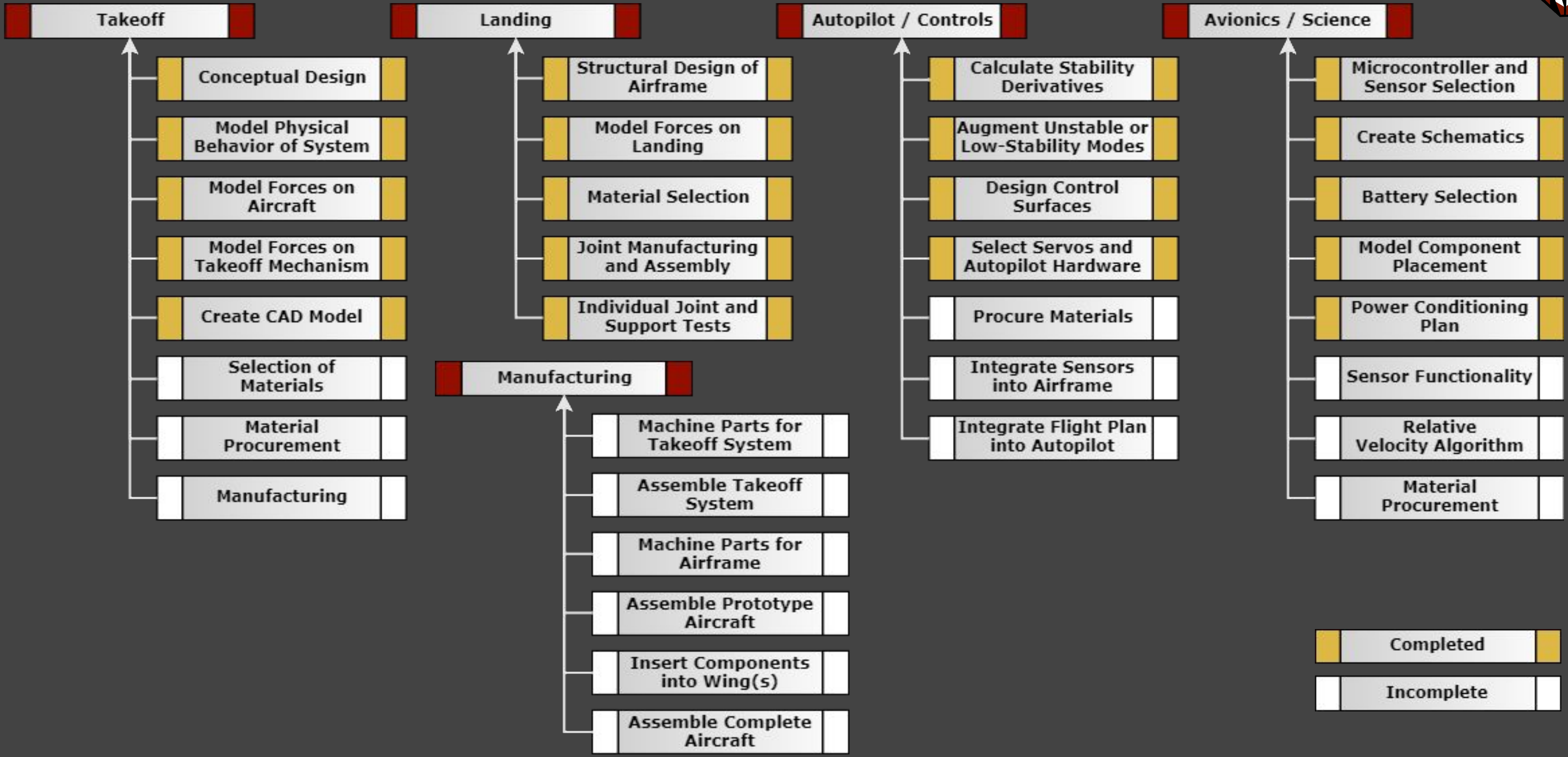
Project Management
- 🟨 ConOps & Functional Block Diagram
- 🟨 Requirement Determination
- 🟨 Schedule
- 🟨 Team Organization Chart
- 🟨 Work Breakdown Structure
- 🟨 Risk Matrix
- 🟨 Mass Budget
- 🟨 Cost Budget
- 🟨 Bill of Materials

Test / Safety
- 🟨 Requirement Validation Plan
- 🟨 Unit / Isolated Testing Plans
- 🟨 Integrated System Test Plan
- 🟨 Determination of Testing Locations
- 🟨 Test Safety Analysis
- ⬜ Safety Risk Mitigation
- ⬜ Execute Tests

Wing Design
- 🟨 Selection of Stable Airframe
- 🟨 Aerodynamic Models w/ Error Analysis
- 🟨 Determine Flight Characteristics
- 🟨 Propulsion Mount Design
- 🟨 Propulsion Component Selection
- 🟨 Conceptual Proof of Endurance Req.
- 🟨 CAD Model of Airframe
- ⬜ Model Loading on Wings
- ⬜ Material Procurement
- ⬜ Manufacturing

🟨 Completed
⬜ Incomplete

WORK BREAKDOWN STRUCTURE

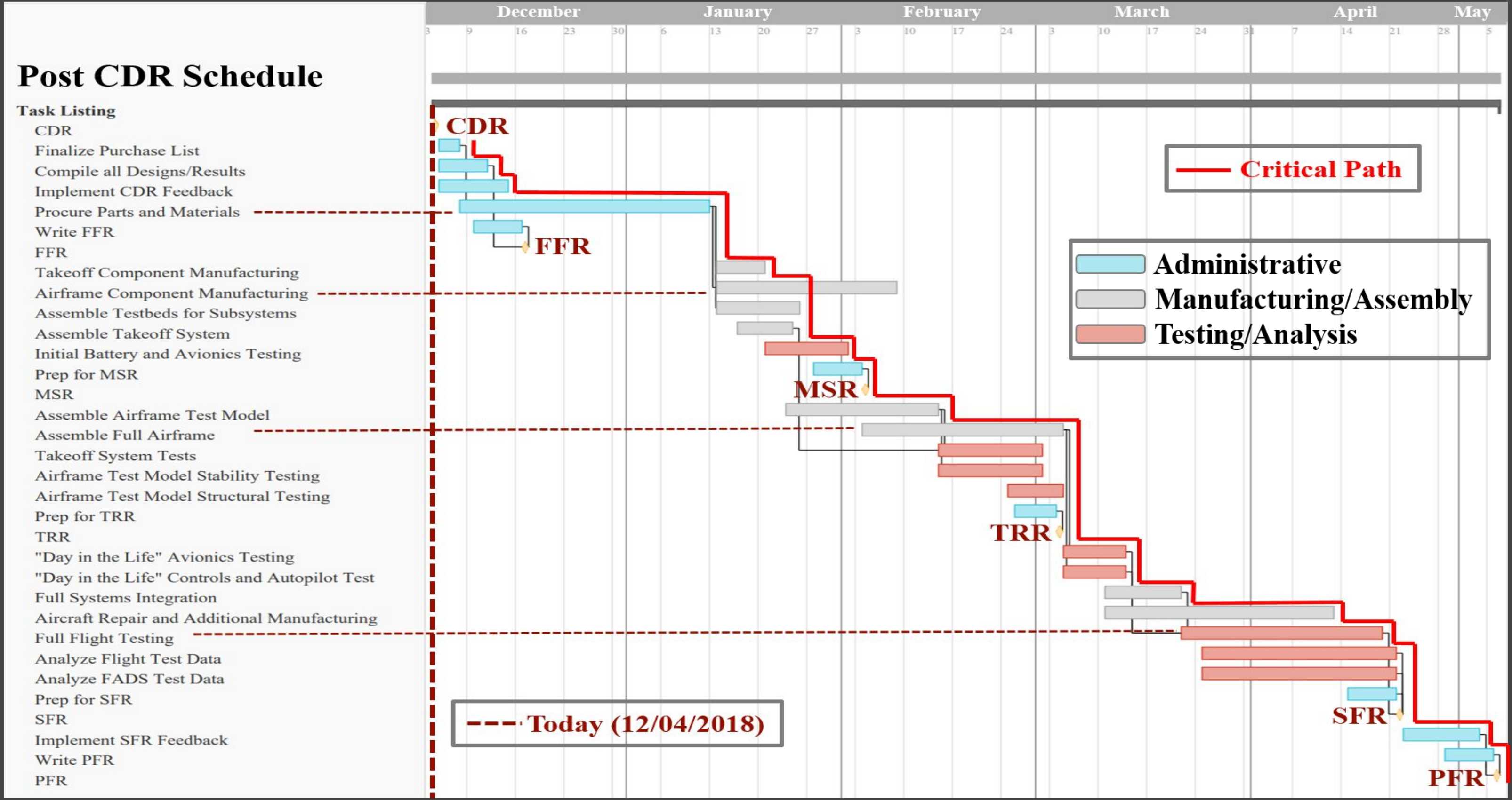


- **Takeoff**
  - 🟨 Conceptual Design
  - 🟨 Model Physical Behavior of System
  - 🟨 Model Forces on Aircraft
  - 🟨 Model Forces on Takeoff Mechanism
  - 🟨 Create CAD Model
  - ⬜ Selection of Materials
  - ⬜ Material Procurement
  - ⬜ Manufacturing
- **Landing**
  - 🟨 Structural Design of Airframe
  - 🟨 Model Forces on Landing
  - 🟨 Material Selection
  - 🟨 Joint Manufacturing and Assembly
  - 🟨 Individual Joint and Support Tests
- **Manufacturing**
  - ⬜ Machine Parts for Takeoff System
  - ⬜ Assemble Takeoff System
  - ⬜ Machine Parts for Airframe
  - ⬜ Assemble Prototype Aircraft
  - ⬜ Insert Components into Wing(s)
  - ⬜ Assemble Complete Aircraft
- **Autopilot / Controls**
  - 🟨 Calculate Stability Derivatives
  - 🟨 Augment Unstable or Low-Stability Modes
  - 🟨 Design Control Surfaces
  - 🟨 Select Servos and Autopilot Hardware
  - ⬜ Procure Materials
  - ⬜ Integrate Sensors into Airframe
  - ⬜ Integrate Flight Plan into Autopilot
- **Avionics / Science**
  - 🟨 Microcontroller and Sensor Selection
  - 🟨 Create Schematics
  - 🟨 Battery Selection
  - 🟨 Model Component Placement
  - 🟨 Power Conditioning Plan
  - ⬜ Sensor Functionality
  - ⬜ Relative Velocity Algorithm
  - ⬜ Material Procurement

🟨 Completed

⬜ Incomplete

WORK PLAN

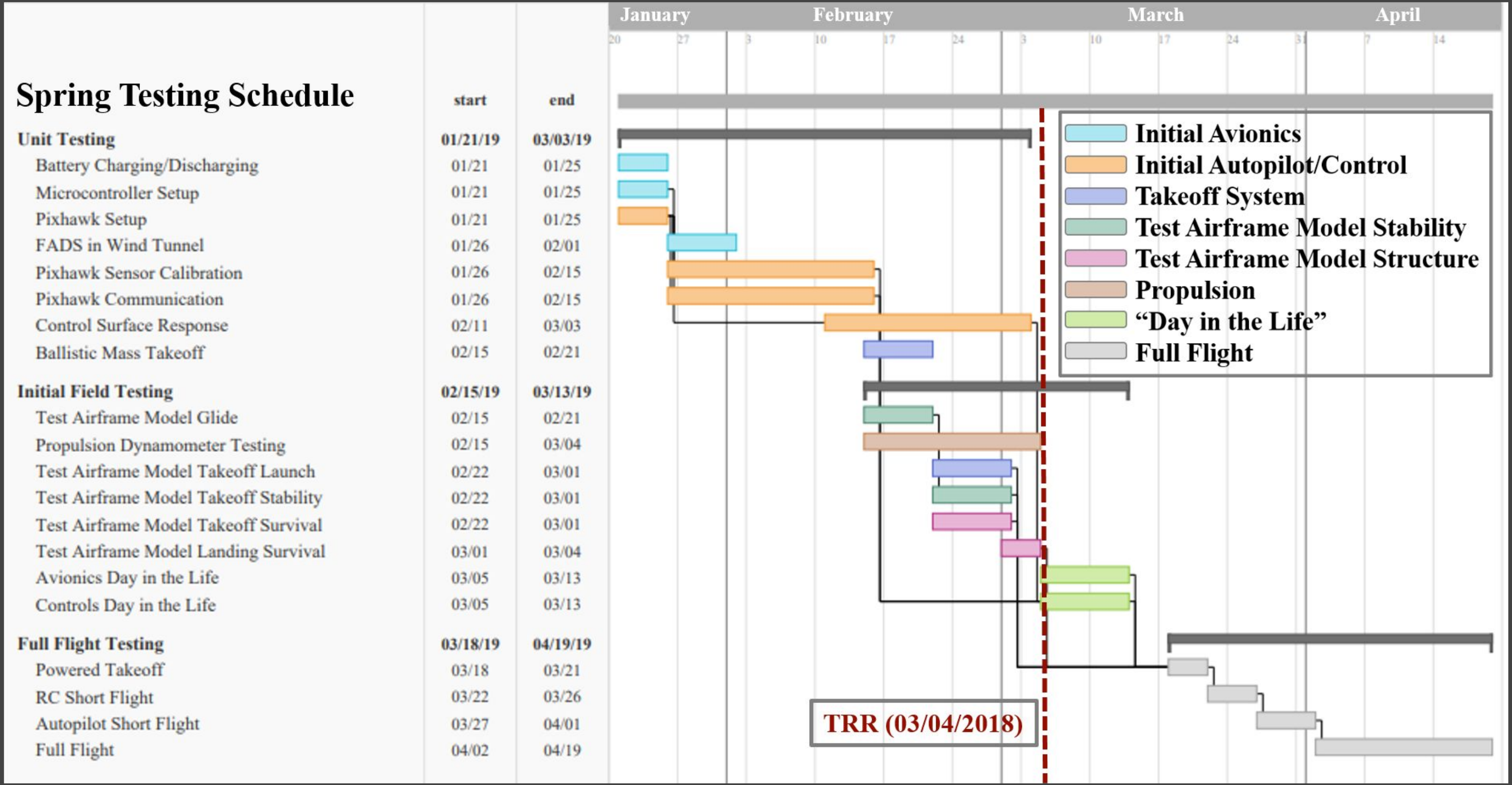


Post CDR Schedule

Task Listing

- CDR
- Finalize Purchase List
- Compile all Designs/Results
- Implement CDR Feedback
- Procure Parts and Materials
- Write FFR
- FFR
- Takeoff Component Manufacturing
- Airframe Component Manufacturing
- Assemble Testbeds for Subsystems
- Assemble Takeoff System
- Initial Battery and Avionics Testing
- Prep for MSR
- MSR
- Assemble Airframe Test Model
- Assemble Full Airframe
- Takeoff System Tests
- Airframe Test Model Stability Testing
- Airframe Test Model Structural Testing
- Prep for TRR
- TRR
- "Day in the Life" Avionics Testing
- "Day in the Life" Controls and Autopilot Test
- Full Systems Integration
- Aircraft Repair and Additional Manufacturing
- Full Flight Testing
- Analyze Flight Test Data
- Analyze FADS Test Data
- Prep for SFR
- SFR
- Implement SFR Feedback
- Write PFR
- PFR

TESTING SCHEDULE

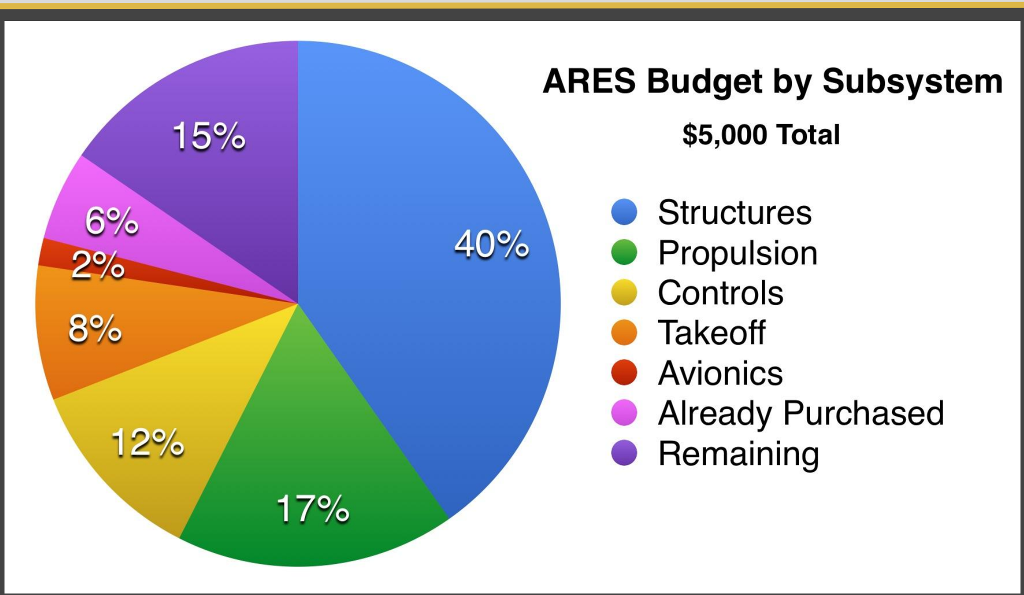


TRR (03/04/2018)

Spring Testing Schedule

	start	end
Unit Testing	**01/21/19**	**03/03/19**
Battery Charging/Discharging	01/21	01/25
Microcontroller Setup	01/21	01/25
Pixhawk Setup	01/21	01/25
FADS in Wind Tunnel	01/26	02/01
Pixhawk Sensor Calibration	01/26	02/15
Pixhawk Communication	01/26	02/15
Control Surface Response	02/11	03/03
Ballistic Mass Takeoff	02/15	02/21
Initial Field Testing	**02/15/19**	**03/13/19**
Test Airframe Model Glide	02/15	02/21
Propulsion Dynamometer Testing	02/15	03/04
Test Airframe Model Takeoff Launch	02/22	03/01
Test Airframe Model Takeoff Stability	02/22	03/01
Test Airframe Model Takeoff Survival	02/22	03/01
Test Airframe Model Landing Survival	03/01	03/04
Avionics Day in the Life	03/05	03/13
Controls Day in the Life	03/05	03/13
Full Flight Testing	**03/18/19**	**04/19/19**
Powered Takeoff	03/18	03/21
RC Short Flight	03/22	03/26
Autopilot Short Flight	03/27	04/01
Full Flight	04/02	04/19

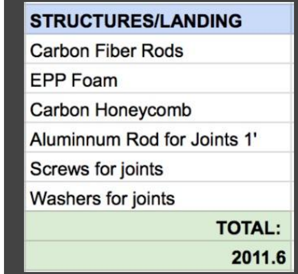
BUDGET BREAKDOWN



Budget includes components needed for 3 complete airframes.

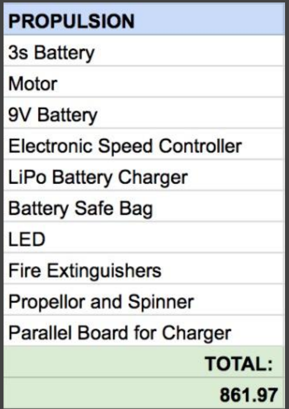
Current Total: $4227.91

Subsystem Components and Totals

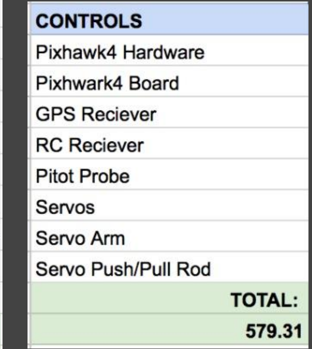


STRUCTURES/LANDING
Carbon Fiber Rods
EPP Foam
Carbon Honeycomb
Aluminnum Rod for Joints 1'
Screws for joints
Washers for joints
TOTAL:
2011.6

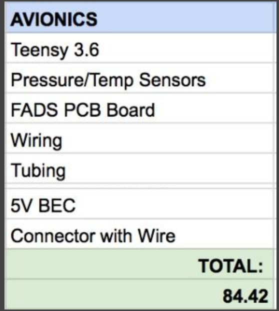
TAKEOFF
Square Alluminum (6061) Rod
Square Alluminum (6063) Rod
Skateboard Bearing
Latches
Bungees
Rubber Stoppers
1/2 inch rebar
Nuts and Bolts 3/8 and 5/16
1/8 in bendable aluminum
12 in X 12in Al 3003 plate
Scrap Metal from Machine Shop
1/2 in release pin
1/4 in rope
TOTAL:
414.2



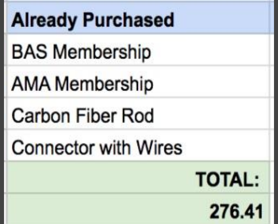
PROPULSION
3s Battery
Motor
9V Battery
Electronic Speed Controller
LiPo Battery Charger
Battery Safe Bag
LED
Fire Extinguishers
Propellor and Spinner
Parallel Board for Charger
TOTAL:
861.97



CONTROLS
Pixhawk4 Hardware
Pixhwark4 Board
GPS Reciever
RC Reciever
Pitot Probe
Servos
Servo Arm
Servo Push/Pull Rod
TOTAL:
579.31



AVIONICS
Teensy 3.6
Pressure/Temp Sensors
FADS PCB Board
Wiring
Tubing
5V BEC
Connector with Wire
TOTAL:
84.42



Already Purchased
BAS Membership
AMA Membership
Carbon Fiber Rod
Connector with Wires
TOTAL:
276.41

*Component Breakdown with Quantities, Price, Shipping, etc. in Backup Slides

ACKNOWLEDGEMENTS

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

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QUESTIONS?

BACKUP SLIDES

BACKUP TABLE OF CONTENTS

WING DESIGN BACKUP SLIDES

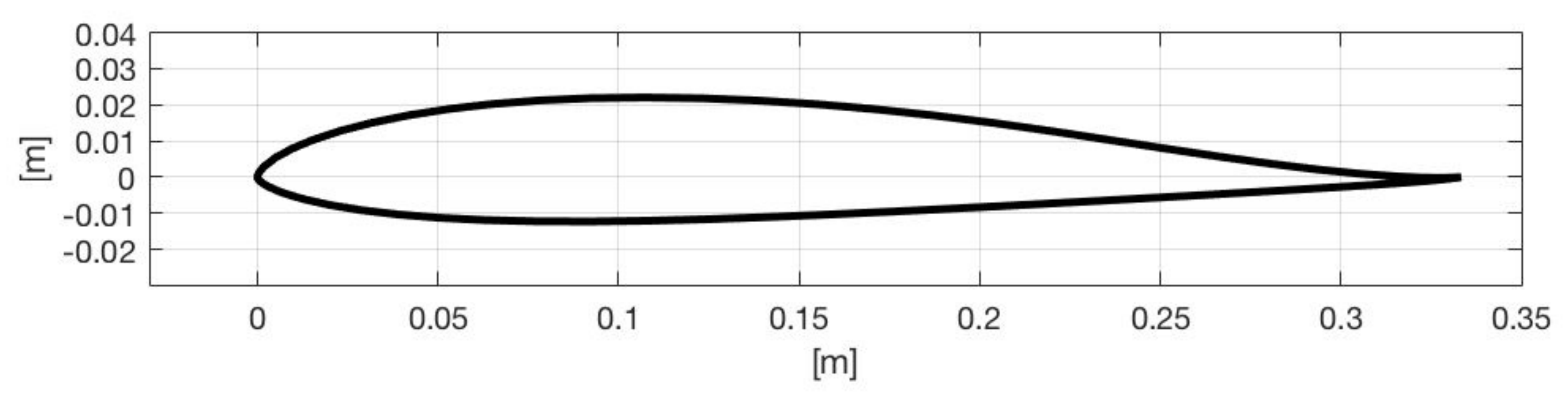
AIRFOIL SELECTION

- MH 61
  - PDR Choice
  - Thin
- EPPLER 339
  - Thick
  - Needs high Reynolds Number
- EH 3.0/12
  - Thick
  - Can operate at lower Reynolds Number

- Criteria
  - $C_{L,max}$
  - Thickness
    - Manufacturability
    - Component fit
  - L/D

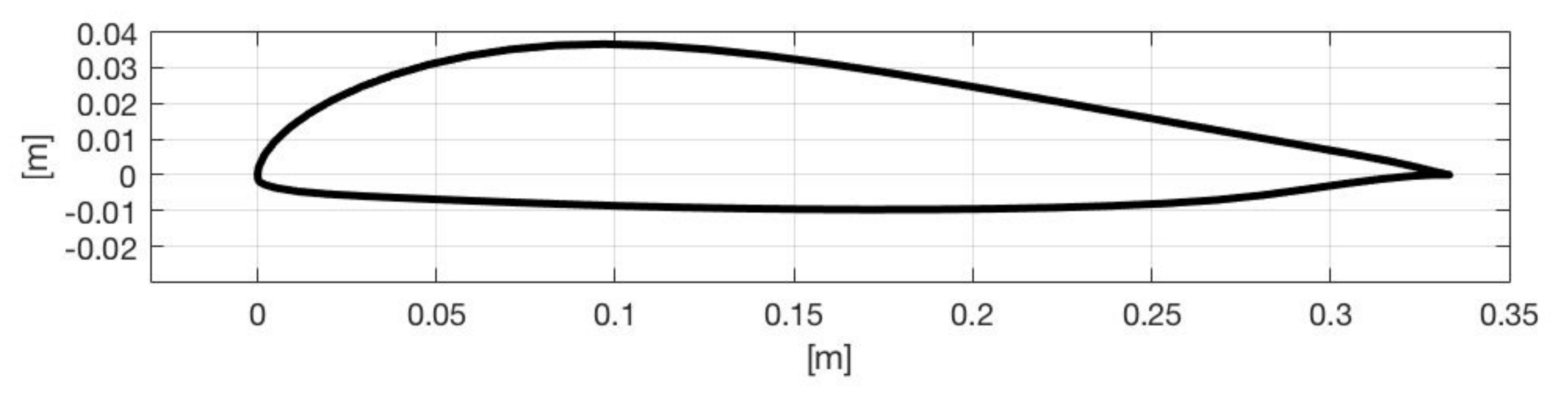
AIRFOIL: MH61

- Cross-sectional area = 0.00713m^2
- Maximum thickness = 3.43cm
- $C_{L,\ max}$ = 1.01



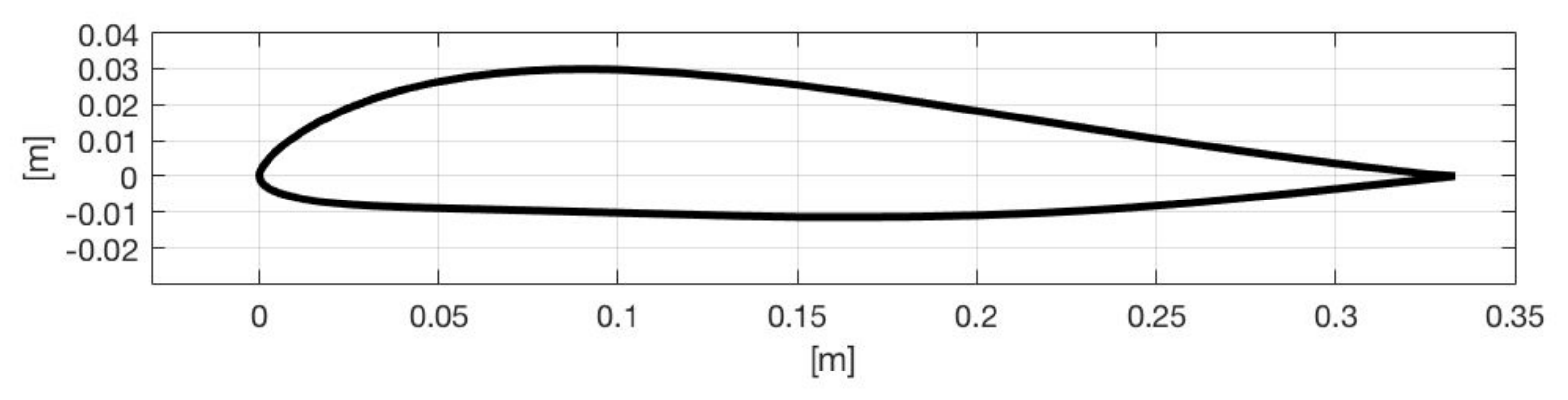
AIRFOIL: EPPLER 339

- Cross-sectional area = $0.01007 m^2$
  - 141% of MH61
- Maximum thickness = 4.63cm
  - 135% of MH61
- $C_{L, max}$ = 1.46

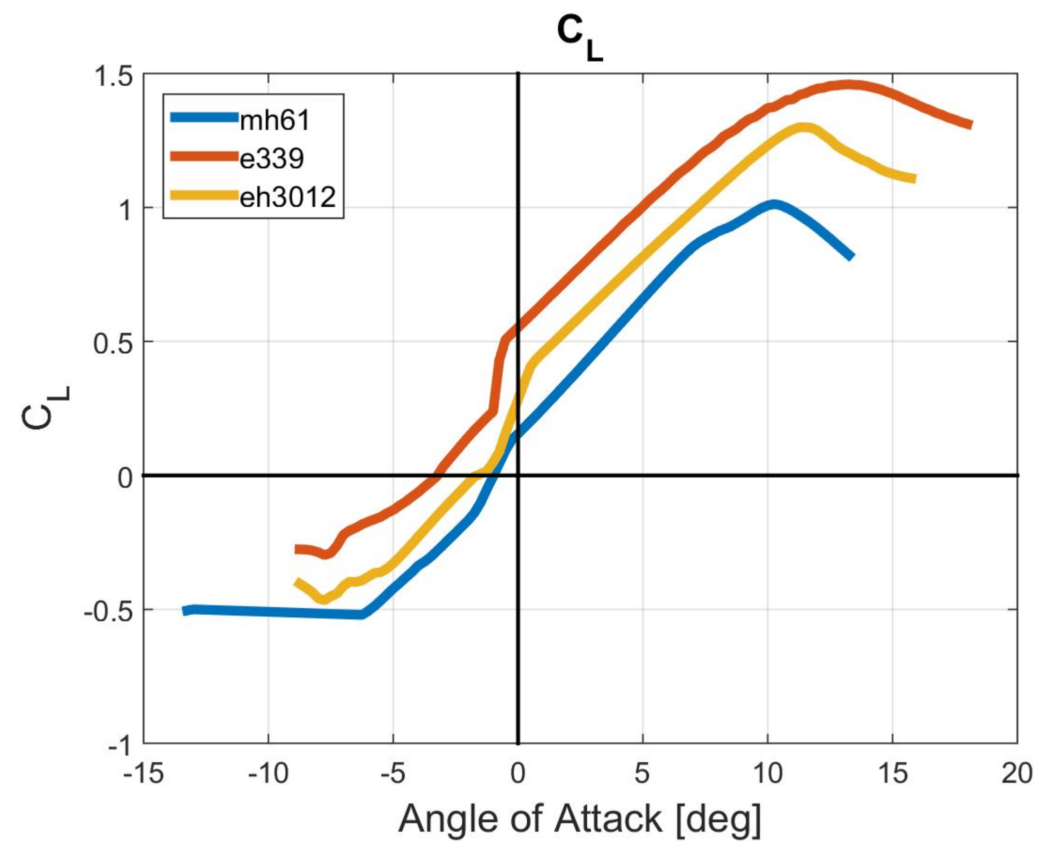


AIRFOIL: EH 3.0/12

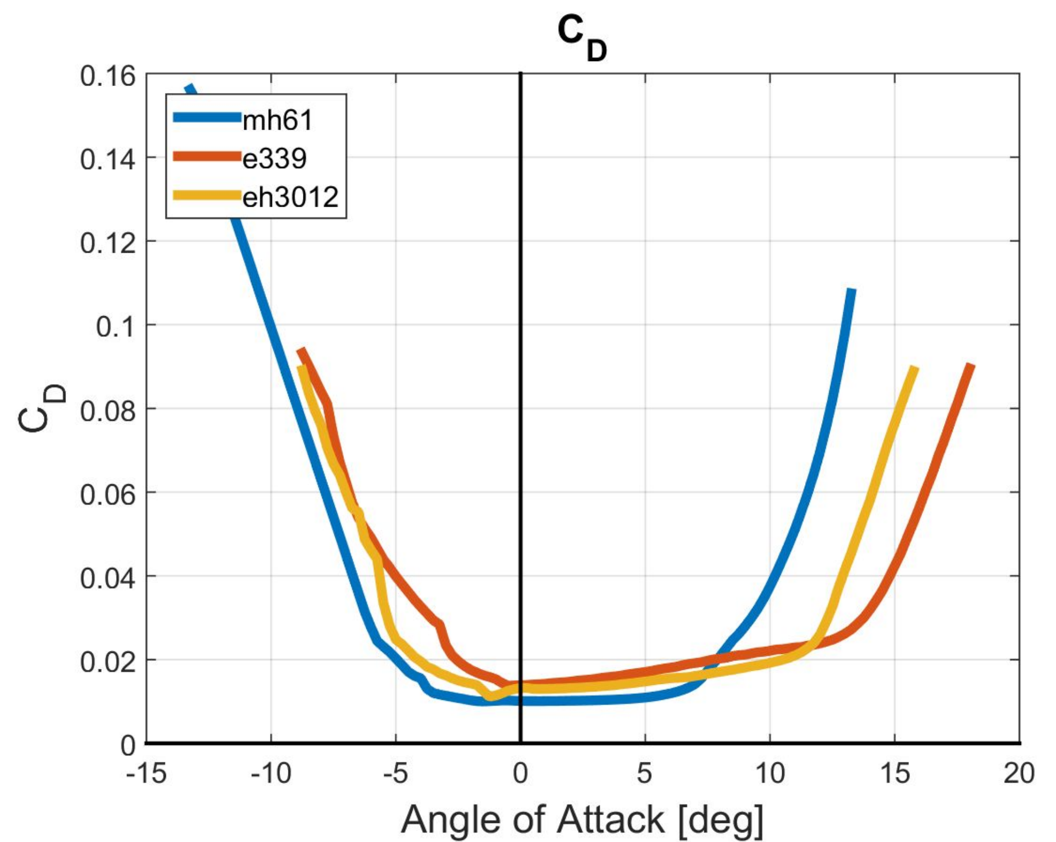
- Cross-sectional area = $0.00872 m^2$
  - 122% of MH61
- Maximum thickness = 4.12cm
  - 120% of MH61
- $C_{L,\ max}$ = 1.30



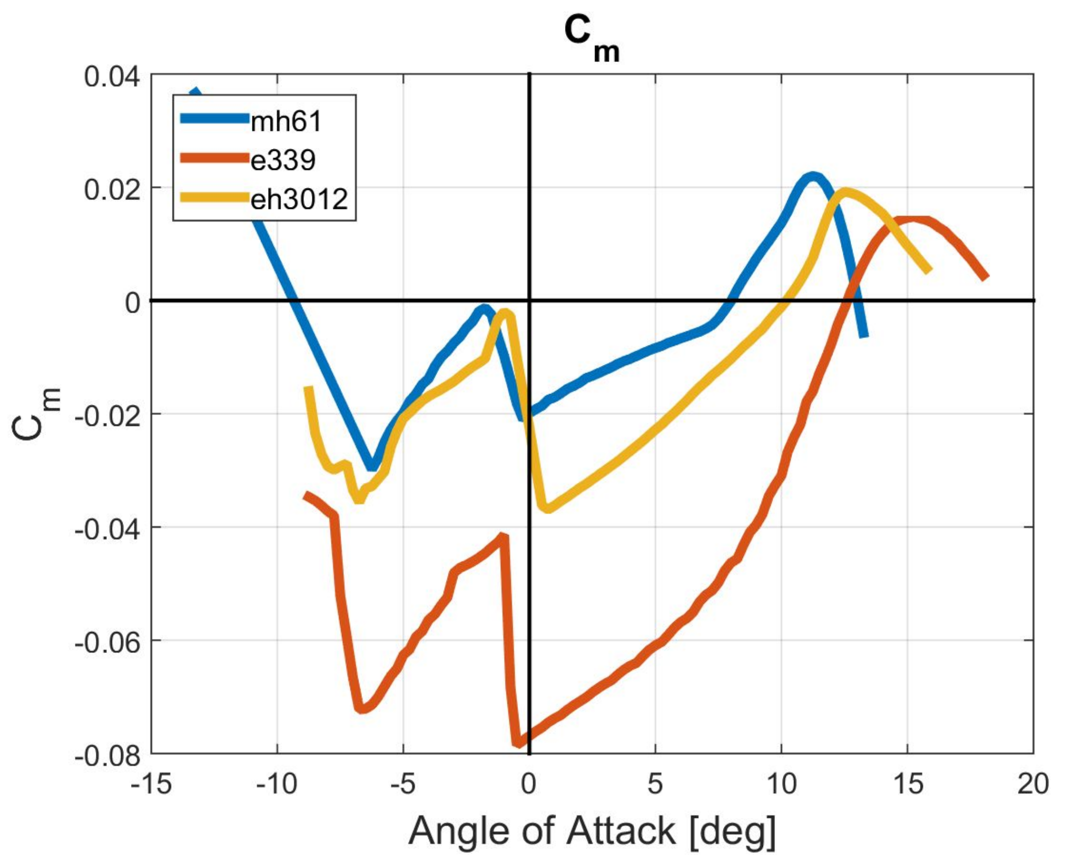
AIRFOIL COMPARISON: C_L



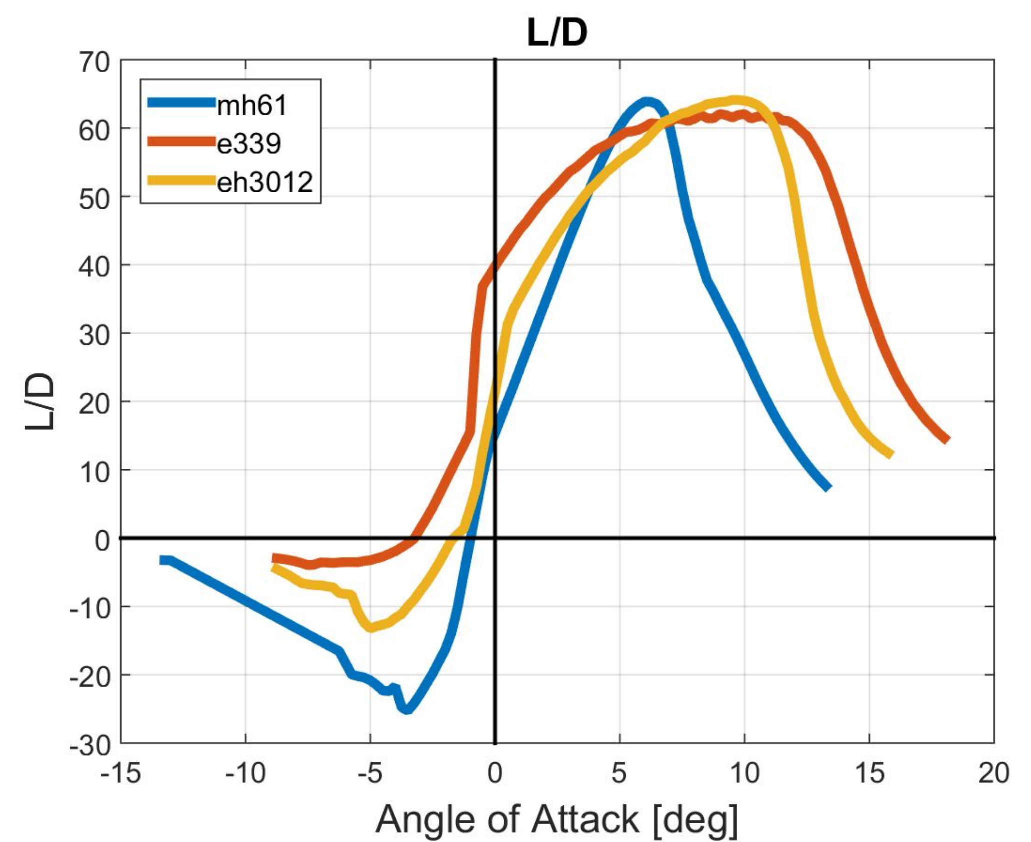
AIRFOIL COMPARISON: C_D



AIRFOIL COMPARISON: C_m



AIRFOIL COMPARISON: L/D

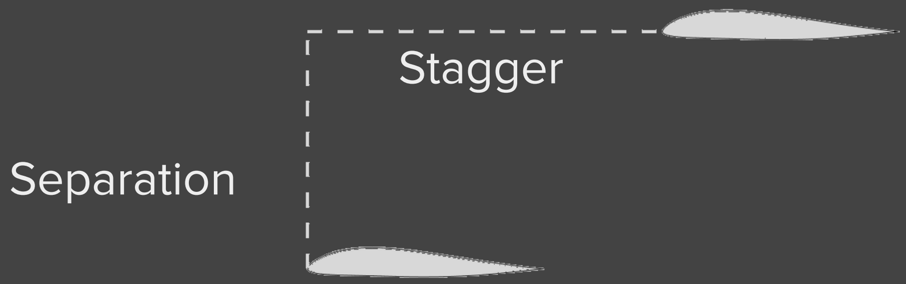


AIRFRAME CONFIGURATION

- Use AVL to test stability
- Stagger
  - Stability
  - Weight
- Separation
  - Flow Interference
  - Weight

Stagger [m]

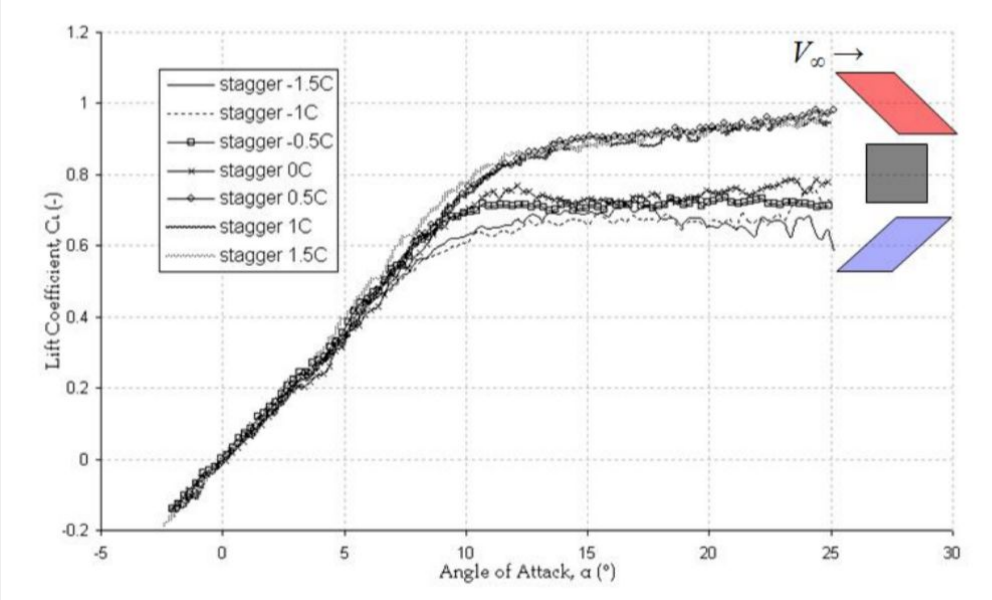
Separation [m]	0.3333	0.5000	0.6666
0.1666			
0.3333		✓	
0.6666			



EFFECT OF NEGATIVE STAGGER

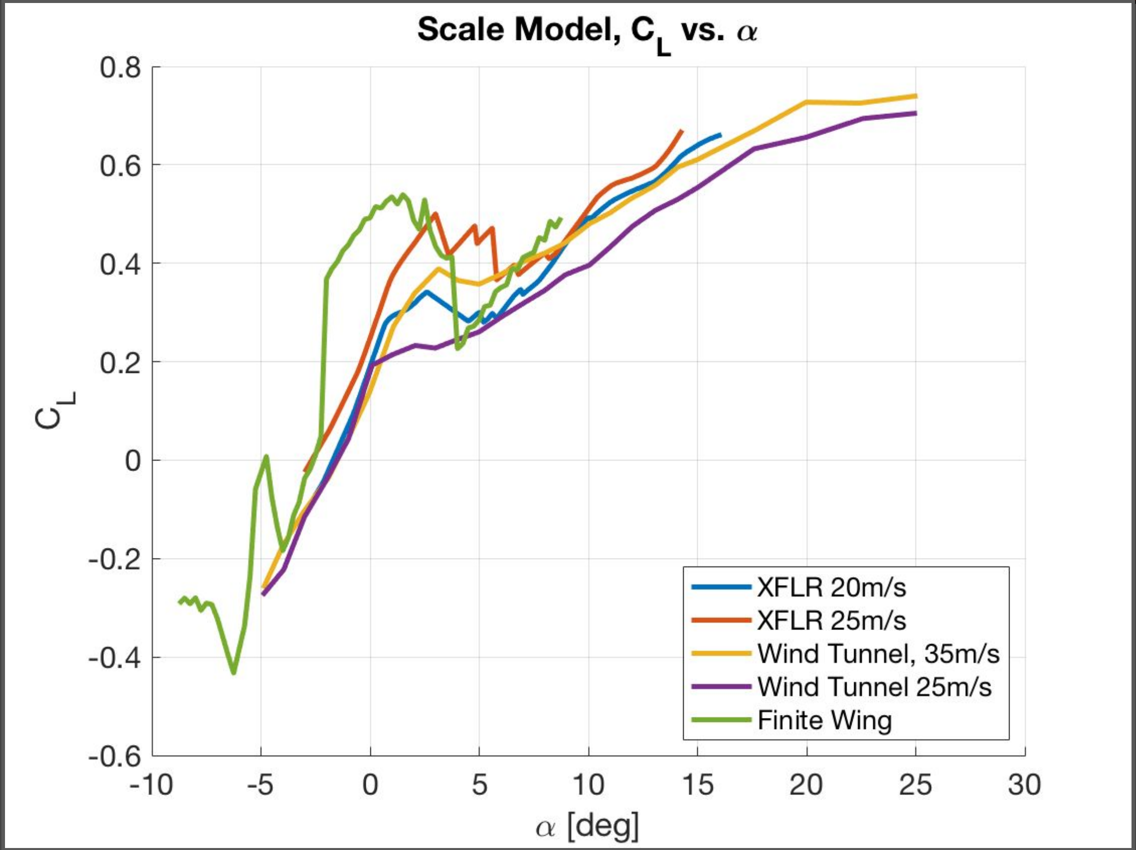
- CL,max is lower than Eagle Owl due to negative stagger
    - “Gap and Stagger Effects on Biplanes with End Plates”

- Negative stagger lowers the $C_{L,max}$ by 22.2%
    - Shown in experimental data
    - Not shown in theoretical calculations by XFLR5
- The presented CL,max takes this loss into account



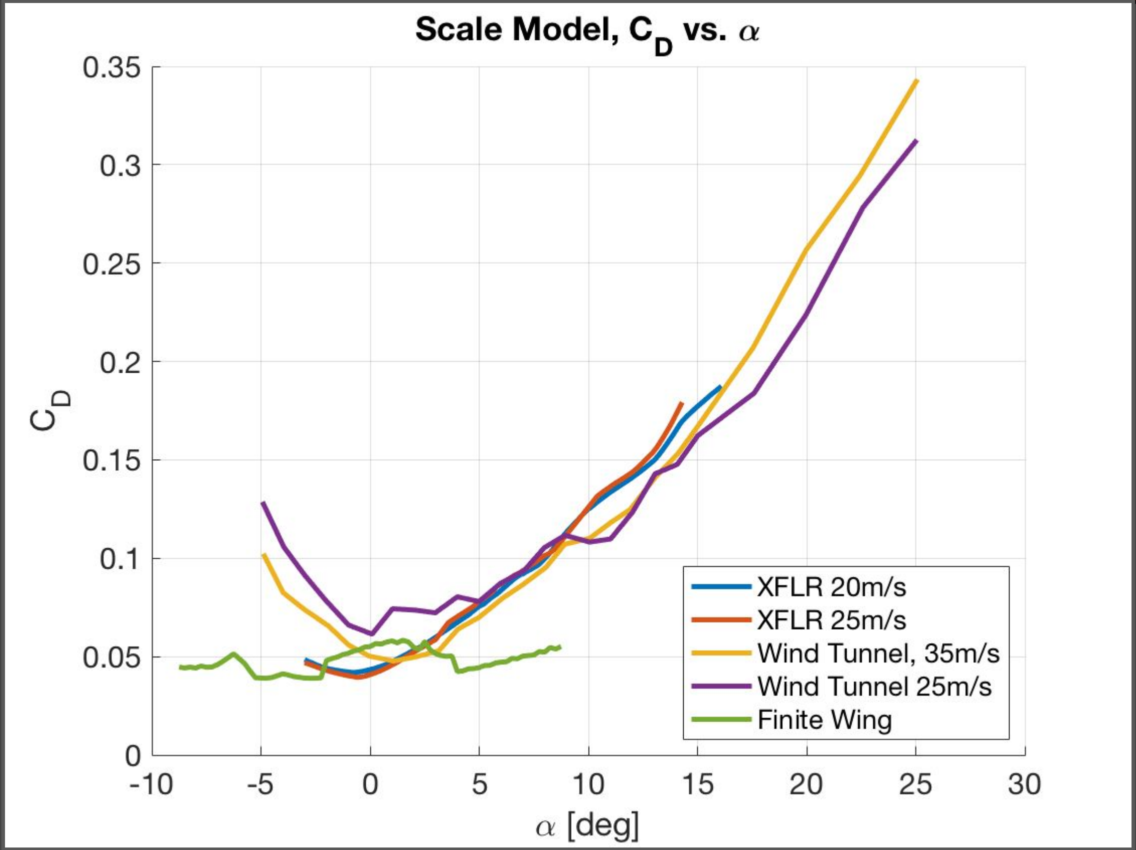
EPPLER 339 C_L MODELING

- Accuracy
  - Trends are similar
  - Room for error - will need to test full size model for full accuracy



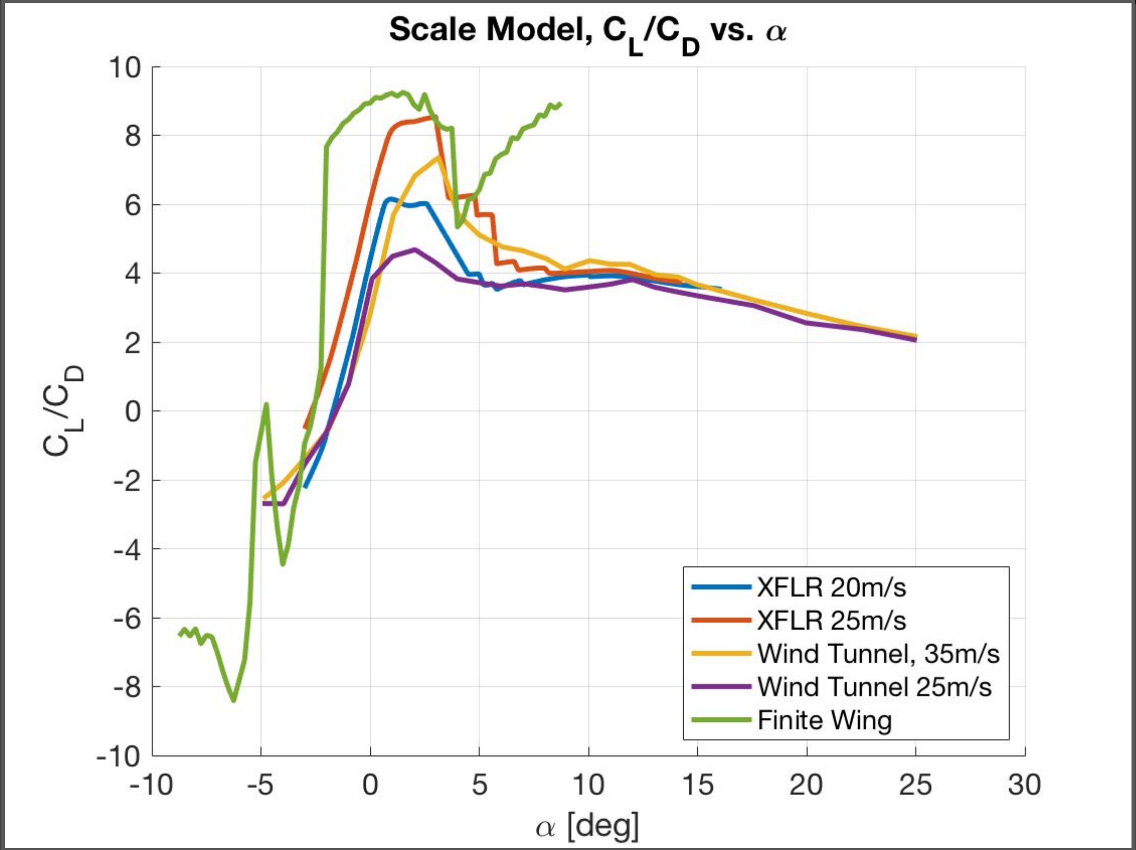
EPPLER 339 C_D MODELING

- Accuracy
  - Trends are similar
  - Room for error - will need to test full size model for full accuracy



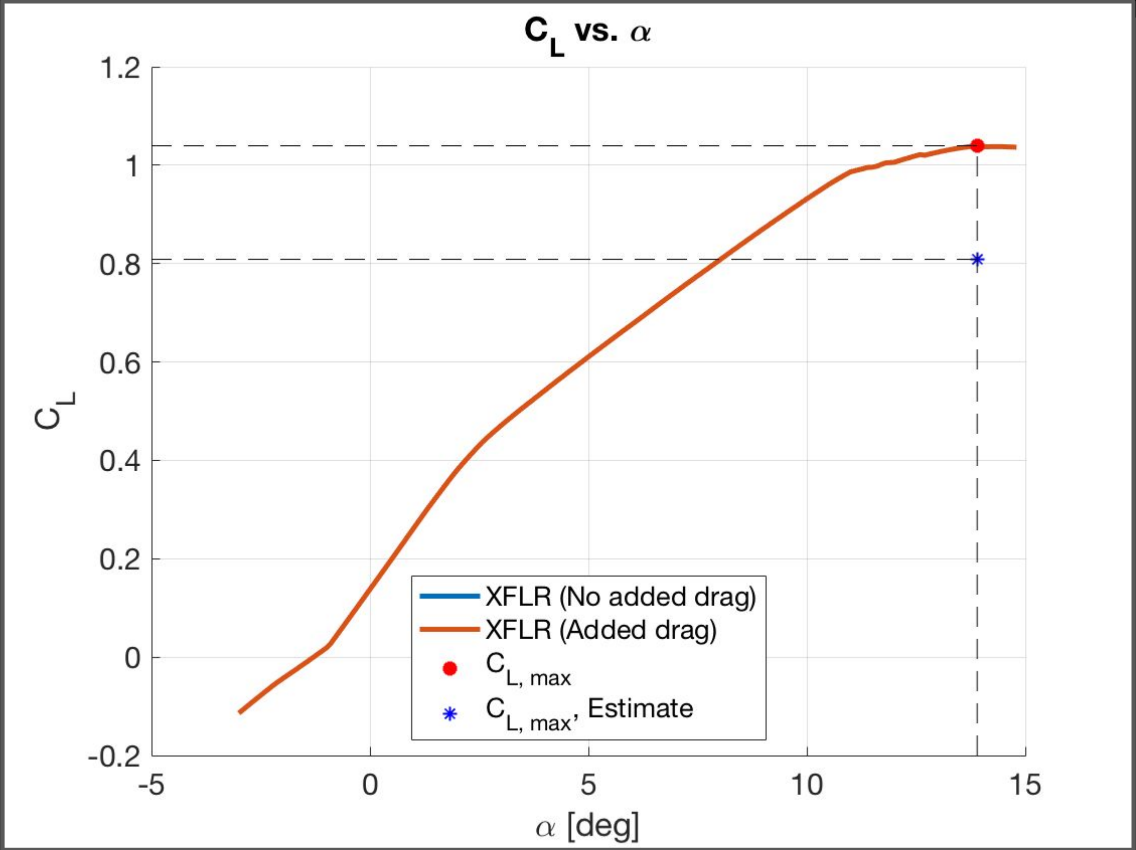
EPPLER 339 C_L/C_D MODELING

- Accuracy
  - Trends are similar
  - Room for error - will need to test full size model for full accuracy



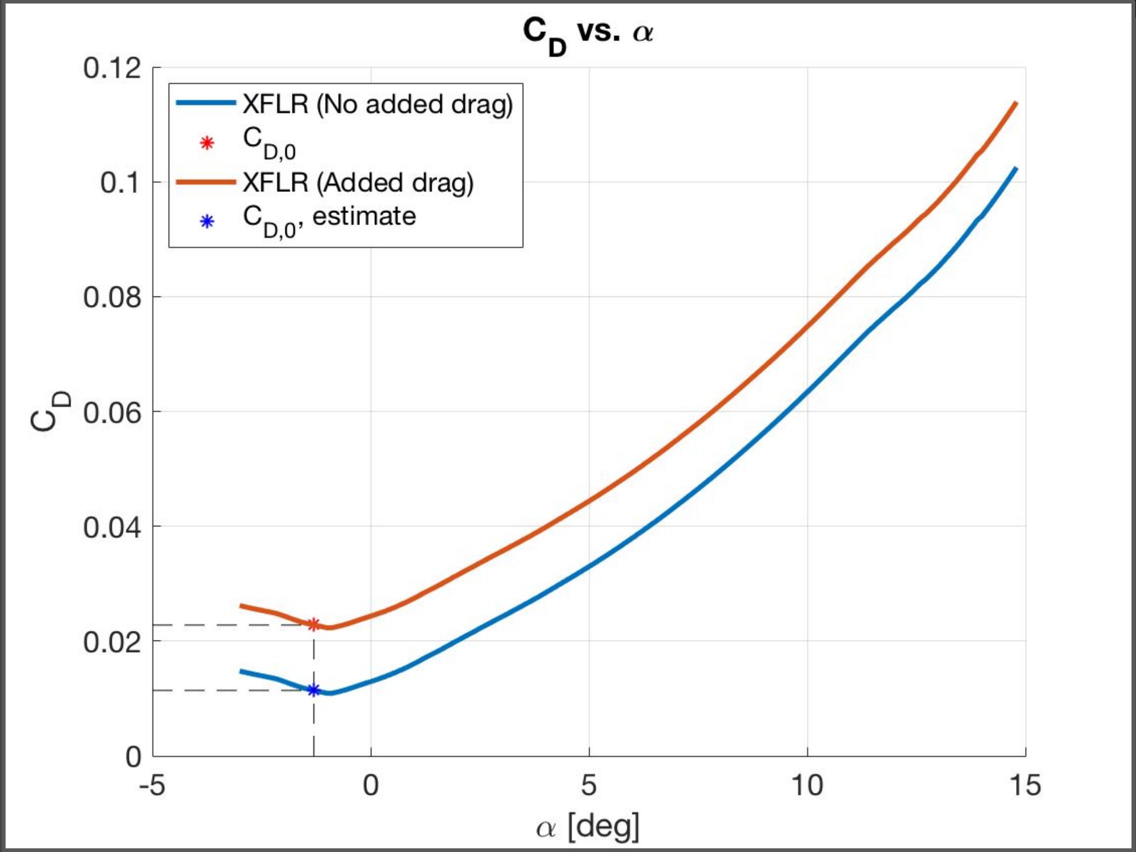
EH 3.0/12 C_L MODELING

- $C_{L, max}$
  - XFLR - 1.04
  - Lift reduced due to reverse stagger effects - 0.8085



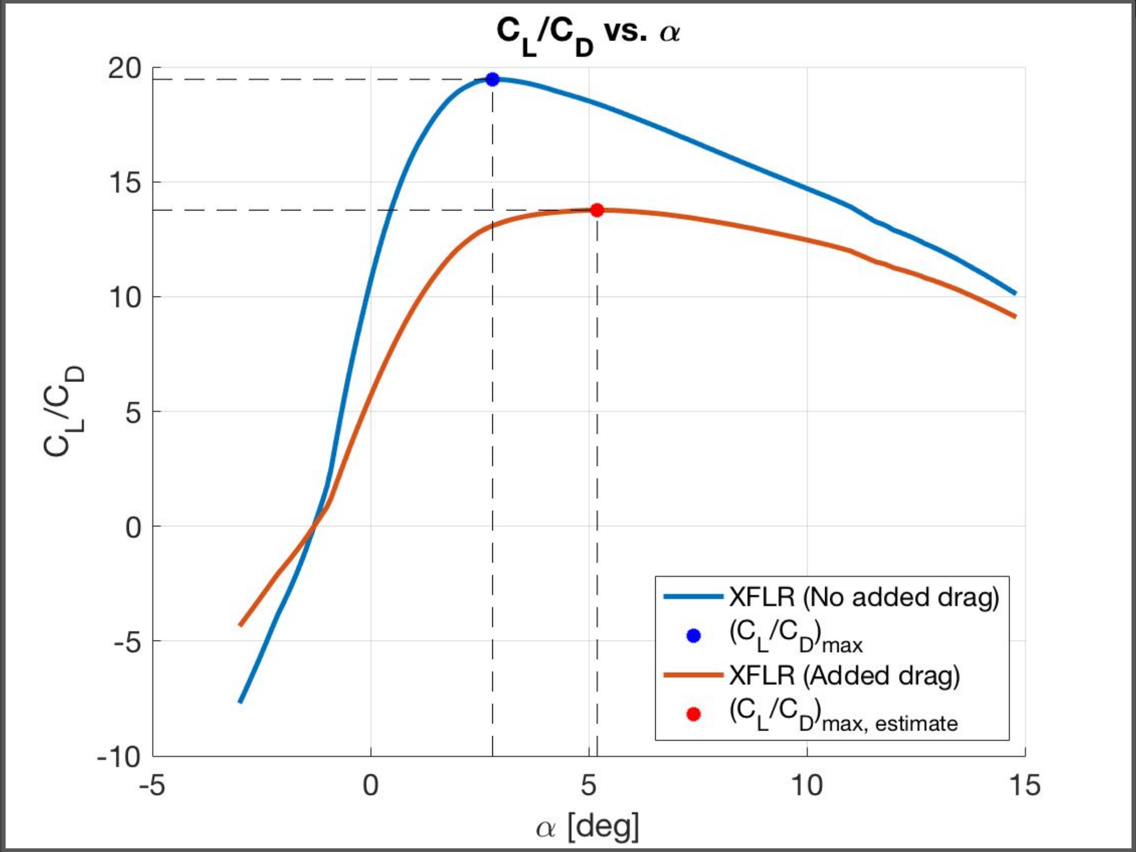
EH 3.0/12 C_D MODELING

- $C_{D,0}$
  - XFLR - 0.0114
  - Doubled in estimate - 0.0228



EH 3.0/12 C_L/C_D MODELING

- L/D
  - XFLR - 19.46
  - Added drag - 13.77



FINITE WING MODELING

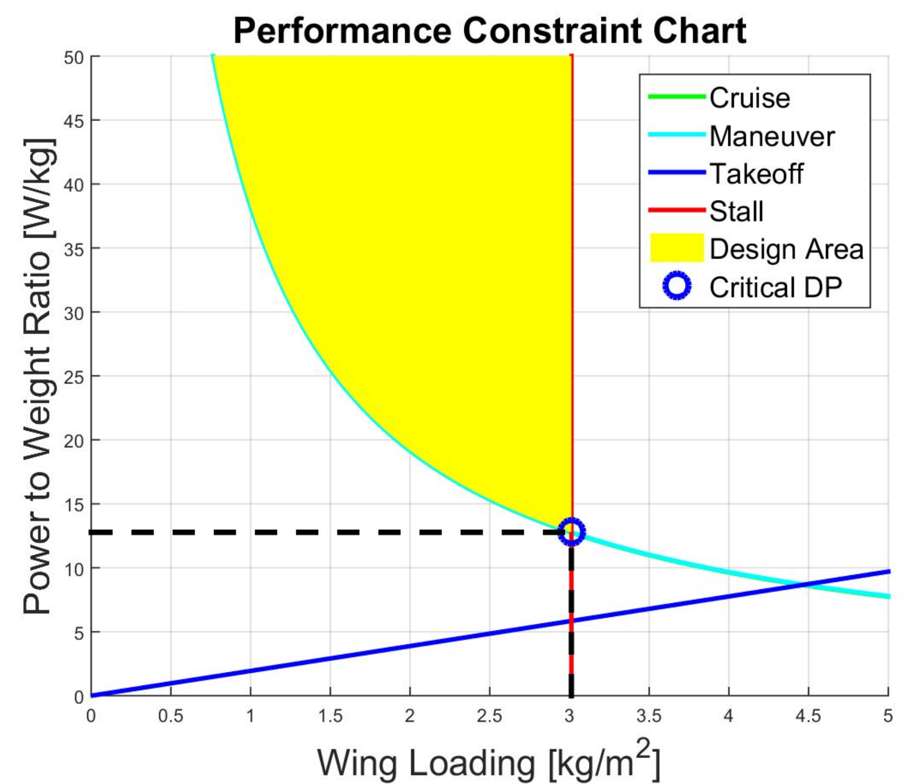
- Induced Angle of attack
  - $\alpha_i = C_{L,inf}/(\pi*AR)$
- Coefficient of Lift
  - $C_L = a_0(\alpha-\alpha_i)$
- Induced coefficient of drag
  - $C_{D,i} = C_L/(\pi*AR*e)$
- Skin friction drag
  - $C_{D,0} = C_{D,inf}|_{(CL = 0)}$
- Coefficient of Drag
  - $C_D = C_{D,i}+C_{D,0}$

FINITE WING MODELING

- Re = ρVL/μ
  - L is very small
- Reynold’s number small (~50,000)
  - Induced angle of attack ~0
  - Infinite wing behavior is about identical to finite wing behavior

PERFORMANCE CONSTRAINT

- Result: Critical Design Pt
- Wing Loading:
  - W/S_max = **3.012 kg/m^2**
    - Holding 4.0 kg
- Power to Weight ratio:
  - **12.78 W/kg** < 14.13 W/kg
  - $P/W_{req} < P/W_{avail}$



Performance Plot Equations

- Maximum wing loading for given stall velocity:

$$\frac{W}{S} = \frac{\rho V_{stall}^2 C_{L_{max}}}{2}$$

- Maneuvering Constraint Equation:

$$\frac{P}{W}_{maneu} = \left[\frac{1}{2}\rho V_c^2 \frac{C_{D0}}{W/S} + \frac{1}{\pi ARe}\left(\frac{n^2}{1/2\rho V_c^2} W/S\right)\right] V_{cruise}$$

where n = G load factor

VELOCITY CALCULATIONS

$$V_{Stall} = \sqrt{\frac{2W}{\rho S C_{L,Max}}}$$

$$V_{cruise} = \sqrt{\frac{2W}{\rho S C_{L,cruise}}}$$

AUTOPILOT & CONTROL BACKUP SLIDES

AUTOPILOT: HARDWARE

Extensive CU Flight Heritage

Open-source Px4 software with custom airframe support

Power

- Accepts 4.9-5.5 V input power
- Servo rail input: 0-36 V
- Power management board included

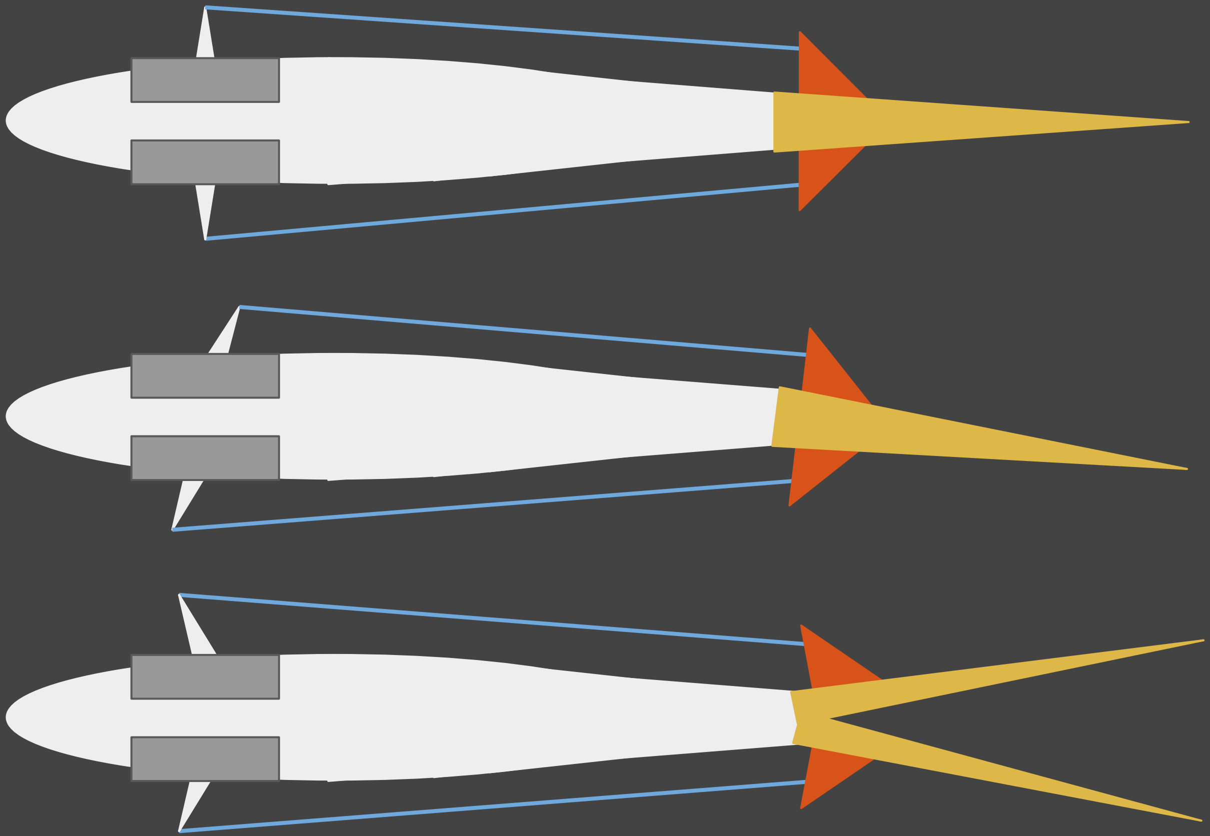
Weight: 15.8 g

Size: 44x84x12 mm

AUTOPILOT: HARDWARE

- Built-in Sensors
  - Accelerometers/Gyros (ICM-20689 & BMI055)
  - Magnetometers (IST8310)
  - Barometer (MS5611)
  - GPS (ublox Neo-M8N)
- External Sensor
  - Pitot tube to detect stall
- Speed controller between Pixhawk and propeller motor
- Handles RC input with external receiver
- Downlinks data to ground station receiver
- Control templates for flying wings with elevons
- SD Card slot to store data

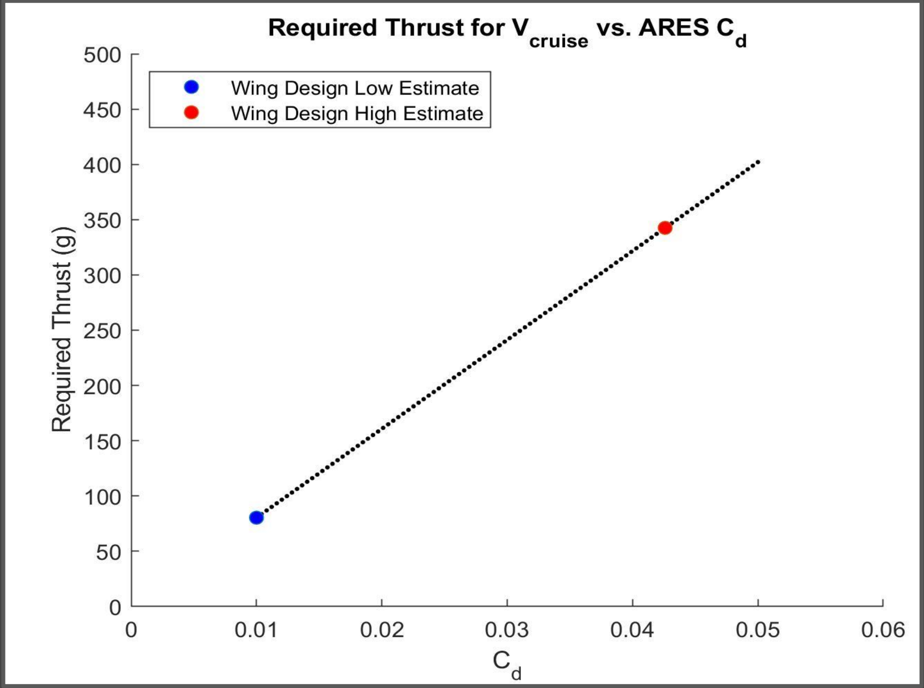
CONTROL SURFACE MOTIONS



PROPULSION BACKUP SLIDES

Propulsion - How did we choose T_{req}?

- C_d is unknown - only given range
- Worst case scenario with safety factor from XFLR: C_d =0.0426
    - ○ T_{req} = 356.9 g
- To account for manufacturing imperfections, flight orientation/control surface deployment, etc. another safety factor of 1.2 was added onto the XFLR number: T_{req} = 428.28 g



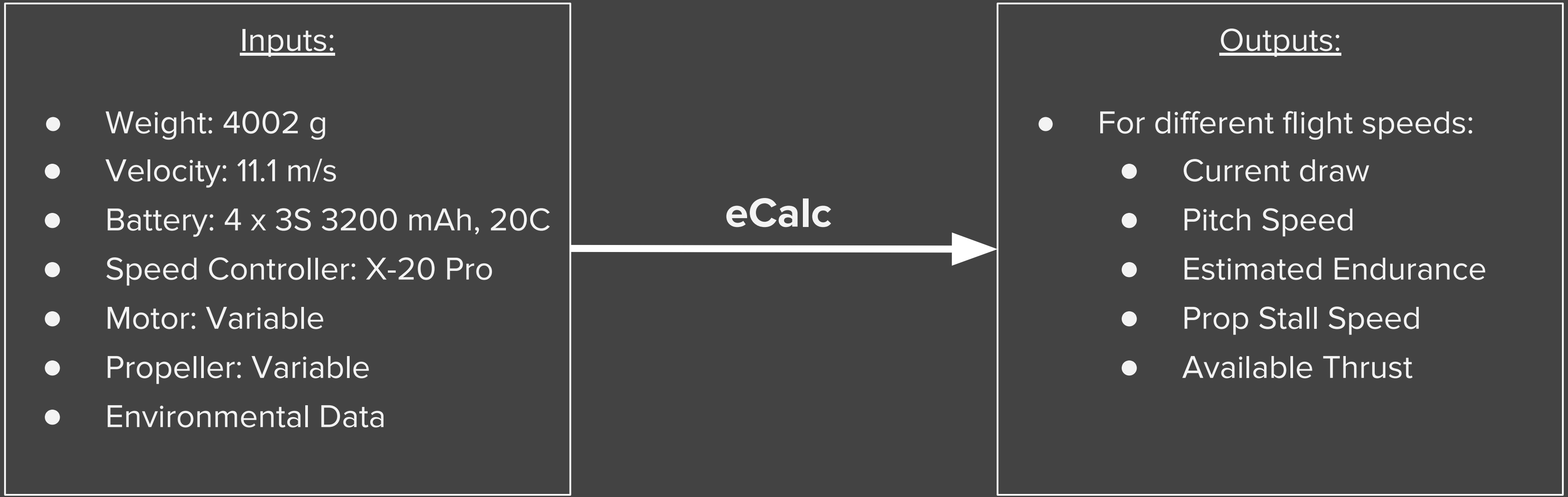
Propulsion - Kv Justification

- Ideal propulsion design:
    - As light as possible - small batteries and motor
    - Smaller propellers
    - Able to produce enough thrust
    - Endurance of over an hour
    - Propellers do not interfere with landing operations or structural integrity

Low KV			**High KV**
● Efficient at low speeds	✓		● Efficient at high speeds
● Bigger prop diameter		✓	● Smaller prop diameter
● More voluminous batteries (higher voltage)		✓	● Less voluminous batteries (lower voltage)
● Less battery capacity required (higher current)	✓		● More battery capacity required (higher current)
● Heavier and bulkier motors		✓	● Lighter and less bulky motors
● Moves heavier loads slower	✓		● Moves lighter loads faster

PROPULSION: PART SELECTION

- Compiled data of different motor/propeller configurations using online performance calculator eCalc
  - Trusted by CU RC propulsion experts
  - Compared past eCalc data to real flight data of MISTRIL for feasibility



Inputs:

- Weight: 4002 g
- Velocity: 11.1 m/s
- Battery: 4 x 3S 3200 mAh, 20C
- Speed Controller: X-20 Pro
- Motor: Variable
- Propeller: Variable
- Environmental Data

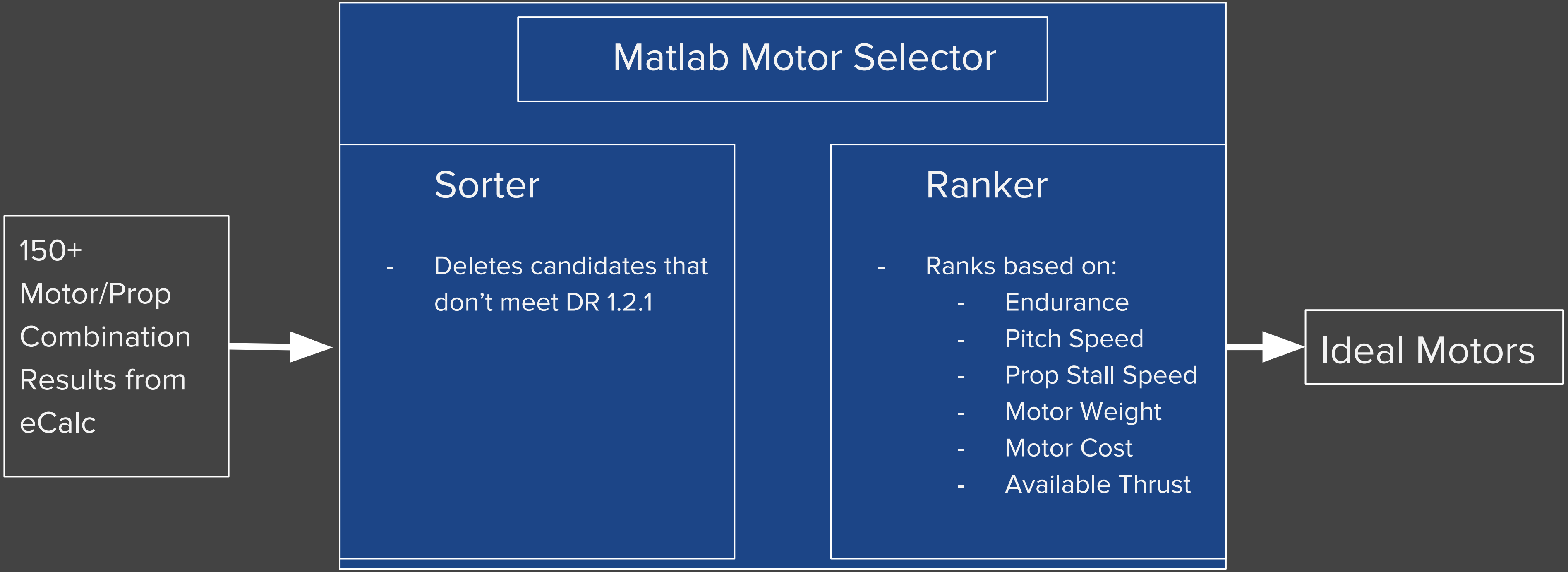
eCalc

Outputs:

- For different flight speeds:
  - Current draw
  - Pitch Speed
  - Estimated Endurance
  - Prop Stall Speed
  - Available Thrust

Propulsion: Part Filtering

- After over 150 computations were performed, data was run through a Matlab sorting and ranking algorithm to find top motor choices:



150+ Motor/Prop Combination Results from eCalc

Matlab Motor Selector

Sorter

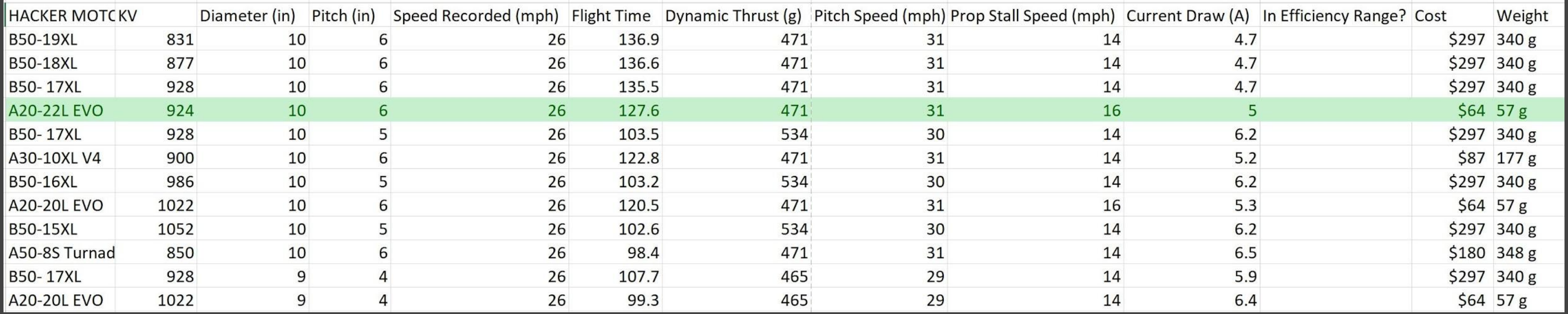
- Deletes candidates that don’t meet DR 1.2.1

Ranker

- Ranks based on:
  - Endurance
  - Pitch Speed
  - Prop Stall Speed
  - Motor Weight
  - Motor Cost
  - Available Thrust

Ideal Motors

Propulsion - Top Motor Choices



HACKER MOTC	KV	Diameter (in)	Pitch (in)	Speed Recorded (mph)	Flight Time	Dynamic Thrust (g)	Pitch Speed (mph)	Prop Stall Speed (mph)	Current Draw (A)	In Efficiency Range?	Cost	Weight
B50-19XL	831	10	6	26	136.9	471	31	14	4.7		$297	340 g
B50-18XL	877	10	6	26	136.6	471	31	14	4.7		$297	340 g
B50- 17XL	928	10	6	26	135.5	471	31	14	4.7		$297	340 g
A20-22L EVO	924	10	6	26	127.6	471	31	16	5		$64	57 g
B50- 17XL	928	10	5	26	103.5	534	30	14	6.2		$297	340 g
A30-10XL V4	900	10	6	26	122.8	471	31	14	5.2		$87	177 g
B50-16XL	986	10	5	26	103.2	534	30	14	6.2		$297	340 g
A20-20L EVO	1022	10	6	26	120.5	471	31	16	5.3		$64	57 g
B50-15XL	1052	10	5	26	102.6	534	30	14	6.2		$297	340 g
A50-8S Turnad	850	10	6	26	98.4	471	31	14	6.5		$180	348 g
B50- 17XL	928	9	4	26	107.7	465	29	14	5.9		$297	340 g
A20-20L EVO	1022	9	4	26	99.3	465	29	14	6.4		$64	57 g

PROPULSION: PART SELECTION

Propeller: 10” diameter, 6” pitch

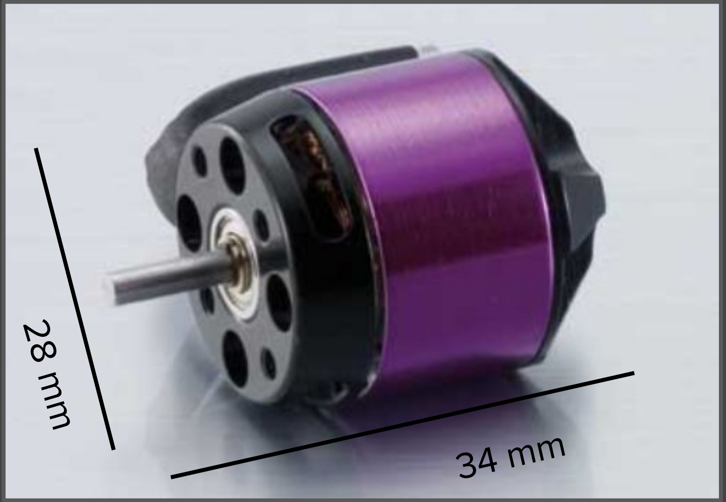
Electronic Speed Controller (ESC): X-20-Pro

- Weight: 16 g

Motor: Hacker A20-22L EVO

- Kv: 924 RPM
- Shaft diameter: 3 mm
- Weight: 57 g
- Dynamic thrust at cruise is 471 g
- Angled at 12.6° to counter CG offset induced torque

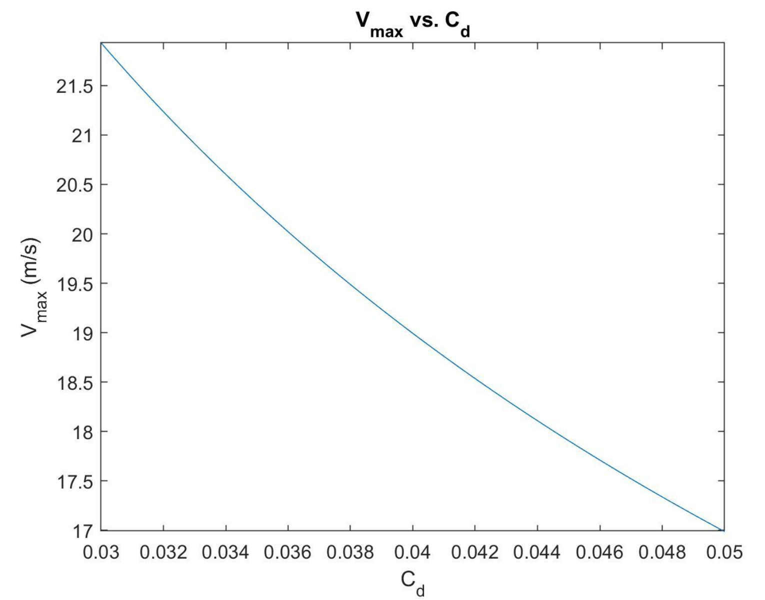
Estimated Endurance: 80-90 min



DR 1.2.1 ✓

Propulsion - Maneuverability

- Key factors describing maneuverability:
    - $V_{max} = ((2T_{max})/(\rho C_d S_{wing}))^{½}$
    - $V_{stall} = 8.36$ m/s
    - Turning Radius**: $R = V^2/g(n^2-1)^{½}$
        - V_{stall}: R = 12.29 m
        - V_{cruise}: R = 21.67 m
    - Turning Rate**: $\omega = V/R$
        - V_{stall}: $\omega = 0.68$ rad/s
        - V_{cruise}: $\omega = 0.51$ rad/s
    - Rate of Climb/Climbing Angle - TBD (Need more aerodynamic modeling and testing)
    - T/W - This depends on our throttling:
        - Cruise: T/W = 0.12
        - Max: T/W = 0.25
        - This means slow, comfortable maneuvers with relatively slow climb; performs like a glider



*Note load factor n = L/W; this was obtained using $L = (L/D)_{max}T$ since we will be trying to fly at $(L/D)_{max}$ in SLF so T = D

**Introduction to Flight, 8th Edition, Anderson

Propulsion - Chosen Motor Data

General
Model Weight: 3402 g / 120 oz – incl. Drive ▼
# of Motors: 1 (on same Battery)
Wing Area: 133.3 dm² / 2066.15 in²
Drag: simplified ▼ – 0.05 Cd
Cross Section: 0 dm² / 0 in²
Field Elevation: 500 m ASL / 1640 ft ASL
Air Temperature: 25 °C / 77 °F
Pressure (QNH): 1013 hPa / 29.91 inHg

Battery Cell
Type (Cont. / max. C) - charge state: custom ▼ - normal ▼
Configuration: 3 S 4 P
Cell Capacity: 3200 mAh / 12800 mAh total
max. discharge: 85% ▼
Resistance: 0.0733 Ohm
Voltage: 3.8 V
C-Rate: 30 C cont. / 50 C max
Weight: 74.67 g / 2.6 oz

Controller
Type: X-20-Pro ▼
Current: 20 A cont. / 28 A max
Resistance: 0.0084 Ohm
Weight: 22 g / 0.8 oz
Battery extension Wire: AWG10=5.27mm² ▼
Length: 0 mm / 0 inch
Motor extension Wire: AWG10=5.27mm² ▼
Length: 0 mm / 0 inch

Motor
Manufacturer - Type (Kv) - Cooling: Hacker ▼ - A20-22L EVO (924) ▼ – medium ▼ – search...
KV (w/o torque): 924 rpm/V – Prop-Kv-Wizard
no-load Current: 0.75 A @ 8.4 V
Limit (up to 15s): 240 W ▼
Resistance: 0.089 Ohm
Case Length: 34 mm / 1.34 inch
mag. Poles: 14
Weight: 50 g / 1.8 oz

Propeller
Type - yoke twist: Carbon-Fold-Prop ▼ - 0° ▼
Diameter: 10 inch / 254 mm
Pitch: 6 inch / 152.4 mm
Blades: 2
PConst / TConst: 1.18 / 1.0
Gear Ratio: 1 : 1
Flight Speed: 40 km/h / 24.83 mph
calculate

Load: 1.27 C
Mixed Flight Time: 40.1 min
electric Power: 169 W
est. Temperature: 43 °C
Thrust-Weight: 0.29 : 1
Pitch Speed: 71 km/h

Remarks:

- The Thrust-Weight-Ratio might be insufficient to fly or to stay in the air. Aim for a ratio of at least 0.5!

Battery		
Load:	1.27	C
Voltage:	10.50	V
Rated Voltage:	11.40	V
Energy:	145.92	Wh
Total Capacity:	12800	mAh
Used Capacity:	10880	mAh
min. Flight Time:	40.1	min
Mixed Flight Time:	40.1	min
Weight:	896	g
	31.6	oz

Motor @ Optimum Efficiency		
Current:	9.42	A
Voltage:	10.80	V
Revolutions*:	8817	rpm
electric Power:	101.8	W
mech. Power:	84.5	W
Efficiency:	83.0	%

Motor @ Maximum		
Current:	16.30	A
Voltage:	10.37	V
Revolutions*:	7796	rpm
electric Power:	169.0	W
mech. Power:	135.1	W
Efficiency:	79.9	%
est. Temperature:	43	°C
	109	°F

Wattmeter readings		
Current:	16.3	A
Voltage:	10.5	V
Power:	171.2	W

Propeller		
Static Thrust:	981	g
	34.6	oz
Revolutions*:	7796	rpm
Stall Thrust:	692	g
	24.4	oz
avail.Thrust @ 40 km/h:	431	g
avail.Thrust @ 24.83 mph:	15.2	oz
Pitch Speed:	71	km/h
	44	mph
Tip Speed:	373	km/h
	232	mph
specific Thrust:	5.81	g/W
	0.2	oz/W

Total Drive		
Drive Weight:	1065	g
	37.6	oz
Power-Weight:	55	W/kg
	25	W/lb
Thrust-Weight:	0.29	: 1
Current @ max:	16.30	A
P(in) @ max:	185.8	W
P(out) @ max:	135.1	W
Efficiency @ max:	72.7	%
Torque:	0.17	Nm
	0.13	lbf.ft

Airplane		
All-up Weight:	3402	g
	120	oz
Wing Load:	26	g/dm²
	8.5	oz/ft²
Cubic Wing Load:	2.2	
est. Stall Speed:	24	km/h
	15	mph
est. Speed (level):	61	km/h
	38	mph
est. Speed (vertical):	-	km/h
	-	mph
est. rate of climb:	2.3	m/s
	458	ft/min

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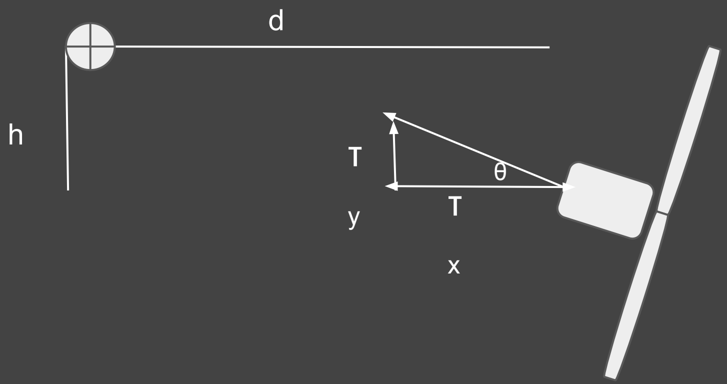
Motor Partial Load

Propeller	Throttle	Current (DC)	Voltage (DC)	el. Power	Efficiency	Thrust		Spec. Thrust		Pitch Speed		Speed (level)		Motor Run Time
rpm	%	A	V	W	%	g	oz	g/W	oz/W	km/h	mph	km/h	mph	(85%) min
1000	11	0.1	11.4	1.0	29.2	16	0.6	16.6	0.59	9	6	-	-	7620.1
1500	16	0.2	11.4	2.0	47.1	36	1.3	17.8	0.63	14	9	-	-	3634.2
2000	21	0.3	11.4	3.8	59.7	65	2.3	17.0	0.60	18	11	-	-	1943.7
2500	27	0.6	11.4	6.5	68.0	101	3.6	15.5	0.55	23	14	-	-	1131.2
3000	32	0.9	11.3	10.5	73.3	145	5.1	13.9	0.49	27	17	-	-	703.9
3500	38	1.4	11.3	15.9	76.6	198	7.0	12.5	0.44	32	20	-	-	462.2
4000	44	2.1	11.3	23.1	78.8	258	9.1	11.2	0.40	37	23	21	13	317.0
4500	50	2.9	11.2	32.3	80.1	327	11.5	10.1	0.36	41	26	35	22	225.2
5000	57	4.0	11.2	43.9	80.8	404	14.2	9.2	0.32	46	28	39	24	164.7
5500	**64**	**5.3**	**11.1**	**58.2**	**81.2**	**488**	**17.2**	**8.4**	**0.30**	**50**	**31**	**43**	**27**	**123.4**
6000	71	6.9	11.0	75.4	81.3	581	20.5	7.7	0.27	55	34	47	29	94.4
6500	78	8.9	10.9	96.0	81.2	682	24.1	7.1	0.25	59	37	51	32	73.4
7000	86	11.3	10.8	120.2	81.0	791	27.9	6.6	0.23	64	40	55	34	57.8
7500	94	14.2	10.6	148.5	80.6	908	32.0	6.1	0.22	69	43	59	37	46.1
7796	100	16.3	10.5	169.0	79.9	981	34.6	5.8	0.20	71	44	61	38	40.1

Propulsion - Shimming Angle

- For steady, level, flight this is just a simple statics problem:



$$\Sigma M = 0 = \tau_x - \tau_y$$

$$\tau_x = \tau_y$$

$$d\sin(\theta) = h\cos(\theta)$$

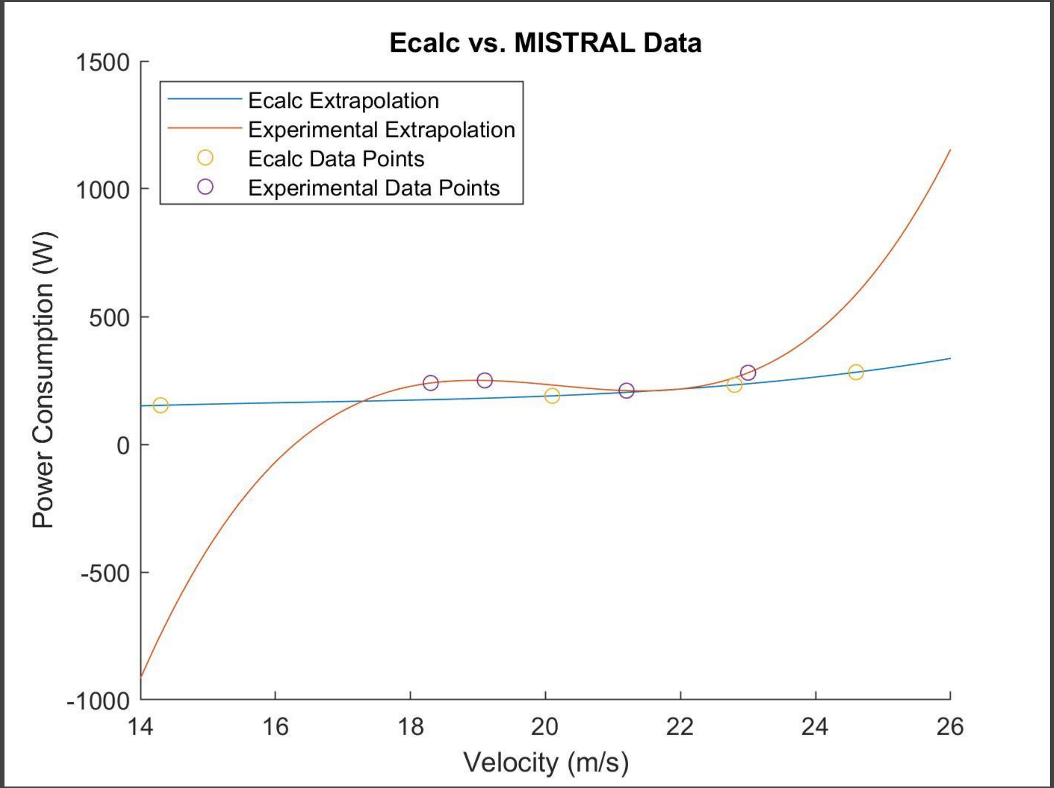
$$\theta = \tan^{-1}(h/d)$$

Propulsion - eCalc Inputs

- When running our eCalc simulations the following items were input:
  - Weight: 3600
  - Velocity: 11.1 m/s (24.83 mph)
  - Batteries: 4 x 3S 3200 mAh LiPo, 20-30C, 85% Discharge Max (recommended by RC experts)
  - Speed Controller: X-20 Pro
  - Carbon Folding Prop
- The following items were varied to choose our motor:
  - Motor type
  - Prop diameter
  - Prop pitch

Propulsion - eCalc Validation

- Compared flight data from MISTRAL data to eCalc outputs using the same design parameters
    - Noticed discrepancy between real data and eCalc data:
        - Average Error = 13.88% (ignoring outliers - focusing on where experimental data was taken)
        - Error caused by eCalc neglecting aerodynamic forces, maneuvering, system inefficiencies, etc.
    - Despite discrepancies, we now have quantified error that allows us to design our system with less uncertainty as we know exactly how much to trust eCalc and can alter our factors of safety



Propulsion Test

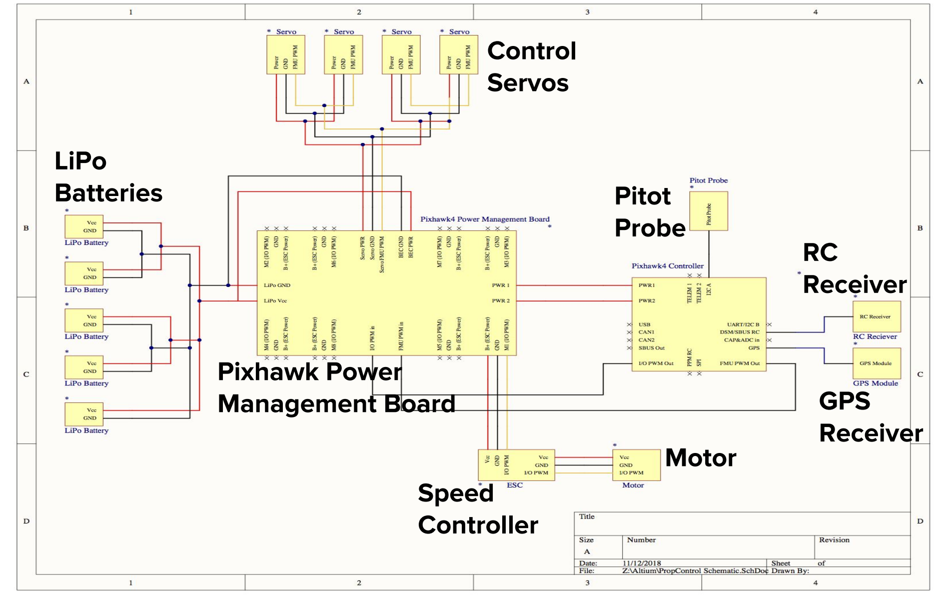
Driving Requirements
DR 1.2.1: The propulsion system shall be capable of producing enough thrust for the aircraft to reach a range of 10-30 [m/s] flight speeds.

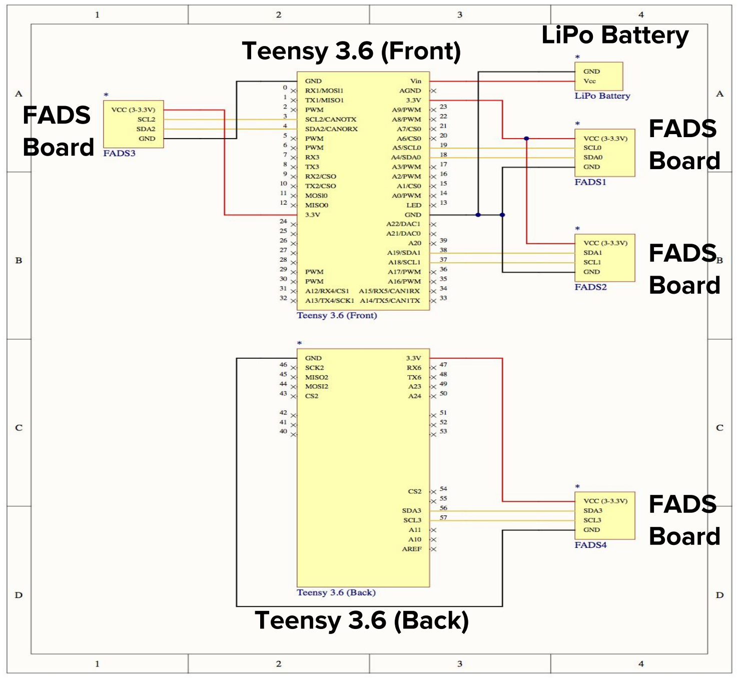
- Test Description:
    - Makeshift box fan configuration with integrated pitot tube to ensure accurate wind speed data
    - Run wind speed at ~12 m/s with different motor and propellor configurations while observing endurance
    - Ammeter will be connected to system to ensure current is the same as outputs of Ecalc

Inputs to Ecalc	Outputs from Ecalc
2500 mAh 3S battery	Flight Endurance
Pitch	Power
Diameter of propeller	Dynamic Thrust

AVIONICS & FADS BACKUP SLIDES

AVIONICS AND FADS





- Schematics showing full connection plan for all avionics and FADS systems

AVIONICS: WIRING

Connection	Cable	Total Length (mm)	Mass (g)
FADS board - Teensy 3.6	14 gauge wire	2200	10
9 volt - Teensy 3.6		**??**	**??**
3s battery - PMB	XT60	400	138
Motor - ESC - PMB	**3 pin (copper)**	**225**	**46**
Servos - PMB	3 pin (14 gauge)	2500	25
PMB - Px4 (Servos)	**10-10 pin (PWM)**	**250**	**5**
PMB - Px4 (Power)	6-6 pin (Data)	250	3
PMB - Px4 (Motor)	**10-10 pin (PWM)**	**250**	**5**
GPS - Px4	10-10 pin (PWM/Data)	260	5
RC Receiver - Px4	**SBUS cable**	**250**	**2.5**
Pitot Probe - Px4	I2c 4 pin	100	1
Total			**240**

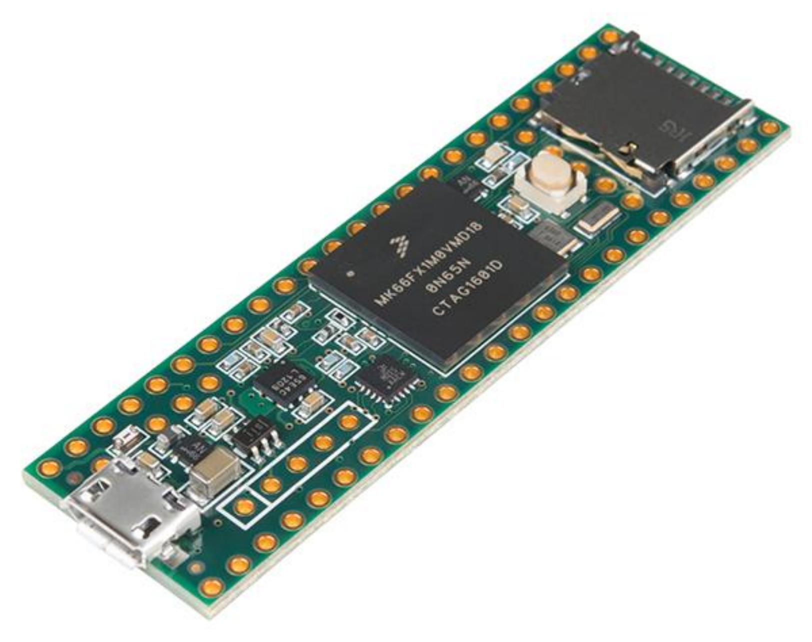
FADS: MICROCONTROLLER

Requirements:

- Data rate: 1 Hz
- Protocol: 4x I2c
- Voltage: 3.3 V
- Storage: 2 Mb

Solution: Teensy 3.6

- Clock speed: 180 MHz
- Protocol: 4x I2c
- Voltage: 3.3 V
- Storage: SD card compatible
- Arduino software compatible



AVIONICS: BATTERY CHOICE

Battery: 3s 30c 3200 mAh LiPo battery (4x)

- LiPo batteries: largest power density
- Safety concerns:
- Fire safety
- If batteries are discharged below 15% they will not be reused
- Batteries will be charged and discharged as a set
- Parallel charging board
- Requirements:
  - Power: 121.2 W
  - Capacity: 11180 mAh
- F.S.: 1.2

AVIONICS: BATTERY CHOICE

From component selection, battery requirements from different sections

Controls

- 4x 3S LiPo batteries: 11.1 V, 30C, 3200 mAh
- Connected in parallel to increase capacity
- Requirement: 121.2 W and 11180 mAh
- Design: 142.1 W and 12800 mAh
- Safety Factor: 1.2
-

FADS

- Traditional 9 V Alkaline battery
- Converted down to 4.5 V to power Teensy
- Teensy powers I2C multiplexer and different sensors

DR 1.1.1:
Provide power for subsystems ✓

DR 1.1.2:
Replaceable / replaceable ✓

AVIONICS: BATTERY SAFETY

- Safety concerns
    - Fire safety
        - If batteries are discharged below 15% they will not be reused
    - Batteries will be charged and discharged as a set
    - Parallel charging board
- Simple replacement
    - Remove foam safe tape and remove batteries
- Typical discharge at 1.56 C during steady flight
    - Well below max rate of 30 C
    - Lower discharge ensures batteries discharge at same rate

AVIONICS: CHARGING

Concern: Unequal charging/discharging

Requirements:

- Power: 142 W (11.1 V * 3.2 Ah * 4 batteries)
- Plug: XT-60
- Balanced parallel charging

Solution:

- Charger:
  - iSDT Q6 Pro
- Parallel Board:
  - iSDT PC-4860 XT60

Q6 Plus

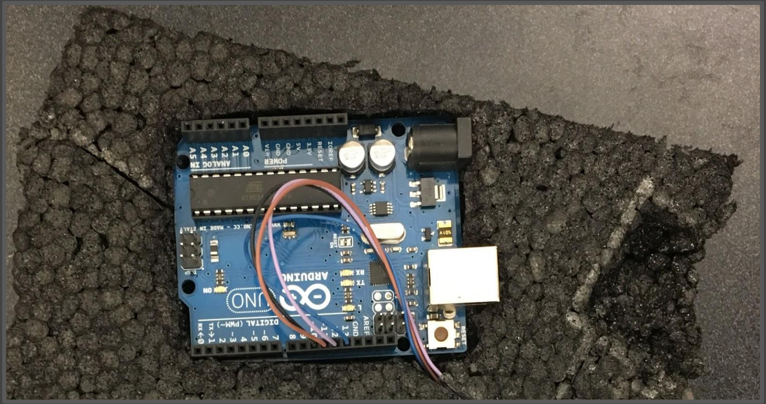
AVIONICS: RECHARGING

Time before replacement (75 minutes)

- Short flight: 5 flights
- Long flight: each flight

Recharging time: 2 hours (parallel charging)

- 2 sets of batteries are being purchased
- Simple replacement
  - Remove foam safe tape and remove batteries

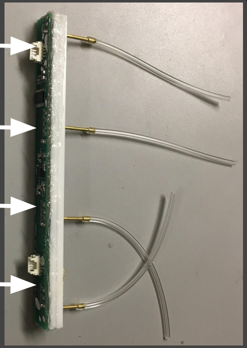


Foam cut out (similar to batteries)

DR 1.1.2 ✓

FADS CALCULATING AIRSPEED

Airspeed can be calculated from static and stagnation pressure measured by the FADS system.



Stagnation Pressure Port (Pt)

Static Pressure Port (P)

Static Pressure Port (P)

Temperature Port (T)

FR 5 ✓

Airspeed Derivation:

Dynamic Pressure

$$q = P_t - P$$

Indicated Airspeed

$$IAS = \sqrt{2q/\rho_o}$$

True Airspeed

$$TAS = IAS\sqrt{\rho_o/\rho}$$

Ideal Gas Law

$$\rho = P_t/RT$$

$$IAS = \sqrt{2(P_t - P)/\rho_o}$$

$$TAS = IAS\sqrt{\rho_o P_t/RT}$$

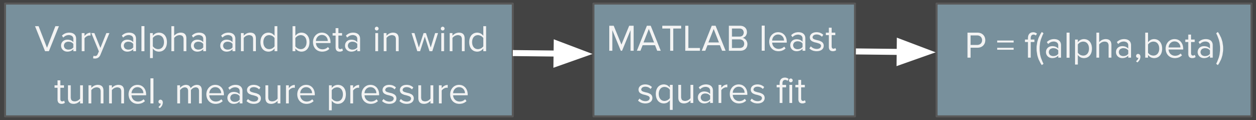
$$TAS = \sqrt{2(P_t - P)/\rho_o} * \sqrt{\rho_o P_t/RT}$$

$$\boxed{TAS = \sqrt{2P_t(P_t - P)/RT}}$$

FADS CALCULATING DIRECTION

Pressure/Alpha/Beta Relationship: Wind Tunnel Testing and Nonlinear Least Squares

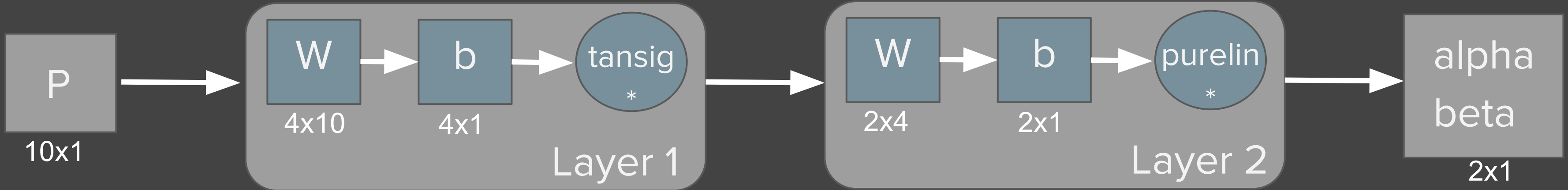
Angle of Attack and Sideslip Algorithm: Neural Networks Method



Problem: there are many combinations of alpha and beta that correspond to a single measured pressure (from FADS)

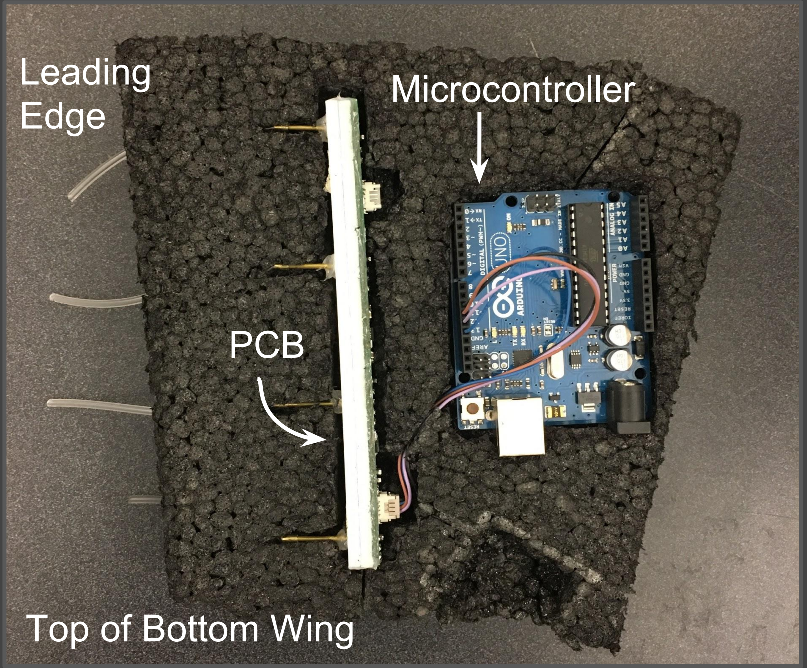
P = measured pressure change, alpha = angle of attack, beta = sideslip

W = weight matrix, b = bias vector, *MATLAB function



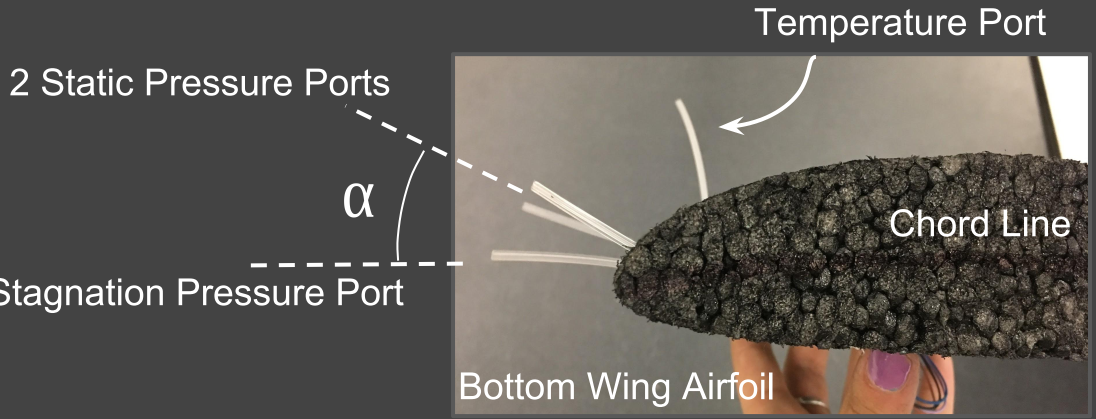
Success Level 3 ✓

FADS INTEGRATION



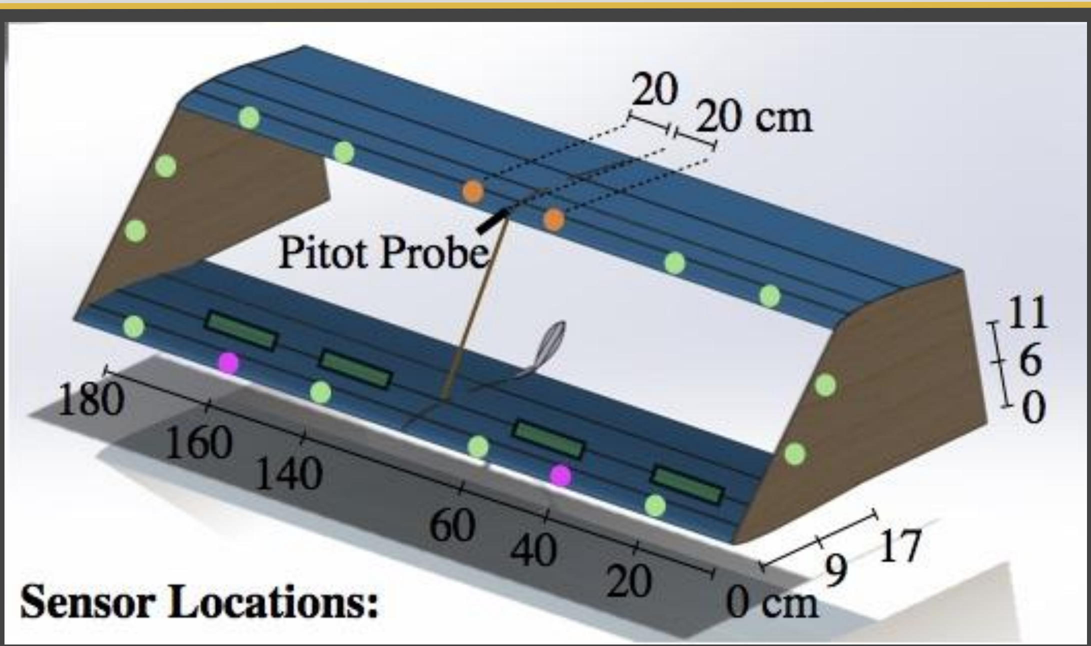
Integration:

- Stagnation pressure measured perpendicular to freestream.
- Static ports must not stagnate - angled with the flight angle of attack.
- Tubing will be cut flush with foam after testing.



DR 5.1 ✓

FADS LOCATIONS



Sensor Locations:

- ● Stagnation Pressure Sensors
- ● Static Pressure Sensors
- ● Temperature Sensors
- 🟩 Printed Circuit Board

Lower Level Design Requirements

- Minimum of 12 pressure sensors and 1 temperature sensor
- Minimum of 4 sensors on top and bottom wings
- Minimum 2 on each side panel

Location Constraints:

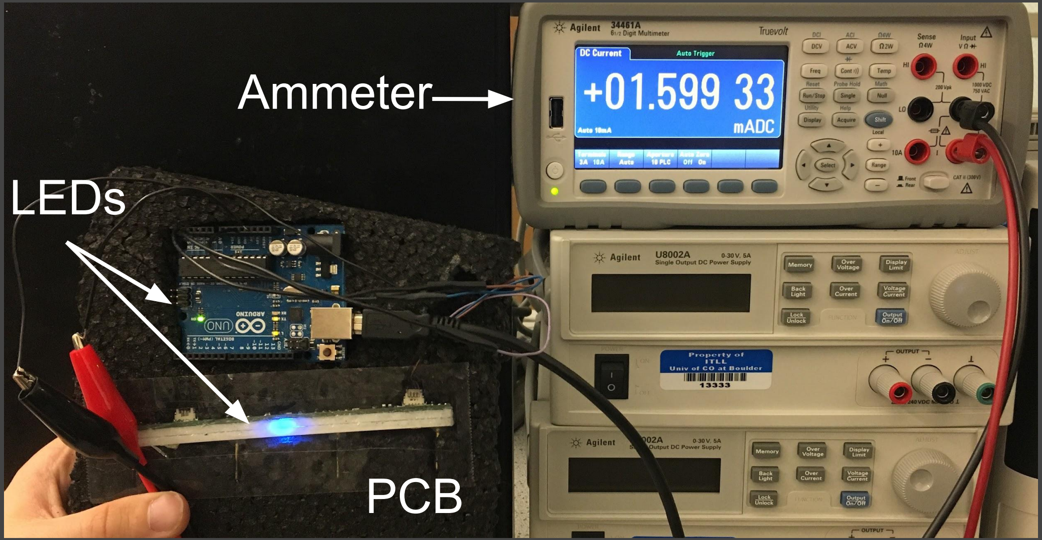
- Temperature sensors cannot be near heat sources
- Stagnation ports must be within 20 cm of the pitot probe for calibration

DR 5.1.1 ✓

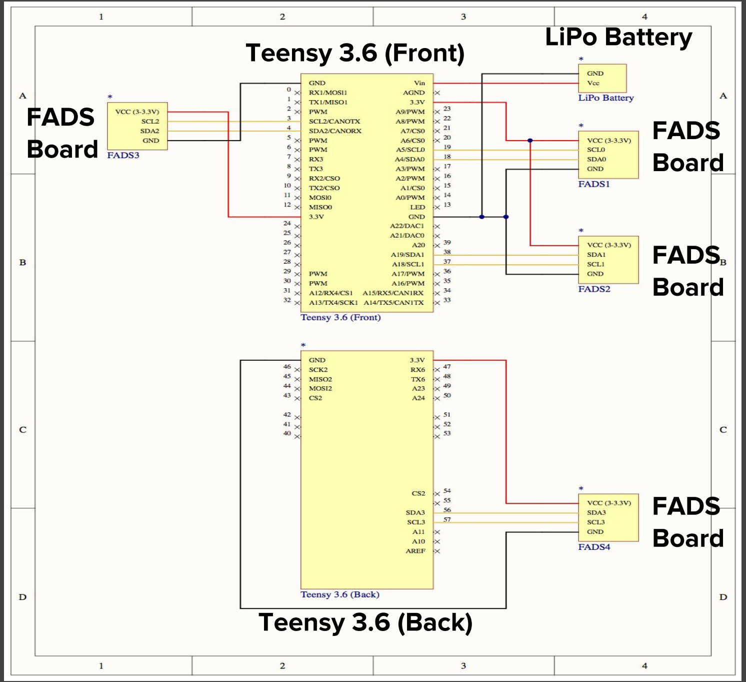
DR 5.1.2 ✓

FADS RECORD & STORE DATA

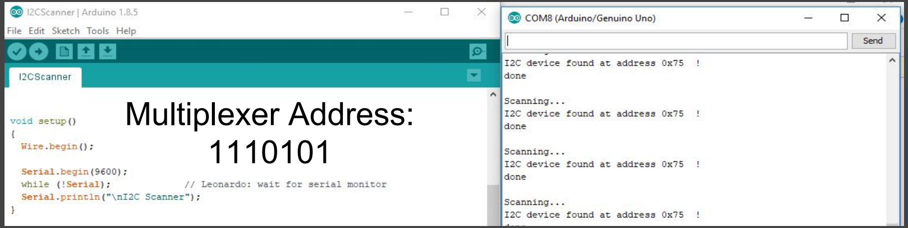
Measured Current Through Sensors



FADS System Schematic



I2C Communication between Multiplexer/Arduino



Multiplexer Address:
1110101

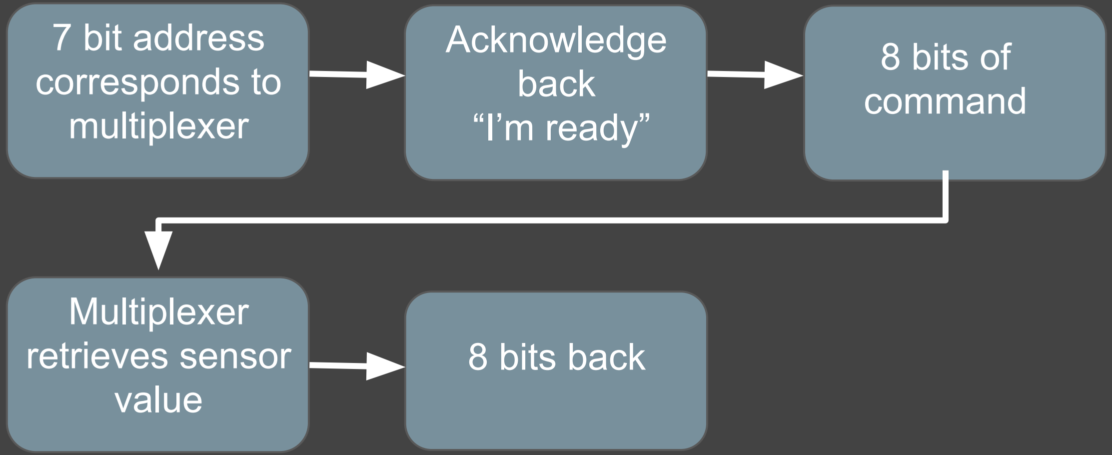
```
void setup()
{
  Wire.begin();

  Serial.begin(9600);
  while (!Serial);             // Leonardo: wait for serial monitor
  Serial.println("\nI2C Scanner");
}
```

```
I2C device found at address 0x75  !
done

Scanning...
I2C device found at address 0x75  !
done

Scanning...
I2C device found at address 0x75  !
done

Scanning...
I2C device found at address 0x75  !
```

DR 5.5 ✓

FADS RECORD & STORE DATA

I2C Scanning for Multiplexer Address Algorithm



I2C Basics:

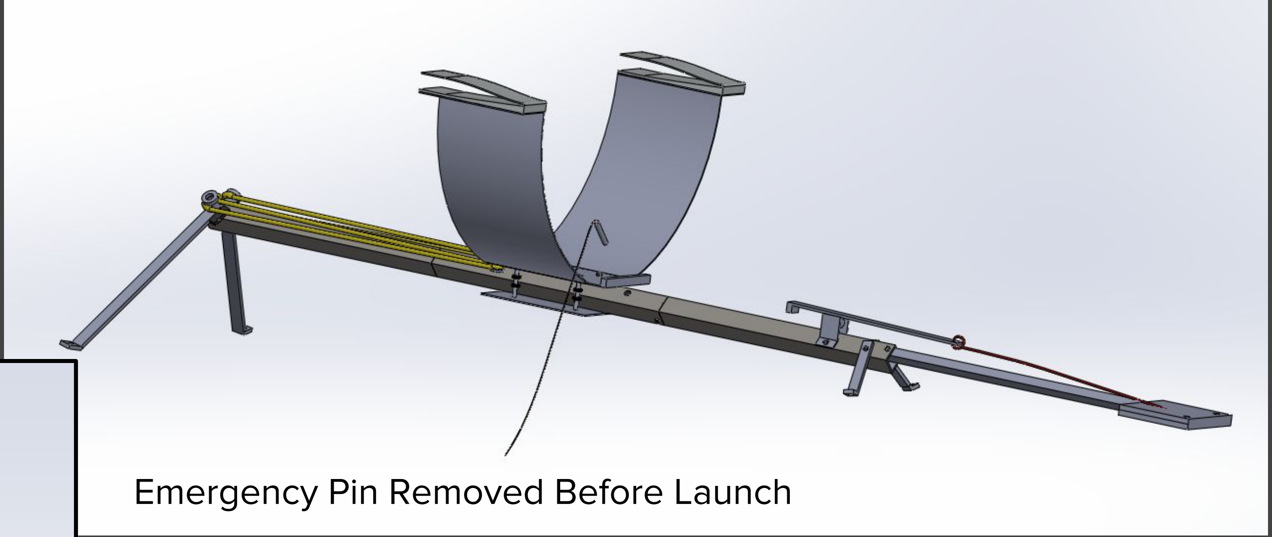
Start Address Read/Write Ackn. Command Ackn. Data Frame Ackn. Stop

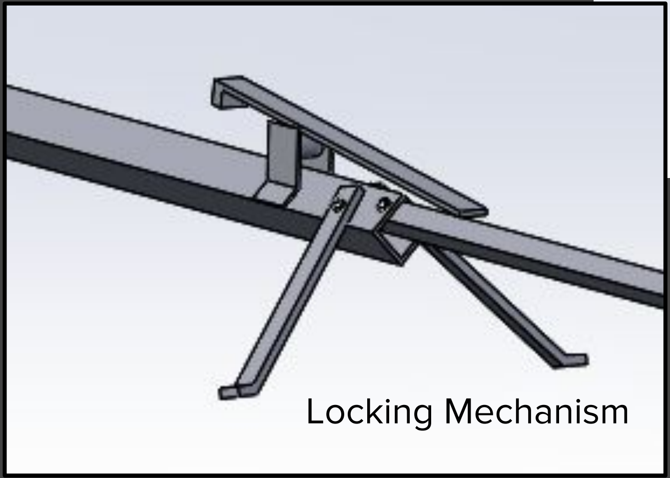
X XXXXXXX X X XXXXXXXX X XXXXXXXX X X

DR 5.5 ✓

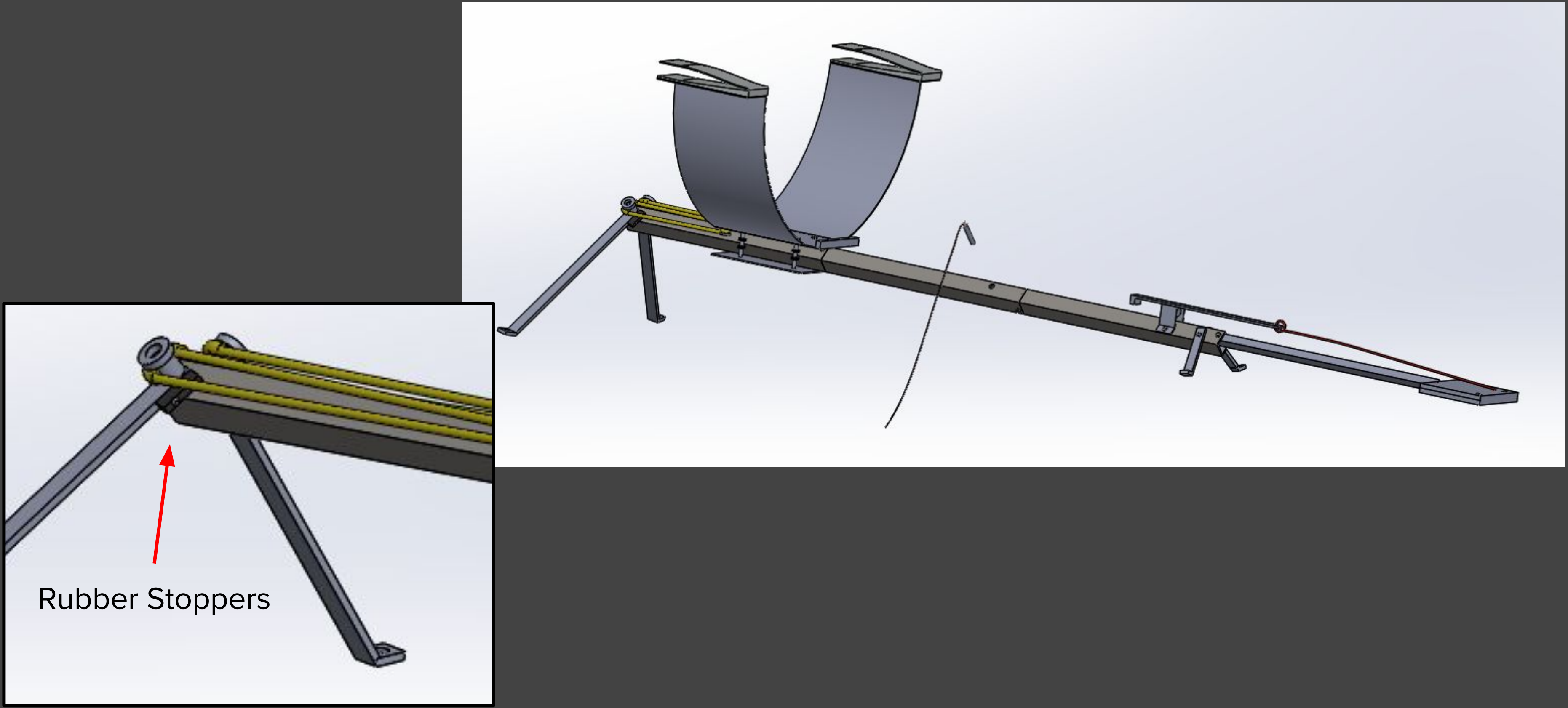
TAKEOFF BACKUP SLIDES

TAKEOFF DESIGN - MID LAUNCH


Emergency Pin Removed Before Launch

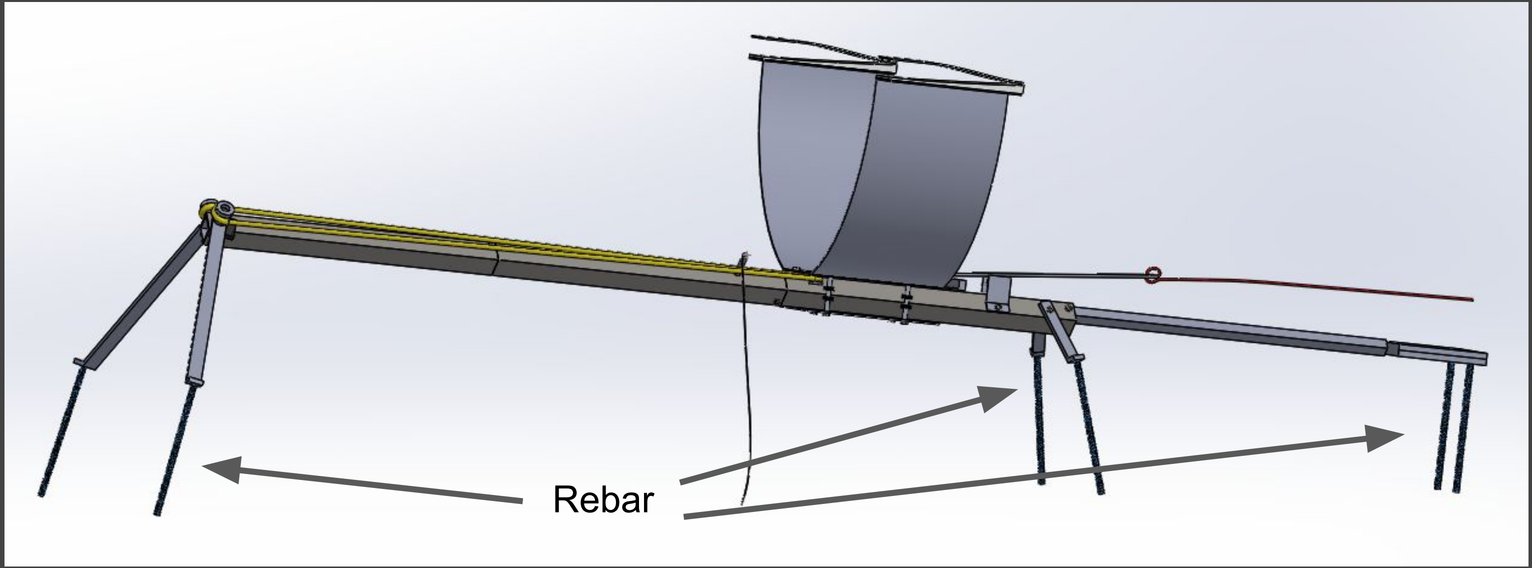

Locking Mechanism

TAKEOFF DESIGN - RELEASE



TAKEOFF SYSTEM

- Grounded with 6 rebar sections (13 mm thickness, 0.305 m length)
- Will counteract moments while applying tension and releasing



TAKEOFF SYSTEM

Bungee Selection: Kband Victory Ropes

Max. allowed load = 534 N

Required tension = 399 N

2 bungees doubled up -> 399 N / 4 = 99.8 N (Tension) per segment

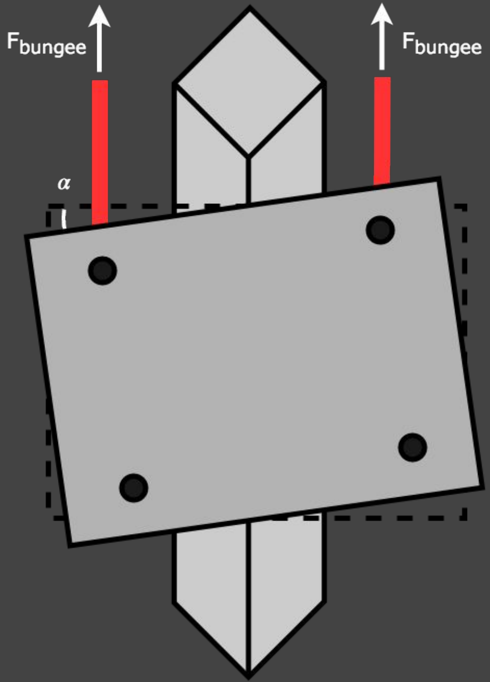
F.O.S. = 5.4

Bungee wrapped in fabric

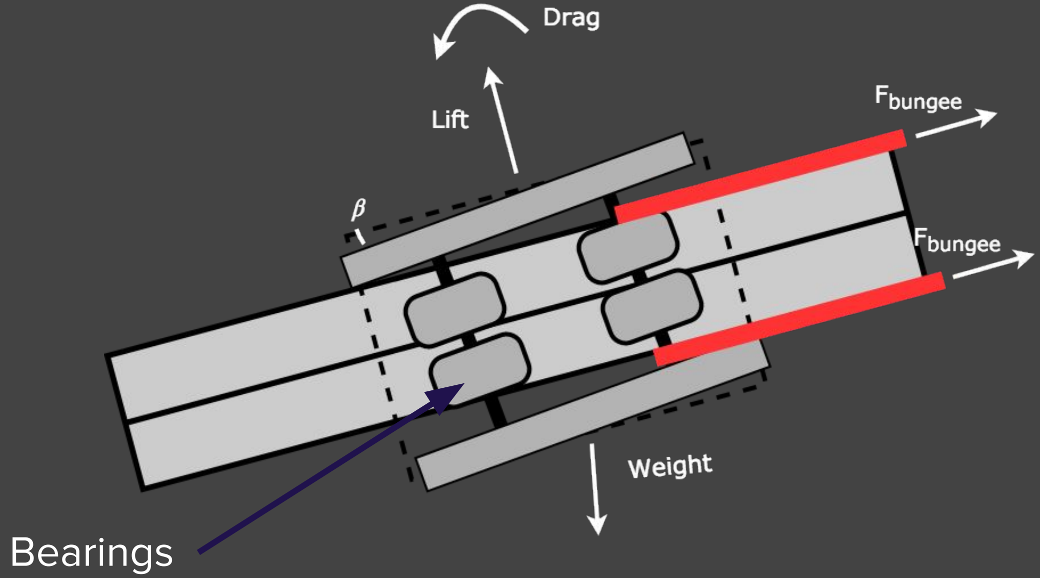
TAKEOFF SYSTEM

Carriage Binding

Top View



Side View



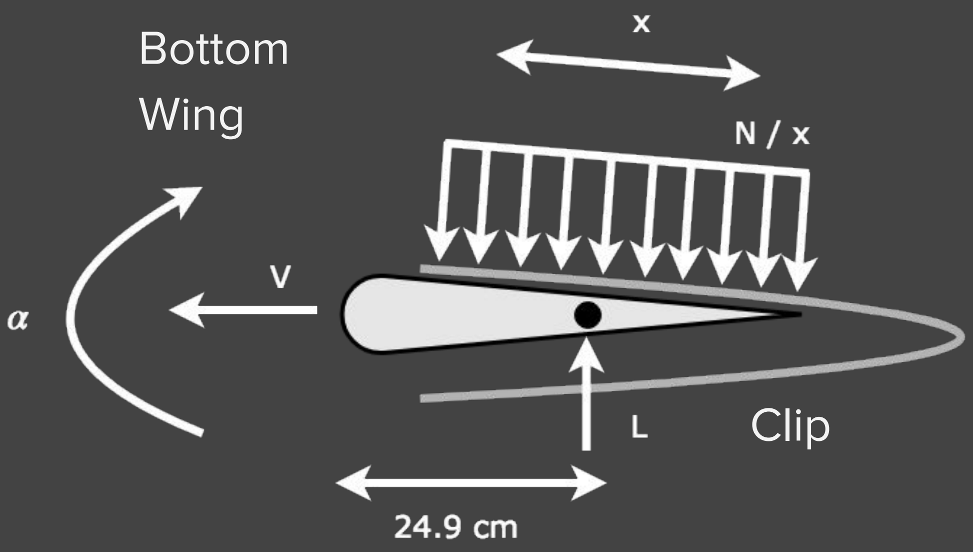
TAKEOFF SYSTEM

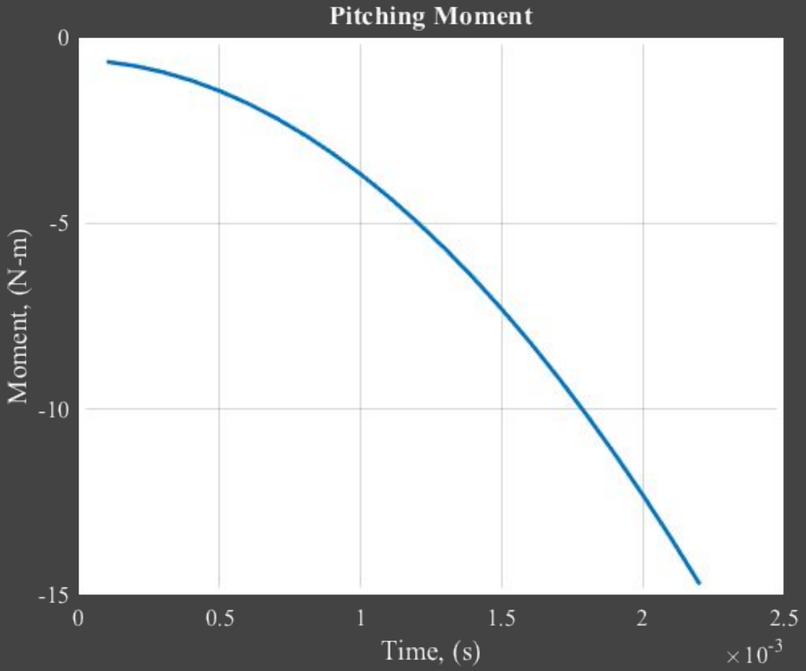
Binding Test

- 5.897 kg, $\cong 1.5 * m_{aircraft}$
- No significant binding
- Noticeable wear in rail

DR 5.1: Able to take off 10 times ✓

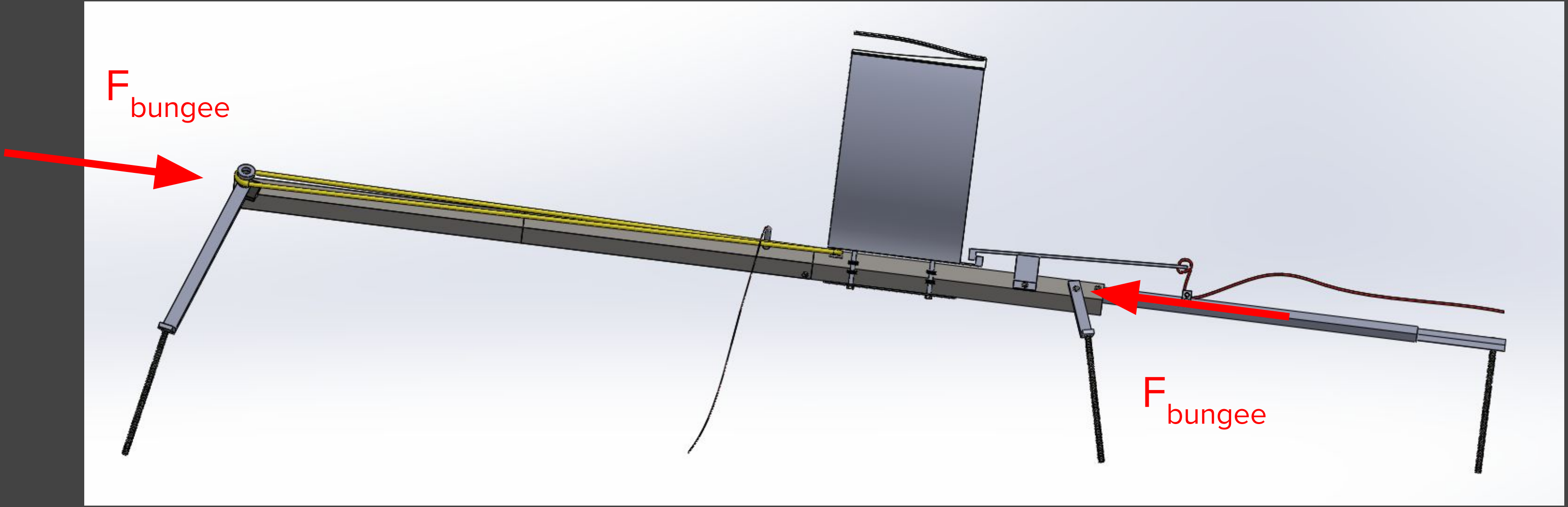
TAKEOFF BACKUP PITCHING





Angular displacement (in pitch) = 0.1 deg

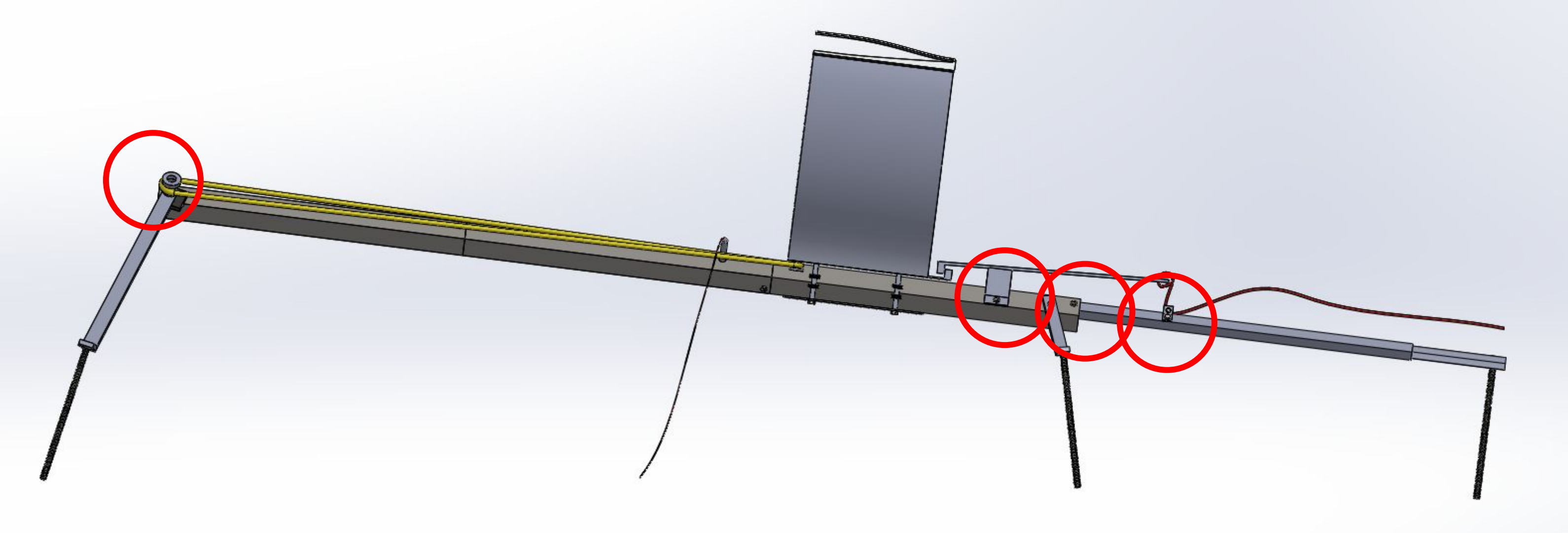
TAKEOFF BACKUP BUCKLING



Compression = 354 kPa << 390 MPa (steel yield stress)

F.O.S = 1095

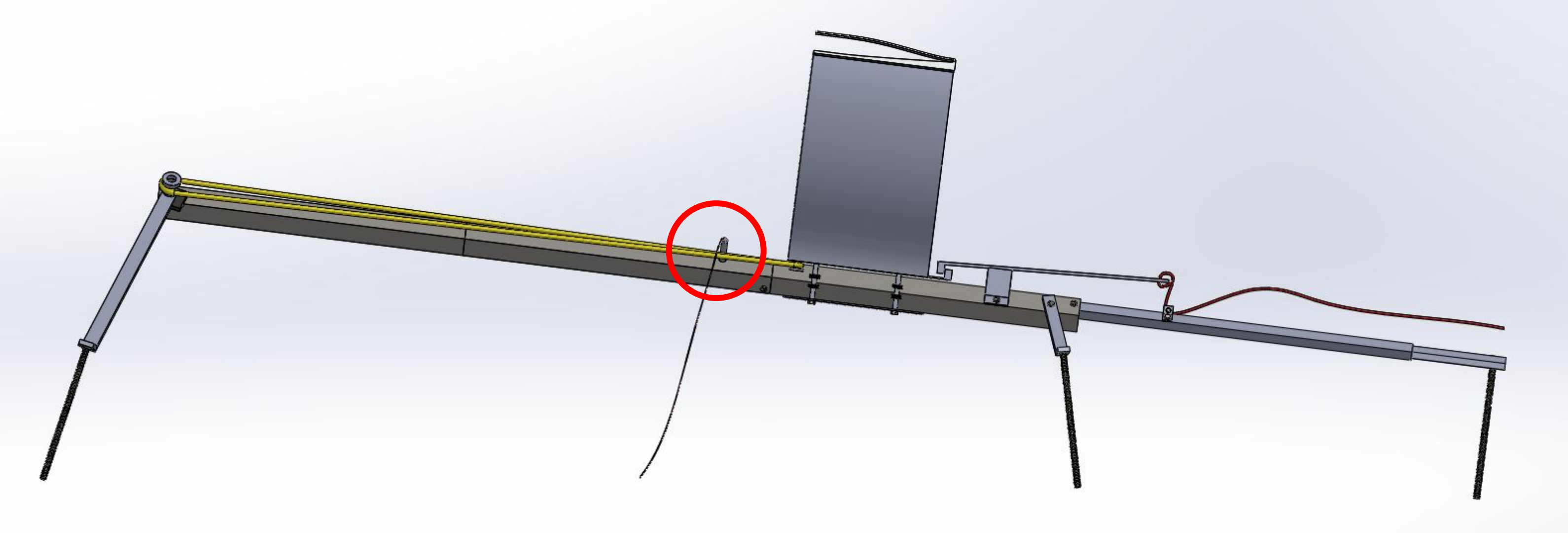
TAKEOFF BACKUP BOLT SHEAR



⅜“ bolts = 5.60 MPa < 390 MPa (steel yield stress)

F.O.S = 70

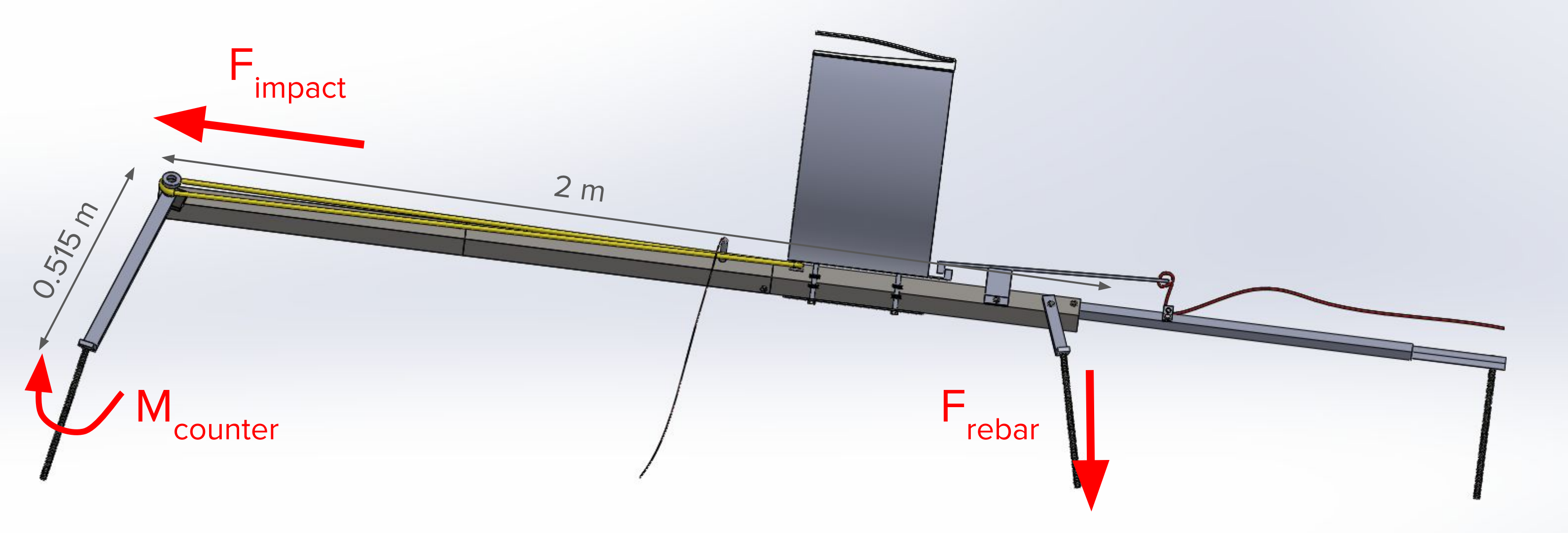
TAKEOFF BACKUP SAFETY PIN



½ “ bolts = 3.15 MPa < 390 MPa (steel yield stress)

F.O.S = 124

TAKEOFF BACKUP REBAR



F_{impact} = 2.64 kN (assuming t_{impact} = 1 ms)

Need F_{rebar} = 660 N (distributed over 2 rebar stakes; 330 N = 74 lbf)

Or need $M_{counter}$ = 1.32 kN-m

TAKEOFF SYSTEM X8 SYSTEM

Flight Heritage Video - x8 Skywalker

Go to time 1:19 to see launch.

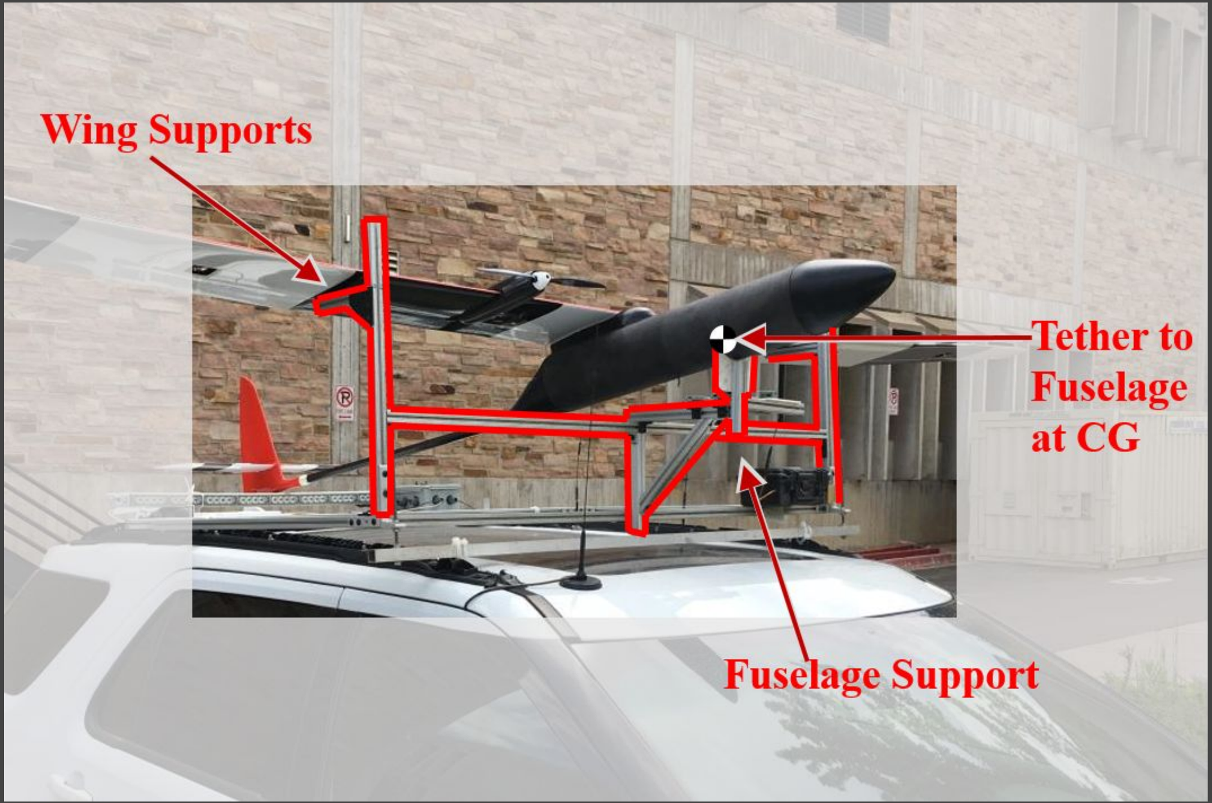
TAKEOFF SYSTEM MATERIALS

Material:	**Items:**
Steel A500	Main Tube, Bearings, Rebar
Aluminum 6061	Release Mechanism, Nuts and Bolts, Legs, Pin
Aluminum 3003	Mount
Synthetic Rubber	Stoppers
Nylon	Rope
Polydac (Dacron Polyester)	Bungees

TAKEOFF: OFF RAMPS

- If the rail launcher does not work we have approval to use the IRISS car launcher (customer required non-car launch)
- Slight modification would be needed for ARES purpose
  - Add carriage to the premade takeoff system
- Has heritage from past UAVs

TAKEOFF: OFF RAMPS

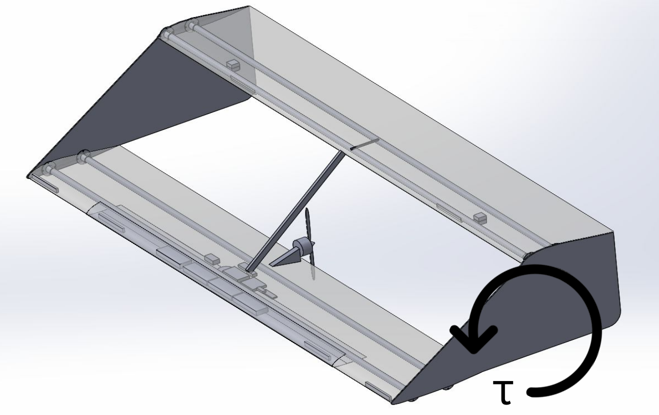


LANDING BACKUP SLIDES

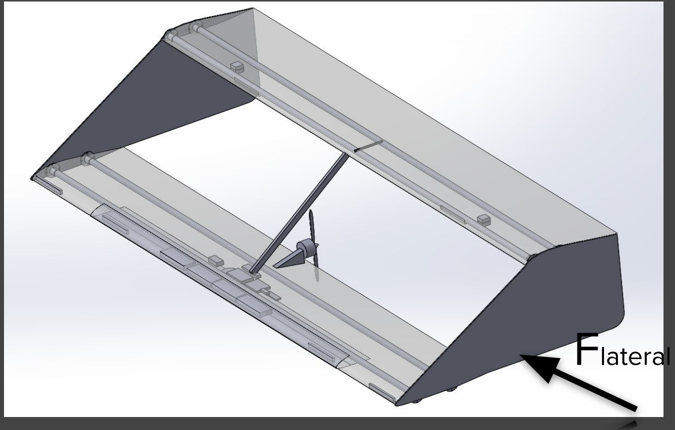
LANDING: LOAD MODELING

Concerns from PDR: Torsion and bending, specifically failure in the joints

Torsion:

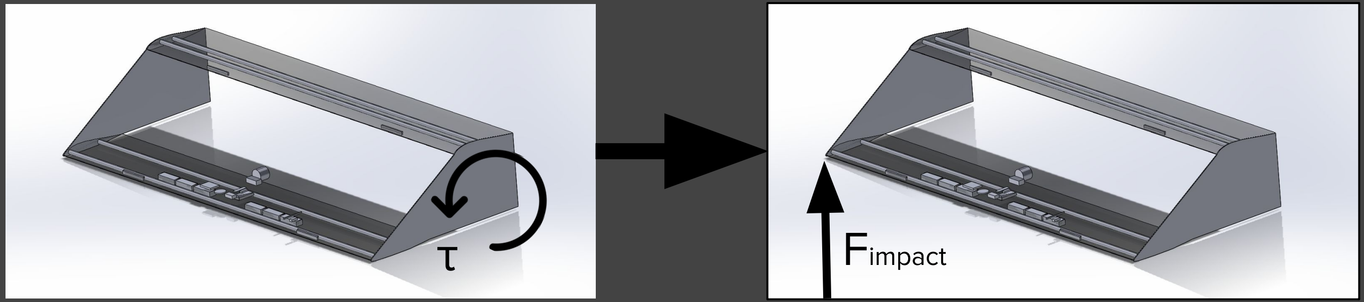


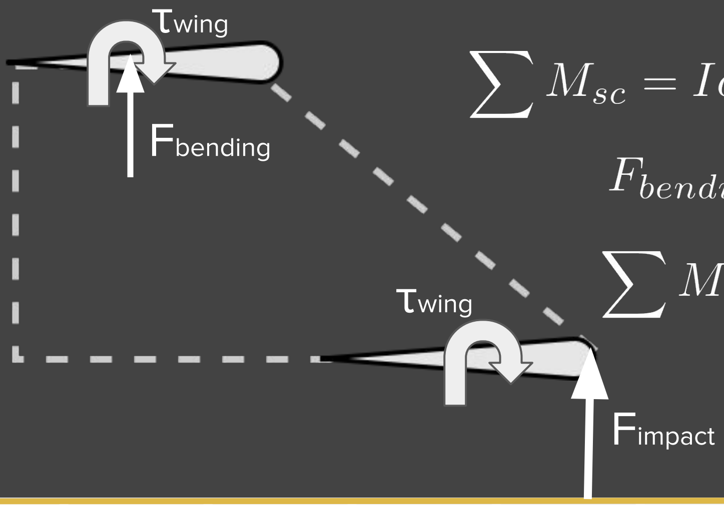
Bending:



LANDING: TORSION ANALYSIS

Torsion:





$$\sum M_{sc} = I\alpha = F_{impact}(c + \frac{S-c}{2}) - 2\tau_{wing} - F_{bending}(\frac{S}{2})$$

$$F_{bending} = \frac{M_{fail}}{2m}2$$

$$\sum M_{sc} = I\alpha = F_{impact}\frac{c+S}{2} - 2\tau_{wing} - M_{fail}(\frac{S}{2})$$

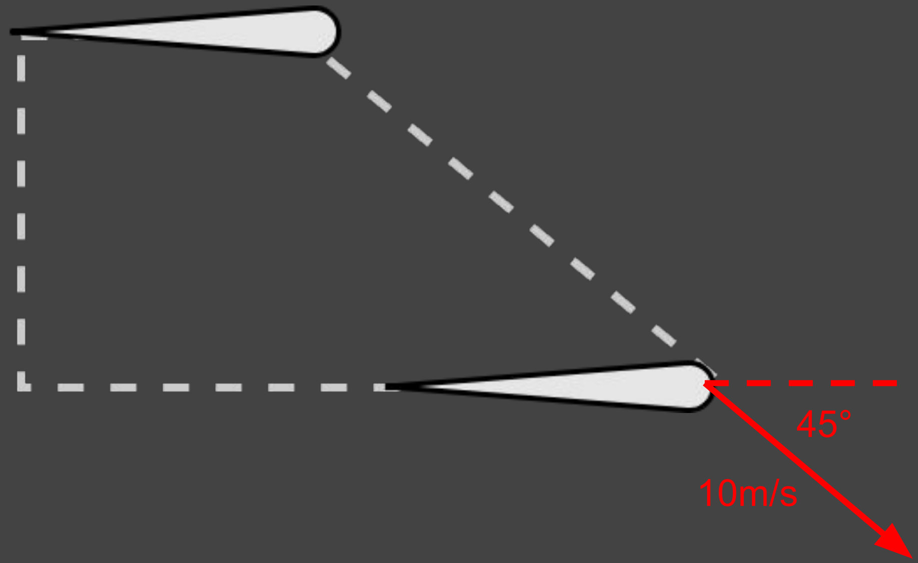
LANDING: FORCE MODELING

$$\sum M_{sc} = I\alpha = 0.365F_{impact} - 271 - 17(0.2)$$

- At max torque we want no positive moment, so we set the moments to zero to find failure impact force

$$F_{impact,max} = 761N$$

- With worst case landing scenario of 10m/s impact at -45° AoA, we find minimum impulse time to handle the landing forces



LANDING: BENDING ANALYSIS

If ARES lands on a corner, it must survive the bending forces during landing.

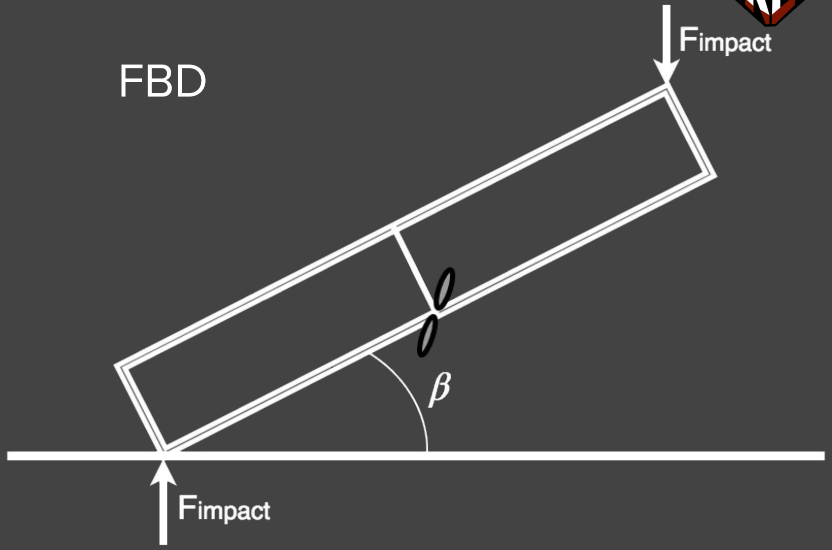
- FBD to the right models a worst case landing scenario where ARES impacts on a corner

$$M_i = \frac{F_{impact} * 0.33m}{2} sin(\beta) M_i = 112Nm * sin(\beta)$$

$$M_{max,experiment} = 35.25Nm = 112Nm * sin(\beta)$$

$$\beta_{max} = 18.3^{\circ}$$

FBD



LANDING: DROP TEST

$$\Delta t_{min} = \frac{\Delta v * m}{F_{impact,max}} = 0.034 seconds$$

Impulse time drop test:

- Weight of bar and honeycomb structure was 4.0kg
- Vertical velocity of 9m/s
- Resultant landing time of 0.04166 seconds
- Factor of safety of 1.13 for torsion on our worst case landing scenario

LANDING: CONTINGENCY PLAN

From torque testing ARES should not fail due to torsion or bending; however if it does:

- Testing shows failure will be a bending failure in the carbon honeycomb sidewalls
  - Maintain structural integrity after initial bending failure
- The honeycomb sidewalls do not tear under forces and moments > maximum expected
  - Aircraft will remain intact
- All honeycomb sections can be replaced in <12 minutes if they are too severely damaged for continued flight

DR 6.1 ✓

TESTING BACKUP SLIDES

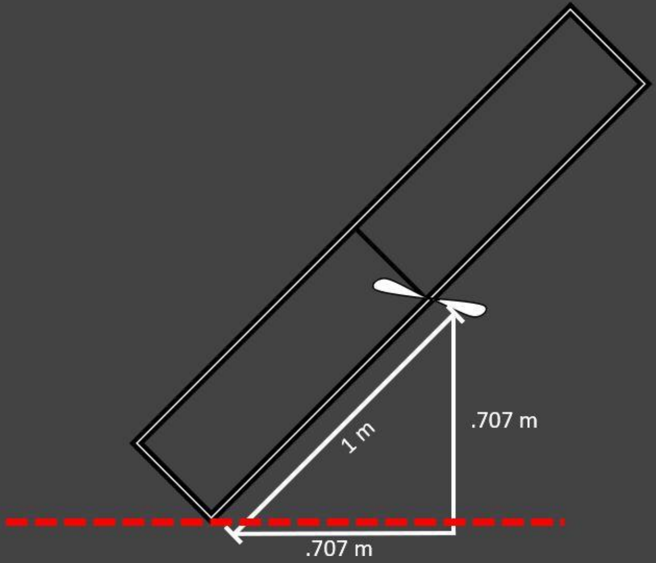
STABLE TAKEOFF TEST

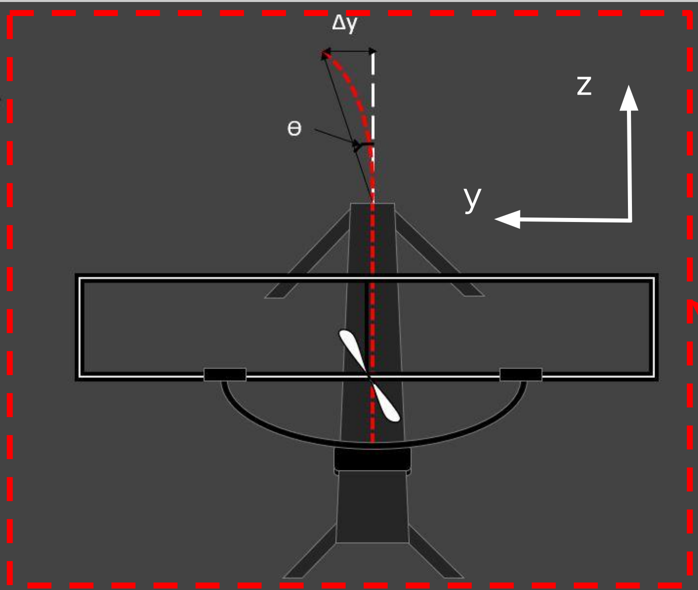
Driving Requirements

DR 3.0: The aircraft shall demonstrate a controlled takeoff.

D.R. 3.1: The takeoff system shall be able to control the heading of the aircraft after takeoff to within plus or minus 45 degrees of the expected lateral heading.

- Objective:
  - Validate the Launch System’s ability to provide even tension to launch ARES
  - Validate and record the deflection of ARES wings during takeoff





STABLE TAKEOFF TEST

Driving Requirements

DR 3.0: The aircraft shall demonstrate a controlled takeoff.

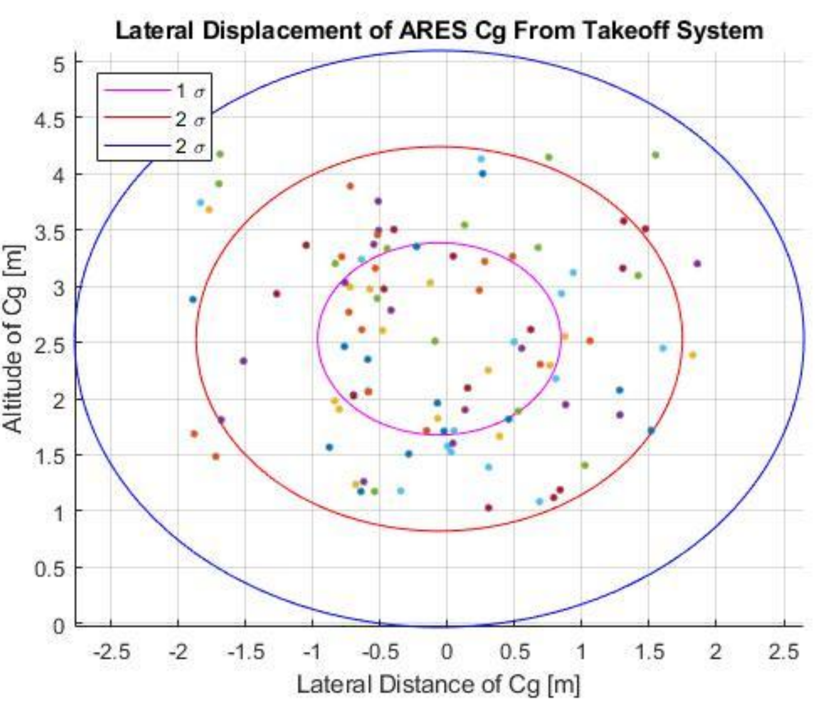
D.R. 3.1: The takeoff system shall be able to control the heading of the aircraft after takeoff to within plus or minus 45 degrees of the expected lateral heading.

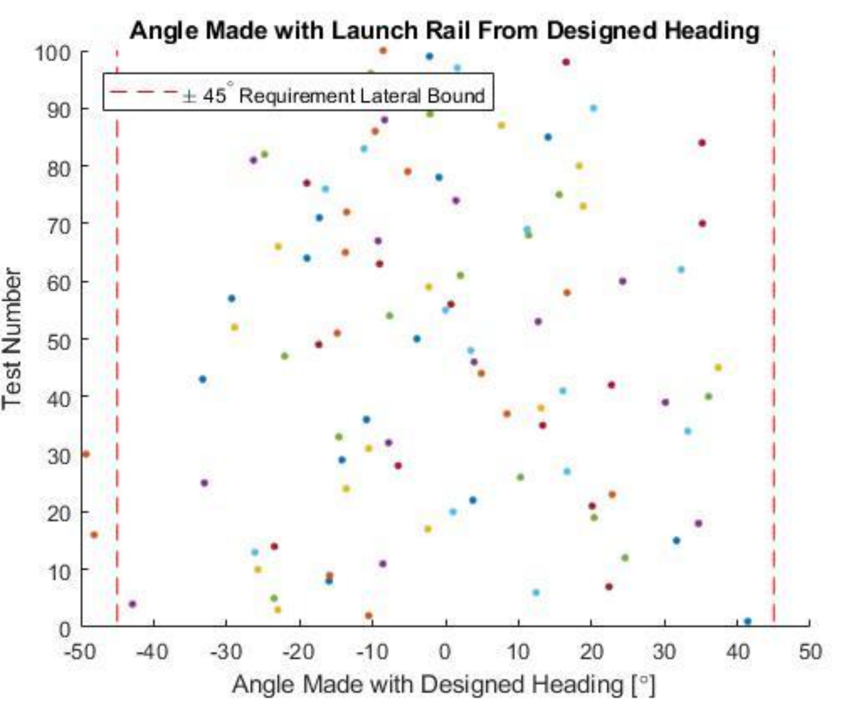
- Test Description:
    - Place Takeoff subsystem components: Takeoff Stand, Bungees, Base Plates, Rebar, and ARES Airframe Test Model with motor, speed controller, receiver and batteries attached
    - Secure ARES Launch Stand to ground in open field via rebar and base plates
    - Launch the Airframe Test Model at 10° AoA
    - Measure the distance moved laterally post takeoff For 2 seconds (Δy) and film each launch
    - Calculate: Launch Velocity (V_f), Launch Force (F)

Device	Measurement	Accuracy
Measuring Tape	Distance [m]	± 1mm
iPhone 10 Camera	Height [m]	± 6.1%

STABLE TAKEOFF TEST

Ballistic Modeling for Comparison





MOTOR DYNAMOMETER TESTING

Driving Requirements

DR 1.2: The system shall have an integrated propulsion system capable of producing enough thrust for flight.

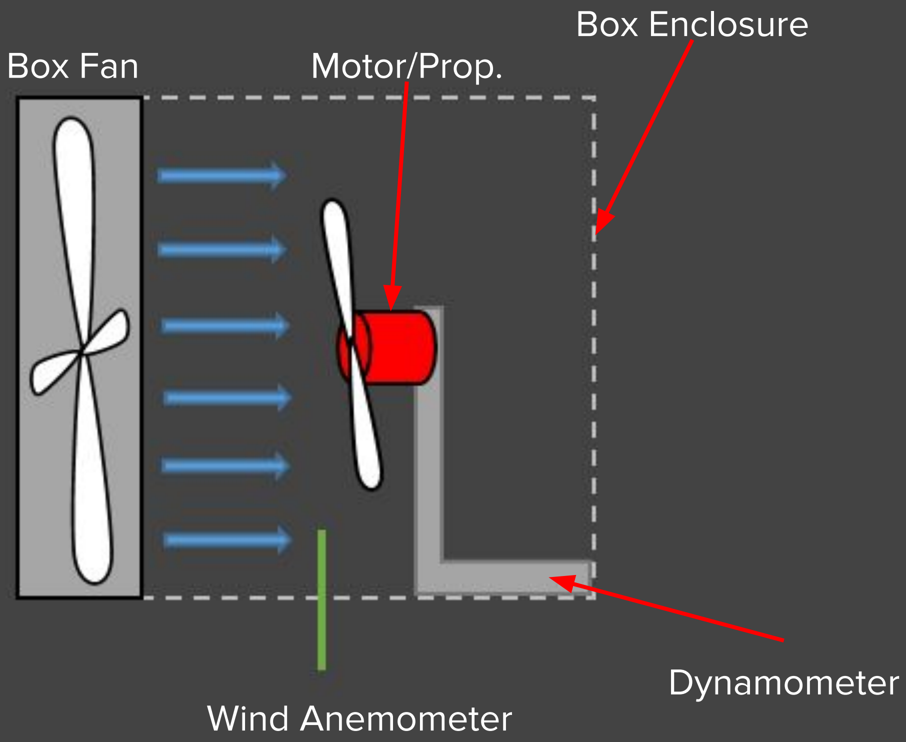
DR 1.2.1: The propulsion system shall be capable of producing enough thrust for the aircraft to reach a range of 10-30 [m/s] flight speeds.

- Test Description:
  - DBF's Dynamometer capable of measuring static thrust of motor compared to RPM/Voltage/Current supplied to motor
  - Place the Dynamometer in a rectangular tunnel with a box fan at front end, Dynamic thrust can be recorded for model comparison
  - An anemometer will be placed in tunnel to measure wind speed

Device	Measurement	Accuracy
Load Cell	Thrust [g]	± 0.5%
Thermal Anemometer	Wind Speed [m/s]	±3%

MOTOR DYNAMOMETER TESTING

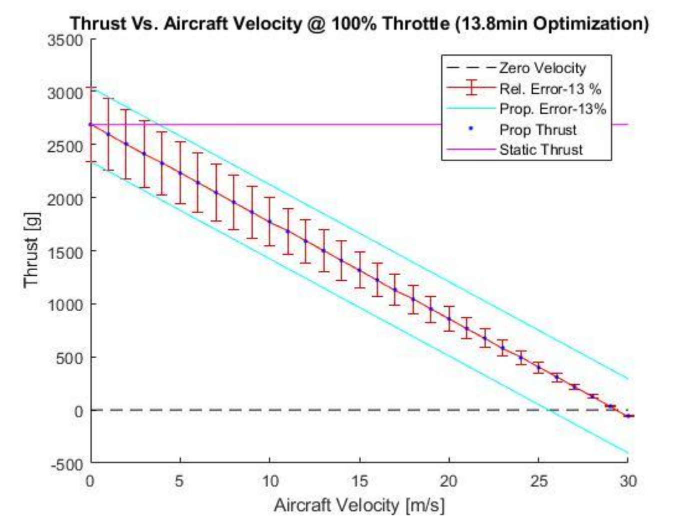
Add Illustration of Test with Labeled Items

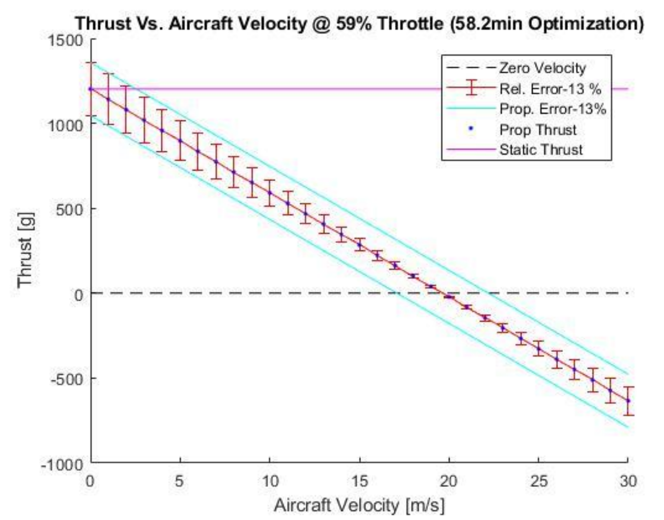


MOTOR DYNAMOMETER TEST

- Static versus Dynamic Model for Testing Comparison/Verification

$$F = \rho\left(\frac{\pi(0.0254\cdot d)^2}{4}\right)\left[\left(RPM\cdot 0.0254\cdot pitch\cdot \frac{1min}{60sec}\right)^2 - \left(RPM\cdot 0.0254\cdot pitch\cdot \frac{1min}{60sec}\right)V_0\right]\left(\frac{d}{3.29546\cdot pitch}\right)^{1.4}$$


Thrust Vs. Aircraft Velocity @ 100% Throttle (13.8min Optimization)


Thrust Vs. Aircraft Velocity @ 59% Throttle (58.2min Optimization)

AVIONICS CHARGING/DISCHARGING

Driving Requirements

DR 1.1.1: The power system shall provide power to the propulsion system, autopilot, GPS, radio controller and flight computer.

D.R. 1.1.2: The power system shall be rechargeable or replaceable between flights.

- Test Description:
  - Using Avionics and Propulsions subsystem components: 4 LiPo batteries (3200mAh), Power Management Board (PMB), ESC, and Propulsions Motor
  - Connect batteries to (PMB), then connect ESC to PMB, then Motor to ESC
  - Run the motor at a constant current
  - Record: the battery voltage (v) and time stamp (t) every minute for one hour
  - Repeat the test once more
  - Calculate: The discharge curve of the 4 LiPo Batteries in parallel

Device	Measurement	Accuracy
Fluke Multimeter	Voltage [V]	± 0.15%
Stopwatch	Time [s]	± .01s

AVIONICS CHARGING/DISCHARGING

Discharge Model of 4 LiPo Batteries in Parallel

- eCalc models calculate Steady Level Flight(71% Throttle) time of 91.4 minutes
- eCalc models calculate Higher Thrust Flight(78% Throttle) time of 71.3 minutes

AVIONICS DAY IN THE LIFE

Driving Requirements

D.R. 1.1: The system shall have an in-flight power system.

DR 1.1.1: The power system shall provide power to the propulsion system, autopilot, GPS, radio controller and flight computer.

D.R. 1.1.2: The power system shall be rechargeable or replaceable between flights.

D.R. 1.1.3: The power system shall have visual indicators to prove when power is being supplied to the aircraft.

- Test Description:
  - Using Avionics, Autopilot, and Propulsions subsystem components: 4 LiPo batteries (3200mAh), Power Management Board (PMB), ESC, Propulsions Motor, 4 servos, Pixhawk 4, RC Receiver, Airspeed Sensor, and Control Surfaces
  - Connect batteries to (PMB), then connect ESC to PMB, then Motor to ESC, then connect servos and airspeed sensor to Pixhawk 4
  - Run the motor at a constant current
  - Simulate perturbations into the Pixhawk 4 through MATLAB
  - Record: the battery voltage (v) and time stamp (t) every minute for one hour and then record the controls response
  - Calculate: The discharge curve of the 4 LiPo Batteries in parallel

Device	Measurement	Accuracy
Fluke Multimeter	Voltage [V]	± 0.15%
Stopwatch	Time [s]	± .01s

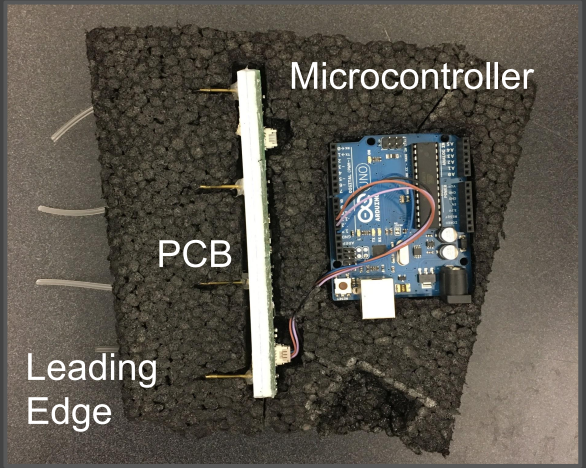
FADS WIND TUNNEL VALIDATION

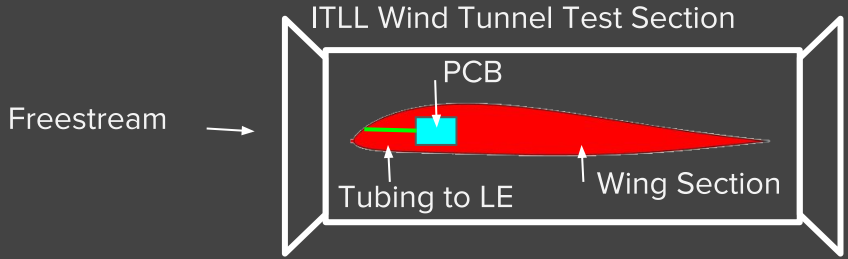
Purpose:

- Confirm ability to record and store data (5.5.1, 5.5.3, 5.6.1)
- Confirm flush manufacturing with no leaks (5.1, 5.1.1)
- Confirm that we have static and stagnation ports (5.0, LS 3)
- Confirm sensor accuracy and calibrate sensors (5.1.3, 5.2.1)

Test Description:

- Integrate FADS into wing section
- Connect microcontroller
- Insert in Wind Tunnel and vary airspeed
- Record pressure and temperature
- Pull FADS and Pitot Probe Data
- Post-process to calculate airspeed



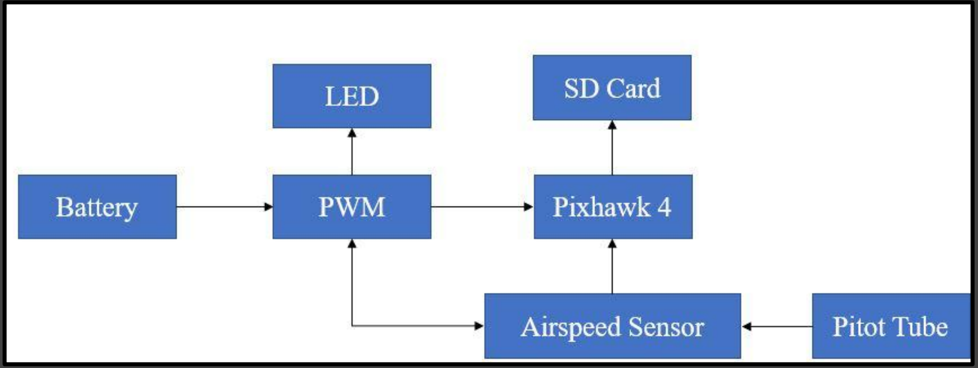


Autopilot Test: Autopilot Power

Driving Requirements

DR 4.3: The autopilot shall be powered by an on-board system within the aircraft

- Test Description:
  - Connect all Autopilot components: Battery, PWM, Pixhawk, Airspeed Sensor, Pitot Tube, SD Card
  - Provide power via battery and verify that power ‘on’ LED is illuminated
  - Fluctuate pressure on Pitot Tube
  - Examine logged data to verify subsystem’s sensors and hardware are logging data as programmed

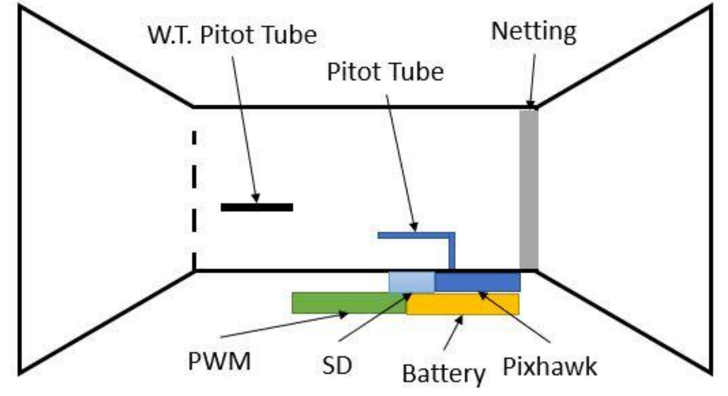


TEST: PITOT TUBE CALIBRATION

Driving Requirements

DR 4.7: The autopilot system shall be able to send commands to actuators and the propulsion system to move control surfaces and make speed adjustments.

- Test Description:
  - Place Autopilot subsystem components: PWM, Pixhawk, Battery, and SD outside of Wind Tunnel Test Section
  - Secure Autopilot Pitot Tube in Test Section
  - Run Wind Tunnel at 5, 6, 7, 8... 20 m/s and save data recorded by A.P. Pitot Tube and W.T. Pitot Tube
  - Use data recorded to calibrate A.P. Airspeed Sensor



Device	Measurement	Accuracy
Sensirion Airspeed Sensor	Press. [Pa]	± 3%
Use Scanivalve instead	Press. [Pa]	± .20%, ± 5 Pa*

*ASEN 2002 Airfoil Pressure Lab

TEST: RC TRANSMITTER

Driving Requirements

DR 4.5: The autopilot shall be able to continuously downlink its data during test flights.

DR 4.4: The aircraft shall be able to receive and complete inputs from customer provided RC ground station.

DR 4.7: The autopilot system shall be able to send commands to actuators and the propulsion system to move control surfaces and make speed adjustments.

- Test Description:
    - Using Autopilot Subsystem components: Pixhawk 4, PWM, Battery, Sensirion Airspeed Sensor, TBD Servos, Speed Controller, Propulsions Motor, and 58D Rec. & Trans.
    - Assemble and connect Autopilot components outside of airframe
    - Power on subsystem and provide RC inputs through Taranix X9D
    - Record: Response Time of Servos and Propulsion motor

TEST: CONTROL SURFACE

Driving Requirements

DR 4.5: The autopilot shall be able to continuously downlink its data during test flights.

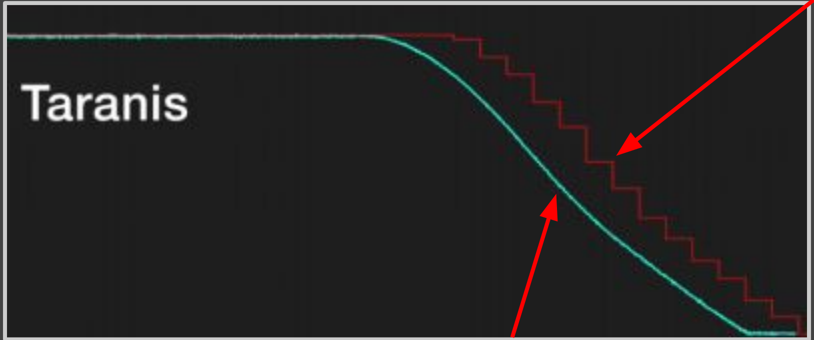
DR 4.7: The autopilot system shall be able to send commands to actuators and the propulsion system to move control surfaces and make speed adjustments.

- Test Description:
    - Using Autopilot Subsystem components: Pixhawk 4, PWM, Battery, Sensirion Airspeed Sensor, TBD Servos, Speed Controller, Propulsions Motor, and 58D Rec. & Trans.
    - **Setup:** fully integrate electronics and actuators into airframe
    - **Motion:** With power off move/shake aircraft. Check and verify that wiring/connections remain intact
    - **Controls:** Turn power on, establish RC link, then use Taranis X9D to actuate control surfaces. Check that wiring/connections remain intact
    - Record: Response Time of Servos and Propulsions Motor

Device	Measurement	Accuracy
Taranis X9D	Res. Time [ms]	0-9ms
iPhone 10	Deflection [Deg]	±3.2%

TEST: CONTROL SURFACE

Digital Conversion



Analog Input

LANDING TESTS: DURABILITY & REPAIR

Driving Requirements

DR 6.1 The aircraft shall land such that it can takeoff again within 15 minutes.

DR 6.3 The aircraft shall be able to land in an outdoor field.

- Test Description:

  1. Test Launch and Landing subsystems will be tested with a full scale mode of the aircraft with no electrical components other than the pixhawk with its accelerometer running. Dummy weights will represent the other missing subsystems.

  - **Setup:** place launch system on flat ground with airframe setup for launch. Stake down the launch system and launch the craft.
  - **Motion:** Aircraft will launch, glide, and land on a semi-flat surface.
  - **Record:** Accelerations, flight trajectory and landing (with video camera)

PROJECT ORGANIZATION BACKUP SLIDES

RISKS

Risk	Mitigation Plan	Post Mitigation Likelihood/Impact
B1) Choosing optimized motor/propeller	● Physical testing will help us understand actual values	3/1
B2) PX4 software hurting schedule	● Begin the software coding early and	2/3
B3) Discharge of LiPo batteries fire risk	● Spare batteries and constantly monitor them ● Charging batteries will be monitored	1/4
B4) Force on bungee cords breaking/ releasing before intended	● Shield takeoff system to keep aircraft safe ● People will stand far from the takeoff system ● Integrate “pull pin” that’s releases for takeoff	2/3
B5) Lack of control authority during complex maneuvers	● Use X-Plane hardware in the loop simulator ● Helps understand control system without putting plane at risk	3/3

1 = lowest likelihood/ probability

5 = highest likelihood/ probability

RISKS

Risk	Mitigation Plan	Post Mitigation Likelihood/Impact
B6) AVL and XFLR inaccuracy to actual aircraft behavior	● Use real world tests such as throwing a scale model to find the glide angle	3/3
B7) Airfoil ability to hold components within wing	● New models to find the different characteristics/ adjust components	1/2
B8) Unstable aircraft due to manufacturability inconsistencies	● Build multiple prototypes as practice to ensure as few errors as possible	1/4
B9) CG shifts aft due to component placement	● Add weights toward the leading edge to counteract weight	3/1
B10) Accidentally reaching stall due to inaccuracy in estimated stall speed	● Controls team will stay a factor of safety away from estimated stall	2/5

1 = lowest likelihood/ probability

5 = highest likelihood/ probability

RISKS

Risk	Mitigation Plan	Post Mitigation Likelihood/Impact
B11) Carbon honeycomb side panels not surviving landing moments	● If the side panels can be changed between flights this won't be an issue	3/2
B12) Insufficient current provided to motor/ servos to perform maneuvers	● Use safety factor of 1.25 when calculating current draw required	2/3
B13) Temperature sensors not receiving accurate results due to being embedded in the wing	● Temperature sensors attached as close to the leading edge as possible ● Review literature of Skywalker	2/2
B14) FADS Battery discharges too low/ microcontroller doesn't receive power	● Batteries recharged after flight with maximum drain being 25% left	1/3
B15) Launcher flips over due to bungee moments	● Legs of launcher will be staked down, and large foot plates will be added	3/3

1 = lowest likelihood/ probability

5 = highest likelihood/ probability

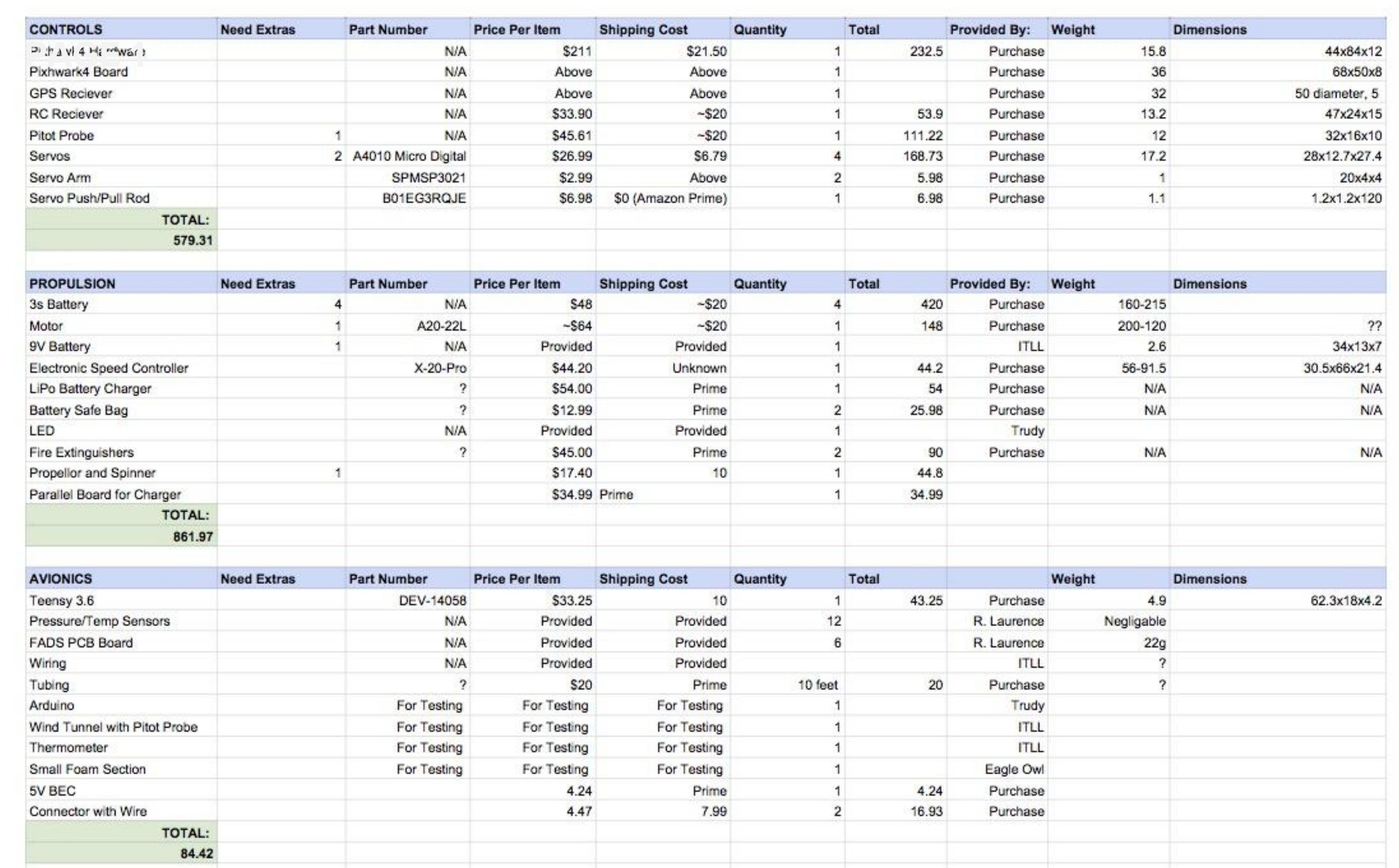
RISKS

Risk	Mitigation Plan	Post Mitigation: Likelihood	Post Mitigation: Impact
1) Accidentally reaching stall due to inaccuracy in estimated stall speed	● Factor of safety introduced to V_{Cruise} ● Additional stall testing planned	2	5
2) AVL and XFLR inaccuracy to actual aircraft behavior	● Scale model testing to validate results	3	3
3) Lack of control authority during complex maneuvers	● Use X-Plane hardware in the loop simulator ● Max T/W above T/W required for cruise	3	3
4) Carbon honeycomb side panels fail during landing	● Manufacture extra side panels to replace any broken components	3	2
5) Battery combustion while charging / after puncture	● Shield batteries with carbon fiber plate ● Charge and discharge together ● Replace if discharged below 15%	1	5

1 = lowest likelihood/ severity

5 = highest likelihood/ severity

BUDGET BREAKDOWN



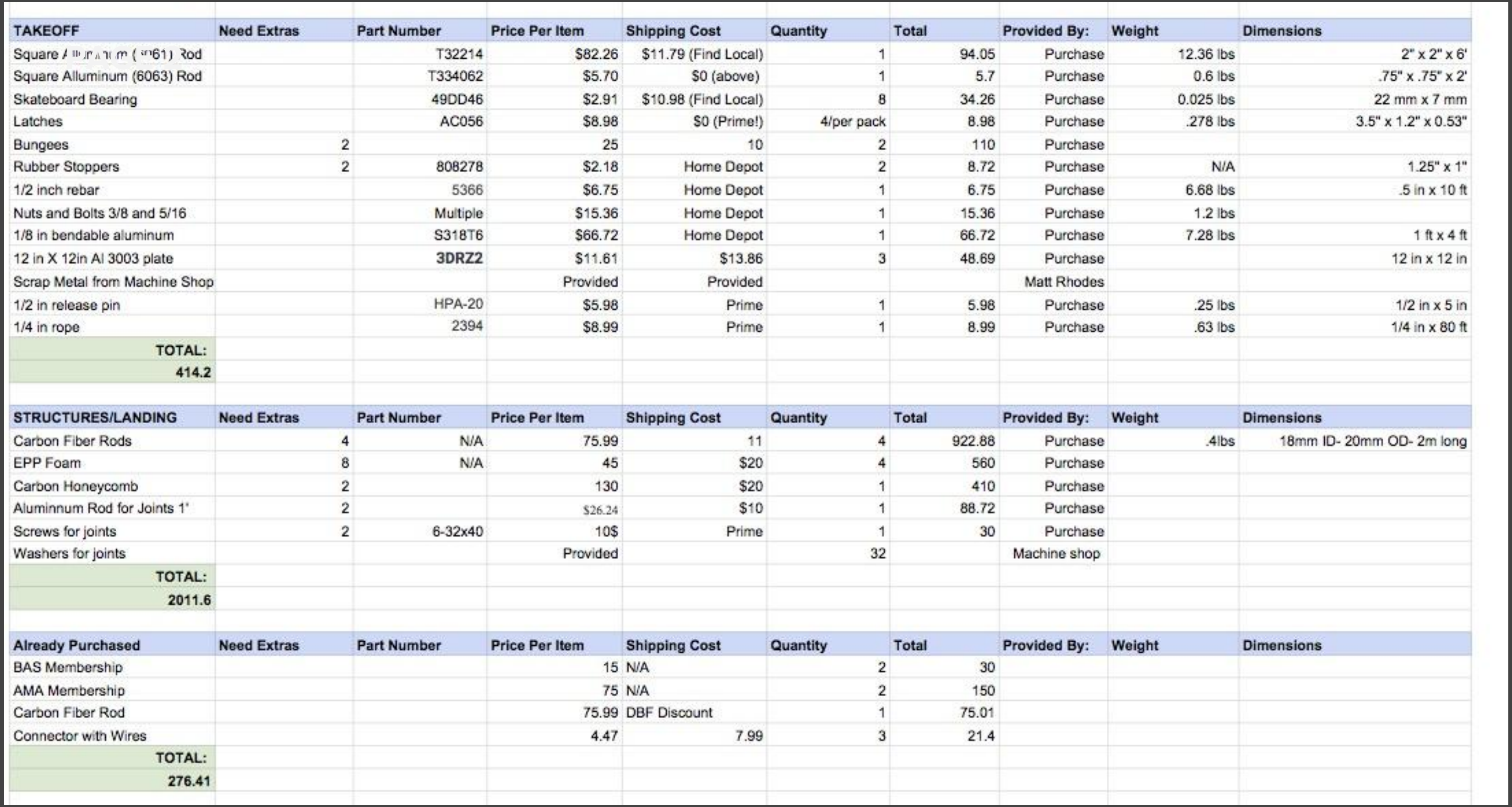
CONTROLS	Need Extras	Part Number	Price Per Item	Shipping Cost	Quantity	Total	Provided By:	Weight	Dimensions
Pixhawk 4 Hardware		N/A	$211	$21.50	1	232.5	Purchase	15.8	44x84x12
Pixhwark4 Board		N/A	Above	Above	1		Purchase	36	68x50x8
GPS Reciever		N/A	Above	Above	1		Purchase	32	50 diameter, 5
RC Reciever		N/A	$33.90	~$20	1	53.9	Purchase	13.2	47x24x15
Pitot Probe	1	N/A	$45.61	~$20	1	111.22	Purchase	12	32x16x10
Servos	2	A4010 Micro Digital	$26.99	$6.79	4	168.73	Purchase	17.2	28x12.7x27.4
Servo Arm		SPMSP3021	$2.99	Above	2	5.98	Purchase	1	20x4x4
Servo Push/Pull Rod		B01EG3RQJE	$6.98	$0 (Amazon Prime)	1	6.98	Purchase	1.1	1.2x1.2x120
TOTAL:									
579.31									

PROPULSION	Need Extras	Part Number	Price Per Item	Shipping Cost	Quantity	Total	Provided By:	Weight	Dimensions
3s Battery	4	N/A	$48	~$20	4	420	Purchase	160-215	
Motor	1	A20-22L	~$64	~$20	1	148	Purchase	200-120	??
9V Battery	1	N/A	Provided	Provided	1		ITLL	2.6	34x13x7
Electronic Speed Controller		X-20-Pro	$44.20	Unknown	1	44.2	Purchase	56-91.5	30.5x66x21.4
LiPo Battery Charger		?	$54.00	Prime	1	54	Purchase	N/A	N/A
Battery Safe Bag		?	$12.99	Prime	2	25.98	Purchase	N/A	N/A
LED		N/A	Provided	Provided	1		Trudy		
Fire Extinguishers		?	$45.00	Prime	2	90	Purchase	N/A	N/A
Propellor and Spinner	1		$17.40	10	1	44.8			
Parallel Board for Charger			$34.99	Prime	1	34.99			
TOTAL:									
861.97									

AVIONICS	Need Extras	Part Number	Price Per Item	Shipping Cost	Quantity	Total		Weight	Dimensions
Teensy 3.6		DEV-14058	$33.25	10	1	43.25	Purchase	4.9	62.3x18x4.2
Pressure/Temp Sensors		N/A	Provided	Provided	12		R. Laurence	Negligable	
FADS PCB Board		N/A	Provided	Provided	6		R. Laurence	22g	
Wiring		N/A	Provided	Provided			ITLL	?	
Tubing		?	$20	Prime	10 feet	20	Purchase	?	
Arduino		For Testing	For Testing	For Testing	1		Trudy		
Wind Tunnel with Pitot Probe		For Testing	For Testing	For Testing	1		ITLL		
Thermometer		For Testing	For Testing	For Testing	1		ITLL		
Small Foam Section		For Testing	For Testing	For Testing	1		Eagle Owl		
5V BEC			4.24	Prime	1	4.24	Purchase		
Connector with Wire			4.47	7.99	2	16.93	Purchase		
TOTAL:									
84.42									

Items needed for 2 additional airframes have been address in the “Need Extras” column.

BUDGET BREAKDOWN



TAKEOFF	Need Extras	Part Number	Price Per Item	Shipping Cost	Quantity	Total	Provided By:	Weight	Dimensions
Square Aluminum (6061) Rod		T32214	$82.26	$11.79 (Find Local)	1	94.05	Purchase	12.36 lbs	2" x 2" x 6'
Square Alluminum (6063) Rod		T334062	$5.70	$0 (above)	1	5.7	Purchase	0.6 lbs	.75" x .75" x 2'
Skateboard Bearing		49DD46	$2.91	$10.98 (Find Local)	8	34.26	Purchase	0.025 lbs	22 mm x 7 mm
Latches		AC056	$8.98	$0 (Prime!)	4/per pack	8.98	Purchase	.278 lbs	3.5" x 1.2" x 0.53"
Bungees	2		25	10	2	110	Purchase		
Rubber Stoppers	2	808278	$2.18	Home Depot	2	8.72	Purchase	N/A	1.25" x 1"
1/2 inch rebar		5366	$6.75	Home Depot	1	6.75	Purchase	6.68 lbs	.5 in x 10 ft
Nuts and Bolts 3/8 and 5/16		Multiple	$15.36	Home Depot	1	15.36	Purchase	1.2 lbs	
1/8 in bendable aluminum		S318T6	$66.72	Home Depot	1	66.72	Purchase	7.28 lbs	1 ft x 4 ft
12 in X 12in Al 3003 plate		**3DRZ2**	$11.61	$13.86	3	48.69	Purchase		12 in x 12 in
Scrap Metal from Machine Shop			Provided	Provided			Matt Rhodes		
1/2 in release pin		HPA-20	$5.98	Prime	1	5.98	Purchase	.25 lbs	1/2 in x 5 in
1/4 in rope		2394	$8.99	Prime	1	8.99	Purchase	.63 lbs	1/4 in x 80 ft
TOTAL:									
414.2									

STRUCTURES/LANDING	Need Extras	Part Number	Price Per Item	Shipping Cost	Quantity	Total	Provided By:	Weight	Dimensions
Carbon Fiber Rods	4	N/A	75.99	11	4	922.88	Purchase	.4lbs	18mm ID- 20mm OD- 2m long
EPP Foam	8	N/A	45	$20	4	560	Purchase		
Carbon Honeycomb	2		130	$20	1	410	Purchase		
Aluminnum Rod for Joints 1'	2		$26.24	$10	1	88.72	Purchase		
Screws for joints	2	6-32x40	10$	Prime	1	30	Purchase		
Washers for joints			Provided		32		Machine shop		
TOTAL:									
2011.6									

Already Purchased	Need Extras	Part Number	Price Per Item	Shipping Cost	Quantity	Total	Provided By:	Weight	Dimensions
BAS Membership			15	N/A	2	30			
AMA Membership			75	N/A	2	150			
Carbon Fiber Rod			75.99	DBF Discount	1	75.01			
Connector with Wires			4.47	7.99	3	21.4			
TOTAL:									
276.41									

AIRCRAFT MASS BUDGET

Component	Mass (g)	Component cont.	Mass (g)	Component cont.	Mass (g)	Component cont.	Mass (g)
Pixhawk4 PMB	36	Motor	55	Carbon side panels	737	Propeller	18
Pixhawk4 Hardware	15.8	ESC	17	Joints (8x)	180	Spinner	14
GPS Receiver	32	Microcontroller	4.9	Carbon fiber rods	616	Motor Mount	78
RC Receiver	13.2	FADS Board (4x)	88	Foam	558	Wiring	243
Pitot Probe	12	Servos (4x)	68	Carbon fiber plate	200	FADS tubing	28
3s battery (4x)	896	9v battery	45	Strut	45.4	Servo rods	1.5
Total	**4002 (g)**						

TAKEOFF MASS BUDGET

Component	Mass (kg)	Component cont.	Mass (kg)	Component cont.	Mass (kg)
Steel Tube 50mm x 50mm	14.72	Rebar 12.7mm	3.03	Mount Spacers	0.0011
Al6061 Tube 19mm x 19mm	0.2722	Nuts and Bolts 9.5mm	0.54	Al6061 Bar 32mm x 12.7mm	0.74
Skateboard Bearings	0.091	Al3003 3.175mm	3.302	Al6061 Bar 12.7mm x 12.7mm	0.272
Latches	0.126	Bungee Posts	0.25		
Bungees	0.463	Release Pin 12.7mm	0.113		
Rubber Stoppers	0.023	Rope	0.286		
Total	~ 24.23 kg	Weight: 53.24 lb			

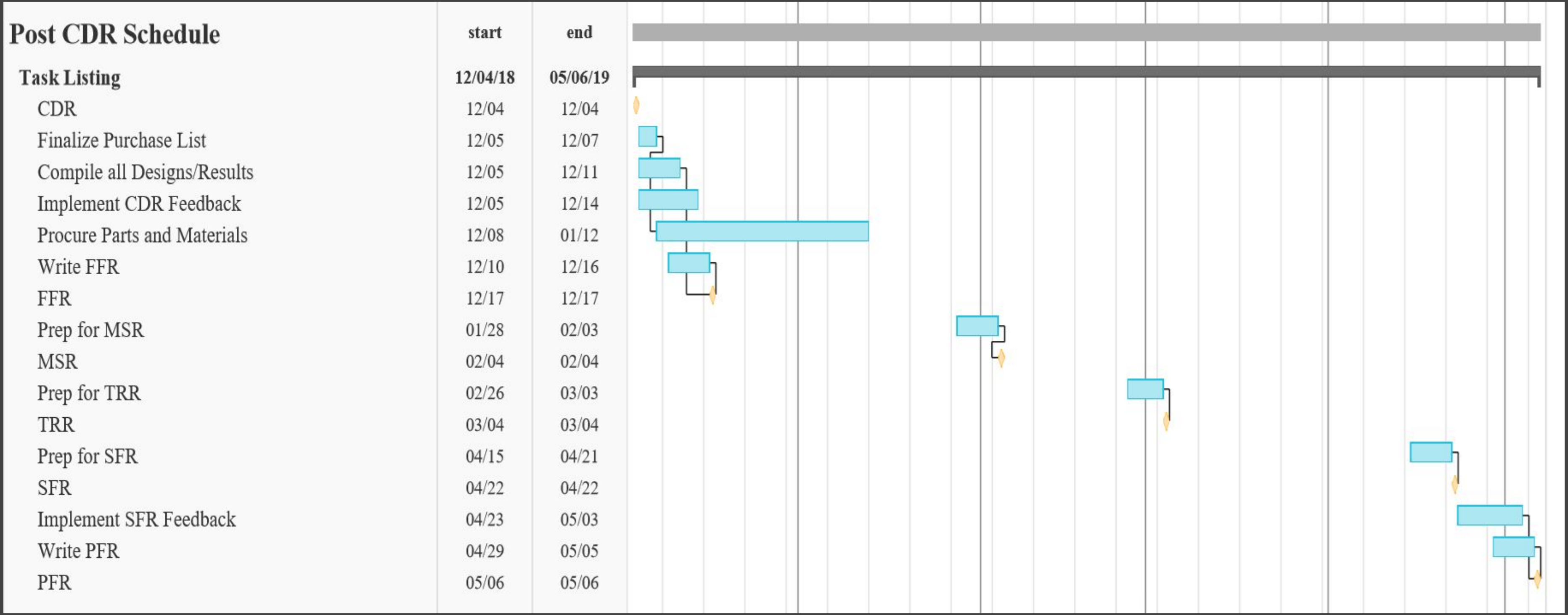
POWER BUDGET: SCIENCE

Subsystem	Capacity (mAh)	Current (A)	Voltage (V)	Power (W)
FADS/Microcontroller	2	0.002	3.3	0.01
Total	**2**	**0.002**	**3.3 (max)**	**0.01**
Batteries	**500**		**9**	**4.5**

POWER BUDGET: CONTROLS

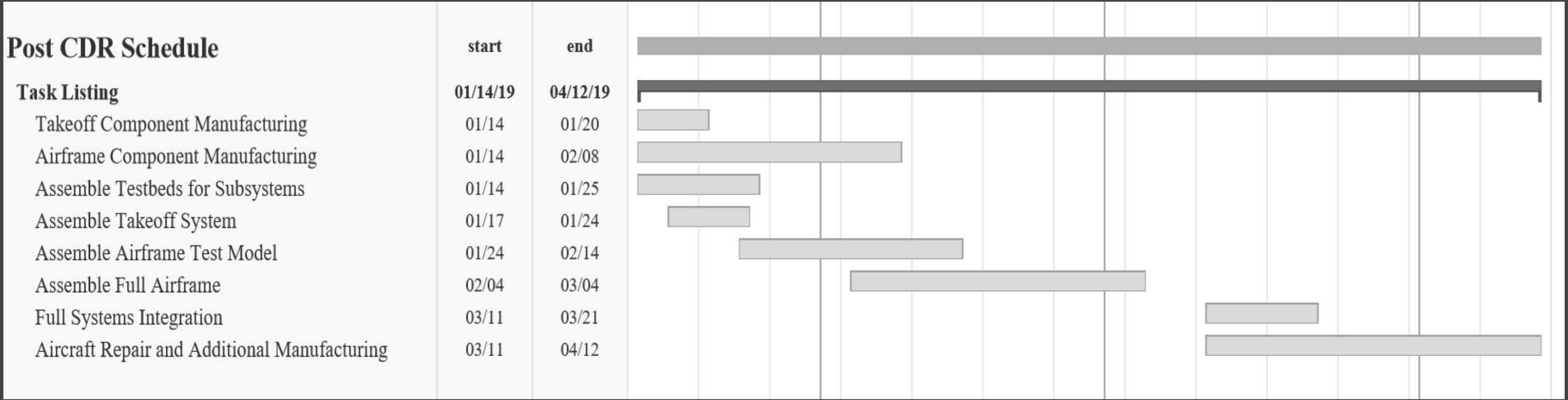
Subsystem	Capacity (mAh)	Current (A)	Voltage (V)	Power (W)
Motor/ESC	10625	5	11.1	118
Servos	200	0.2	6	1.2
Pixhawk 4	175	0.175	5	1.1
Pitot Probe	25	0.025	5	0.125
GPS	55	0.055	5	0.275
RC receiver	100	0.1	5	0.5
Total	**11180**	**5.43**	**11.1 (max)**	**121.2**
Batteries	**12800**	**12.8**	**11.1 (max)**	**142.1**

Scheduling - Administrative



Post CDR Schedule	start	end
Task Listing	**12/04/18**	**05/06/19**
CDR	12/04	12/04
Finalize Purchase List	12/05	12/07
Compile all Designs/Results	12/05	12/11
Implement CDR Feedback	12/05	12/14
Procure Parts and Materials	12/08	01/12
Write FFR	12/10	12/16
FFR	12/17	12/17
Prep for MSR	01/28	02/03
MSR	02/04	02/04
Prep for TRR	02/26	03/03
TRR	03/04	03/04
Prep for SFR	04/15	04/21
SFR	04/22	04/22
Implement SFR Feedback	04/23	05/03
Write PFR	04/29	05/05
PFR	05/06	05/06

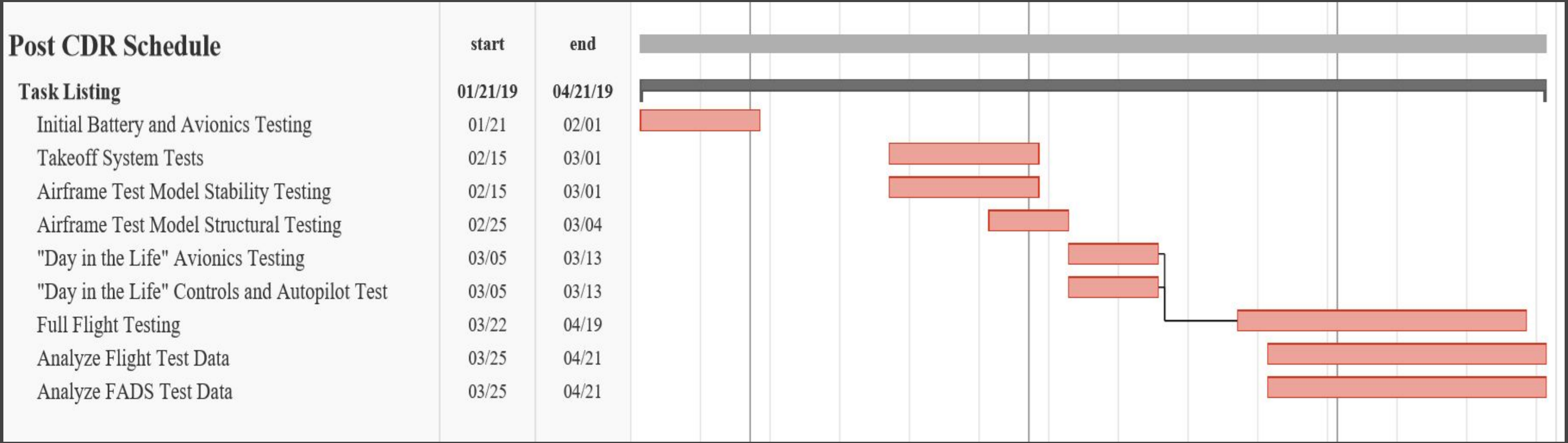
Scheduling - Manufacturing



Post CDR Schedule

	start	end
Task Listing	**01/14/19**	**04/12/19**
Takeoff Component Manufacturing	01/14	01/20
Airframe Component Manufacturing	01/14	02/08
Assemble Testbeds for Subsystems	01/14	01/25
Assemble Takeoff System	01/17	01/24
Assemble Airframe Test Model	01/24	02/14
Assemble Full Airframe	02/04	03/04
Full Systems Integration	03/11	03/21
Aircraft Repair and Additional Manufacturing	03/11	04/12

Scheduling - Testing



Post CDR Schedule

Task Listing	start	end
Task Listing	**01/21/19**	**04/21/19**
Initial Battery and Avionics Testing	01/21	02/01
Takeoff System Tests	02/15	03/01
Airframe Test Model Stability Testing	02/15	03/01
Airframe Test Model Structural Testing	02/25	03/04
"Day in the Life" Avionics Testing	03/05	03/13
"Day in the Life" Controls and Autopilot Test	03/05	03/13
Full Flight Testing	03/22	04/19
Analyze Flight Test Data	03/25	04/21
Analyze FADS Test Data	03/25	04/21