Aspect-ratio **R**edesign of **E**agle owl for **S**tormchasing

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CUSTOMER: Dr. Brian Argrow

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Mission Statement

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 Air Data Sensing (FADS) system to measure relative wind velocity with the objective of creating a high endurance system that can eventually fly into extreme weather conditions.

Agenda

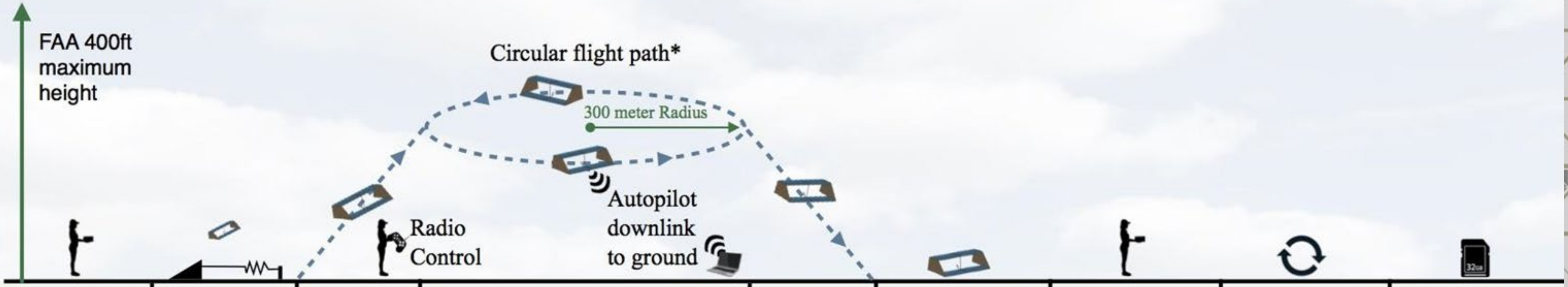
Project Overview

Baseline Design

Feasibility Study

Summary

Concept of Operations



Preflight	Takeoff	Ascent	Controlled Steady Flight	Descent	Landing	Recovery	Repeat	Post-flight
Verify power to system	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*

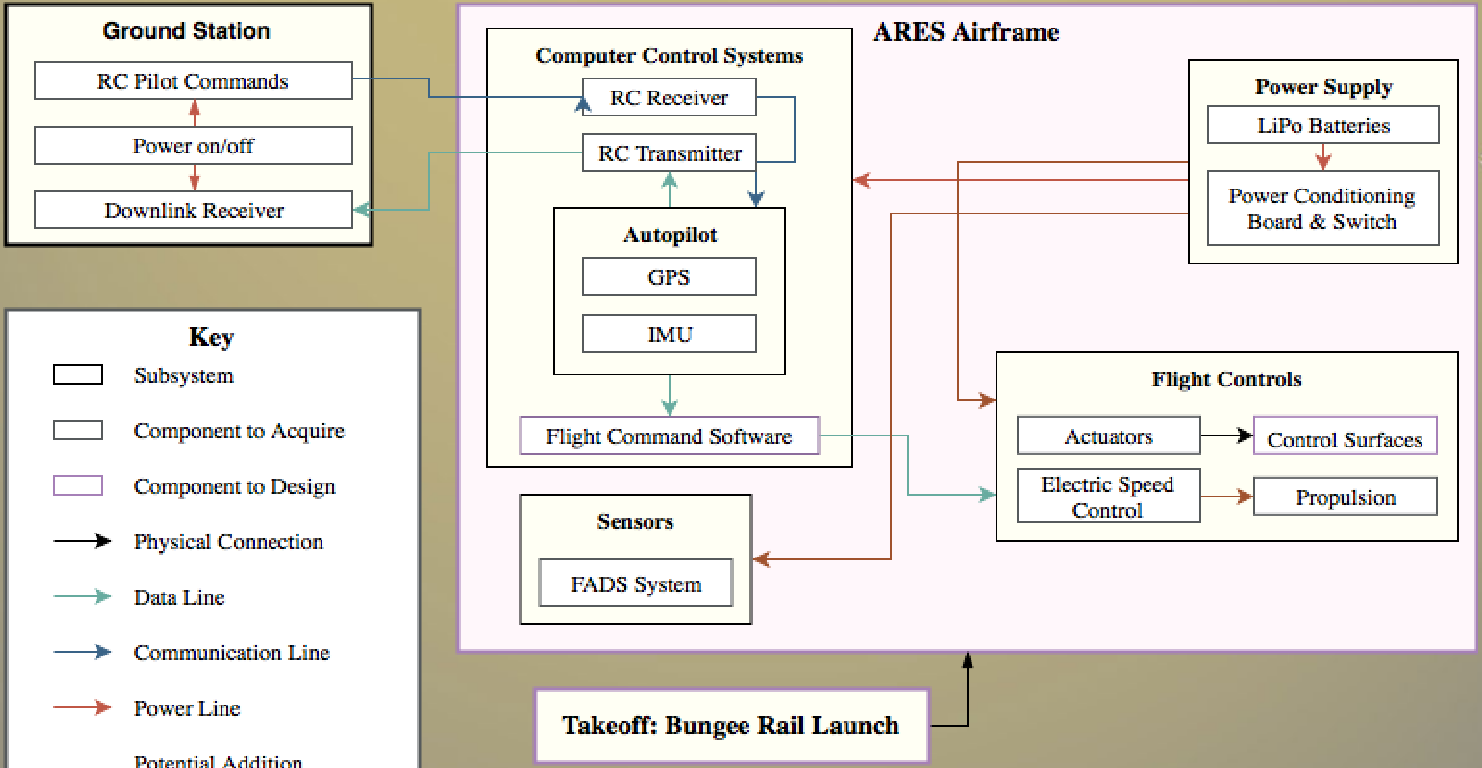
Flight Time 1 hour*

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

Functional Block Diagram



Key

▭	Subsystem
▭	Component to Acquire
▭	Component to Design
→	Physical Connection
→	Data Line
→	Communication Line
→	Power Line
	Potential Addition

Critical Project Feasibility Elements

- **ARES**
  - Takeoff
  - Wing Design
  - Propulsion & Power
  - Science
  - Landing

Baseline Design

Project Overview

Baseline Design

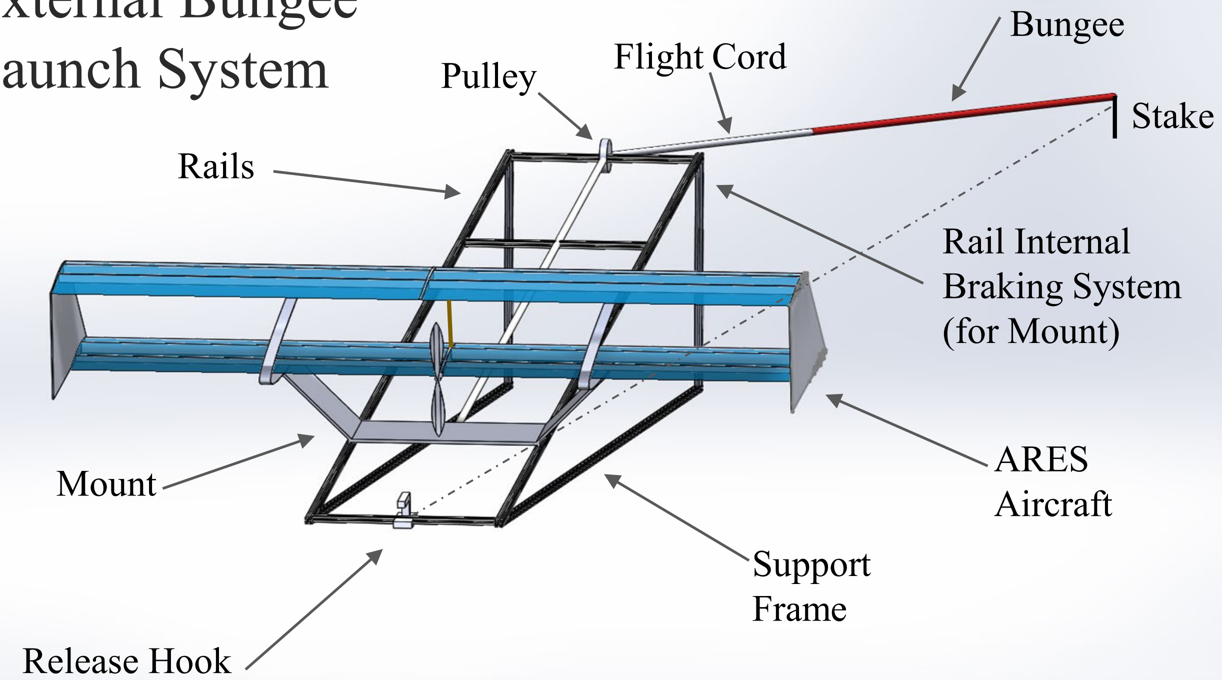
Feasibility Study

Summary

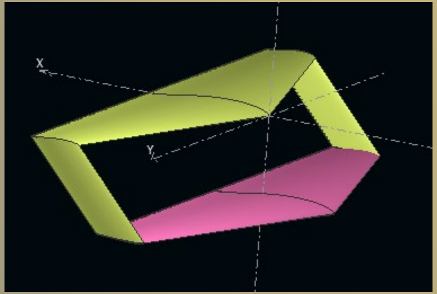
Takeoff Baseline Design

FR 3.0: The aircraft shall demonstrate a controlled takeoff.

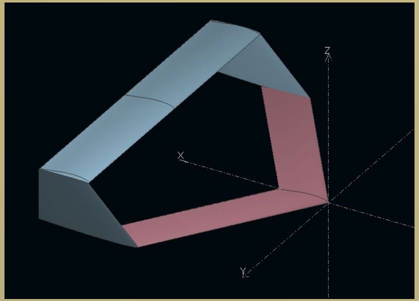
External Bungee Launch System



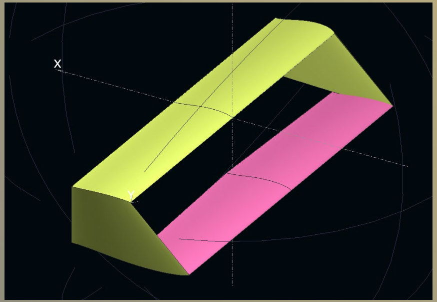
Baseline Wing Design



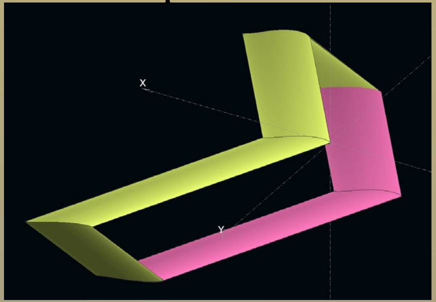
Pentagonal Wing



Rectangular Top
Swept Bottom

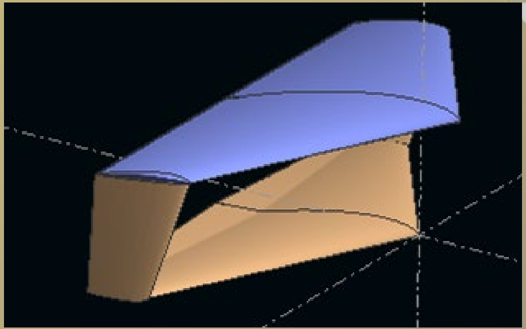


Rectangular Wing



Swept Back Wing

XFLR5 Models



Eagle Owl

Note: Not to scale, ARES AR = 3, Eagle Owl AR = 1.39

Baseline Wing Design

	$C_{L,max}$	L/D_{max}	$C_{m,\alpha}$ [rad^{-1}]	V_{stall} [m/s]	V_{cruise} [m/s]
Rectangular	**0.728**	**26.3**	**-0.0393**	**7.60**	**11.1**
Pentagon	0.708	24.2	-0.0498	7.71	10.2
RTSB	0.709	24.7	-0.0412	7.70	11.9
Swept Back	0.710	25.4	-0.1310	7.69	11.6

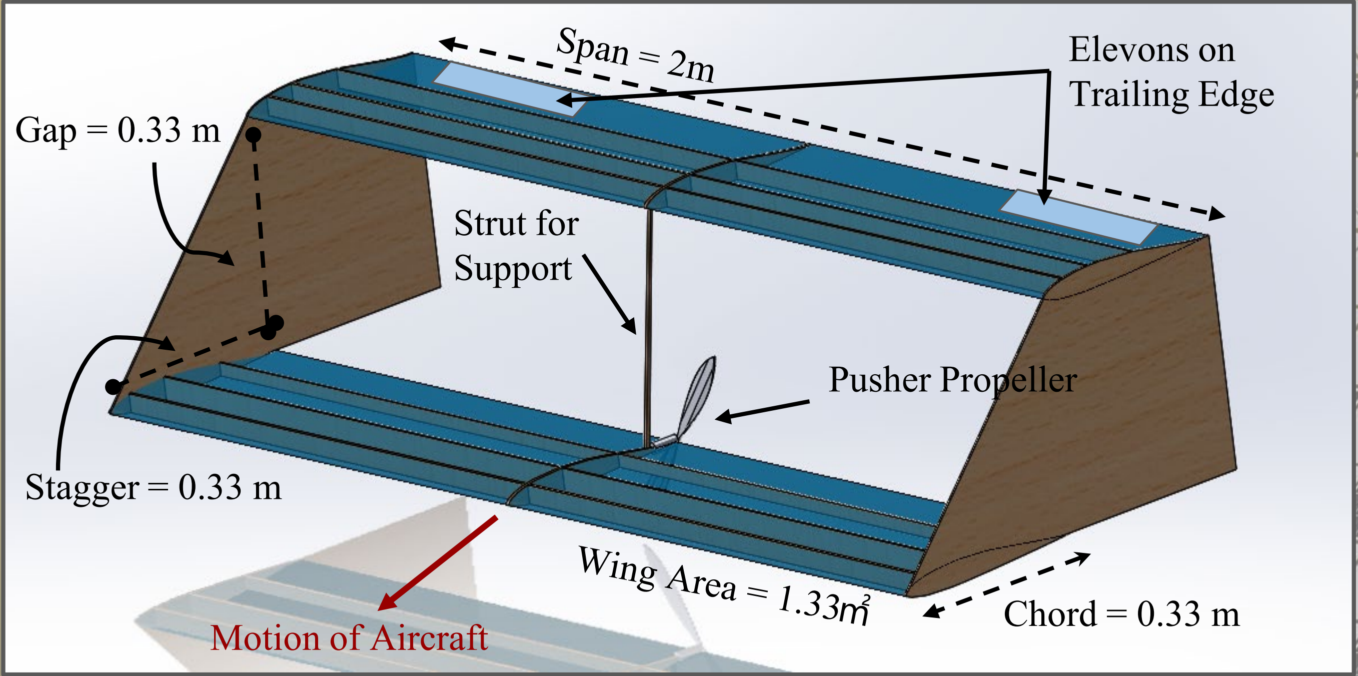
<u>Main Takeaway</u>: The rectangular wing combined excellent flight characteristics with simpler manufacturability

Baseline Wing Design

FR 2.0: The system shall be an aircraft with a box wing configuration with a span no larger than 2 meters.

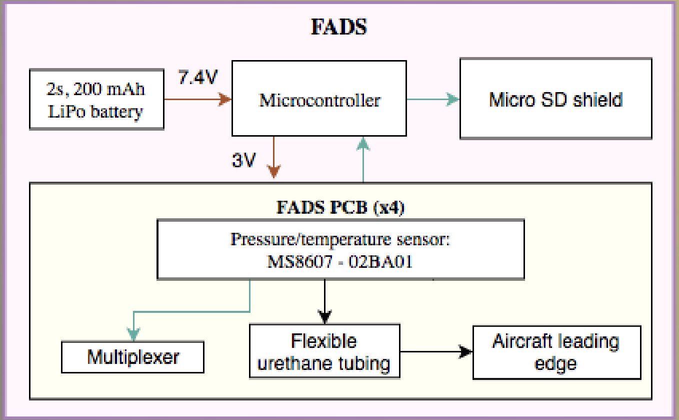
Materials:
Balsa Wood
EPP Foam

Main Takeaway: Rectangular planform chosen for aerodynamic efficiency (C_L vs AoA, C_D vs AoA)



Power/Avionics Baseline Design

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



FADS

2s, 200 mAh LiPo battery

7.4V

Microcontroller

Micro SD shield

3V

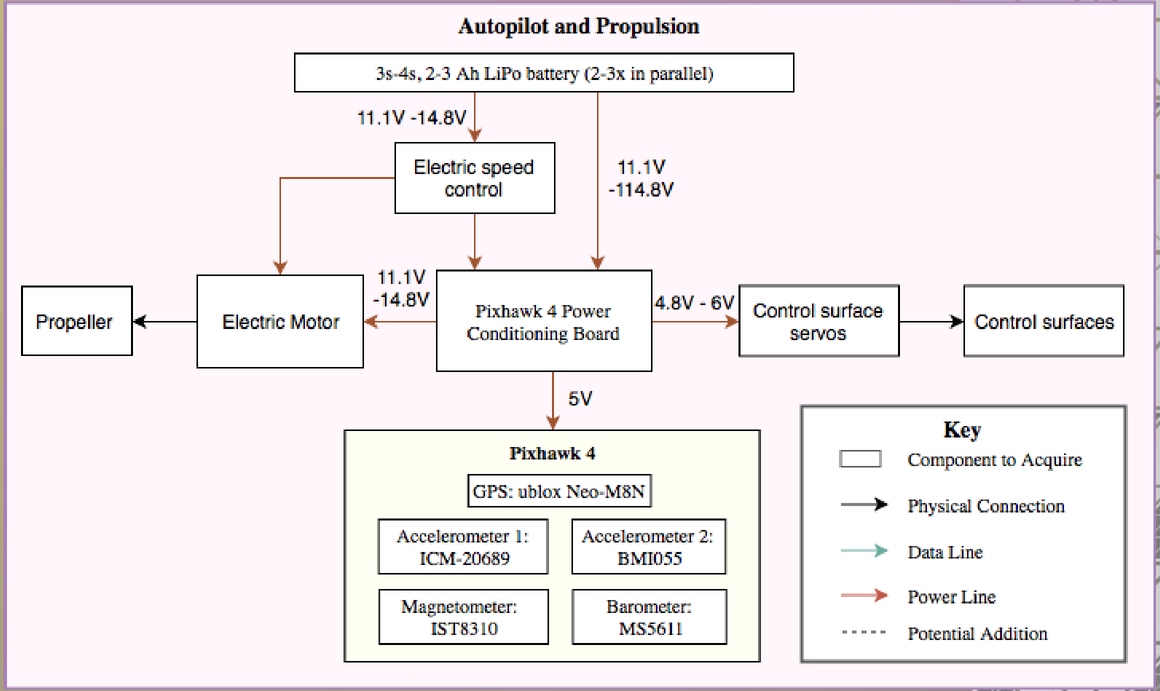
FADS PCB (x4)

Pressure/temperature sensor: MS8607 - 02BA01

Multiplexer

Flexible urethane tubing

Aircraft leading edge



Autopilot and Propulsion

3s-4s, 2-3 Ah LiPo battery (2-3x in parallel)

11.1V -14.8V

Electric speed control

11.1V -114.8V

Propeller

Electric Motor

11.1V -14.8V

Pixhawk 4 Power Conditioning Board

4.8V - 6V

Control surface servos

Control surfaces

5V

Pixhawk 4

GPS: ublox Neo-M8N

Accelerometer 1: ICM-20689

Accelerometer 2: BMI055

Magnetometer: IST8310

Barometer: MS5611

Key

☐ Component to Acquire

→ Physical Connection

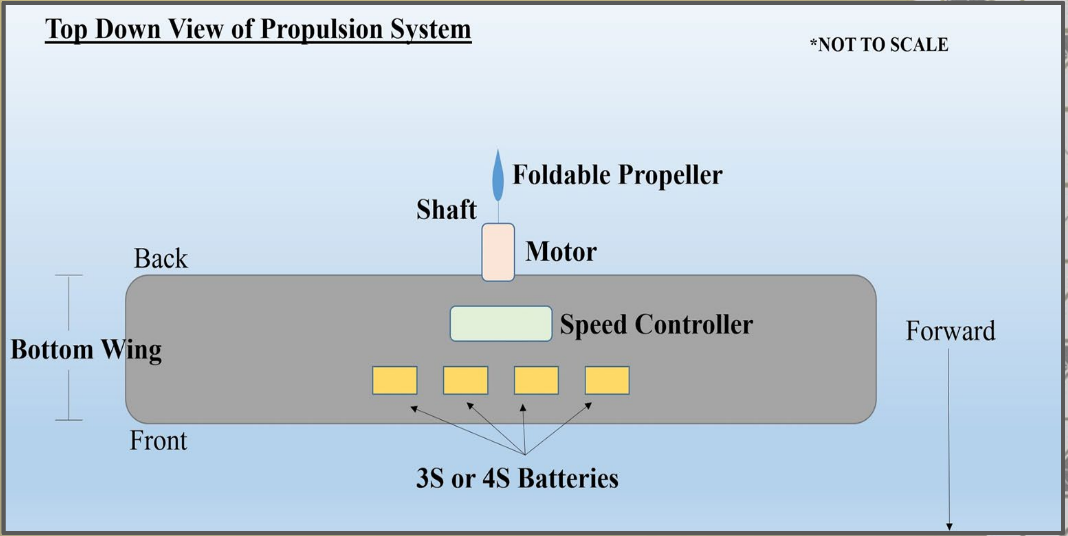
→ Data Line

→ Power Line

---- Potential Addition

Propulsion Baseline Design

- Propulsion consists of bottom mounted shimmed pusher
    - Mounted on bottom to lower CG and prevent prop moment
- Electric motor chosen due to reusability, simplicity, heritage, and size
- Components:
    - Motor:
        - T/W: 0.2 - 0.25
        - Rating: 500 - 1000 Kv
    - Propeller:
        - Able to fold back
        - Diameter: 10” - 12”
        - Pitch: 6” - 10”
    - Speed Controller:
        - Castle Phoenix Edge Lite 40-100 A

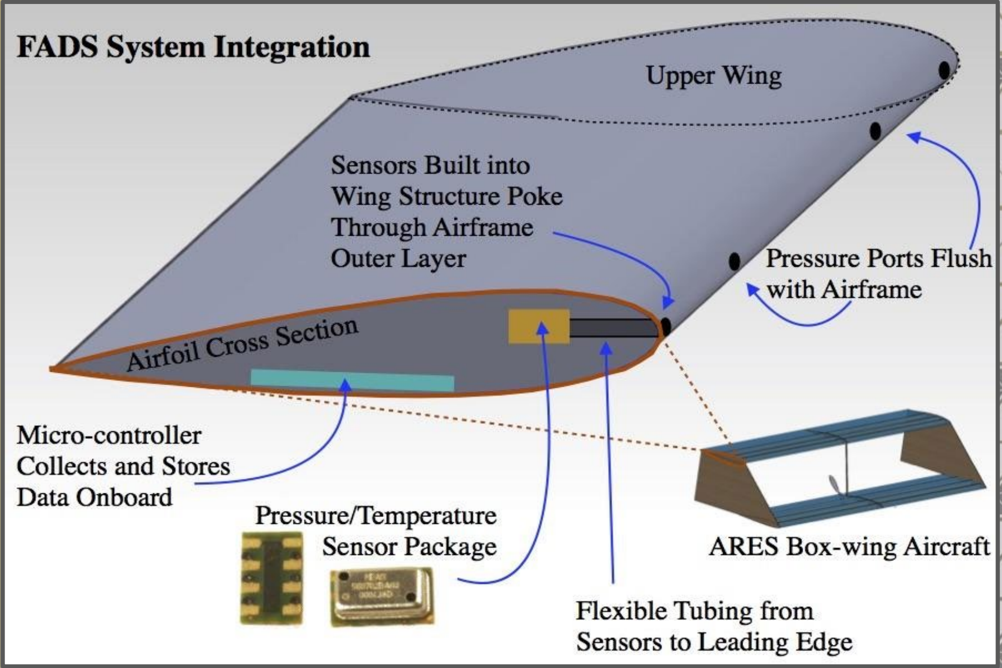


Science Baseline Design

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. The recorded data shall be stored on-board and converted to relative wind speed after flight.

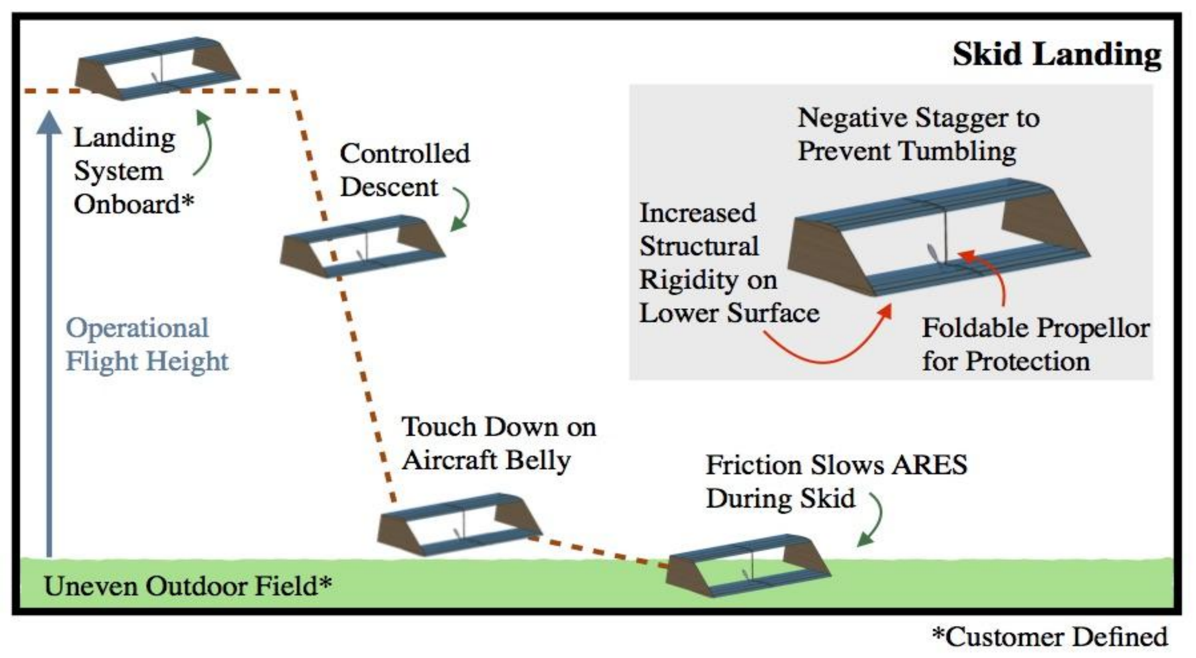
Flush Airdata Sensing System

A FADS system measures pressure at multiple points on the aircraft in order to compute angle of attack and sideslip, which can then be combined to get wind velocity.



Landing Baseline Design

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.



Skid Landing

Landing System Onboard*

Controlled Descent

Operational Flight Height

Touch Down on Aircraft Belly

Friction Slows ARES During Skid

Uneven Outdoor Field*

Negative Stagger to Prevent Tumbling

Increased Structural Rigidity on Lower Surface

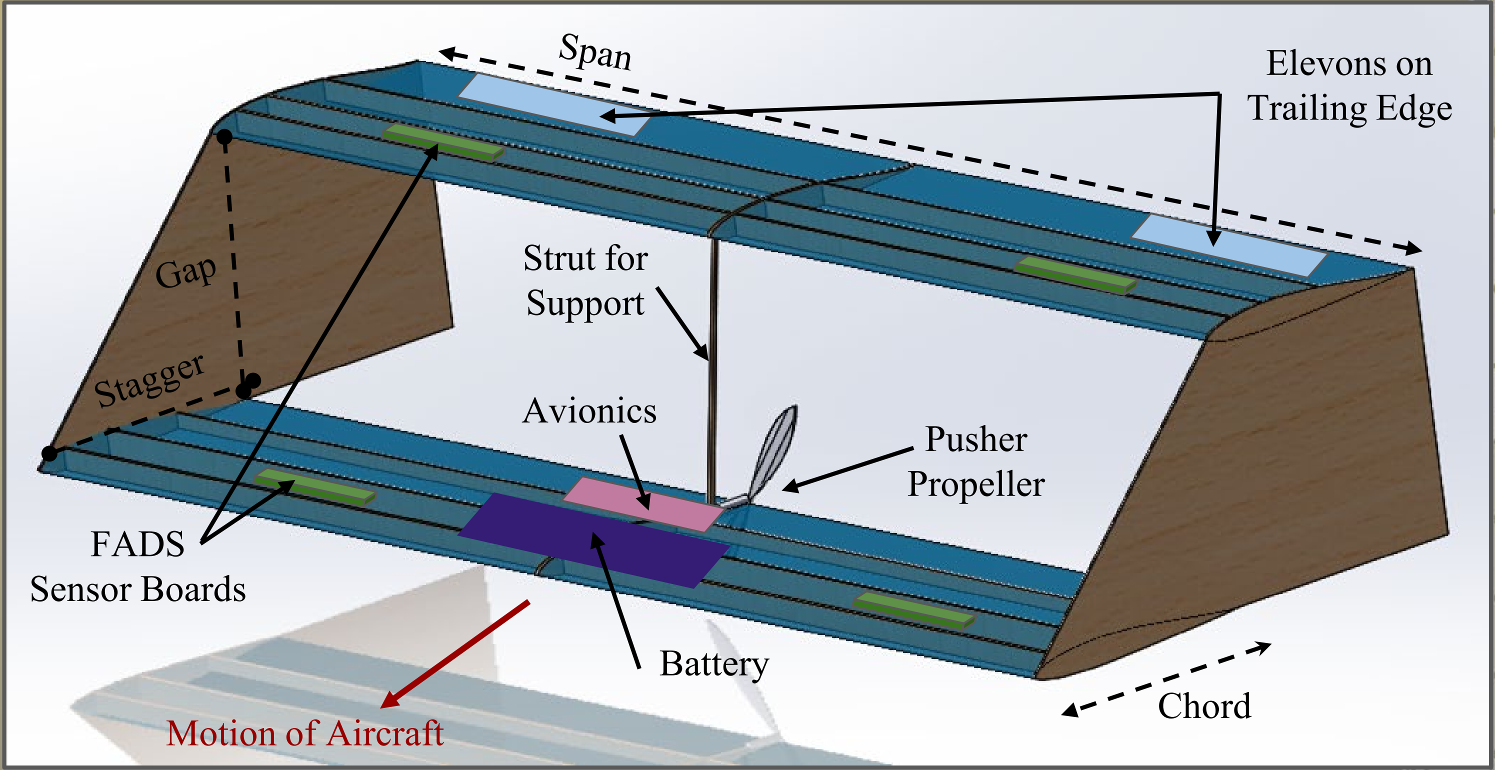
Foldable Propellor for Protection

*Customer Defined

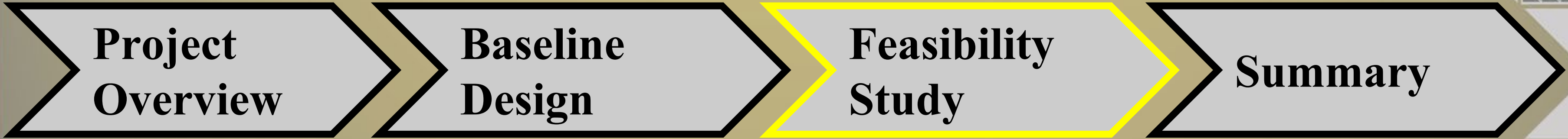
Integrated Baseline Design

<u>Avionics:</u>
-autopilot
-FADS microcontroller
-power management

*Components Not to Scale



Feasibility Studies



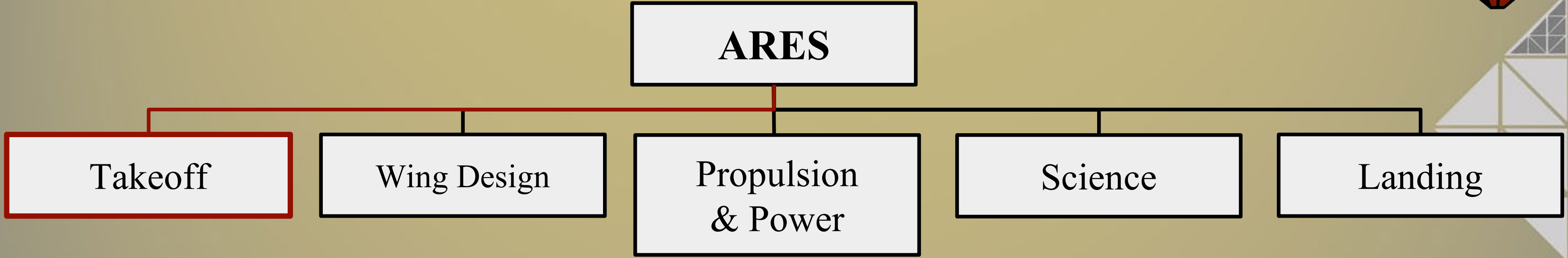
Project Overview

Baseline Design

Feasibility Study

Summary

Critical Project Feasibility Elements



ARES

Takeoff

Wing Design

Propulsion & Power

Science

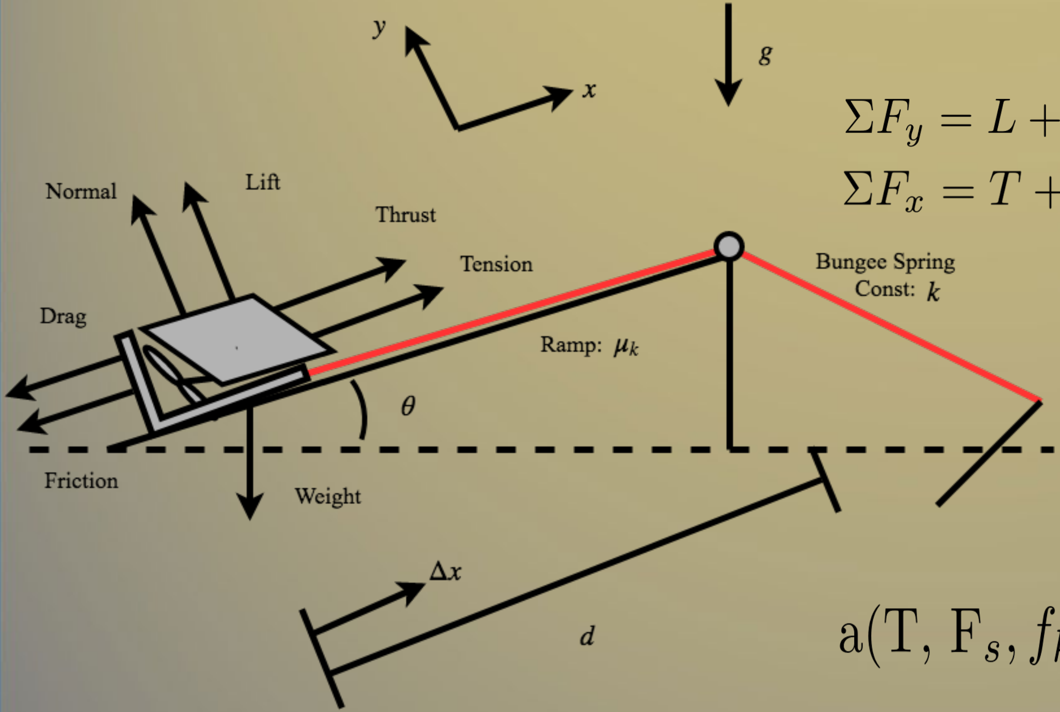
Landing

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 3.4: The aircraft shall not require repairs, due to takeoff, that last longer than 15 minutes after a full flight cycle.

Takeoff System: Model

Free-Body-Diagram



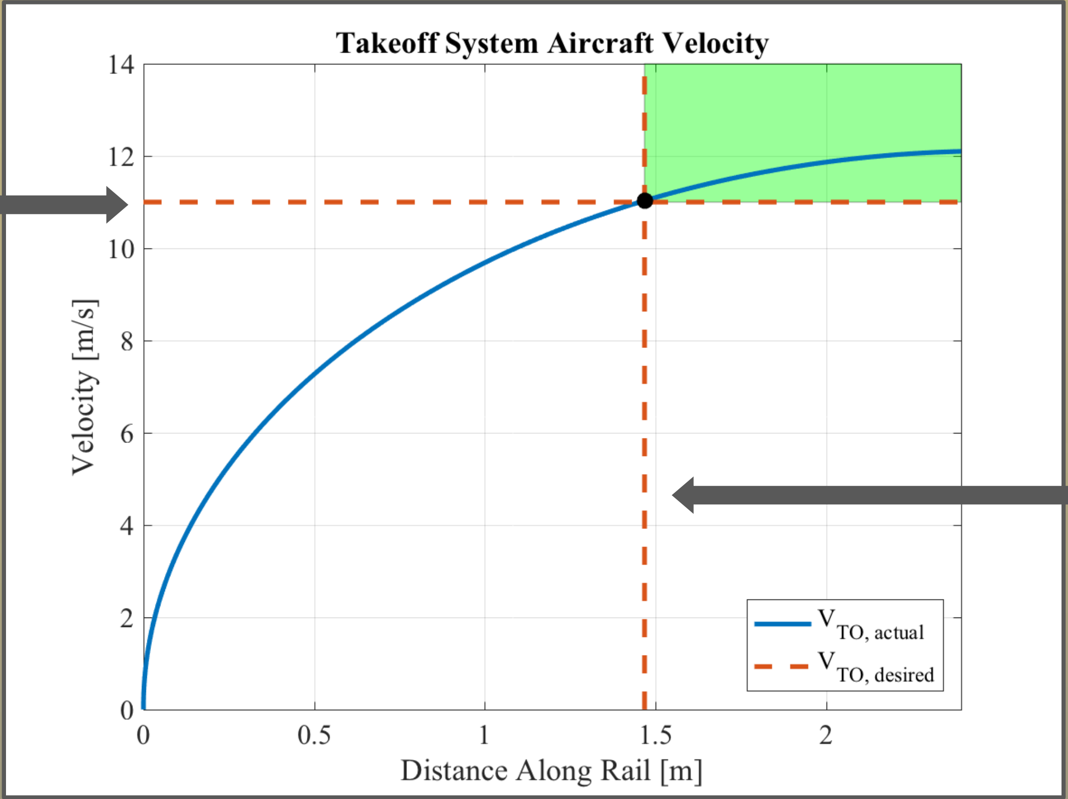
$$\Sigma F_y = L + N - \sin(90 - \theta)W = ma_y$$

$$\Sigma F_x = T + F_s - f_k - D - \cos(90 - \theta)W = ma_x$$

$$\mathrm{a}(\mathrm{T}, \mathrm{F}_s, f_k, D) = \frac{T + F_s - f_k - D - \cos(90-\theta)W}{m}$$

Takeoff System: DR 3.2 Feasibility

Desired takeoff velocity (cruise velocity) of 11 m/s

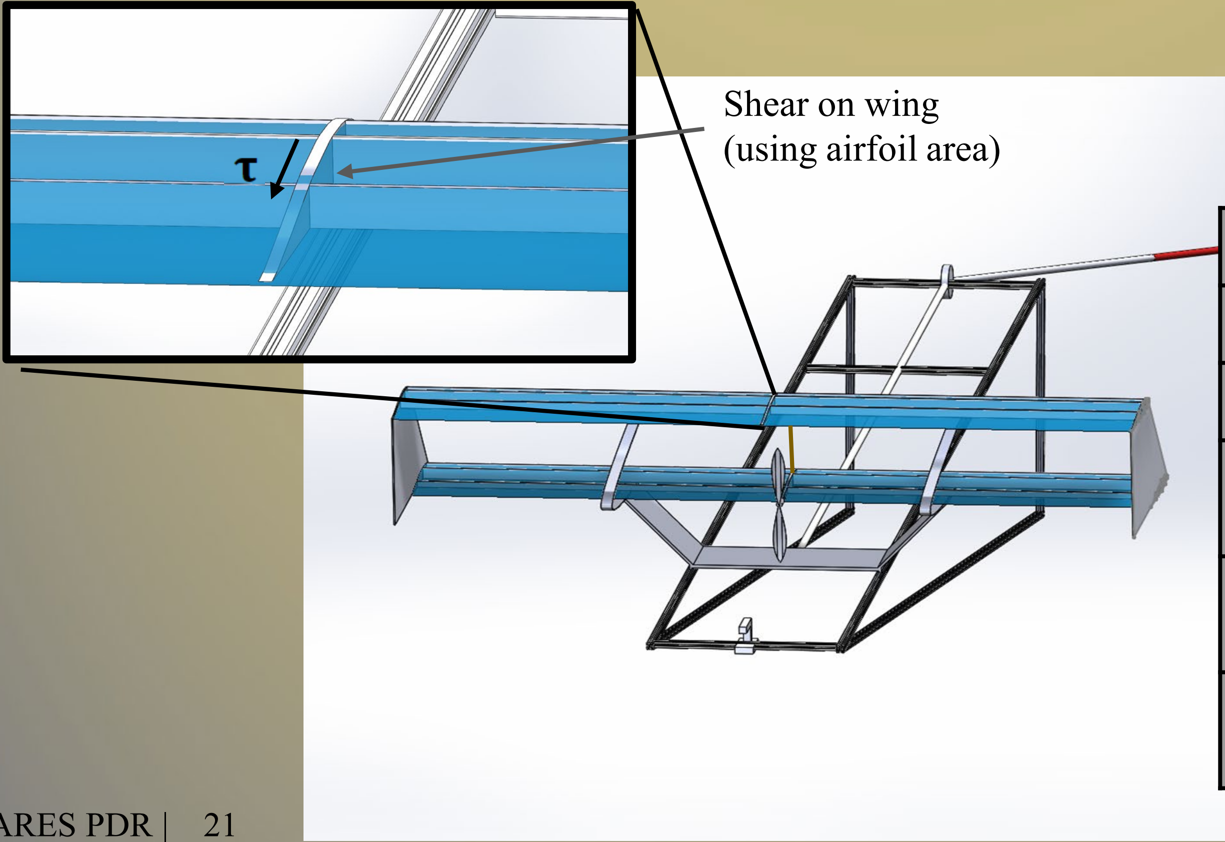


Factor of Safety: 1.1

Minimum rail length of 1.5 m

DR 3.2: Bring the aircraft to desired initial velocity ✓

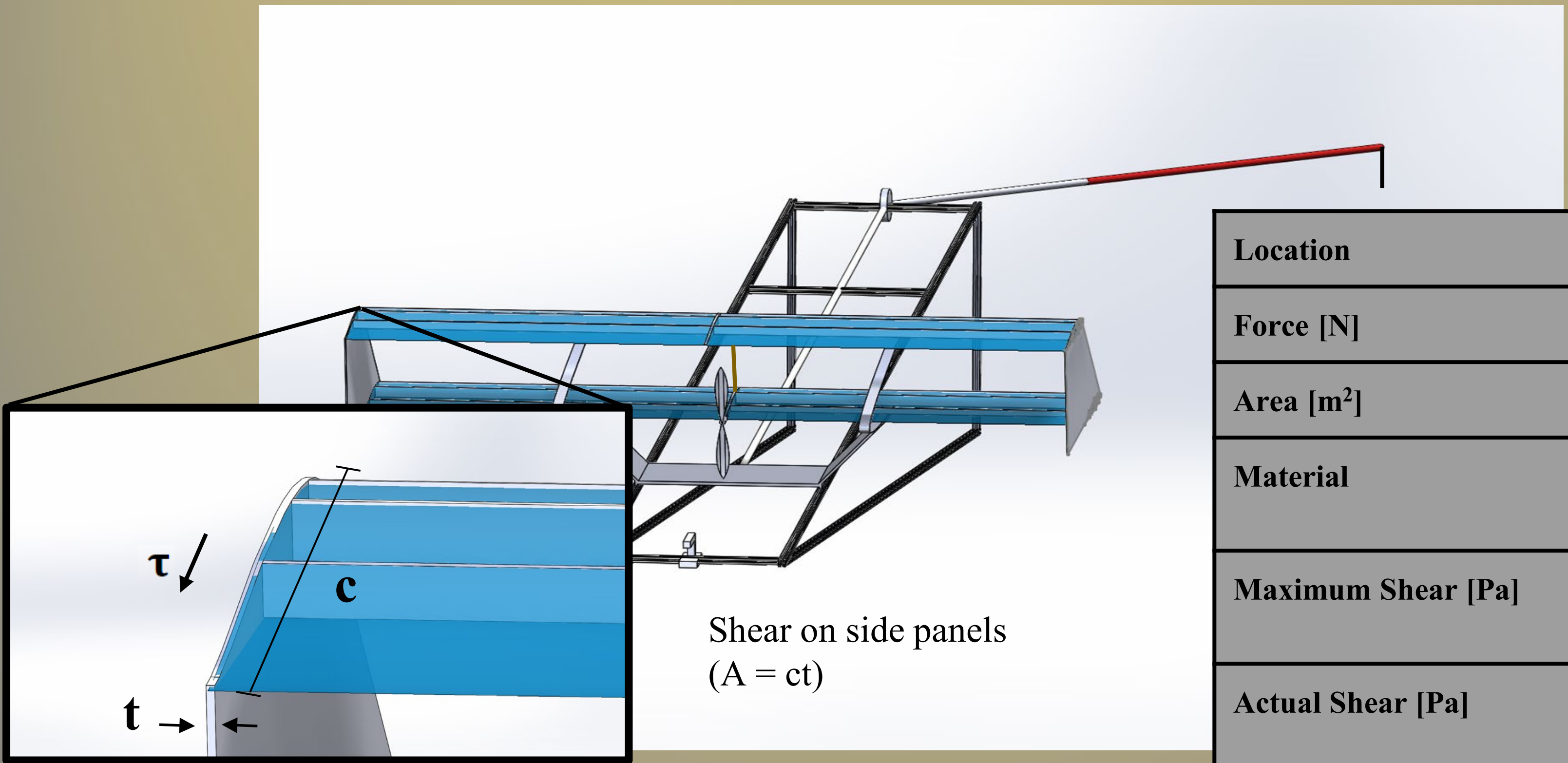
Takeoff System: DR 3.4 Feasibility



Shear on wing
(using airfoil area)

Location	Wing
Force [N]	515
Area [m^2]	0.17
Material	Polystyrene Foam
Maximum Shear [Pa]	0.29×10^6 (shear)
Actual Shear [Pa]	3.03×10^3 (shear)

Takeoff System: DR 3.4 Feasibility



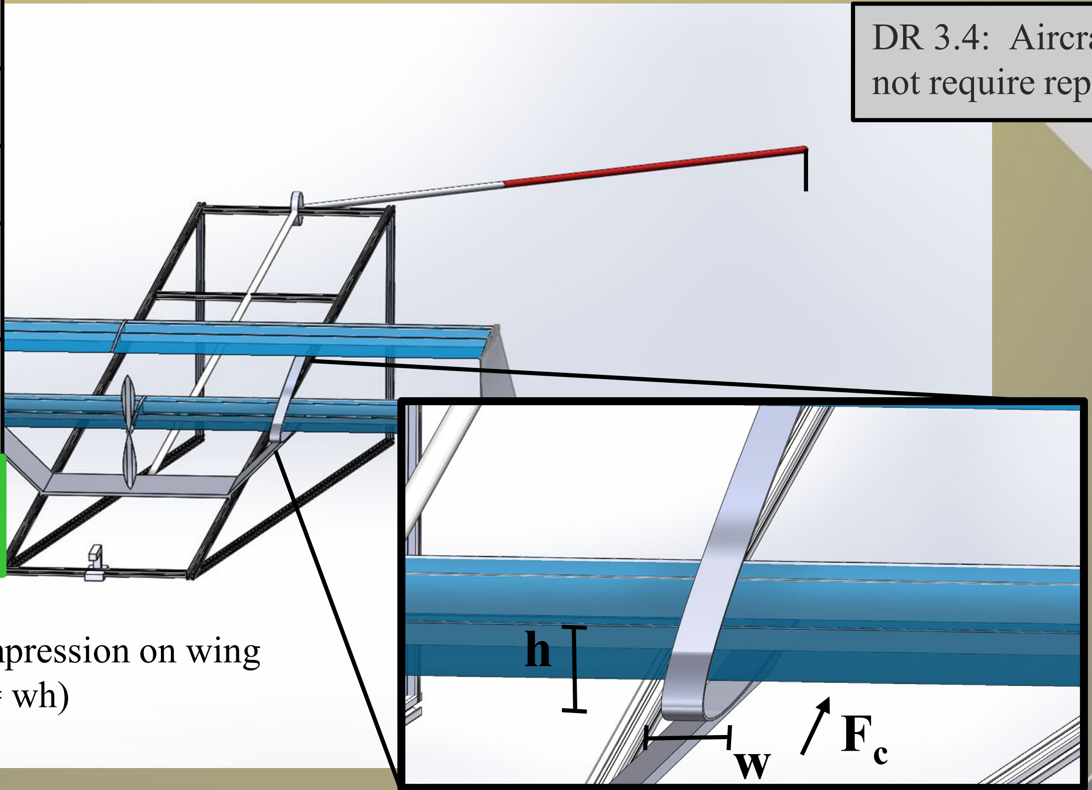
Shear on side panels
(A = ct)

Location	Side Panel
Force [N]	515
Area [m^2]	1.2×10^{-3}
Material	Balsa Wood
Maximum Shear [Pa]	3.0×10^{8} (shear)
Actual Shear [Pa]	4.39×10^{5} (shear)

Takeoff System: DR 3.4 Feasibility

Location	Wing Mount
Force [N]	515
Affected Area [m^2]	8.0×10^{-4}
Material	Polystyrene Foam
Maximum Compression [Pa]	1.77×10^{7} (compression)
Actual Compression [Pa]	6.44×10^{5} (compression)

DR 3.4: Aircraft shall not require repairs... ✓



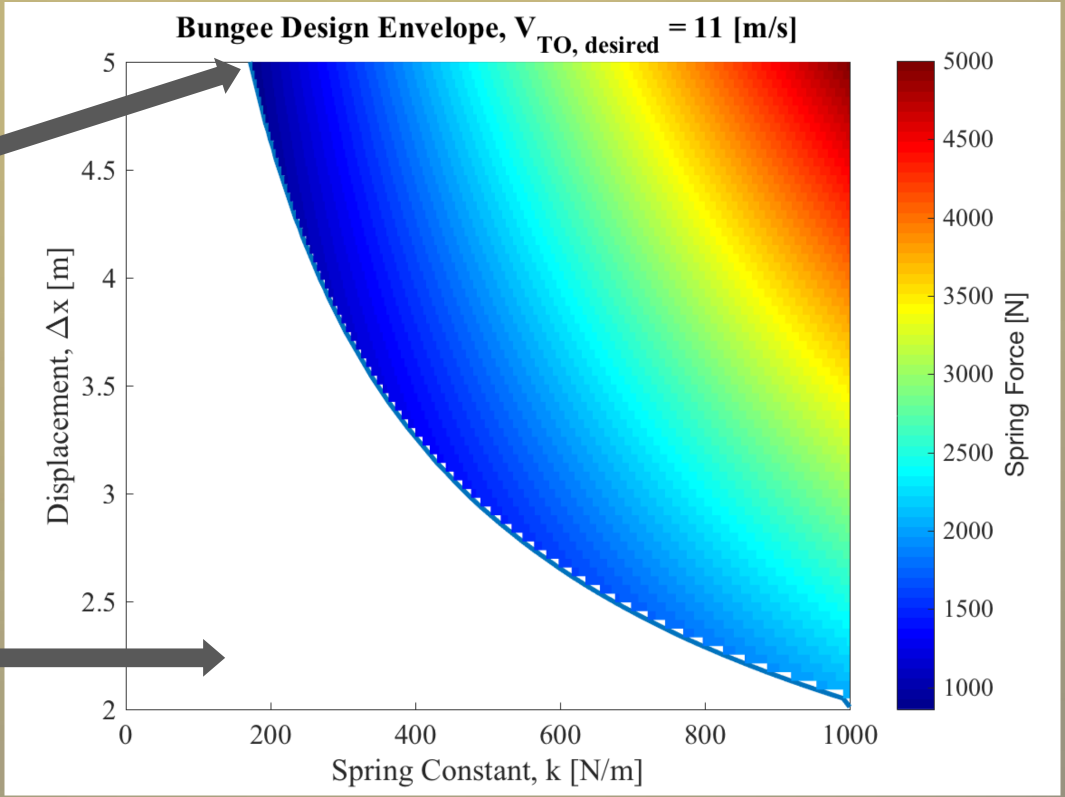
Compression on wing (A = wh)

Takeoff System: Bungee Feasibility

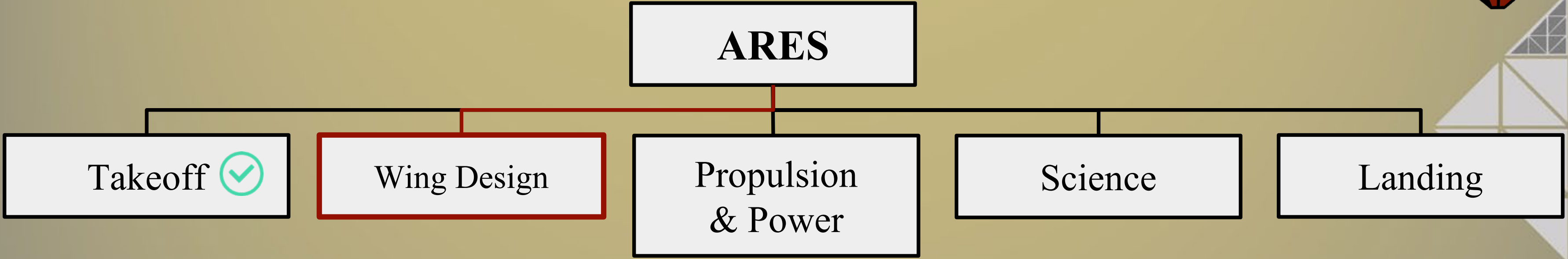
Target Bungee Design:
$\Delta x = 5$ m
$k = 172$ N/m
$F = 860$ N

Divided into 3 bungees:
$F = 287$ N (per bungee)

Infeasible Region: Bungee design does not achieve takeoff velocity



Critical Project Feasibility Elements



ARES

Takeoff ✓

Wing Design

Propulsion & Power

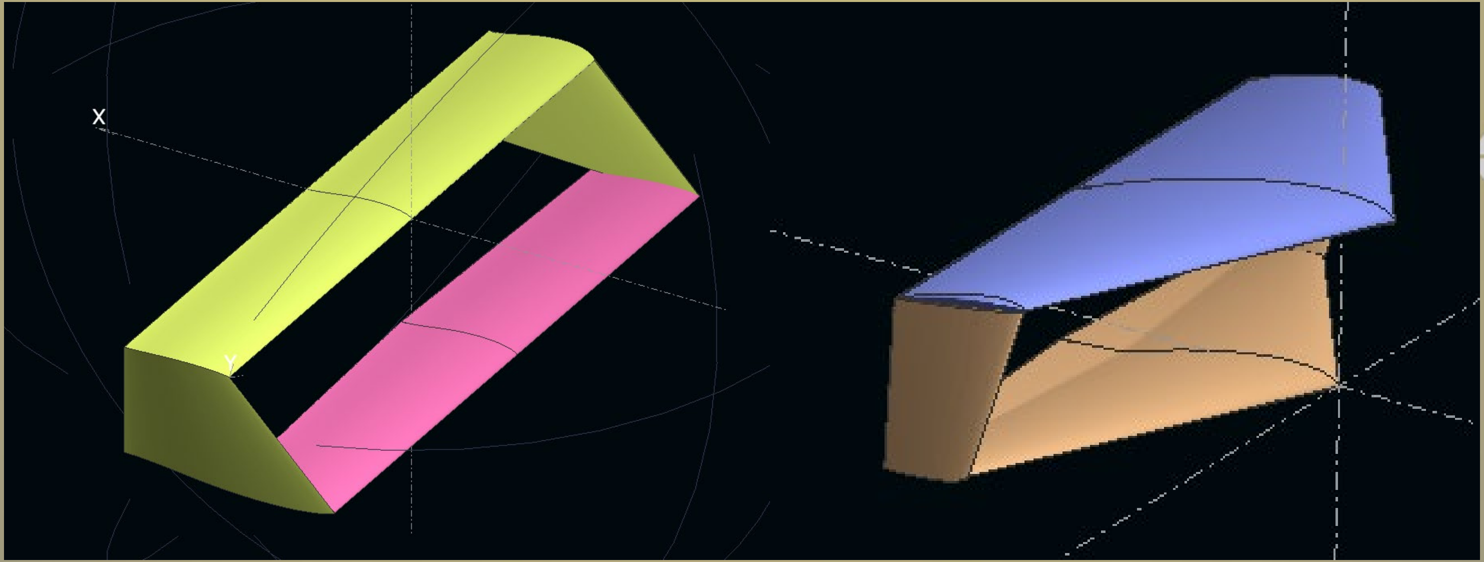
Science

Landing

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.

Wing Design: Choices



ARES

Eagle Owl

XFLR5 Models

DR 2.1: Box shaped tailless biplane configuration ✓

Note: Not to scale, ARES has twice the AR of Eagle Owl

Wing Design: Feasibility Analysis

	Span [m]	AR	$C_{L,max}$	L/D_{max}	$C_{m,\alpha}$ [rad^{-1}]	V_{stall} [m/s]	V_{cruise} [m/s]
Eagle Owl	0.925	1.39	1.04	12.2	-0.0206	6.36	10.5
ARES	**2**	**3**	**0.728**	**26.3**	**-0.0393**	**7.60**	**11.1**

DR 2.2: Greater Lift-to-Drag Ratio than Eagle Owl ✓

Main Takeaway: ARES shows feasibility for flight with similar aerodynamic characteristics to Eagle Owl

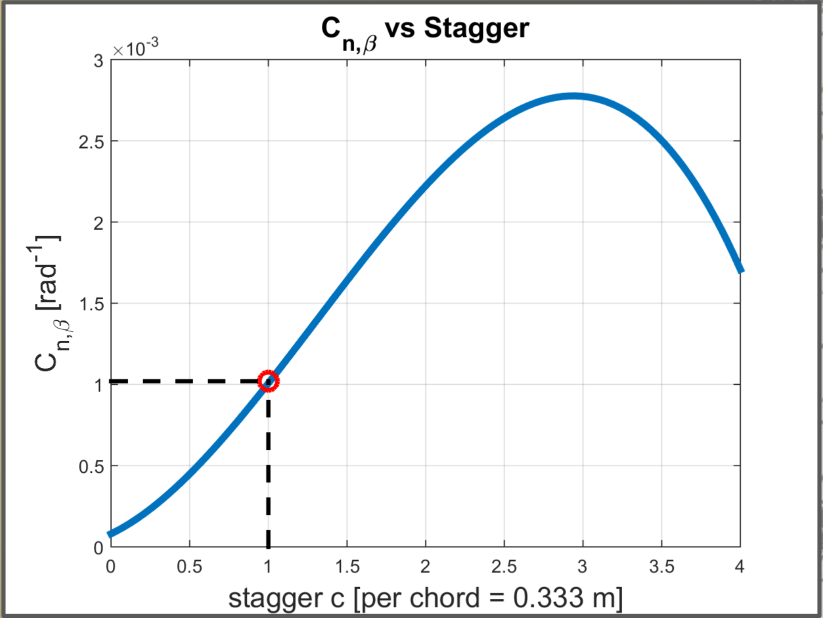
Lateral Static Stability

Equation: Yaw Stiffness

$$C_{n_\beta} = 2V_V a_F \left(\frac{V_F}{V}\right)^2 \left(1 - \frac{\partial\sigma}{\partial\beta}\right)$$

BOTE calculation:

	$C_{n,\beta}$ [rad^{-1}]
Eagle Owl	0.001504
ARES	0.001008

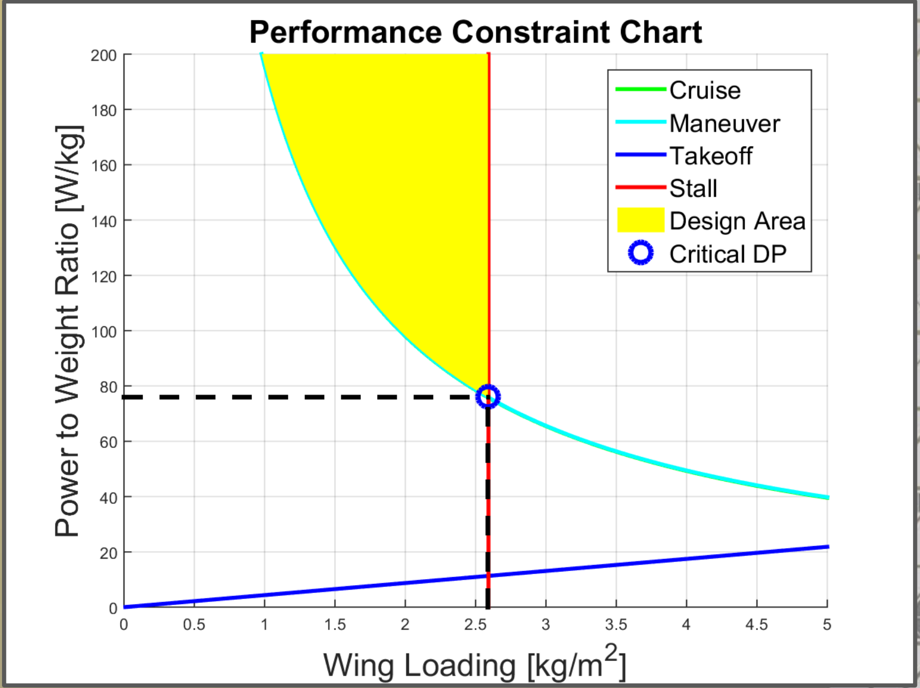


<u>Main Takeaway</u>: Positive yaw stiffness proves a laterally stable aircraft design (without rudder)

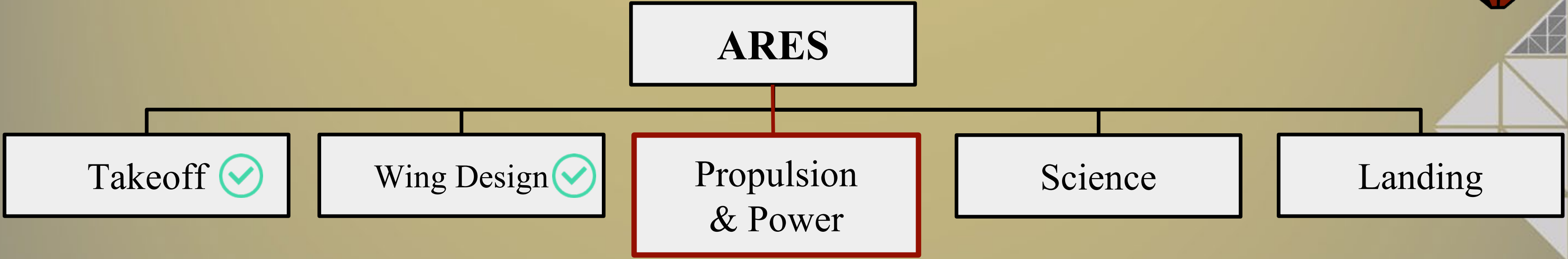
Performance Constraint Analysis

Generated result:

- Estimated S_w: 1.333 m^2
- W/S = 2.59 kg/m^2
  - Estimated Weight = 3.45 kg
  - 0.5% higher stall speed
- P/W = 76.0 W/kg (34.5 W/lb)
  - Assumed 25 % efficiency propulsion system



Critical Project Feasibility Elements



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

Propulsion: Power Budgeting

- Maximum mass allowed for batteries: 1.29 kg
  - Max mass shown feasible with mathematical modeling - beyond this is too impacting to design

__Assumptions:__

$(L/D)_{max} = 20$
-> SF = 1.3

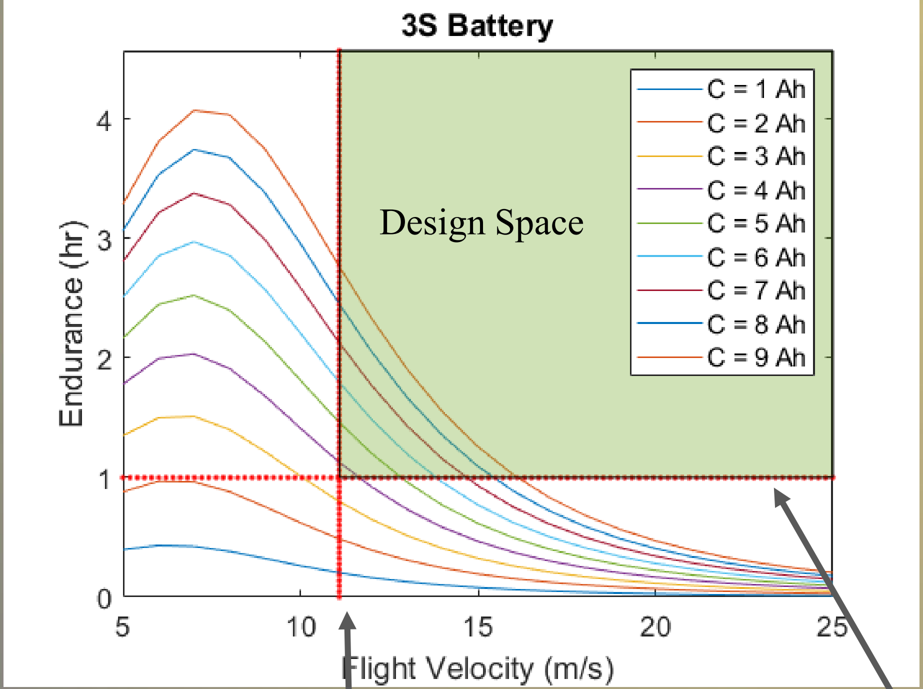
$V_0 = 11.1$ m/s

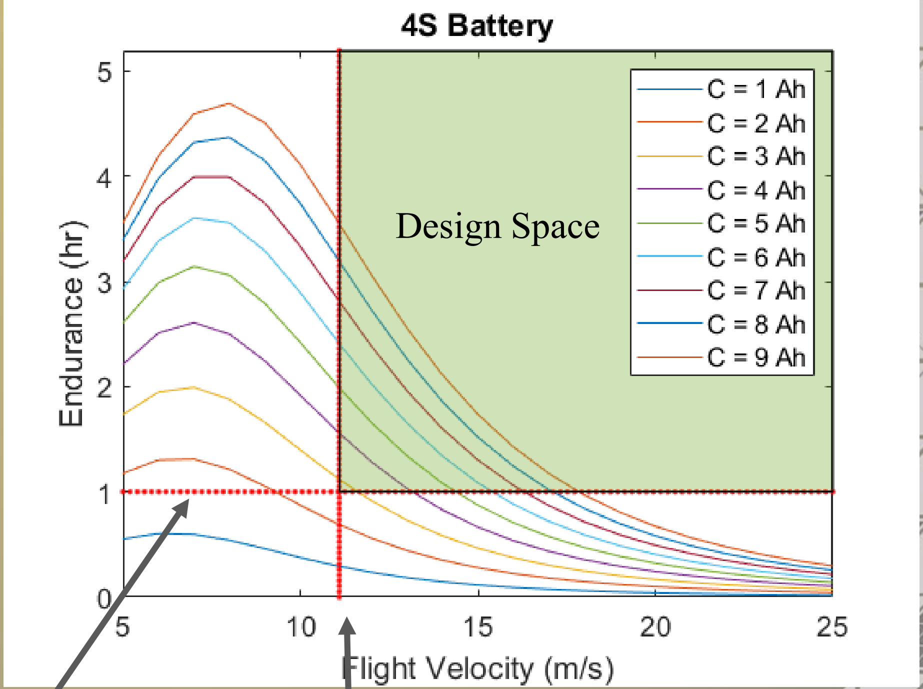
$W_{max} = 33.36$ N

$\eta_p = 1$

Thrust	Voltage [V]	Current [A]: $I = TV_0/V_{batt}$	Required Battery Capacity [mAh]	Estimated Battery Weight [kg]	
$T_{min} = W_{max}(0.2)$	11.1 (3S)	5.132	5132.31	0.3992	Best Case
	14.8 (4S)	3.849	3849.23	0.4219	
$T_{max} = W_{max}(0.25)$	11.1 (3S)	6.415	6415.38	0.4990	
	14.8 (4S)	4.811	4811.54	0.5273	Worst Case

Propulsion: Power Budgeting


3S Battery


4S Battery

Desired cruise velocity (11 m/s)

Desired endurance: 1 hr

Desired cruise velocity (11 m/s)

Propulsion: Feasibility

- Proposed ARES propulsion design and strategy is feasible
    - T/W = 0.2-0.25: Comfortable flying with low maneuverability
        - RC Endurance flight Heritage - Mistral, Twister, DataHawk, etc.
        - Mathematical modeling suggests current design can meet design requirements
        - Expert consultation - RC propulsion experts have approved of design
        - Online resources - ECalc, MotoCalc
- Propulsion is easily modifiable during construction and testing stage
    - Evaluate performance using dynamic wind tunnel testing
    - Propeller performance is tunable by changing yoke
        - Helps endurance at consequence of higher propeller stall speed

DR 1.2.1: 1 hour endurance at 10-30 m/s ✓

Main Takeaway: Proposed propulsion design can provide enough thrust and maintain speed for 1 hr.

Propulsion/Power: Battery

- Propulsion Requirements:

Battery Voltage	**Capacity [mAh]**	**Endurance [hr]**	**Mass [g]**
11.1V (3S)	3800-9000	1-3	290-695
14.8V (4S)	2900-9000	1-3.5	320-990

- Science Specifications:
  - Voltage: 2S (7.4 V)
  - Capacity: 72-102 mAh (200 mAh is smallest possible battery)
- Will be charged under supervision and stored safely
  - Assistance and training provided by the Boulder Aeromodeling Society (BAS)

Propulsion/Power: Summary

Subsystem	Cost [$]	Mass [g]	Capacity [mAh]
Propulsion	100-200	290-990	2900-9000
Science	15	20	200

- Batteries can be purchased to achieve 1 hour of flight time.
  - Batteries can be ordered online from E-flite or Venom that are 3-4s with capacities between 200-5000 mAh

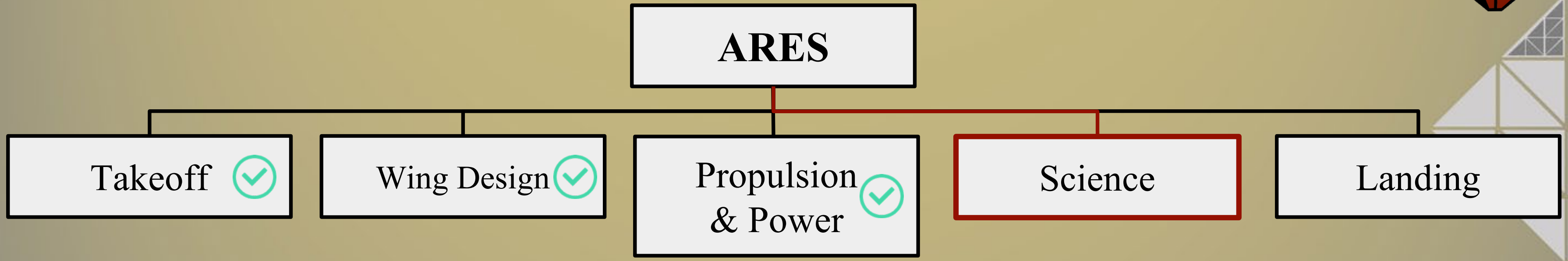
FR 1.0: 1 hour endurance... ✓

- The batteries can provide a flight speed greater than 10 m/s.

DR 1.2.1: flight speeds 10-30 m/s ... ✓

- Batteries needed for all subsystems do not weigh more than 1.29 kg

Critical Project Feasibility Elements



ARES

- Takeoff ✓
- Wing Design ✓
- Propulsion & Power ✓
- Science
- Landing

DR 5.1: An array of pressure sensors shall be integrated flush to the exterior of the airframe.

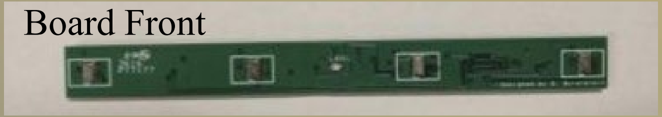
DR 5.5.3: The on-board computer shall be capable of communicating with a minimum of 12 pressure sensors and 1 temperature sensor.

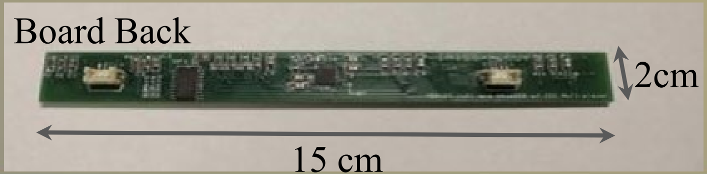
Science: Pressure Sensors

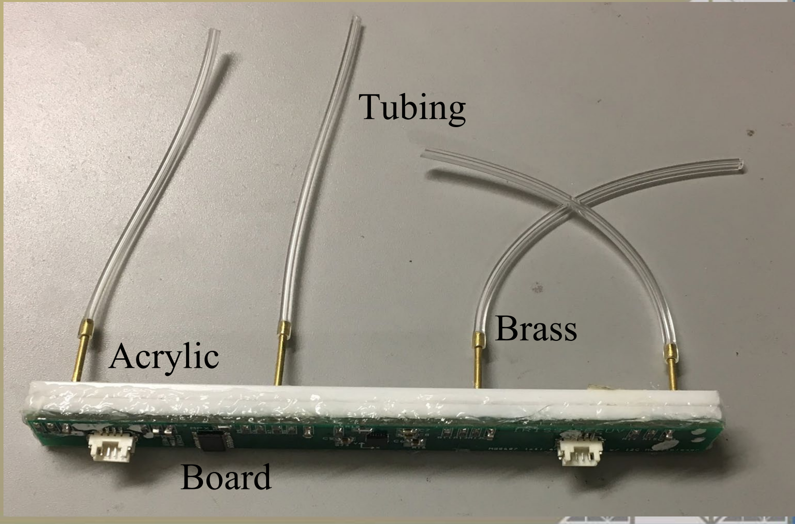
- MS8607 - 02BA01 Pressure/Temperature Sensors
  - CU FADS expert, Roger Laurence, provided us with custom boards used on Skywalker that house 4 sensors
  - Sensors are housed in acrylic slots that connect to flexible urethane tubing via brass fittings
- Microcontroller
  - Must have 4 ports that accept I2c data

DR 5.1: Pressure Sensors ✓

DR 5.5.3: Onboard computer capable of communicating with 13 sensors ✓

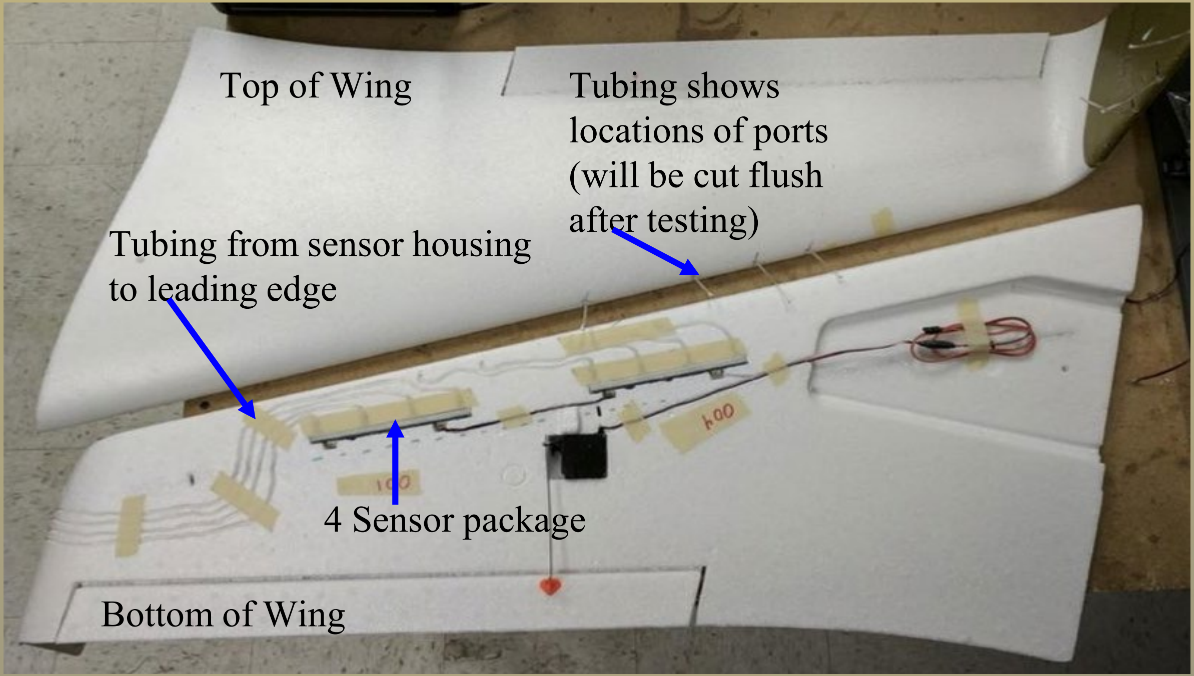






Science: Manufacturing

From CU FADS expert, Roger Laurence on his dissertation work with the Skywalker


Top of Wing

Tubing shows locations of ports (will be cut flush after testing)

Tubing from sensor housing to leading edge

4 Sensor package

Bottom of Wing

DR 5.1: Sensors integrated flush to airframe ✓

<u>Main Takeaway</u>: FADS have been integrated on aircraft before and we have been given documentation on how to manufacture.

Science: Calibration of FADS

Our pressure measurements will be imperfect so we will need to calibrate our measurements with some "true" values. All techniques can be conducted without flying the aircraft.

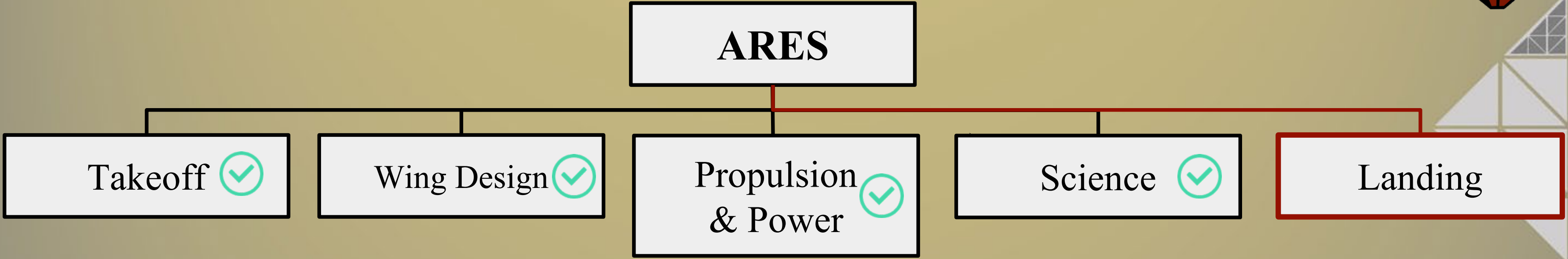
Technique for Finding "True" Values: **Computational Fluid Dynamics Analysis**

- CFD simulation is capable of determining the pressure felt by the surface of the aircraft
- We will need to:
  - Import a model of our aircraft
  - Determine exactly which grid points correspond to the locations of our our FADS sensors
  - Vary the angle of attack and sideslip
  - Compare the expected pressure from the CFD to the measured FADS pressure using least squares regression

FR 5.0: The data shall be converted to relative wind speed ✓

Main Takeaway: We will calibrate our system using predicted pressure values from CFD analysis instead of flying a multi-hole probe.

Critical Project Feasibility Elements



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

DR 6.2: The landing system shall be attached to the aircraft and not rely on an external device.

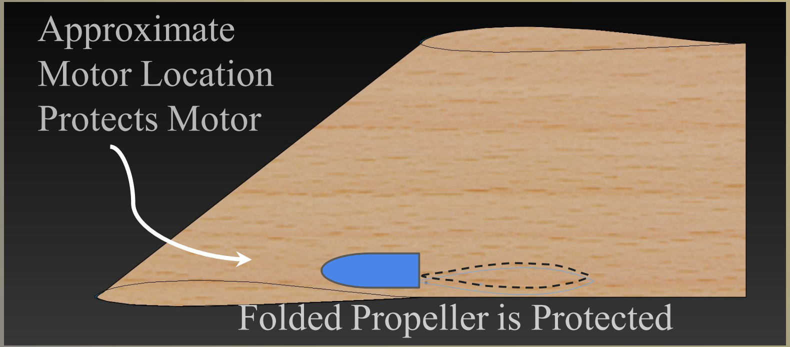
Landing

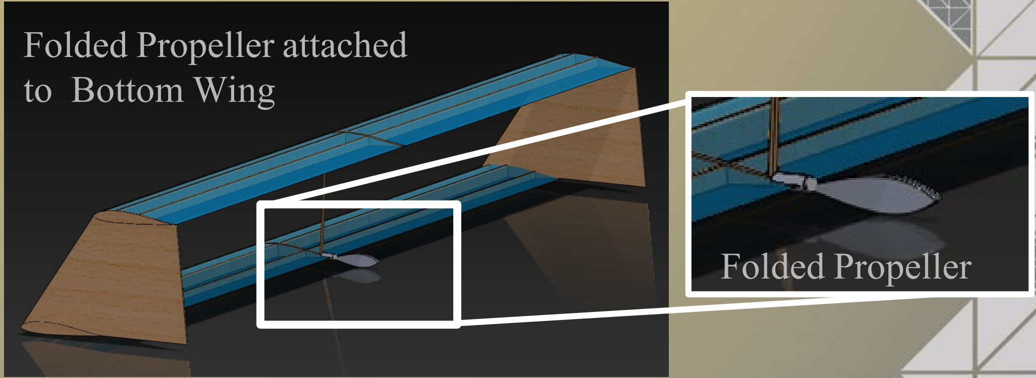
Chosen Solution: Skid Landing

DR 6.2: Attached to aircraft ✓

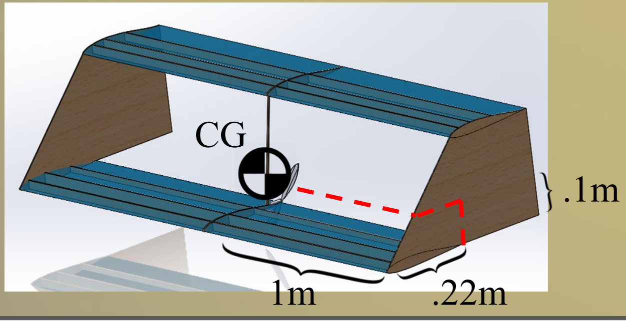
To be feasible:

- The propeller needs to fold to avoid damage
- The CG will be low to decrease the chance of tumbling
    - Preventing tumbling will protect engine shaft and other weak components
- The body needs to withstand the landing forces

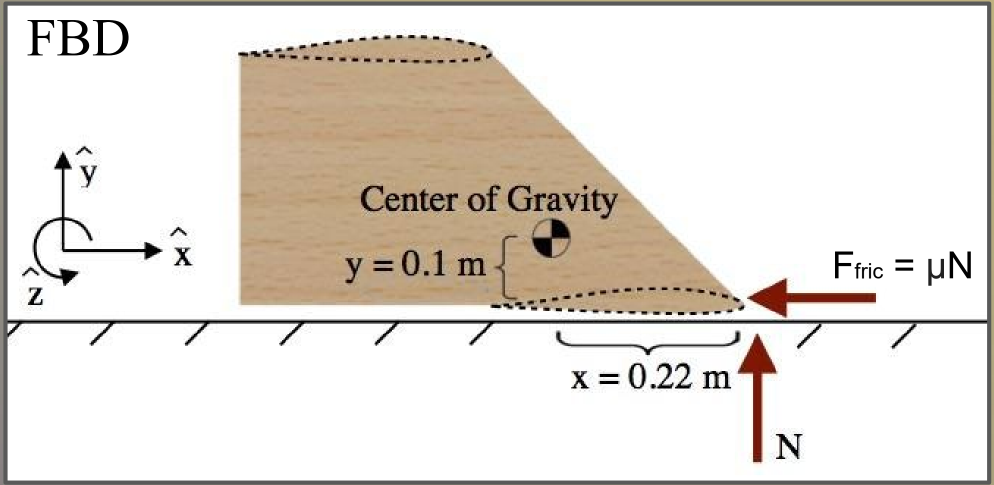




Landing Feasibility: Sliding



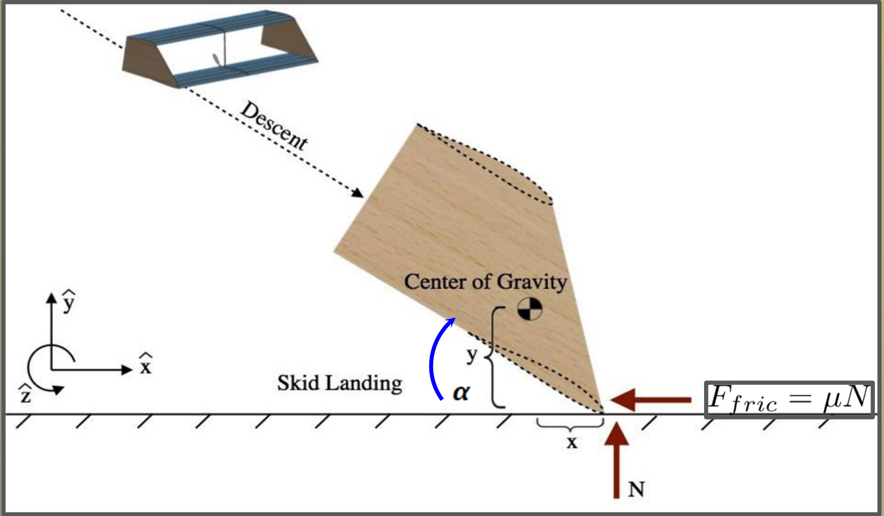
What is the coefficient of friction that will result in sliding rather than flipping?



$$\sum M_{cg} = 0.22N - 0.1\mu N$$

$$0 = N(0.22 - 0.1\mu)$$

Landing Feasibility: Sliding



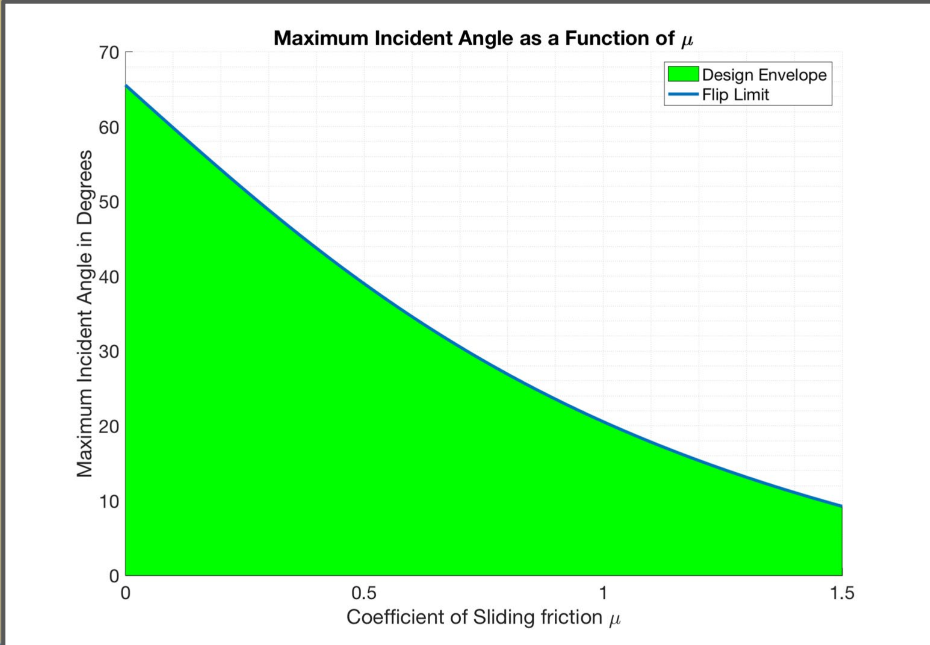
$$x = -0.1 sin(\alpha) + 0.22 cos(\alpha)$$

$$y = 0.22 sin(\alpha) + 0.1 cos(\alpha)$$

$$0 \leq \sum M_{cg} = xN - y\mu N$$

$$tan(\alpha) \leq \frac{0.22 - 0.1\mu}{0.1 + \mu 0.22}$$

Variation in Incident Angle Analysis

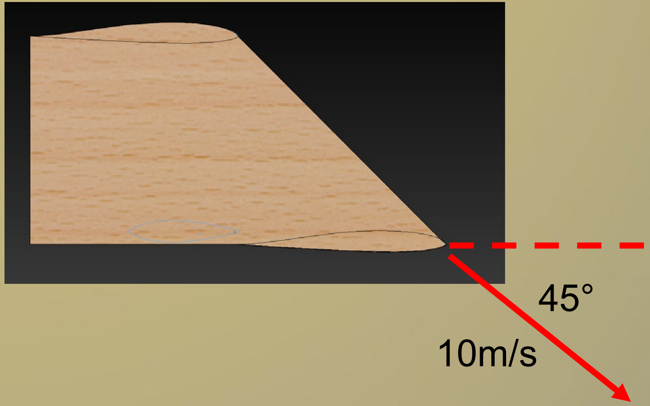


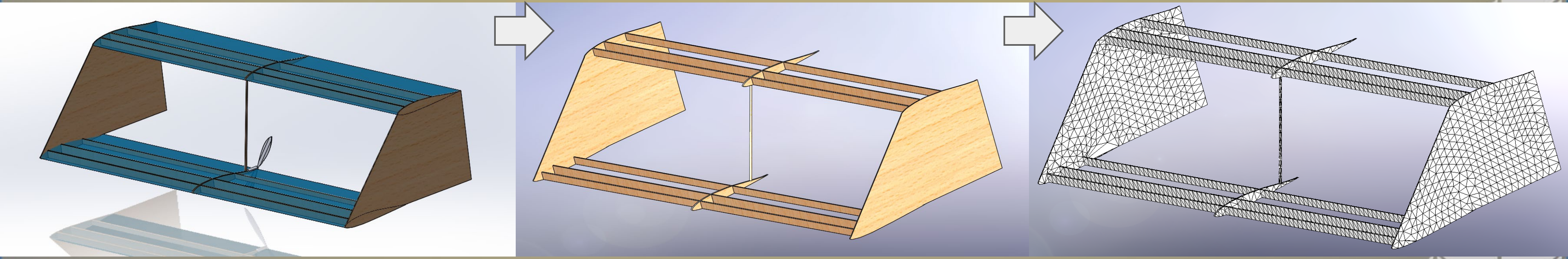
Landing Feasibility: Simulation

$V_{stall} = V_{land} = 7.60$ m/s

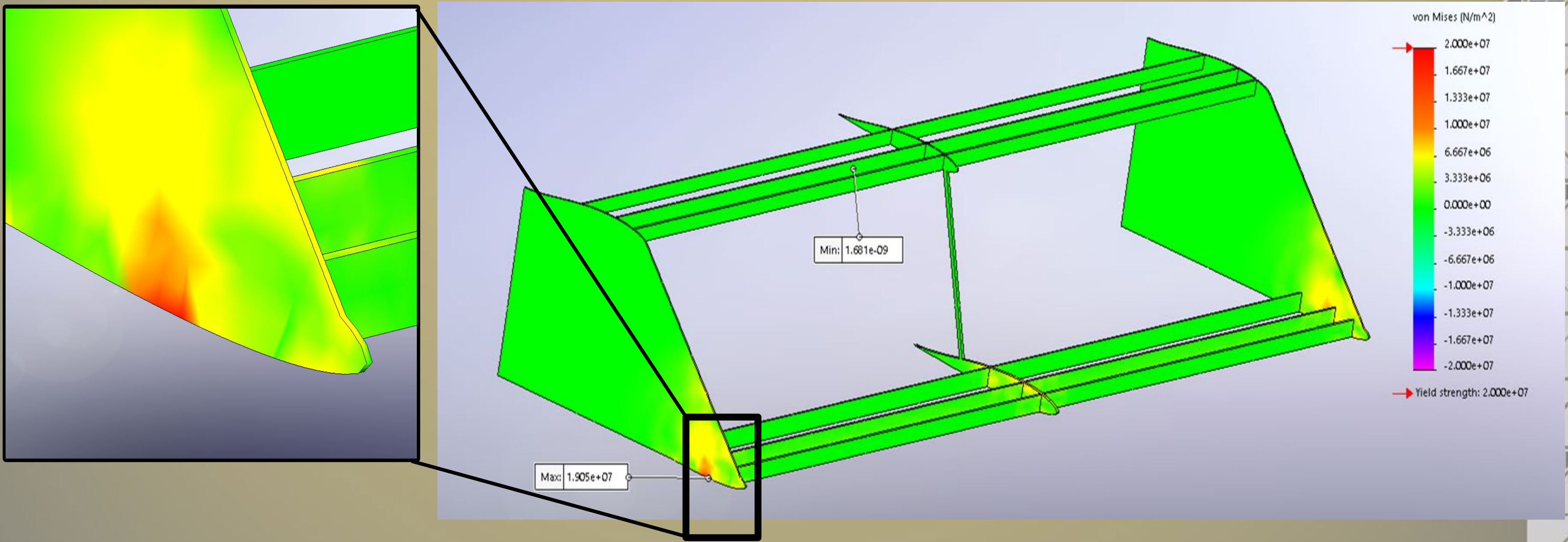
Simulate a “worst case” landing scenario

Simplifications to design for simulation





Landing: Stress



DR 6.1: Land such that it can take-off again ✓

<u>Main Takeaway</u>: Max landing force occurs on back of aircraft. We do not exceed our yield strength.

Summary

ARES

- Takeoff ✓
- Wing Design ✓
- Propulsion & Power ✓
- Science ✓
- Landing ✓

Project Overview → **Baseline Design** → **Feasibility Study** → **Summary**

Mass Totals

Component	**Mass [kg]**
Airframe	1.6
Science (Microcontroller, P/T sensors, housing)	(0.010-0.050) + (0.020) + (0.020)
Battery (Propulsion, Science)	(.29-1) + (0.05-0.1)
Autopilot	0.016
Propulsion (Propellers, motors)	(0.05) + (0.3)
Controls (Servos)	0.05
Total	**2.36 - 3.14**
Lift Constraint	**3.5kg at V_{cruise} = 11.1m/s**

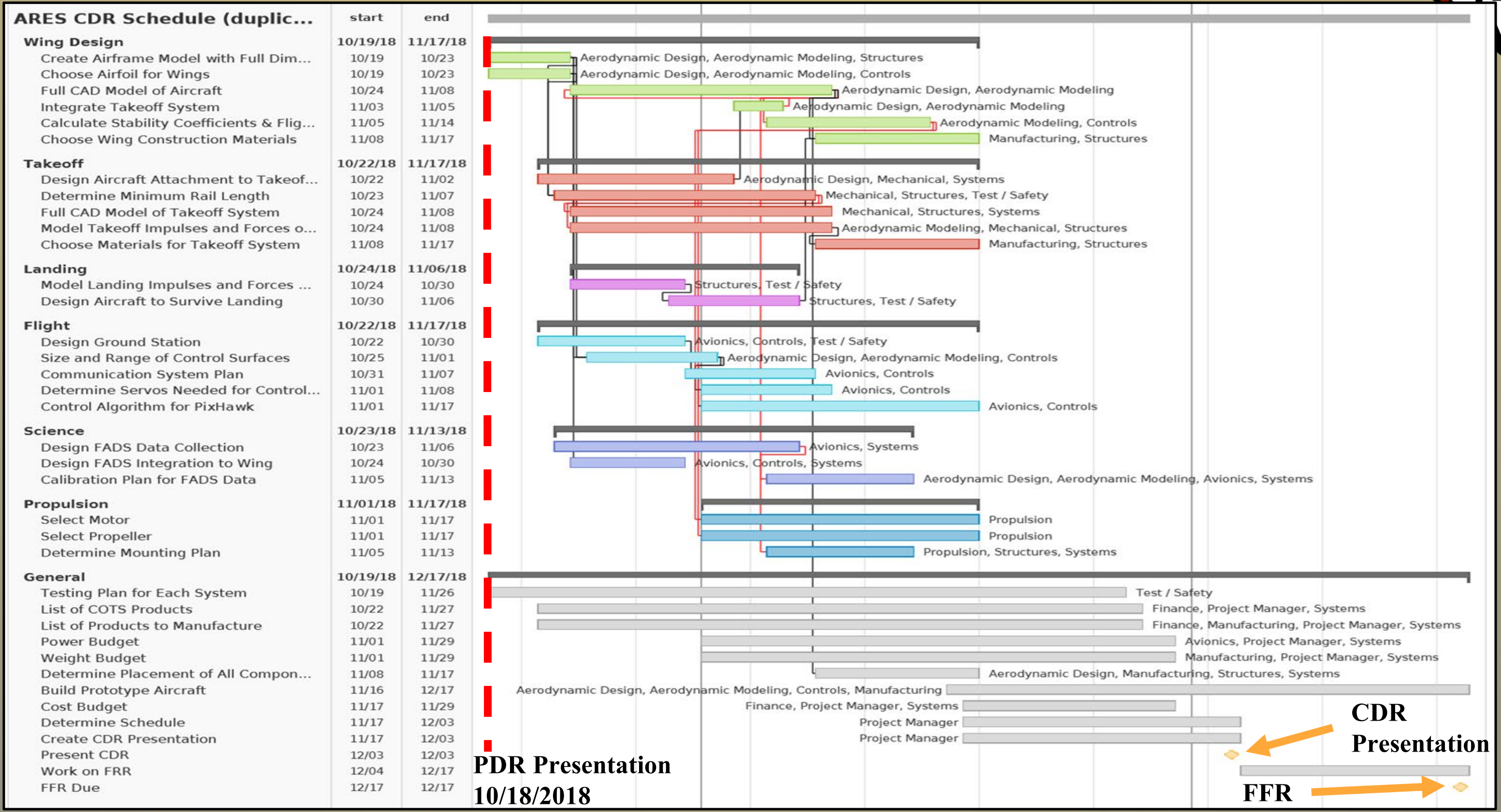
Budget Totals

System	**Components**	**Total Cost**
Takeoff	Frame, Bungee, Rails, Miscellaneous	$185
Airframe	Materials	$300
Propulsion	Motor, Propeller, Yoke	$60 - $140
Controls	Servos	$50
Autopilot	Pixhawk 4	$180
Science	P/T Sensors, Microcontroller, Housing	$350 - $390
Landing	Rails	$40
Power	Batteries	$150 - $200
Miscellaneous	Pilot training, posters, copies, etc.	$150 - $200
Total		**$1,465 - 1,685**

Power Budget

Subsystem	Component	Power [Wh]	Current [A]	Capacity [mAh]	Voltage [V]
Science	Microcontroller	0.15 - 0.35	0.03 - 0.05	30 - 50	7.4
Science	Pressure transducers	4.2e-3	1.4e-3	1.4	3.0
Science total		**0.15-0.35**	**0.03-0.05**	**31-51**	**Peak: 7.4**
Propulsion	Propulsion	61-148	6-10	2900-9000	11.1-14.8
Controls	Autopilot	2	0.4	400	5
Controls	Actuators	0.06 - 0.60	0.010 - 0.100	10 - 100	4.8 - 6
Prop/Control total		**63-133**	**6.4-10.5**	**3310-9500**	**Peak: 14.8**

Gantt Chart - CDR



ARES CDR Schedule (duplic...	start	end
Wing Design	10/19/18	11/17/18
Create Airframe Model with Full Dim...	10/19	10/23
Choose Airfoil for Wings	10/19	10/23
Full CAD Model of Aircraft	10/24	11/08
Integrate Takeoff System	11/03	11/05
Calculate Stability Coefficients & Flig...	11/05	11/14
Choose Wing Construction Materials	11/08	11/17
Takeoff	10/22/18	11/17/18
Design Aircraft Attachment to Takeof...	10/22	11/02
Determine Minimum Rail Length	10/23	11/07
Full CAD Model of Takeoff System	10/24	11/08
Model Takeoff Impulses and Forces o...	10/24	11/08
Choose Materials for Takeoff System	11/08	11/17
Landing	10/24/18	11/06/18
Model Landing Impulses and Forces ...	10/24	10/30
Design Aircraft to Survive Landing	10/30	11/06
Flight	10/22/18	11/17/18
Design Ground Station	10/22	10/30
Size and Range of Control Surfaces	10/25	11/01
Communication System Plan	10/31	11/07
Determine Servos Needed for Control...	11/01	11/08
Control Algorithm for PixHawk	11/01	11/17
Science	10/23/18	11/13/18
Design FADS Data Collection	10/23	11/06
Design FADS Integration to Wing	10/24	10/30
Calibration Plan for FADS Data	11/05	11/13
Propulsion	11/01/18	11/17/18
Select Motor	11/01	11/17
Select Propeller	11/01	11/17
Determine Mounting Plan	11/05	11/13
General	10/19/18	12/17/18
Testing Plan for Each System	10/19	11/26
List of COTS Products	10/22	11/27
List of Products to Manufacture	10/22	11/27
Power Budget	11/01	11/29
Weight Budget	11/01	11/29
Determine Placement of All Compon...	11/08	11/17
Build Prototype Aircraft	11/16	12/17
Cost Budget	11/17	11/29
Determine Schedule	11/17	12/03
Create CDR Presentation	11/17	12/03
Present CDR	12/03	12/03
Work on FRR	12/04	12/17
FFR Due	12/17	12/17

PDR Presentation 10/18/2018

CDR Presentation

FFR

Moving Forward

- Most difficult CPEs driving design
    - Battery size/weight impact on endurance
    - Efficiency of propulsion system
    - Structural integrity of airframe on takeoff and landing
- Improvement of models and assumptions to confirm current design
- Details of airframe and control surface design
- Prototype construction
    - Allows for real-life aerodynamic/stability testing
    - Experience gained manufacturing will help during production

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- Project Advisory Board
- Dr. Roger Laurence
- Ian Cooke
- Christine Reilly
- Chris Choate
- Boulder Aeromodeling Society

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Thank You

Are there any questions?

Backup Slides

Baseline Design Selection

Takeoff	**Flight**	**Science**	**Landing**	**Power/Electronics**
External bungee launch system	Rectangular planform, lower wing forward Autopilot: PX4 Bottom mounted pusher propeller	FADS integration Calibration Temperature sensor	Skid landing	Parallel LiPo batteries for propulsion and control External battery for FADS

Mission Success Criteria

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

Motivation

- Obtaining data from inside extreme weather events can be a challenging task
- Getting into a stormcell requires an extremely steady, robust unmanned aircraft
    - Options exist but are expensive
- Implementing a flush airdata sensing system can help eliminate risk of damage to expensive sensors
    - Past renditions used protruding pitot probes but they can break on landing
- Helps to further understand atmospheric patterns

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. The recorded data shall be stored on-board and converted to relative wind speed after flight.
- 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.

Schedule

- Important upcoming dates:
    - 10/21/2018 Implement feedback on PDR
    - 10/23/2018 Complete final feasibility analysis (including PAB feedback)
    - 10/23/2018 Complete identification of CPE’s most threatening to success
    - 10/23/2018 Final determination of potential off-ramps
- Future milestones:
    - 11/08/2018 Begin prototype aircraft
    - 11/29/2018 Finalized component selection
    - 12/03/2018 Conceptual Design Review
    - 12/17/2018 Fall Final Report due

Take-off
Backup Slides

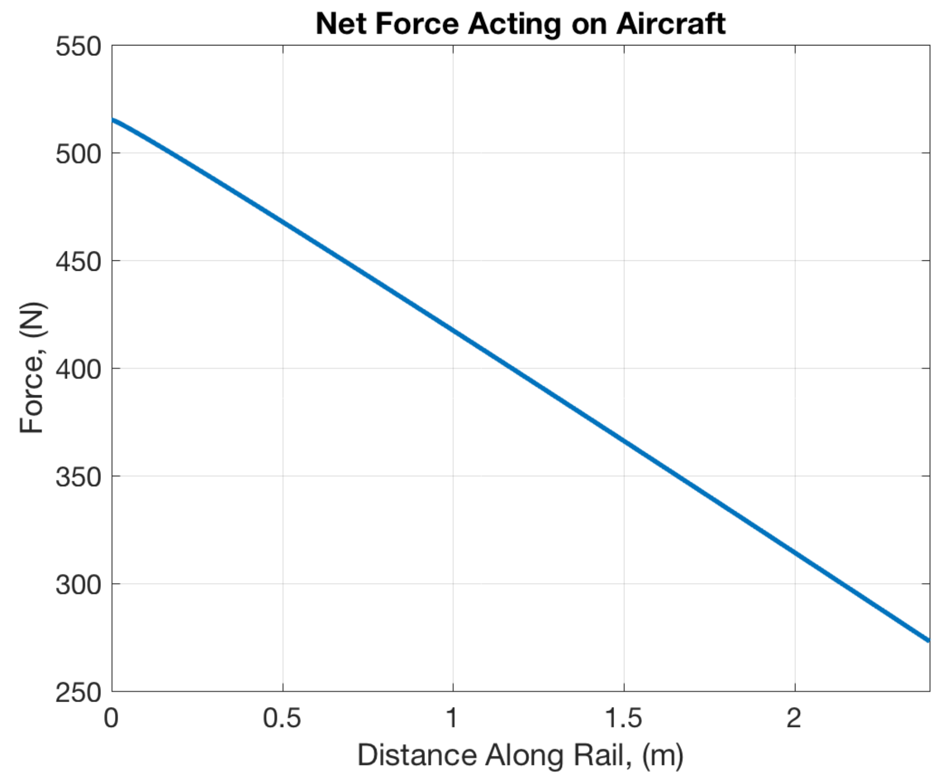
Takeoff System

FR 3.0: The aircraft shall demonstrate a controlled takeoff

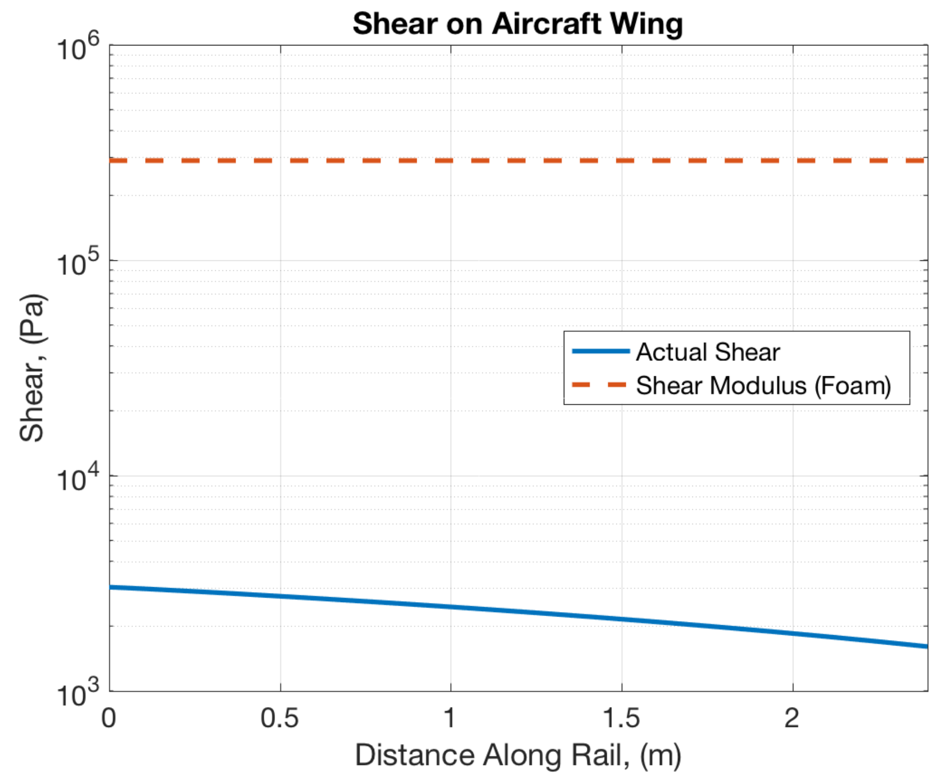
Chosen: External Bungee Launch System

- Abundance of flight heritage/documentation
- Easy to dictate final takeoff velocity
    - Determined by length of rails, bungee spring constant, bungee displacement
- Simple to manufacture and cost effective
    - 80/20 for rails and other structure, aluminum for other components
    - Many commercial options for bungee
- Mobile
    - Easy to assemble and disassemble

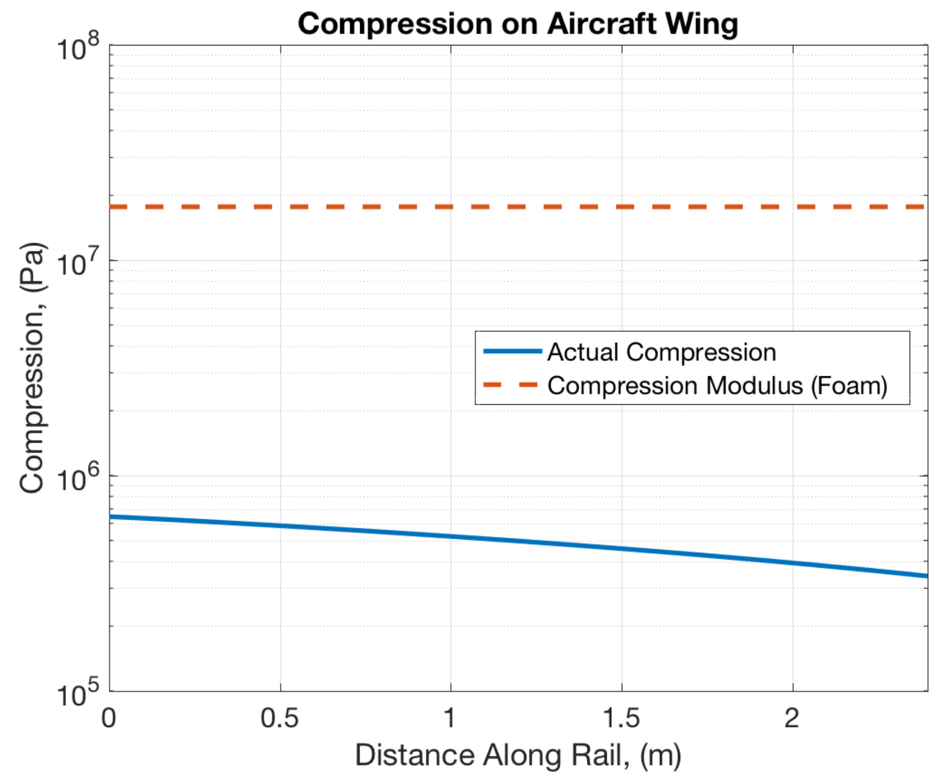
Takeoff System - Extra



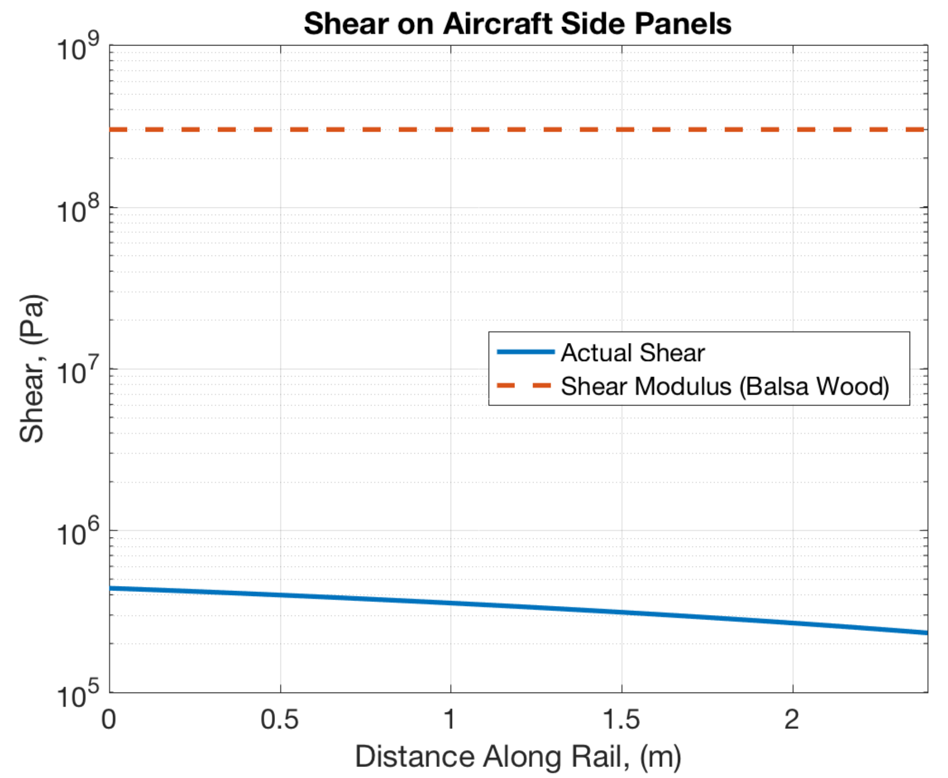
Takeoff System - Extra



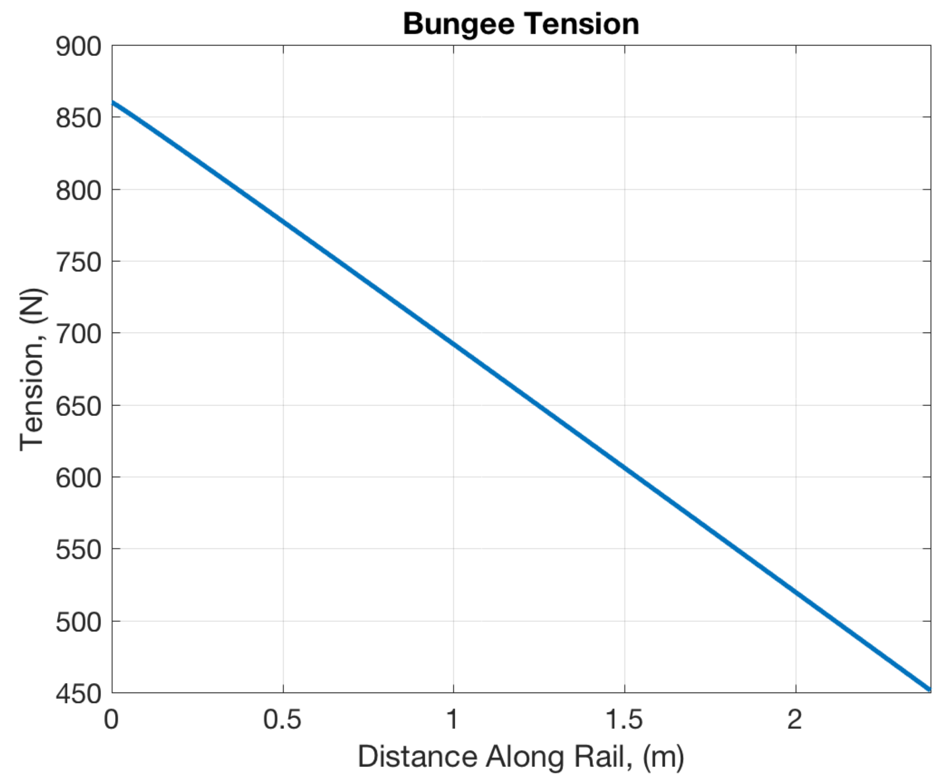
Takeoff System - Extra



Takeoff System - Extra



Takeoff System - Extra



Takeoff System - Extra

Manufacturing Feasibility

- Very few machined parts
    - Base plate to hold aircraft
    - Release mechanism
    - All other components will be purchased
- Material: Aluminum
- Nothing machined should exceed capabilities of Lathe, Drill Press, Mill.
- Techniques: facing, turning, milling, drilling, tapping, deburring, grinding.

Takeoff System - Extra

Cost Feasibility (approximate)

- Bungee ~ $25 (KBand Training)
- Rails ~ $30 (80/20 Inc.)
- Stock Aluminum ~ $100 (Online Metals)
- Ground Stake ~ $ 5 (Home Depot)
- Misc: Screws, Hooks, Pulley, etc. ~ $25 (Home Depot)

Total = $185

Takeoff System - Calculations

Model

General Forces

$$f_k(N) = \mu_k N$$

$$\mathrm{N(L)} = (\sin 90 - \theta)W - L$$

$$\mathrm{F}_s = k(d - \Delta x)$$

Aerodynamic Forces

$$D(v) = \frac{1}{2}\rho v^2 C_D S$$

$$L(v) = \frac{1}{2}\rho v^2 C_L S$$

Kinematics

$$x(t) = vt + \frac{1}{2}at^2 + x_0$$

$$v(t) = at + v_0$$

Takeoff System - Calculations

Model (cont.)

$$\Sigma F_x = T + F_s - f_k - D - \cos(90 - \theta)W = ma_x$$

$$\Sigma F_y = L + N - \sin(90 - \theta)W = ma_y$$

$$\mathrm{a}(\mathrm{T},\ \mathrm{F}_s, f_k, D) = \frac{T + F_s - f_k - D - \cos(90 - \theta)W}{m}$$

Wing Design Backup Slides

Wing Baseline Design

FR 2.0: The system shall be an aircraft with a box wing configuration with a span no larger than 2 meters.

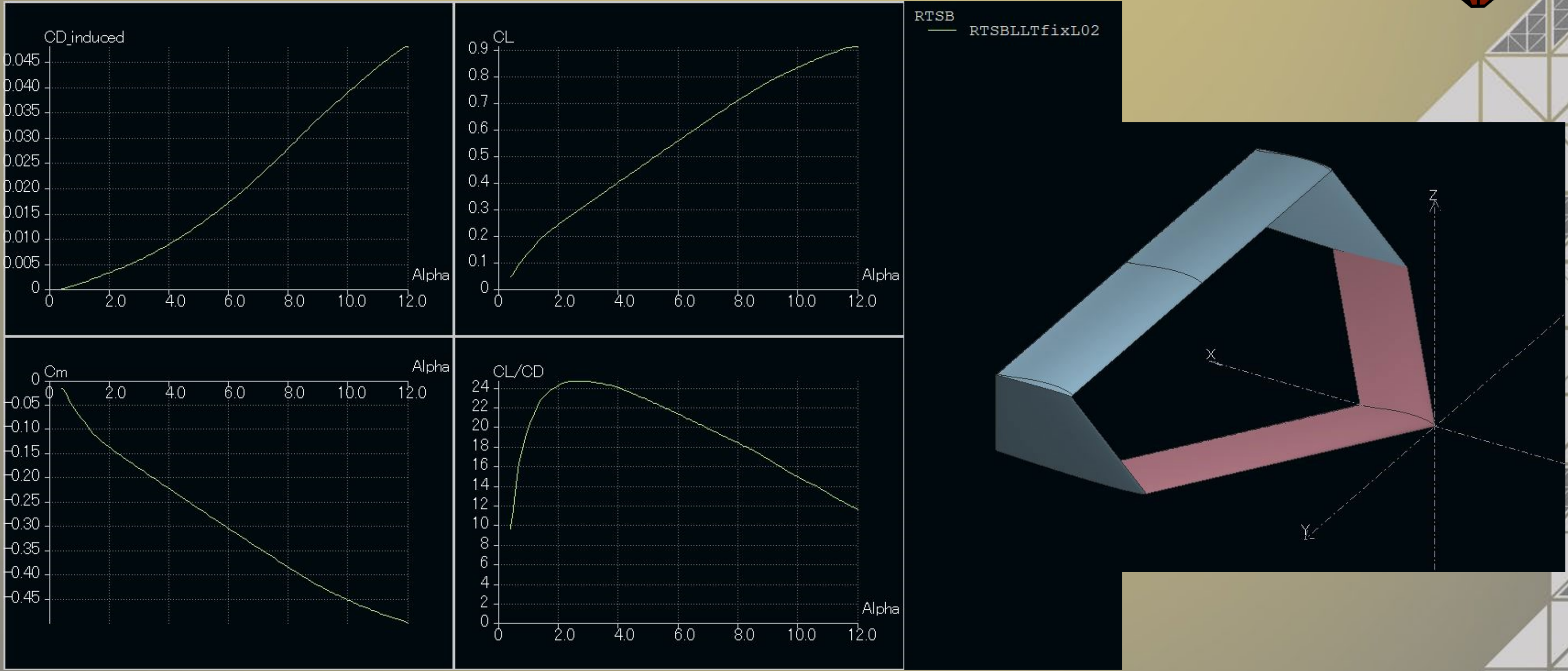
Chosen: Rectangular planform

- AR = 3,
- S = 1.333 m^2,
- b = 2 m
- c = 0.333 m
- 0.333 m stagger (bottom wing forward)
- 0.333 m vertical separation
- Mass: 1.6kg

- Airfoil: MH61 -
  - Used for feasibility analysis
  - Commonly used reflex airfoil for RC flying wings

Main Takeaway: Rectangular planform chosen for aerodynamic efficiency (Cl vs AoA, Cd vs AoA)

Baseline Wing Design: XFLR5



Wing Design: $C_{L,max}$ loss

$C_{L,max}$ is lower than Eagle Owl due to Negative Stagger

According to “Gap and Stagger Effects on Biplanes with End Plates”,

- ➢ Negative stagger lowers the $C_{L,max}$ by 22.2%. This is an experimental data not shown in XFLR5
- ➢ The presented $C_{L,max}$ takes this loss into account

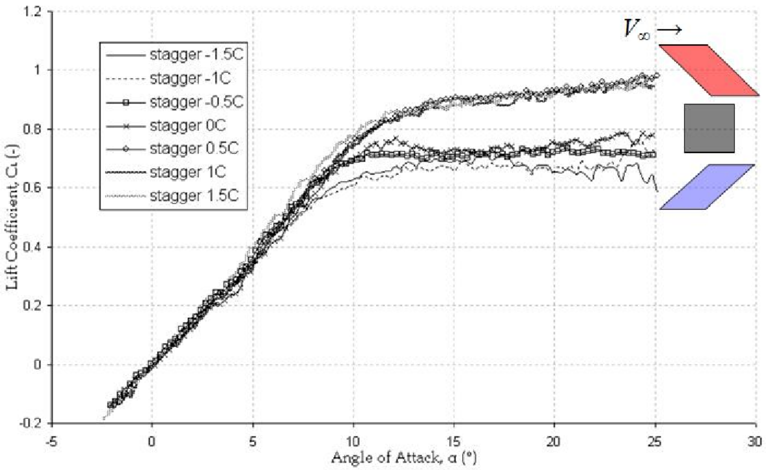


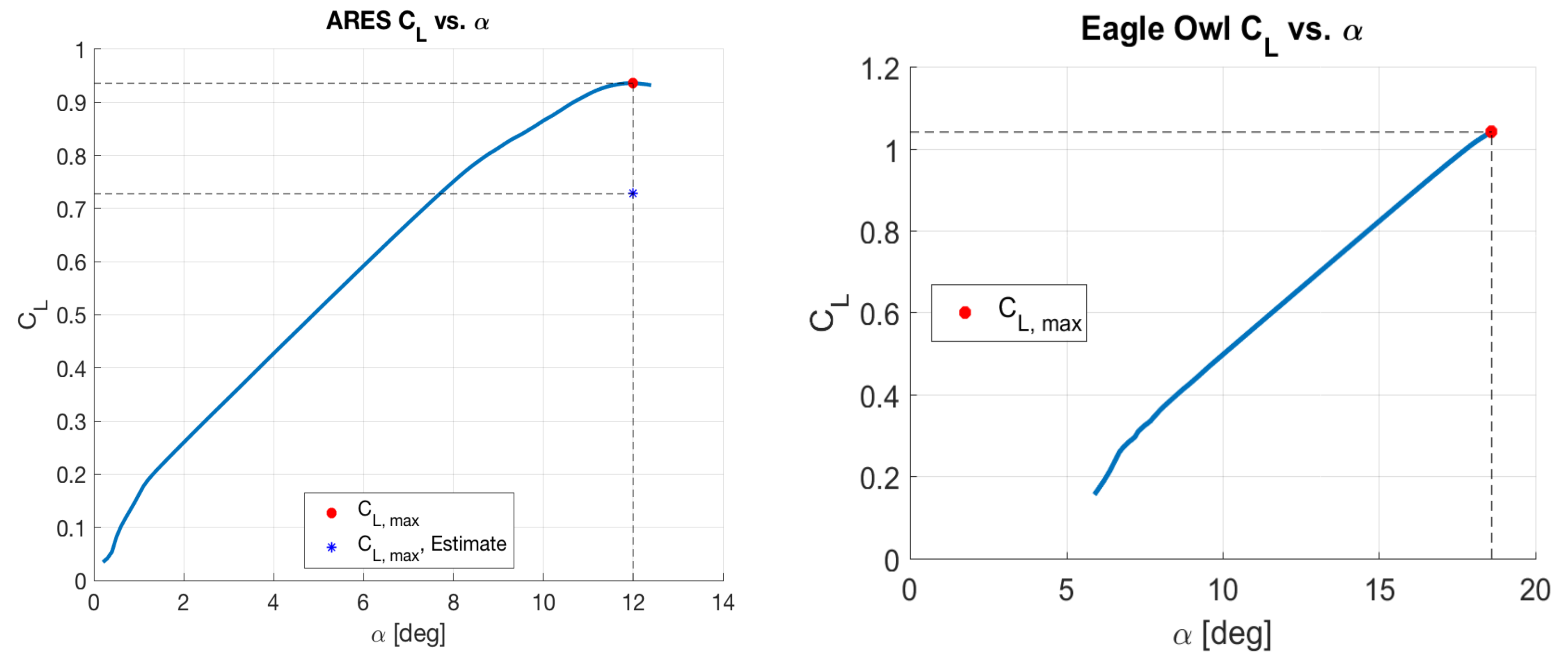
Figure 9 *shows dependence of lift on stagger at constant gap with decreasing effect at a higher gap. G = 1c, Re = 60,000.*

Wing Design - Extra

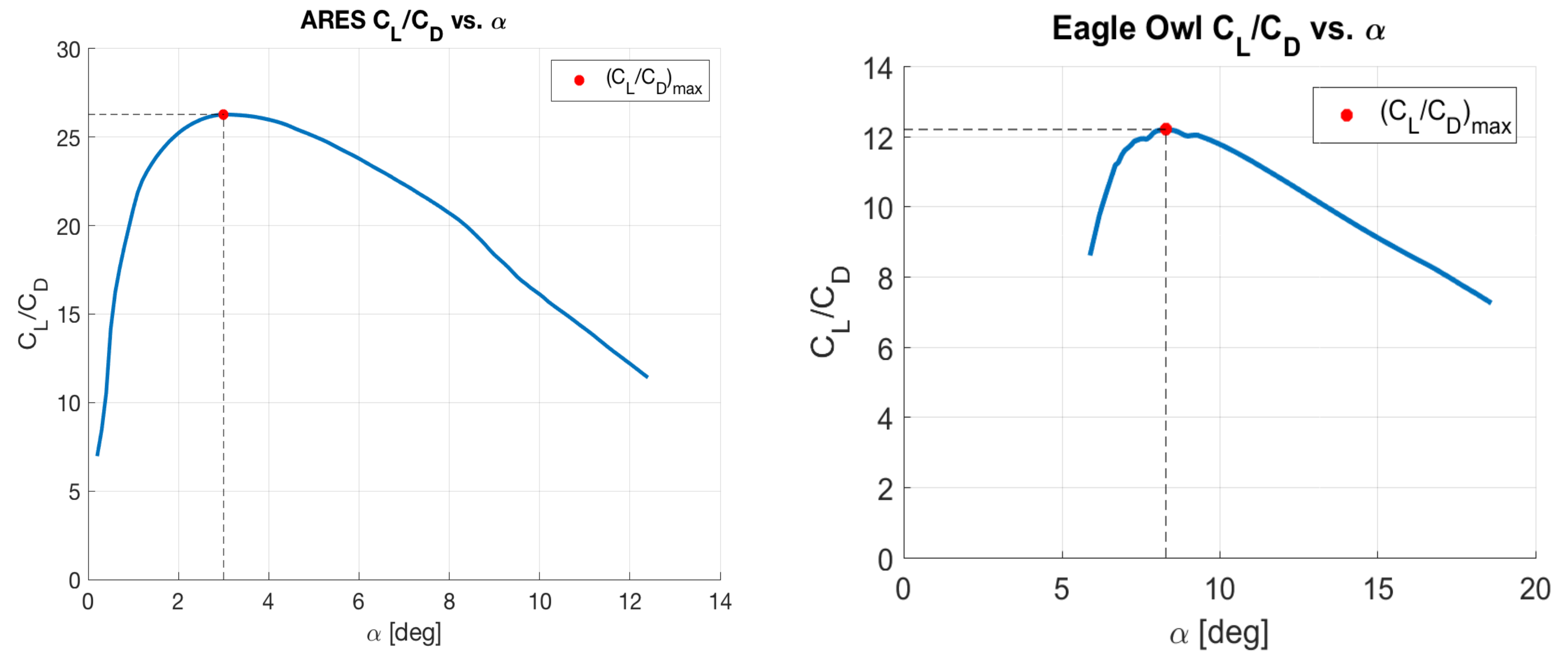
$$V_{Stall} = \sqrt{\frac{2W}{\rho S C_{L,Max}}}$$

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

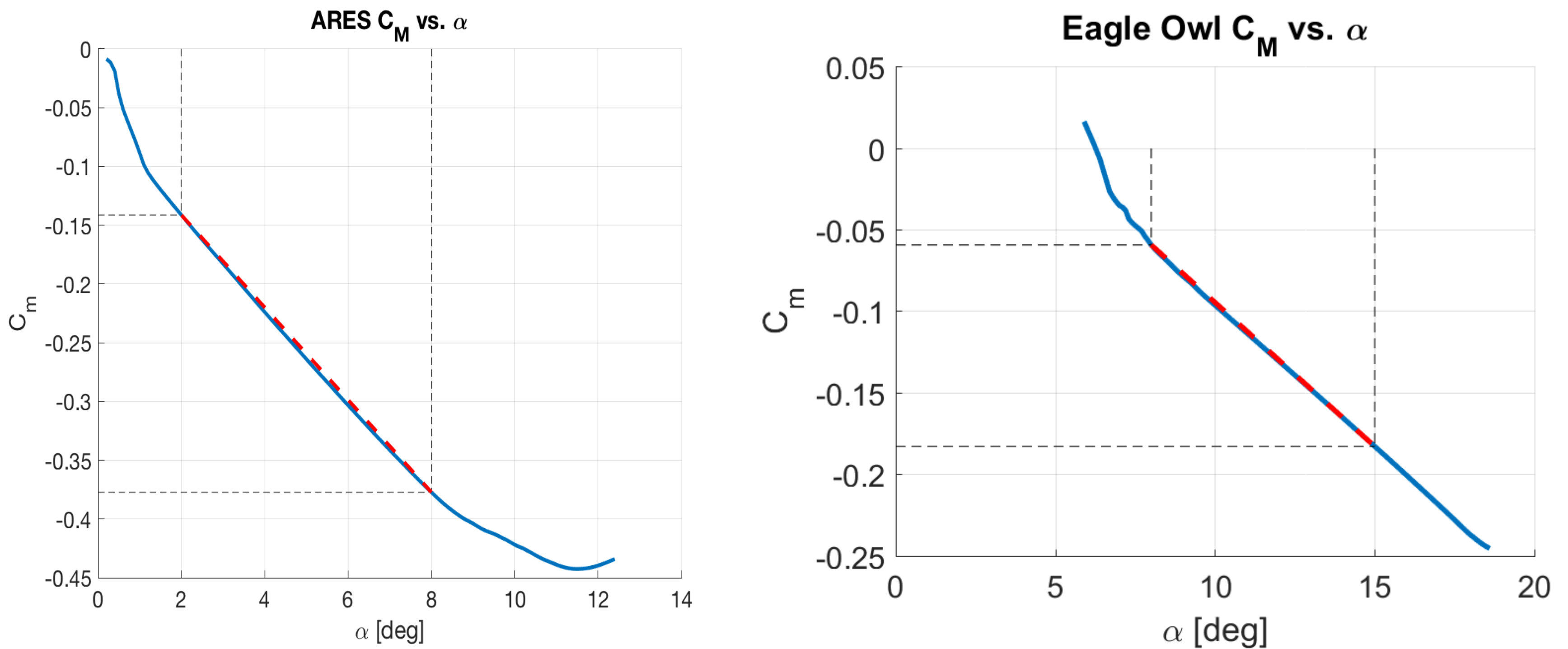
Wing Design: C_L - Extra



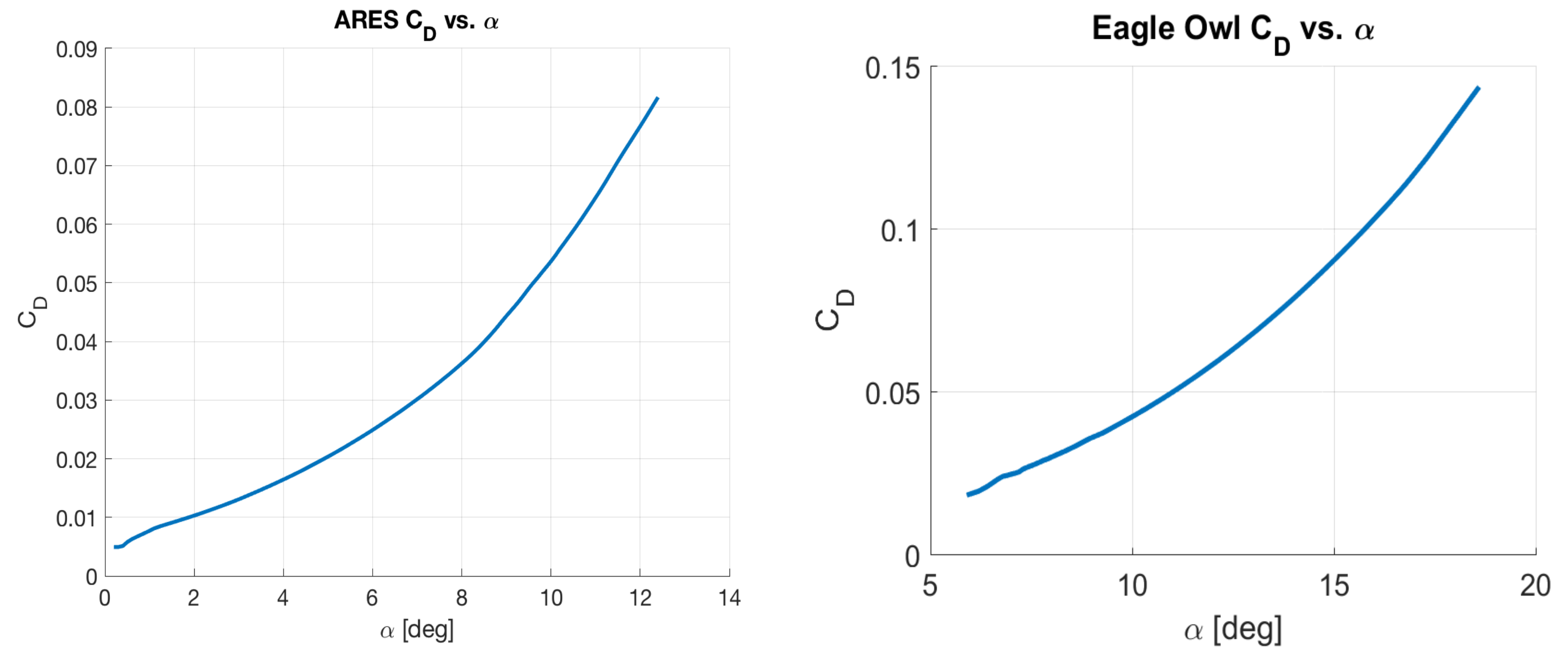
Wing Design: C_L/C_D - Extra



Wing Design: C_M - Extra



Wing Design: C_D - Extra



Wing Design - Extra

Yaw Stiffness Equation:

$$C_{n_\beta} = 2V_V a_F \left(\frac{V_F}{V}\right)^2 \left(1 - \frac{\partial\sigma}{\partial\beta}\right)$$

Sidewash derivative approximation:

$$\frac{\partial\sigma}{\partial\beta} = -0.276 + 3.06\frac{S_F}{S}\frac{1}{1 + cos(\Lambda_{c/4})} + 0.4\frac{Z_W}{d} + 0.009AR$$

Wing Design - Extra

Performance Plot Equations

- Maximum wing loading for given stall velocity:

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

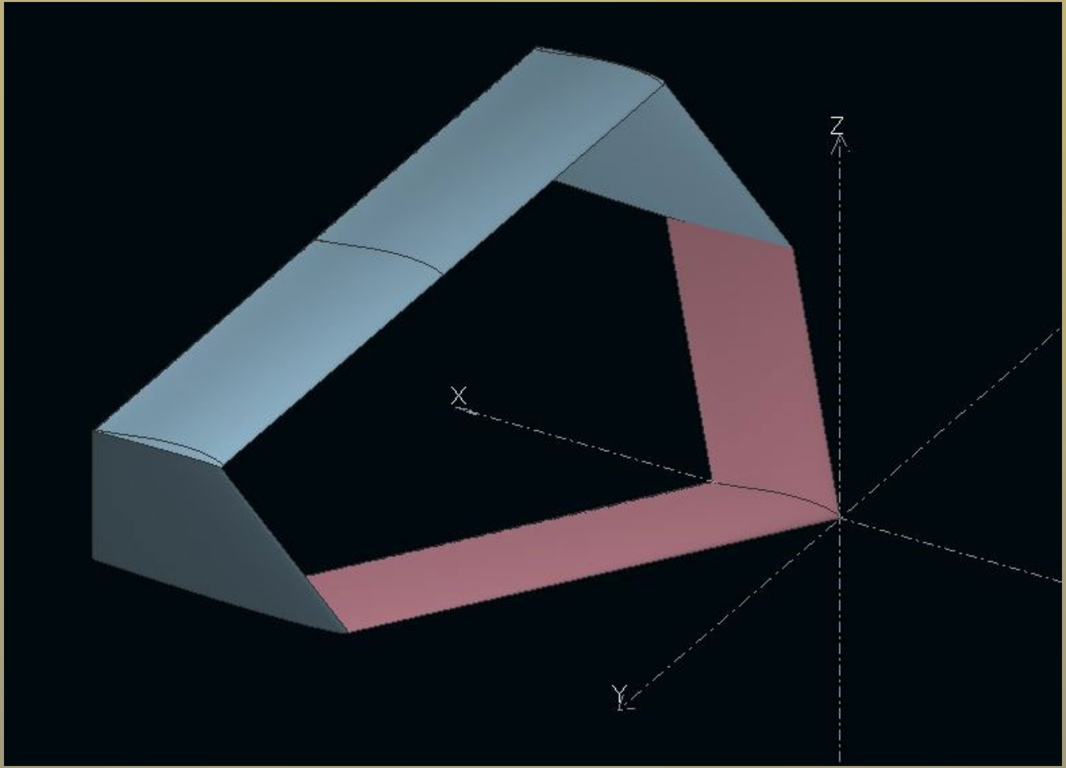
- Maneuvering Constraint Equation:

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

where n = G load factor

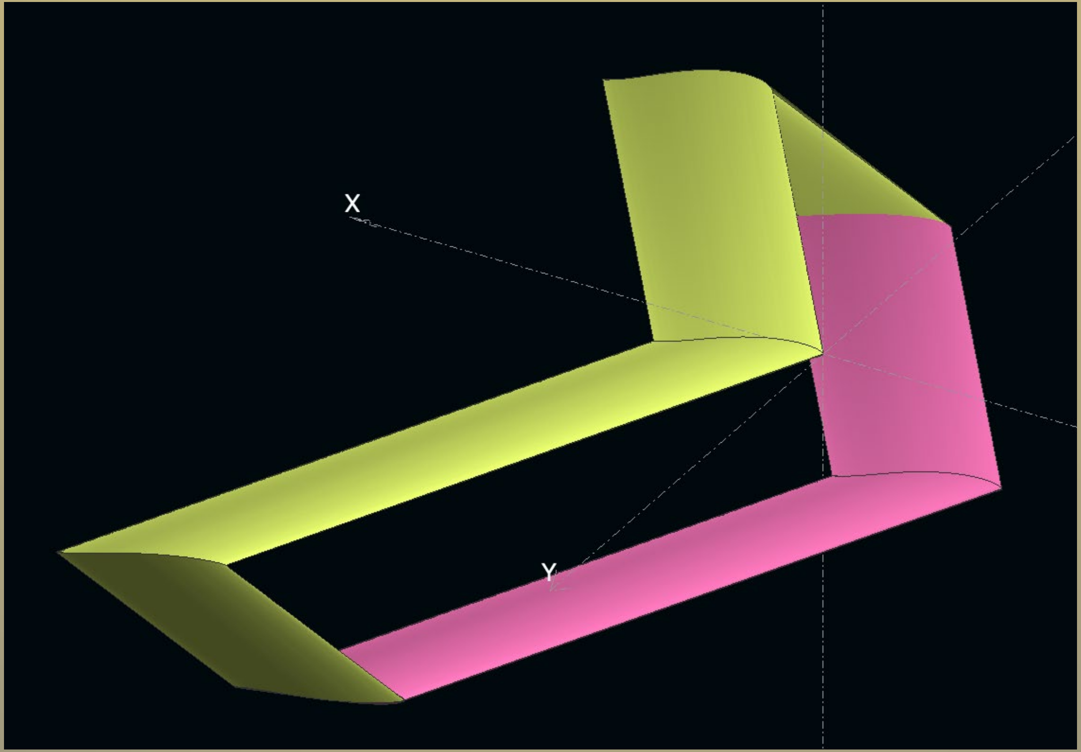
Wing Design - Extra

Rectangular top, swept bottom (RTSB)



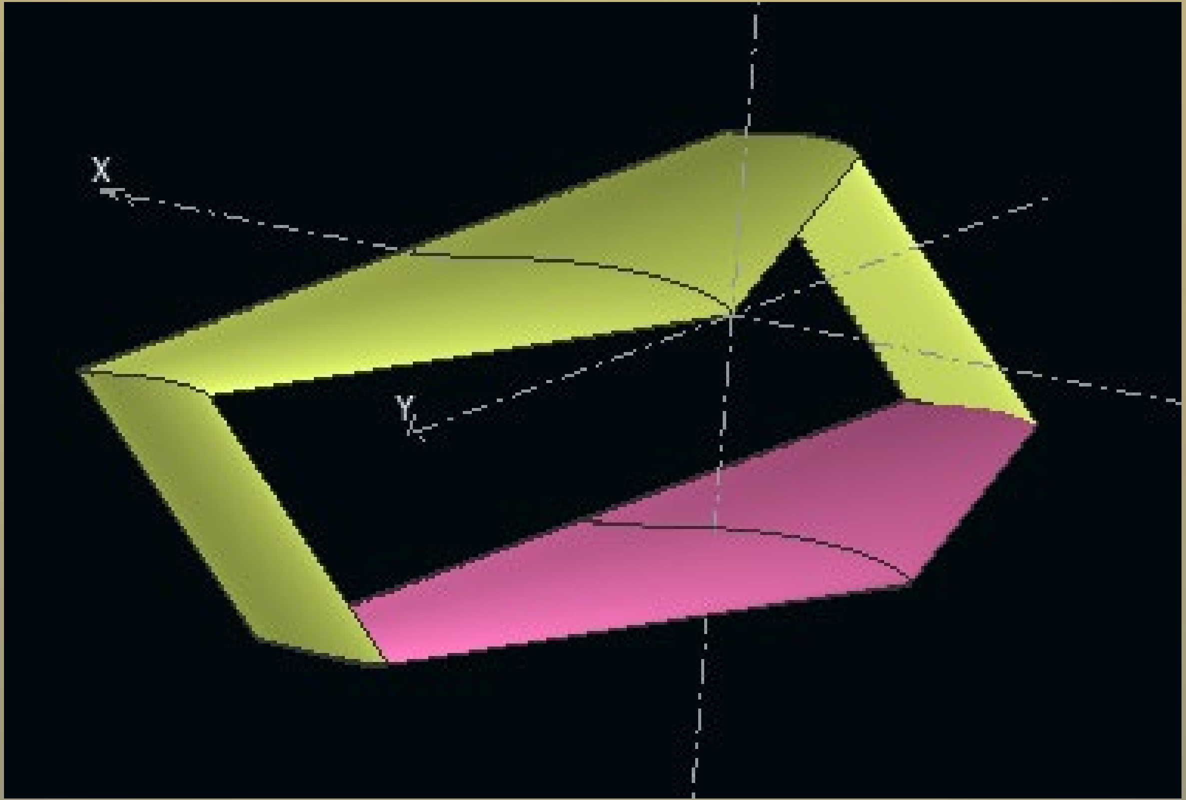
Wing Design - Extra

Swept wing



Wing Design - Extra

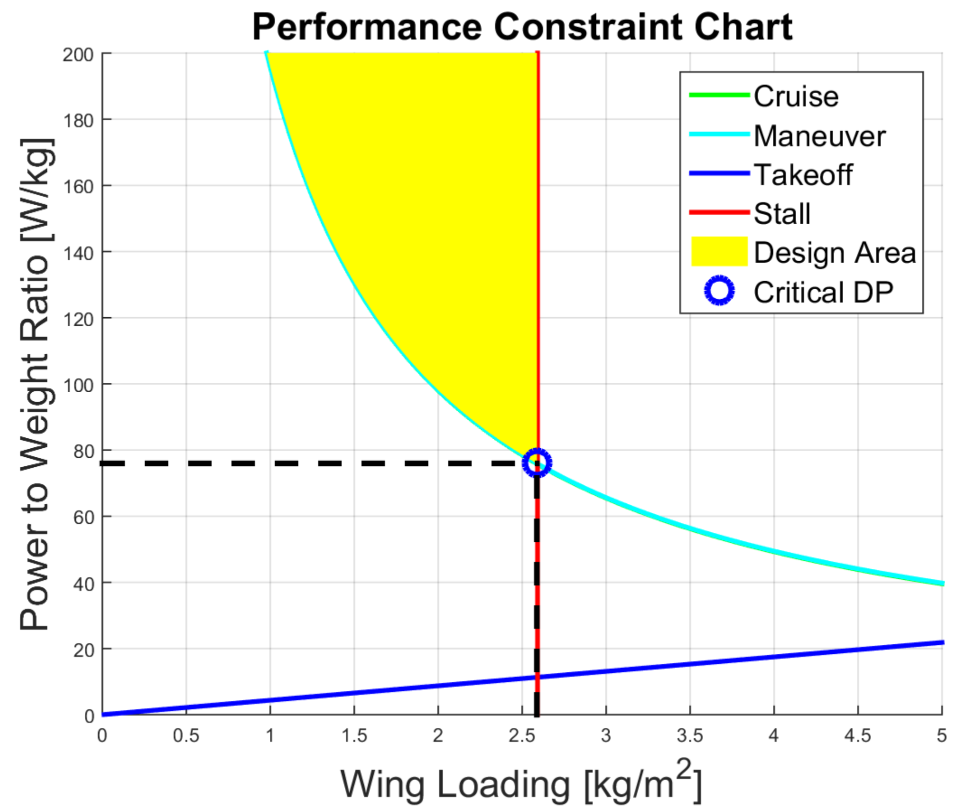
Pentagonal Wing



Performance Constraint Analysis

Input:

- Airfoil: MH-61
- $C_{L,\ cruise}$ = 0.35
- $C_{L,\ max}$ = 0.728
- V_{cruise} = 11.1 m/s
- V_{stall} = 7.6 m/s



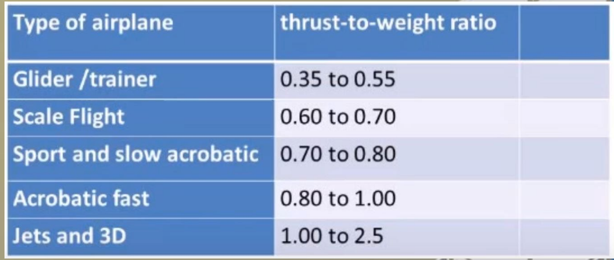
Propulsion Backup Slides

Propulsion - Table Explanation

- Flight Speed: $V_0 = 11.1$ m/s
- Thrust: $T = W(T/W)$
- Battery type determined by type of motor used and size of batteries:
  - Dictated by weight - want a lighter motor
  - Lighter motors have higher Kv - 4S and 3S allow for desired thrust when matched correctly
  - 3S and 4S batteries tend to be relatively small and easy to implement

Propulsion: T/W Justification

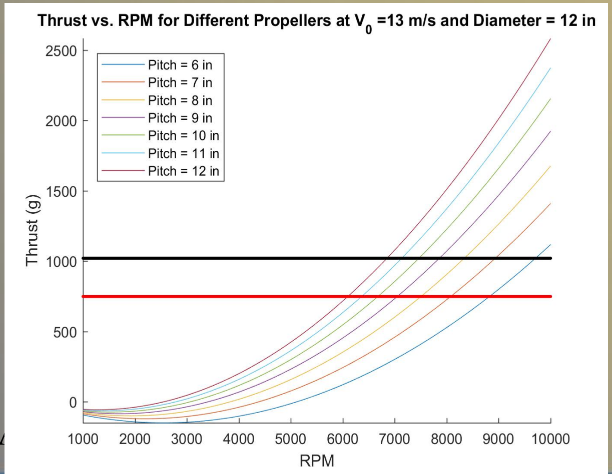
- T/W is qualitatively determined based on how you want your aircraft to behave:
  - High T/W (>0.45) - Higher ROC and maneuverability, more power draw
    - Fighter jet like characteristics
  - Low T/W (0.05-0.3) - Lower ROC and maneuverability, less power draw
    - Airliner or glider like characteristics
  - To minimize fuel consumption and based on low maneuverability missions, we want our aircraft to behave like a glider (T/W<0.55)[1]
    - Chose range based on heritage:
      - Eagle Owl - T/W = 0.1*[2]
      - Twister = 0.35, Mistral T/W = 0.4*[3]
    - Eagle Owl did not fly well enough, Twister/Mistral reportedly had too much T/W (in the works to lower) - we compromised: 0.22-0.3
      - Will decide exact value for CDR using heavier analysis

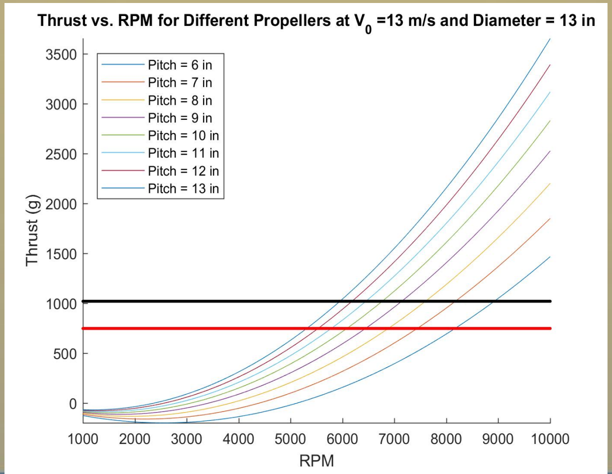


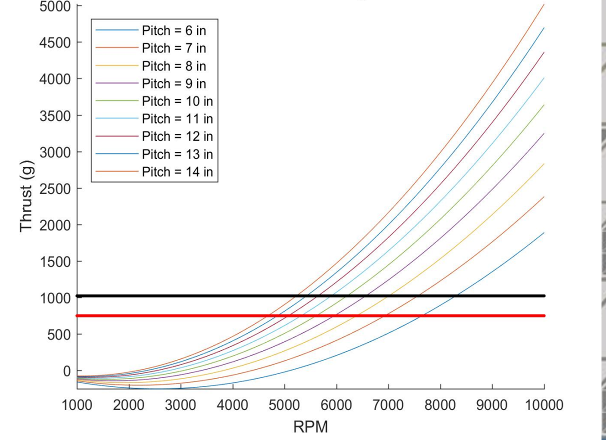
Type of airplane	thrust-to-weight ratio
Glider /trainer	0.35 to 0.55
Scale Flight	0.60 to 0.70
Sport and slow acrobatic	0.70 to 0.80
Acrobatic fast	0.80 to 1.00
Jets and 3D	1.00 to 2.5

Propulsion: Kv Justification - Extra

- Kv is dependent on what RPM we want
  - Correlate RPM to thrust (from T/W)
  - Approximate prop size to get range - use design constraints
  - Decide on an RPM based on mission - i.e. aircraft speed
- Once RPM is determined, choose Kv based on desired output voltage
  - Kv = RPM/V







Propulsion

- Battery: 10000-16000 mAh (3-5S=11.1-18.5V)
    - ECalc* illustrates capability of each of these batteries providing cruise thrust to the motor for 90-120+ minutes
    - Depending on motor and propellor choice, cell requirements and battery capacity will vary
- Speed Controller (ESC): Castle Phoenix Edge Lite 40-100 A
    - The Speed Controller is dependent upon the max amperage draw by the motor
    - Castle is considered an exceptional brand for ESC
- Propeller: Diameter 11-16 in. x Pitch 7-16 in.
    - Propeller will be designed to provide enough thrust at cruise of 13 m/s
    - Dimensions dependent upon final motor choice
    - Foldable prop. due to reduction of damage risk associated with impacts
        - 355kv - 14x9
        - 410kv - 13x8

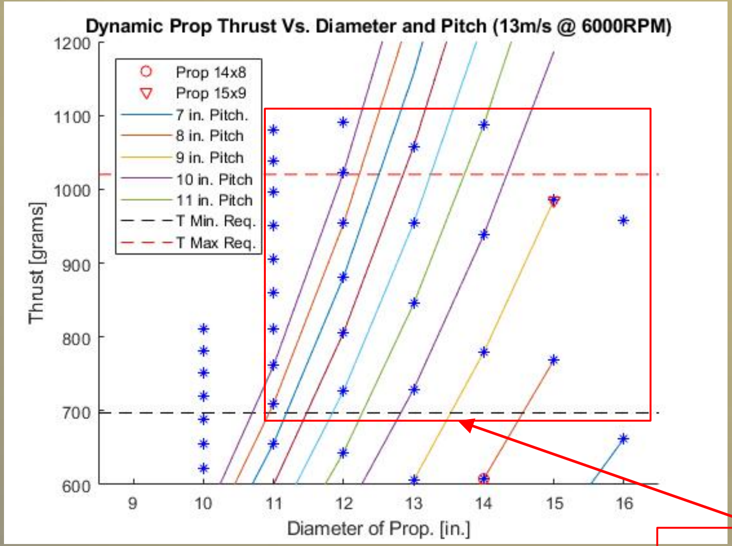
*from ecalc.ch/motorcalc.php (Widely Used Resource for RC Vehicle Estimation +/- 10% Acc)

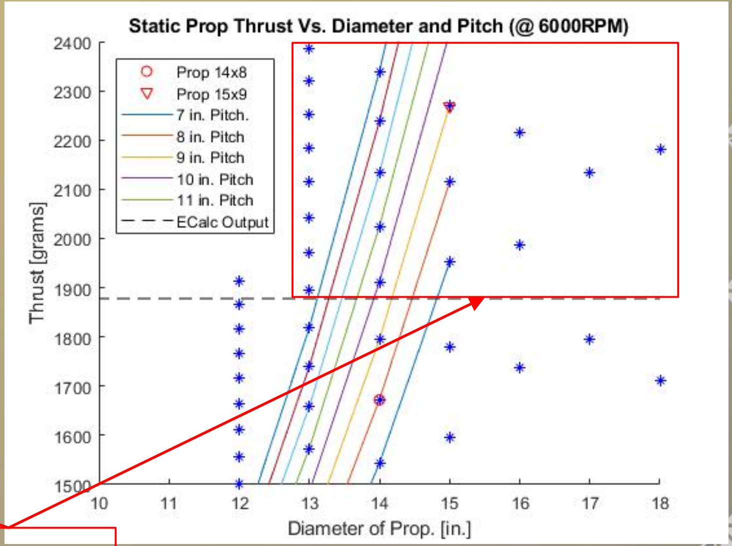
Propulsion - Propeller Size

- Possible Propellor Combinations

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

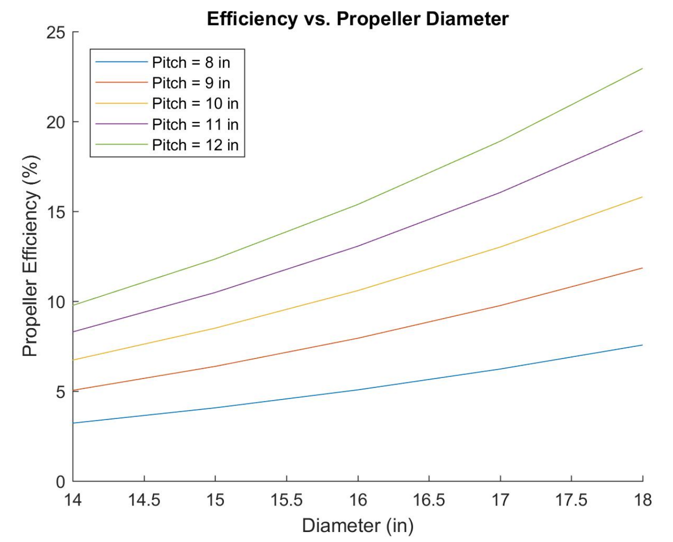
- Tmin = 680.4 g
- Tmax = 850.5 g

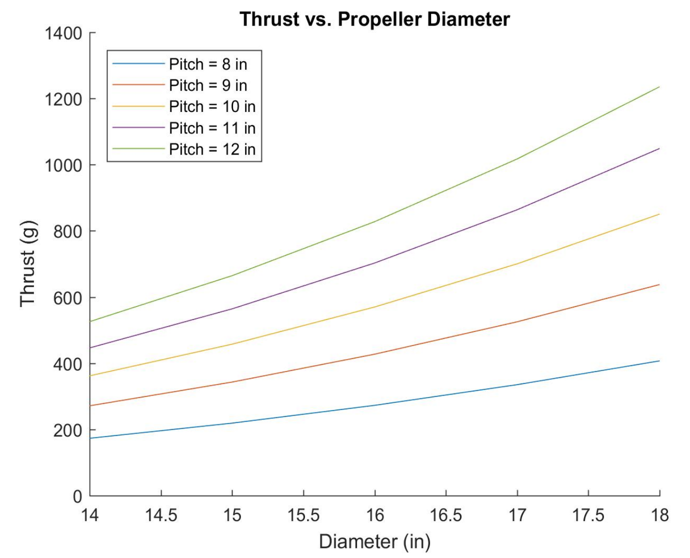




Design Space

Propulsion: Propeller Size





Propulsion: ECalc Outputs - Extra

Motor	**Kv** [RPM/V]	**Propellor** [in]	**Battery** [mAh]	**RPM**	**Avail. Thrust at 11m/s** [g]	**Flight Time at 13m/s** [min]
Hacker A-40 12L	410	15x10	10,000 (4S)	4000	1270 (550)	53.2
Hacker A-40 12L	410	15x10	12,000 (4S)	4000	1270 (550)	63.8
Hacker A-40 12L	410	15x10	14,000 (4S)	4000	1270 (550)	74.5
Hacker A-40 14L	355	14x9	10,000 (4S)	3900	1189 (469)	50.6
Hacker A-40 14L	355	14x9	12,000 (4S)	4000	1189 (469)	60.8
Hacker A-40 14L	355	14x9	14,000 (4S)	4000	1189 (469)	71.0
Hacker A-30 12XL	700	13x8	5x2,500 (4S)	5400	1205 (528)	58.2

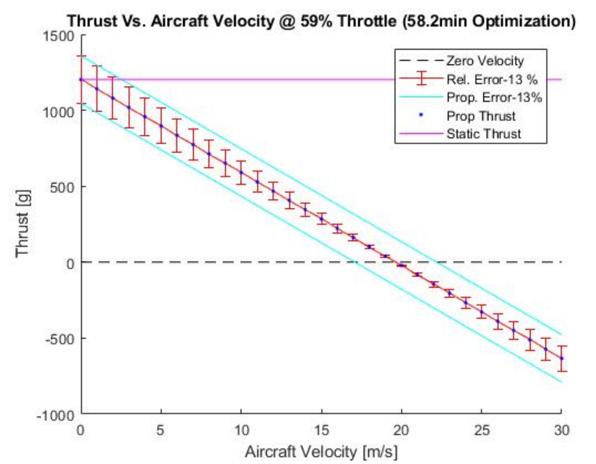
Main Takeaway: Best motors at Kv > 700 and 4S

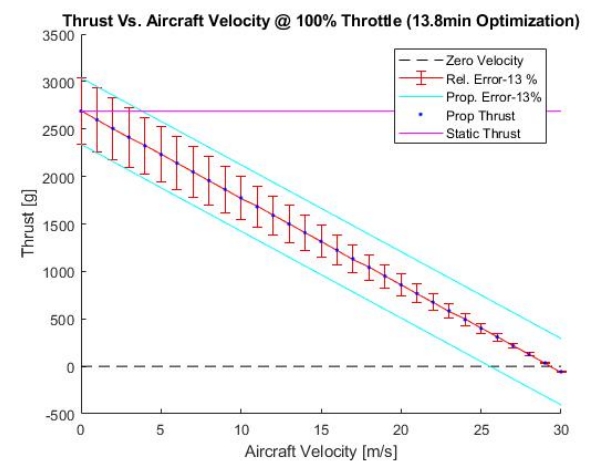
Propulsion: MATLAB Models T vs V

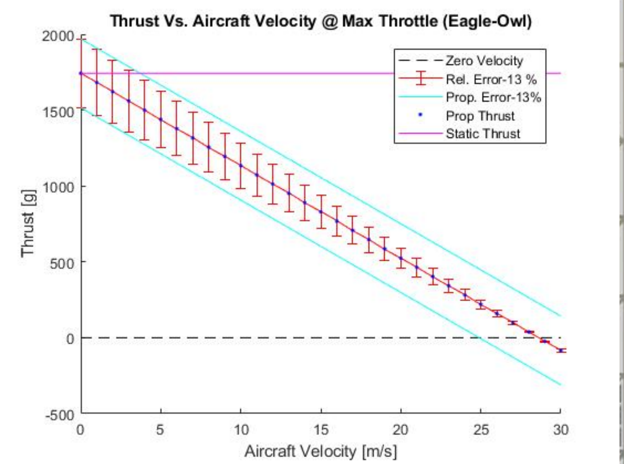
Dynamic and Static Thrust Vs Airspeed

ARES

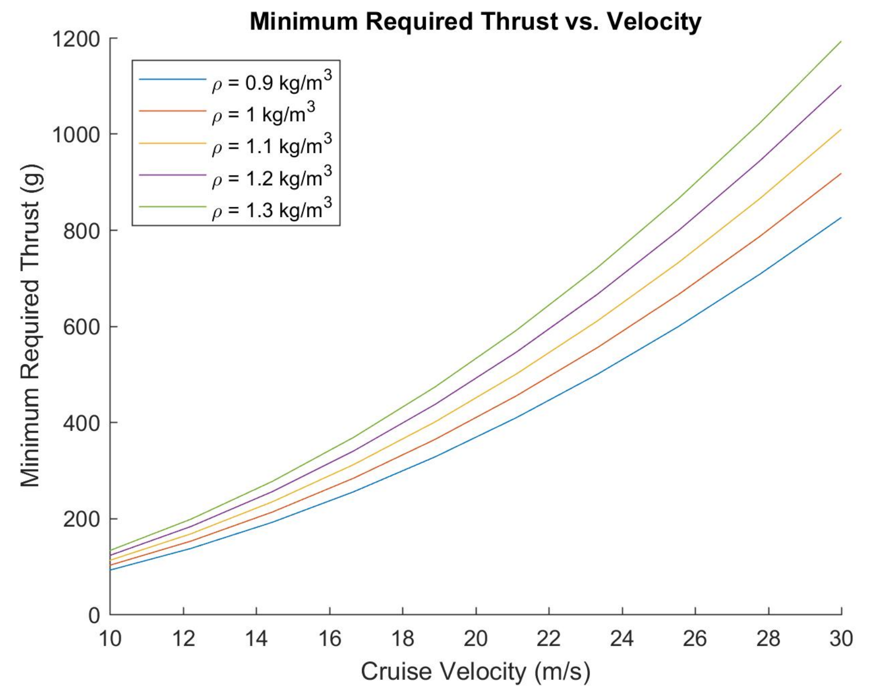
ARES







Propulsion: T vs V - Extra



Propulsion - Power Budgeting

- Using T/W = 0.2-0.25, the following parameters could be determined:
  - Range Minimum max thrust - T_{max}= 0.2*120 oz = 24 oz = 680.4g = 1.5 lbs
  - Range Maximum* max thrust - T_{max}= 0.25*120 oz = 30 oz = 850.5g = 1.88 lbs
  - Maximum P_r > 255 W (Upper weight limit = 8.5 lbs)
    - General rule of thumb is 50 W/lb to fly[1]
    - Weight limit decided as team - governed by wing design

Propulsion

Motor:

- T/W range of 0.20-0.25*
    - Minimum T/W ~ 0.05[1] (want to fly at 4-5 times that)
        - Computed from $(L/D)^{-1}_{max} = (T/W)_{min}$
    - T/W generally determines the performance of the the aircraft
        - Based on CONOPS: need slow maneuvering, efficient design - low T/W
        - Could define range based on heritage (Eagle Owl, Mistral, Twister) and how those craft performed
        - Shimming negates motor torque on airframe
        - Kv (RPM/V) range of 500-1000
            - Low Kv (100 - 500) = high torque, low RPM**
                - Heavy - requires more coils for more torque
            - High Kv (>1500) = low torque, high RPM**
                - Lighter - Doesn't need as many coils
            - Mission calls for lightweight motor with low power consumption

*from RCGroups.com 1 Mistral plane uses this
*from HobbyWarehouse.com

Propulsion: Motor Selection - Extra

1. Characterize your aircraft:
   1. Heavy, slow - Low Kv, big prop
   2. Light, fast - High Kv, small prop
2. Determine $(T/W)_{min}$ based on design $(L/D)_{max}$
3. Determine functional T/W range using:
   1. $(T/W)_{Lower} = 4(T/W)_{min}$
   2. $(T/W)_{Upper} = 5(T/W)_{min}$
4. Decide if we want a fast or a slow plane to choose Kv (RPM/V) Value:
   1. Higher Kv = Low torque, high speed - Lighter loads at higher speeds; smaller props
   2. Lower Kv = High torque, low speed - Heavier loads at slower speed; larger props
5. Use mathematical models with CONOPS/aircraft parameters in mind to identify propeller size range
   1. Matlab function: TvRPMplotter
   2. Verify with resources like eCalc and MotoCalc
6. Find motor current with $I = TV_0/V_{battery}$
   1. Use this to calculate power demand
7. Use current to find speed controller

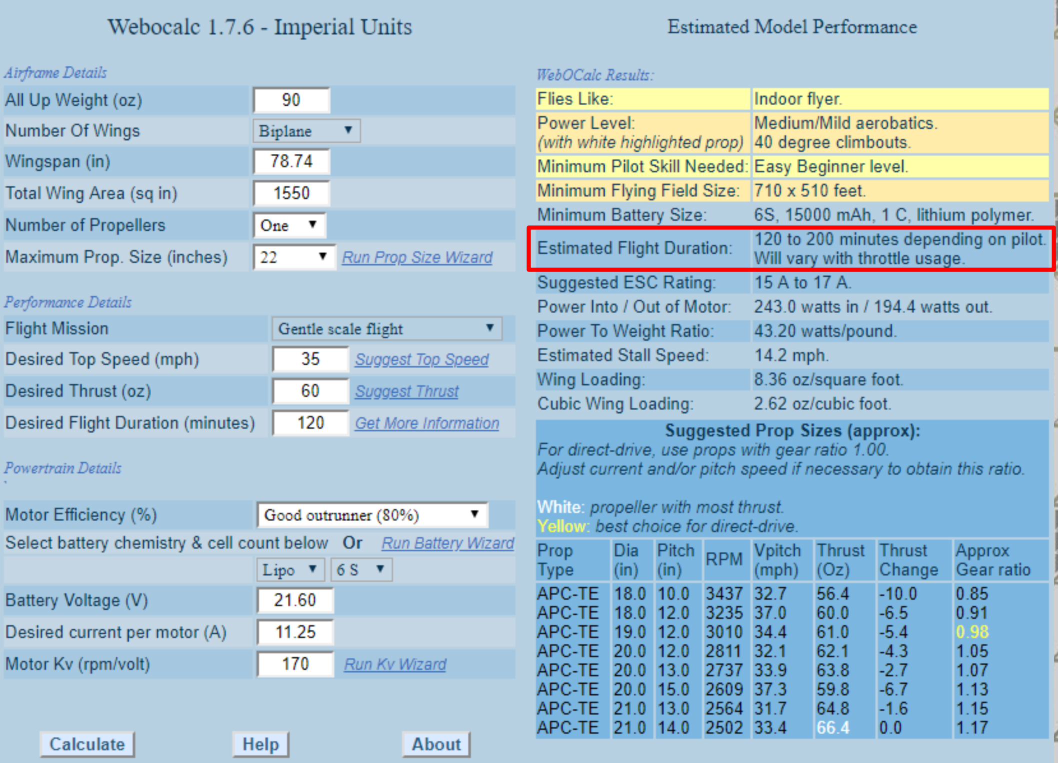
Propulsion - Extra

Trade study of pusher vs puller

Metric Characteristics		Configuration					
		Pusher		Puller/Tractor		Push/Pull	
Metric	Metric Weight	Score	Value	Score	Value	Score	Value
Weight	25%	3.5	0.875	4	1	2.5	0.625
Cost	15%	5	0.75	5	0.75	3	0.45
Prop/Motor Protection	20%	3	0.6	3	0.6	3	0.6
Flight Heritage	15%	5	0.75	1	0.15	1	0.15
Motor Efficiency	25%	3	0.75	5	1.25	1	0.25
TOTAL	**100%**		**3.725**		**3.75**		**2.075**

Propulsion: 2hr Time - Extra

WeboCalc Example



Webocalc 1.7.6 - Imperial Units

Airframe Details

All Up Weight (oz)	90
Number Of Wings	Biplane
Wingspan (in)	78.74
Total Wing Area (sq in)	1550
Number of Propellers	One
Maximum Prop. Size (inches)	22

Performance Details

Flight Mission	Gentle scale flight
Desired Top Speed (mph)	35
Desired Thrust (oz)	60
Desired Flight Duration (minutes)	120

Powertrain Details

Motor Efficiency (%)	Good outrunner (80%)
Select battery chemistry & cell count below Or	
	Lipo 6 S
Battery Voltage (V)	21.60
Desired current per motor (A)	11.25
Motor Kv (rpm/volt)	170

Estimated Model Performance

WebOCalc Results:

Flies Like:	Indoor flyer.
Power Level: *(with white highlighted prop)*	Medium/Mild aerobatics. 40 degree climbouts.
Minimum Pilot Skill Needed:	Easy Beginner level.
Minimum Flying Field Size:	710 x 510 feet.
Minimum Battery Size:	6S, 15000 mAh, 1 C, lithium polymer.
Estimated Flight Duration:	120 to 200 minutes depending on pilot. Will vary with throttle usage.
Suggested ESC Rating:	15 A to 17 A.
Power Into / Out of Motor:	243.0 watts in / 194.4 watts out.
Power To Weight Ratio:	43.20 watts/pound.
Estimated Stall Speed:	14.2 mph.
Wing Loading:	8.36 oz/square foot.
Cubic Wing Loading:	2.62 oz/cubic foot.

Suggested Prop Sizes (approx):

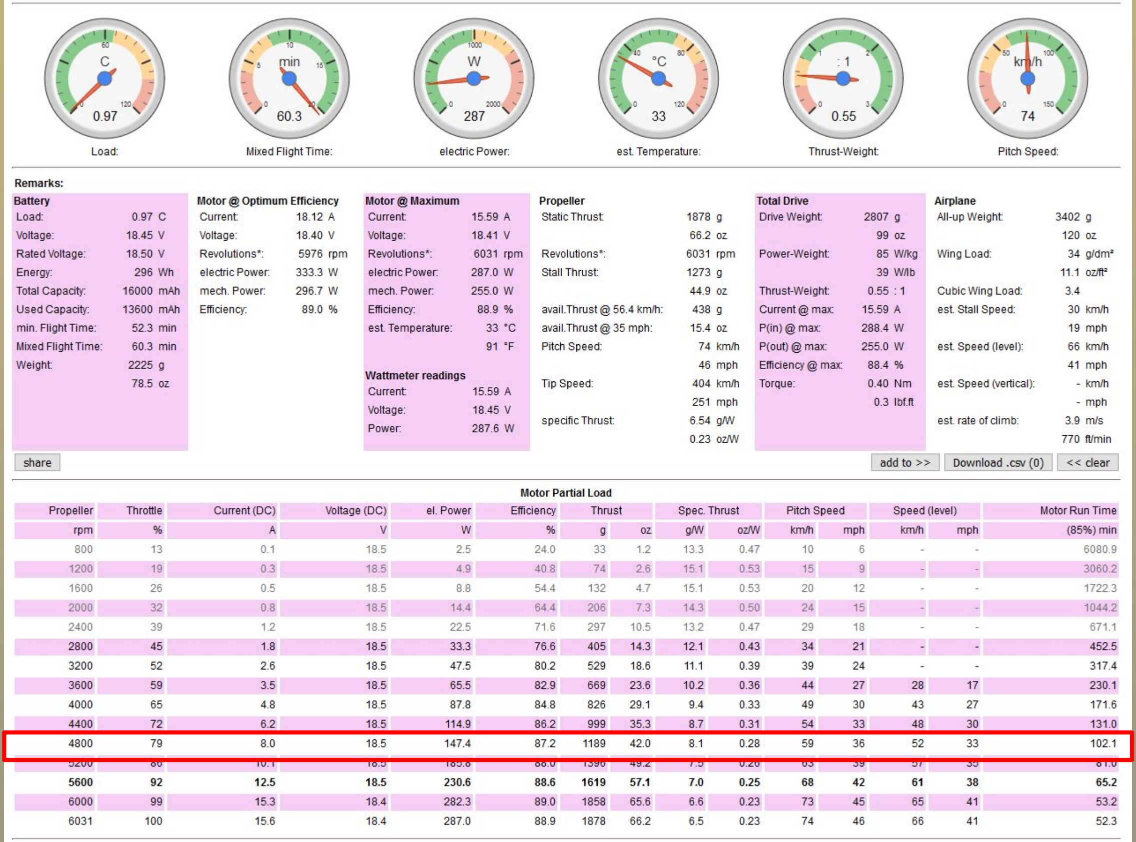
For direct-drive, use props with gear ratio 1.00.
Adjust current and/or pitch speed if necessary to obtain this ratio.

White: *propeller with most thrust.*
Yellow: *best choice for direct-drive.*

Prop Type	Dia (in)	Pitch (in)	RPM	Vpitch (mph)	Thrust (Oz)	Thrust Change	Approx Gear ratio
APC-TE	18.0	10.0	3437	32.7	56.4	-10.0	0.85
APC-TE	18.0	12.0	3235	37.0	60.0	-6.5	0.91
APC-TE	19.0	12.0	3010	34.4	61.0	-5.4	0.98
APC-TE	20.0	12.0	2811	32.1	62.1	-4.3	1.05
APC-TE	20.0	13.0	2737	33.9	63.8	-2.7	1.07
APC-TE	20.0	15.0	2609	37.3	59.8	-6.7	1.13
APC-TE	21.0	13.0	2564	31.7	64.8	-1.6	1.15
APC-TE	21.0	14.0	2502	33.4	66.4	0.0	1.17

Propulsion: ECalc Results - Extra

Sample Ecalc Output



Remarks:

Battery		
Load:	0.97	C
Voltage:	18.45	V
Rated Voltage:	18.50	V
Energy:	296	Wh
Total Capacity:	16000	mAh
Used Capacity:	13600	mAh
min. Flight Time:	52.3	min
Mixed Flight Time:	60.3	min
Weight:	2225	g
	78.5	oz

Motor @ Optimum Efficiency		
Current:	18.12	A
Voltage:	18.40	V
Revolutions*:	5976	rpm
electric Power:	333.3	W
mech. Power:	296.7	W
Efficiency:	89.0	%

Motor @ Maximum		
Current:	15.59	A
Voltage:	18.41	V
Revolutions*:	6031	rpm
electric Power:	287.0	W
mech. Power:	255.0	W
Efficiency:	88.9	%
est. Temperature:	33	°C
	91	°F

Wattmeter readings		
Current:	15.59	A
Voltage:	18.45	V
Power:	287.6	W

Propeller		
Static Thrust:	1878	g
	66.2	oz
Revolutions*:	6031	rpm
Stall Thrust:	1273	g
	44.9	oz
avail.Thrust @ 56.4 km/h:	438	g
avail.Thrust @ 35 mph:	15.4	oz
Pitch Speed:	74	km/h
	46	mph
Tip Speed:	404	km/h
	251	mph
specific Thrust:	6.54	g/W
	0.23	oz/W

Total Drive		
Drive Weight:	2807	g
	99	oz
Power-Weight:	85	W/kg
	39	W/lb
Thrust-Weight:	0.55	: 1
Current @ max:	15.59	A
P(in) @ max:	288.4	W
P(out) @ max:	255.0	W
Efficiency @ max:	88.4	%
Torque:	0.40	Nm
	0.3	lbf.ft

Airplane		
All-up Weight:	3402	g
	120	oz
Wing Load:	34	g/dm²
	11.1	oz/ft²
Cubic Wing Load:	3.4	
est. Stall Speed:	30	km/h
	19	mph
est. Speed (level):	66	km/h
	41	mph
est. Speed (vertical):	-	km/h
	-	mph
est. rate of climb:	3.9	m/s
	770	ft/min

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
800	13	0.1	18.5	2.5	24.0	33	1.2	13.3	0.47	10	6	-	-	6080.9
1200	19	0.3	18.5	4.9	40.8	74	2.6	15.1	0.53	15	9	-	-	3060.2
1600	26	0.5	18.5	8.8	54.4	132	4.7	15.1	0.53	20	12	-	-	1722.3
2000	32	0.8	18.5	14.4	64.4	206	7.3	14.3	0.50	24	15	-	-	1044.2
2400	39	1.2	18.5	22.5	71.6	297	10.5	13.2	0.47	29	18	-	-	671.1
2800	45	1.8	18.5	33.3	76.6	405	14.3	12.1	0.43	34	21	-	-	452.5
3200	52	2.6	18.5	47.5	80.2	529	18.6	11.1	0.39	39	24	-	-	317.4
3600	59	3.5	18.5	65.5	82.9	669	23.6	10.2	0.36	44	27	28	17	230.1
4000	65	4.8	18.5	87.8	84.8	826	29.1	9.4	0.33	49	30	43	27	171.6
4400	72	6.2	18.5	114.9	86.2	999	35.3	8.7	0.31	54	33	48	30	131.0
4800	79	8.0	18.5	147.4	87.2	1189	42.0	8.1	0.28	59	36	52	33	102.1
5200	86	10.1	18.5	185.8	88.0	1396	49.2	7.5	0.26	63	39	57	35	81.0
5600	**92**	**12.5**	**18.5**	**230.6**	**88.6**	**1619**	**57.1**	**7.0**	**0.25**	**68**	**42**	**61**	**38**	**65.2**
6000	99	15.3	18.4	282.3	89.0	1858	65.6	6.6	0.23	73	45	65	41	53.2
6031	100	15.6	18.4	287.0	88.9	1878	66.2	6.5	0.23	74	46	66	41	52.3

Propulsion: Calculations - Extra

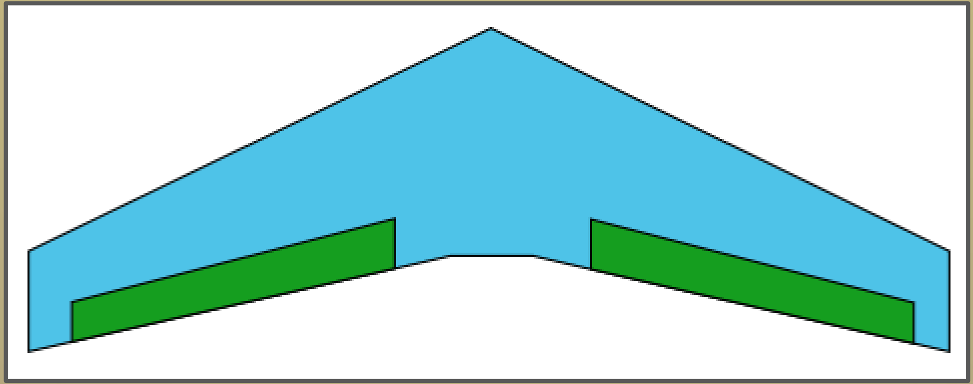
$P_r = W(T/W)(0.00017Kv+0.09)$

$T_{min,steady} = 0.5\rho V^2 C_d S = W/(L/D)_{max}$

- For required thrust, $C_d = 0.02$ from wing design data

Autopilot
Backup Slides

Control Surfaces



- Aircraft will use elevons as control surfaces
- Flight heritage and resources on controlling flying wings with elevons
- Elevons on the top wing (farther from c.g.) = larger moment.
- Control surfaces moved physically using servo (same as Eagle Owl and SCUA)
- Most flying wings are swept for yaw stiffness
  - if additional stability is necessary, static or controlled split rudders can be installed on the sides.

Autopilot

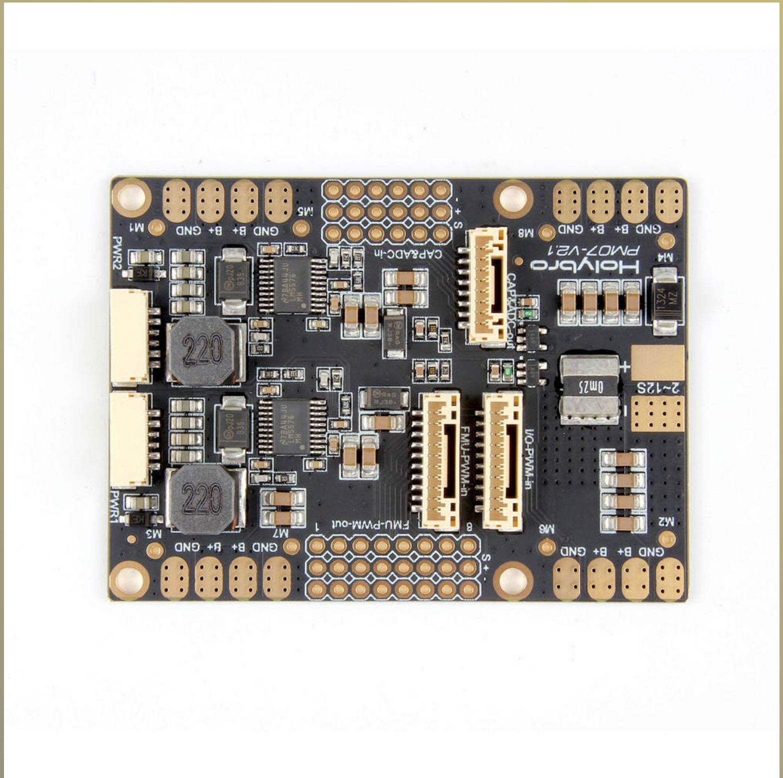
FR 4.0: The aircraft shall be piloted by an autopilot during the steady flight regime of the mission

- Flight Heritage
- Open-source software with custom airframe support
- Power
  - Accepts 4.9-5.5 V input power
  - Servo rail input: 0-36 V
  - Power management board included
  - Need 5V BEC (6.2 g) to power servos
- Weight: 15.8 g
- Size: 44x84x12 mm

Autopilot

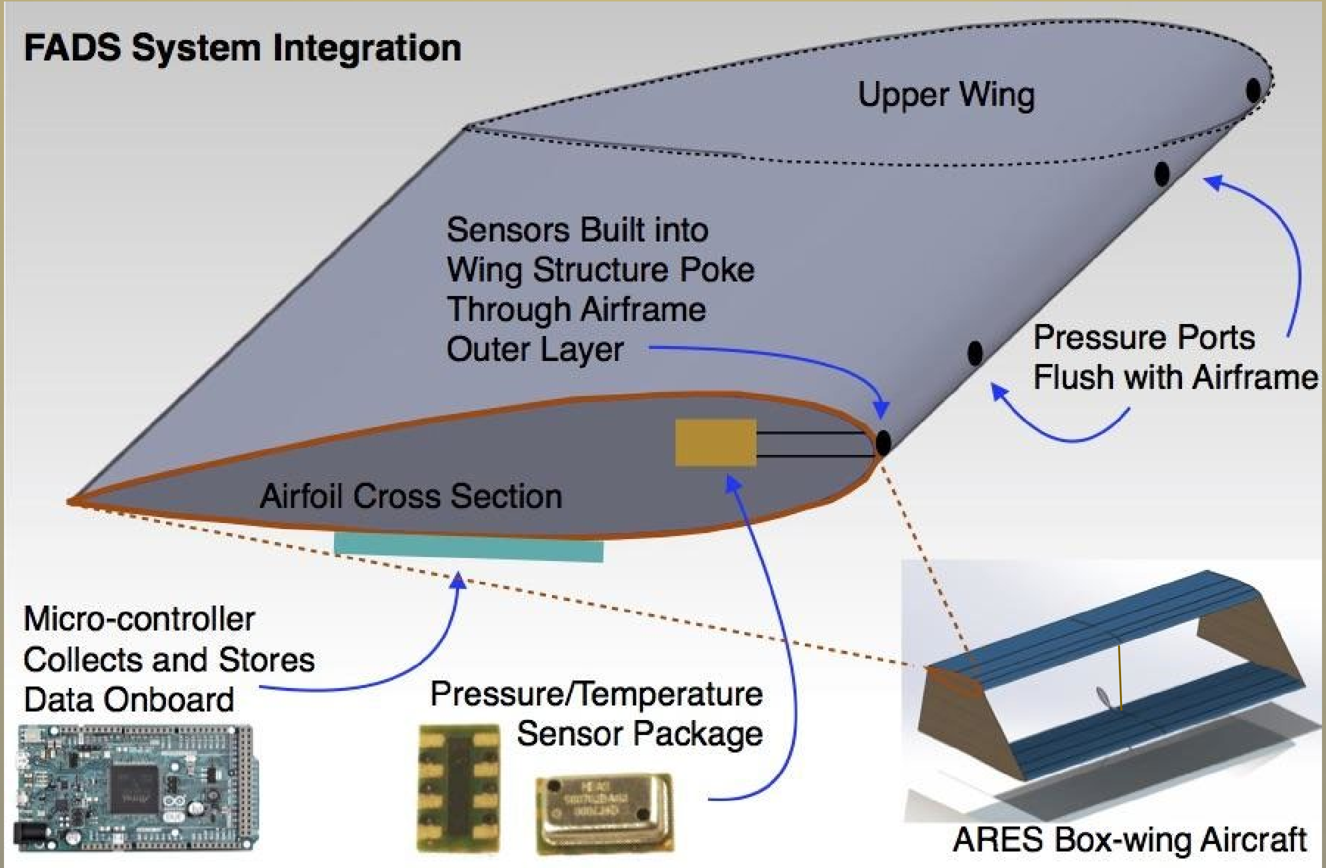
- Built-in Sensors
  - Accelerometers/Gyros (ICM-20689 & BMI055)
  - Magnetometers (IST8310)
  - Barometer (MS5611)
  - GPS (ublox Neo-M8N)
- External Sensor
  - Airspeed sensor to detect stall
- Speed controller between Pixhawk and propeller motor
- Handles RC input with external receiver
- Downlinks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

Autopilot: Pixhawk Connections



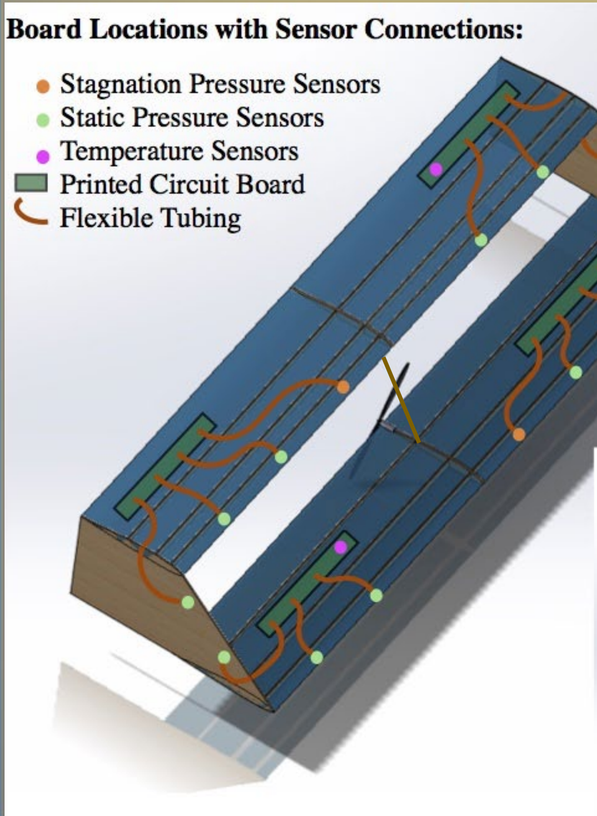
Science
Backup Slides

Science Baseline Design

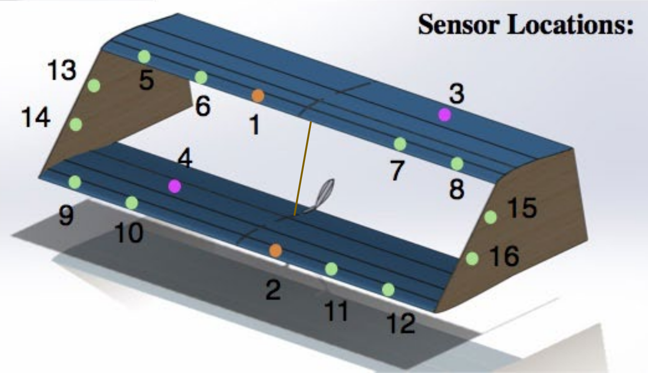


Science: Sensor Locations

- Located on the leading edge of the wings and sidewalls
- Embedded in the structure so that the sensor is flush with the airframe
- Ideally where pressure changes the most
- 2 stagnation ports at center and 14 static ports along wings

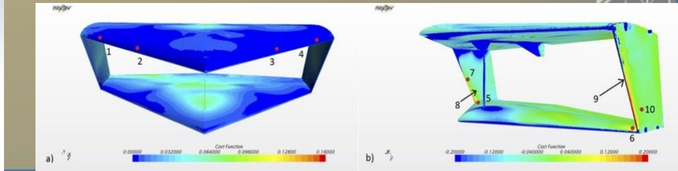


Board Locations with Sensor Connections:



Sensor Locations:

Optimal Locations from Wind Tunnel Testing the Eagle Owl



Science: Calibration - Extra

Calibration Techniques for Finding “True” Values:

- Multi-hole Probe
    - Compare calculated angle of attack and sideslip with multi-hole probe measured angle of attack and sideslip.
    - Cons: $12,000 piece of equipment, extremely breakable
- Pitot Probe
    - Compare FADS measured pressure with pitot probe measured pressure.
    - Cons: can only compare pressures, extremely breakable
- Computational Fluid Dynamics Analysis
    - Set angle of attack and sideslip in simulation in order to calculate an expected pressure that FADS system should see. Compare to measured results.
    - Cons: need accurate model of pressure sensor locations

Science: Microcontroller

- Design specifications:
  - Memory: 1.5 Mb (factor of safety of 2)
  - Pins: 16 digital I/O pins
    - 16 pressure/temperature transducers
  - Input voltage: 7.4 V
    - 2S LiPo battery for power
  - Processing speed:
    - 48 Kb a second is not a concern
- Feasibility
  - A microcontroller following specifications can be purchased online
  - Mass and power does not exceed expectations
  - Memory can be achieved through MicroSD shield
  - Integration is shown in the power system section

Science: Microcontroller Calculations

- Storage
    - Pressure and temperature bits (48) * 16 sensors *3600 s * 2 hrs / 8 bits per byte
- Pins
    - 16 pins are required as 16 pressure/temperature sensors will be used on the aircraft. Pressure and temperature are given as 24 bit digital.
- Voltage
    - Defined by the power management board of the Pixhawk 4
- Processing Speed: ????

Science - Manufacturing

From CU FADS expert, Roger Laurence on his dissertation work with the Skywalker.

Holes can be drilled in wing material to ensure tubing is flush with leading edge

Paths can be carved in wing material to fit flexible tubing

Science: Logistics

Component	**Cost ($)**	**Mass (g)**	**Power (Wh)**
Sensor Boards	300	20	.0042
Microcontroller	20-50	10-50	0.15 - 0.35
Housing (tube, acrylic, brass)	40	20	0

Scheduling: All parts can be ordered online with normal shipping times. The manufacturing is expected to take 1 week once the aircraft structure is complete. The calibration simulation is expected to take 2 weeks and can begin as soon as an accurate CAD model of the aircraft exists. Calibration testing and comparison is expected to take 1 week once the FADS is integrated.

Landing
Backup Slides

Landing Feasibility: Sliding

$$x = -.1 * sin(\alpha) + .22 * cos(\alpha)$$

$$y = .22 * sin(\alpha) + .1 * cos(\alpha)$$

$$0 \leq \sum M_{cg} = x * N - y * \mu * N$$

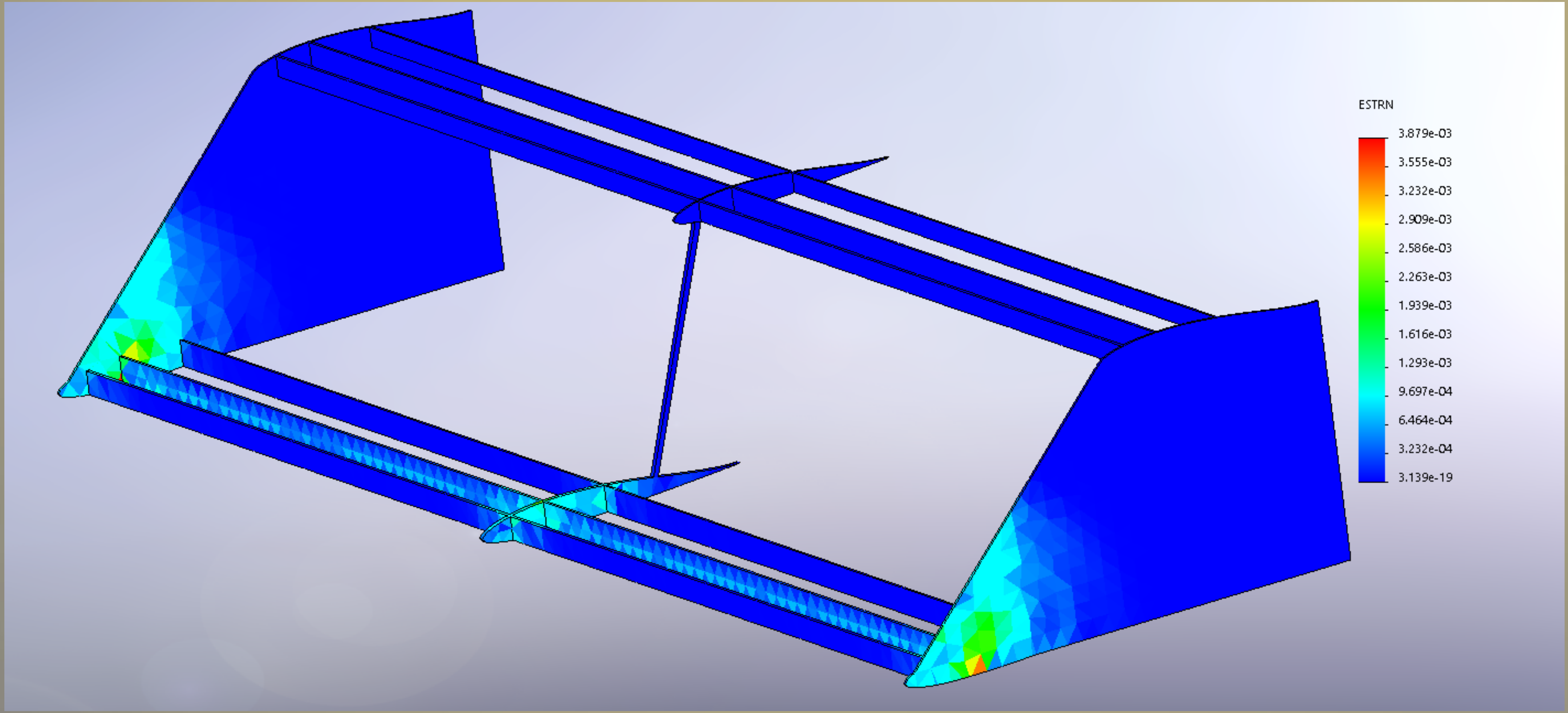
$$0 \leq N * ((.22 * cos(\alpha) - .1 * sin(\alpha)) - \mu * (.22 * sin(\alpha) + .1 * cos(\alpha)))$$

$$0 \leq cos(\alpha) * (.22 - .1 * \mu) + sin(\alpha) * (-.1 - \mu * .22)$$

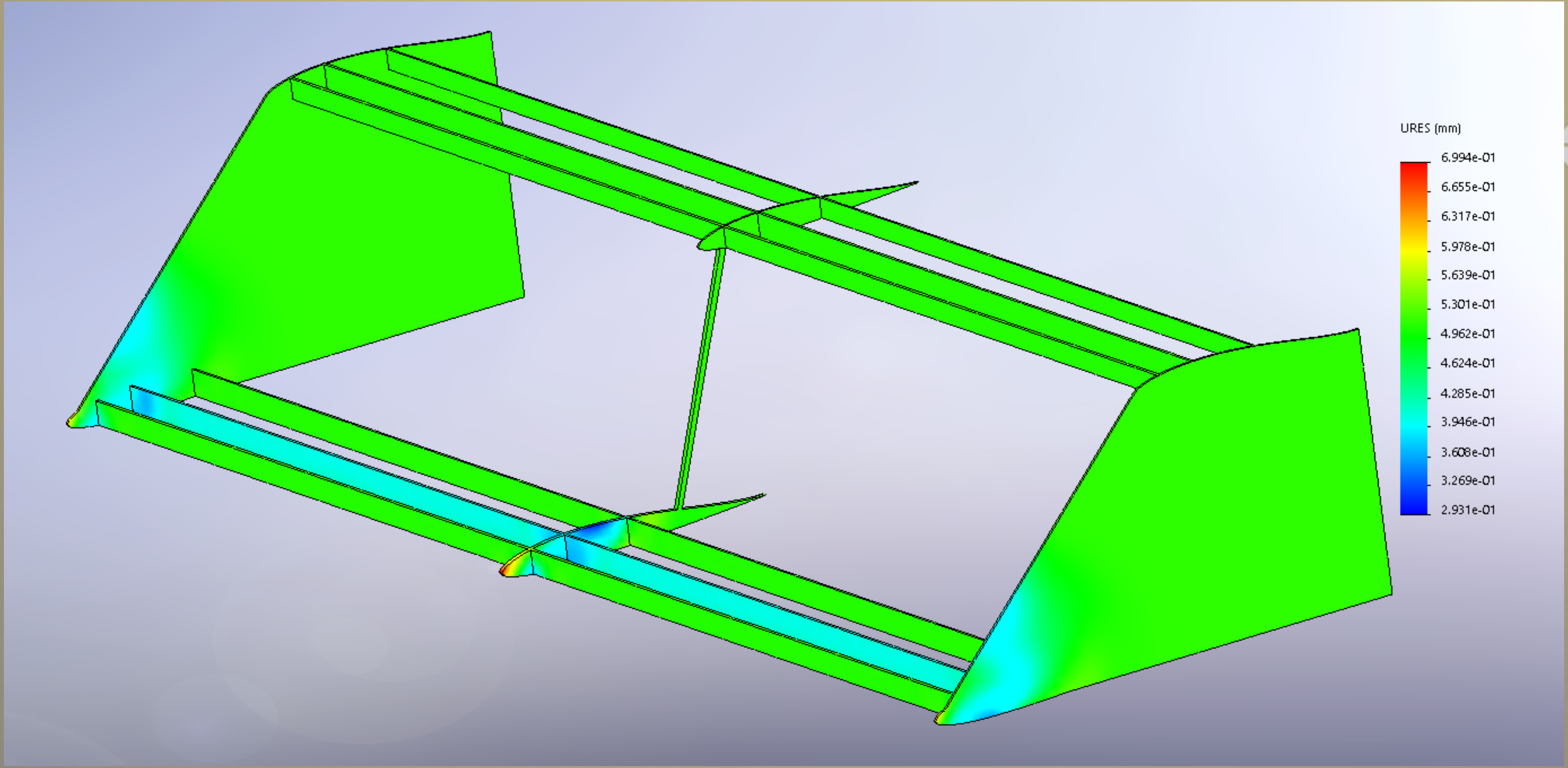
$$sin(\alpha) * (.1 + \mu * .22) \leq cos(\alpha) * (.22 - .1 * \mu)$$

$$tan(\alpha) \leq \frac{.22 - .1 * \mu}{.1 + \mu * .22}$$

Landing Extra: Strain



Landing Extra: Displacement



Landing Extra: Displacement

Power
Backup Slides

Propulsion: power budgeting calc.

$$\overset{\text{Endurance}}{E} = R\underset{\text{Time for capacity}}{t}^{1-n}\left[\frac{\overset{\text{Total efficiency}}{\mu_{tot}}\overset{\text{Voltage}}{V}\overset{\text{Capacity}}{C}}{\frac{1}{2}\underset{\text{Air density}}{\rho}\underset{\text{Flight velocity}}{U}^{3}S\underset{\text{Minimum Cl/Cd}}{C_{D0}} + \frac{2\overset{\text{Weight}}{W}^{2}k}{\rho U\underset{\text{Wing area}}{S}}}\right]^{n}$$

Propulsion: Power calculations cont.

E: Dependent variable

U: Independent variable

S: 1.333 m^2
(function of C)

Rho: 1.056 kg/m^3

Voltage: 11.1-14.8 V

Capacity: Independent variable

Rt = 1 hour

muTot = 0.5

Weight: 1.6 + battery

CD0 = 0.015

n = 1.3 (for LiPo batteries)

k = .13 (experimental)

Power: Battery Types Trade Study

- Common RC batteries: Lithium Polymer (LiPo), Nickel Cadmium (NiCad), Nickel Metal Hydride (NiMH).

Battery	**LiPo**	**NiCad**	**NiMH**
Pros	● High discharge rate ● Highest power to weight ratio ● Highest capacity	● Low self-discharge ● Low internal resistance (high current)	● No voltage depression effect ● Long lifespan (1000 cycles)
Cons	● Short lifespan (150-250 cycles) ● Fire risk	● Heavy and bulky ● Voltage depression effects	● Lower average capacity ● Heavier than LiPo

Power: Subsystem Battery Trade

Propulsion power	**Seperate batteries**	**Single battery**
Pros	- Redundancy as systems are separated - No conditioning is necessary - Lighter than single battery	- None
Cons	- Weight distribution complications	- Voltage must be conditioned for the Science subsystem - Heavier due to additional capacity needed for single battery at higher voltage

- Should the aircraft’s flight battery/batteries also be used to power the science subsystem

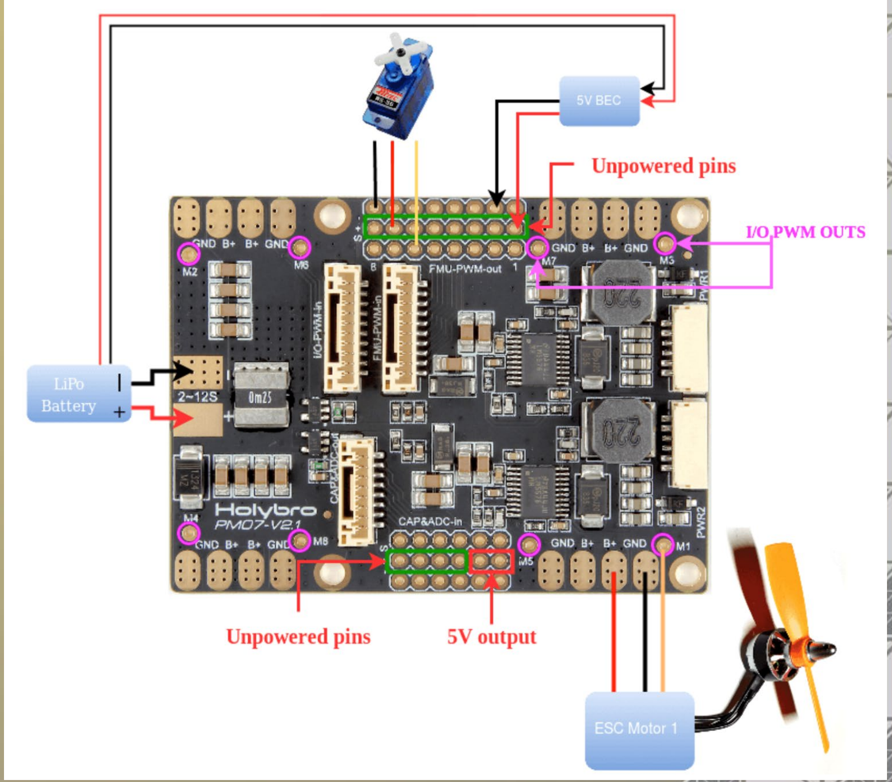
Power: Parallel vs. Single Trade Study

Propulsion power	Multiple batteries in parallel	Single battery
Pros	● Distribution of loading along the wing ● Significant flight heritage	● Low integration complexity
Cons	● Risky and more complex to integrate batteries in parallel	● Challenging to find really high capacity LiPo batteries ● Increased wing loading near battery

- Similar weight and cost between the two options

Power: Conditioning

- Pixhawk power conditioning board takes in a 2-12s battery
- Creates 2 5V outputs for the autopilot power ports
- A 5V BEC will power the servos
- An electronic speed controller will connect to the board and to the motor from the board



Preliminary Testing Plan

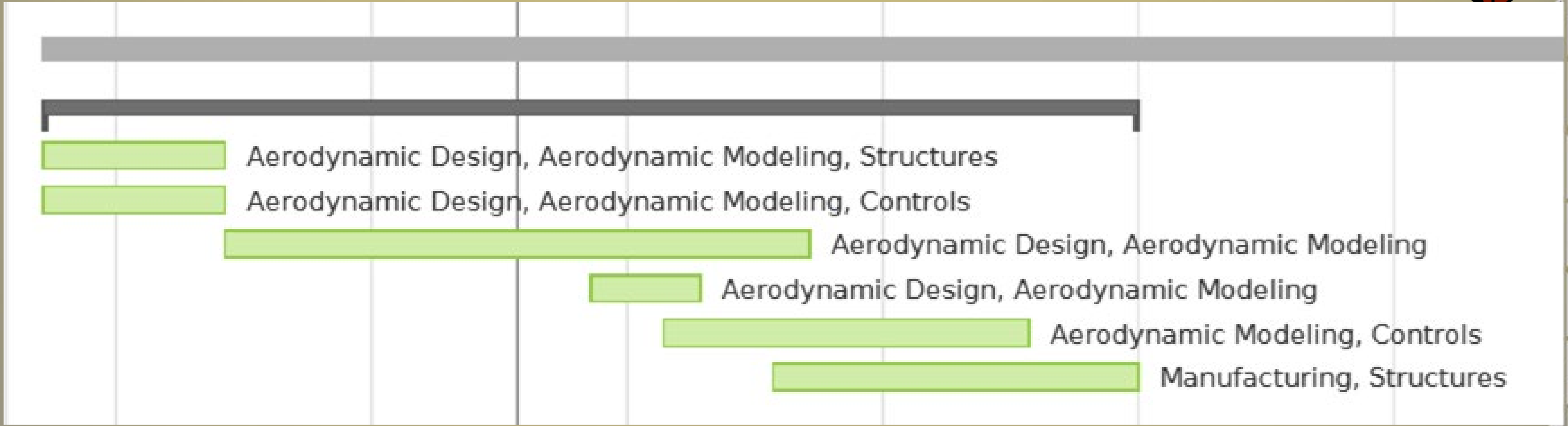
- Plans for testing/verifying difficult requirements
  - FADs - Cold Temperature Plugged Tube Testing
  - Takeoff - Launch a Simulated Mass to Calculate Rail Exit Velocity
  - Landing - Simulate an Expected Force on the Body
  - Propulsion - Static and Dynamic Propulsion Thrust Testing (wind tunnel)
  - Battery - Full System Power Draw Testing (Battery Life Testing)
- Pilot training plan (potential for outside pilot options)
- 2 Battery Flight Testing
  - Two different testing scenarios
    - First Set of Batteries is for running all Avionic and Propulsions Sub-systems for some flight time
    - Second Set of Batteries is for only running Propulsions system for 2+ hours
      - Dynamic testing - Wind tunnel experimentation

Critical Project Elements and Solutions

Critical Project Elements	**Description**	**Solutions**
Surviving Impacts	Landings that do not break the aircraft or propeller	Utilize a foldable propeller system
Endurance	2 hour flight endurance	Descoped to 1 hour and use 3S batteries in parallel with a strong motor used at low power
Reusability	Ability to take-off and land 10+ times	Utilize materials such as EPP foam and carbon fiber honeycomb
Power	Weight of the battery for the propulsion system	Using 3-4 3S batteries for propulsion and a separate power system for FADS

Scheduling
Backup Slides

Schedule Close View

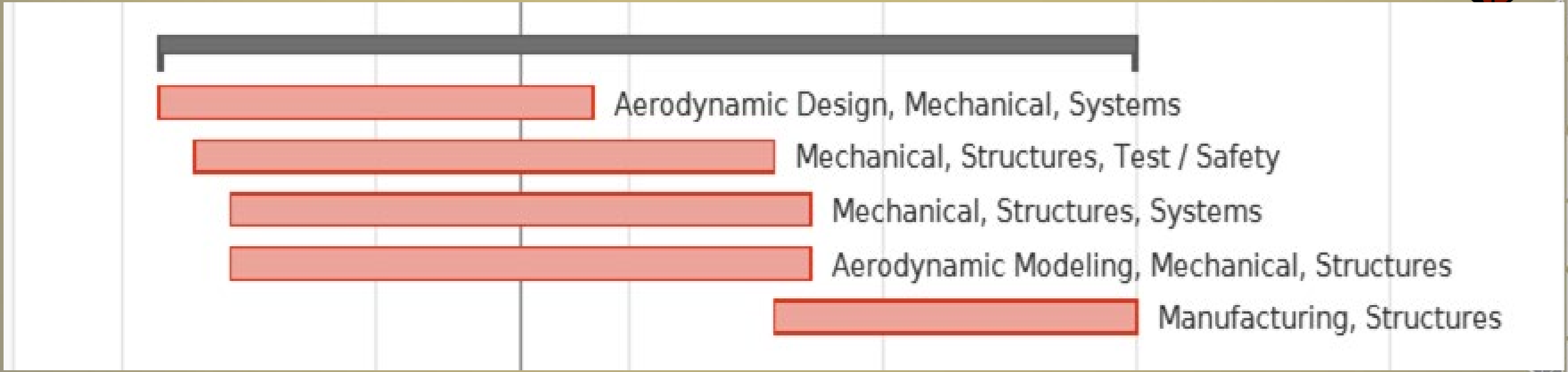


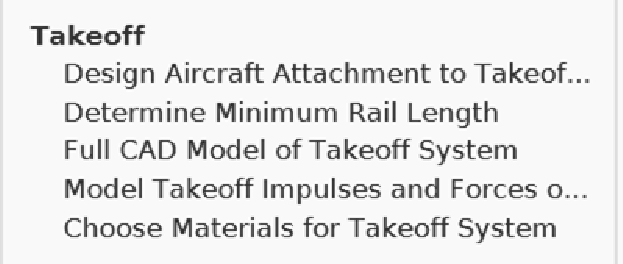
ARES CDR Schedule

Wing Design

- Create Model with Full Dimensions
- Choose Airfoil for Wings
- Create CAD Model
- Integrate Takeoff System
- Calculate Stability Coefficients & Flig...
- Choose Construction Materials

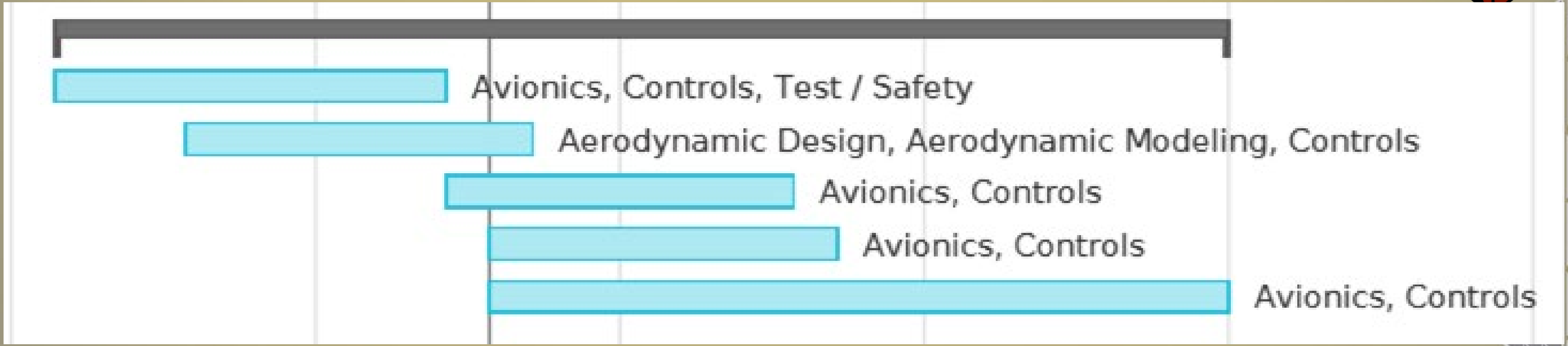
Schedule Close View

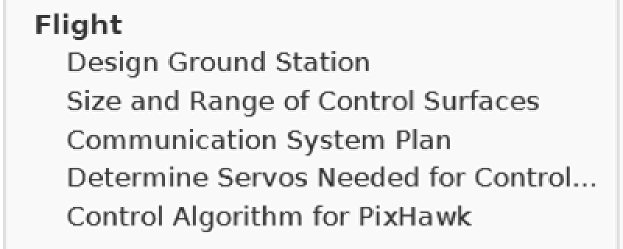



Takeoff

- Design Aircraft Attachment to Takeof...
- Determine Minimum Rail Length
- Full CAD Model of Takeoff System
- Model Takeoff Impulses and Forces o...
- Choose Materials for Takeoff System

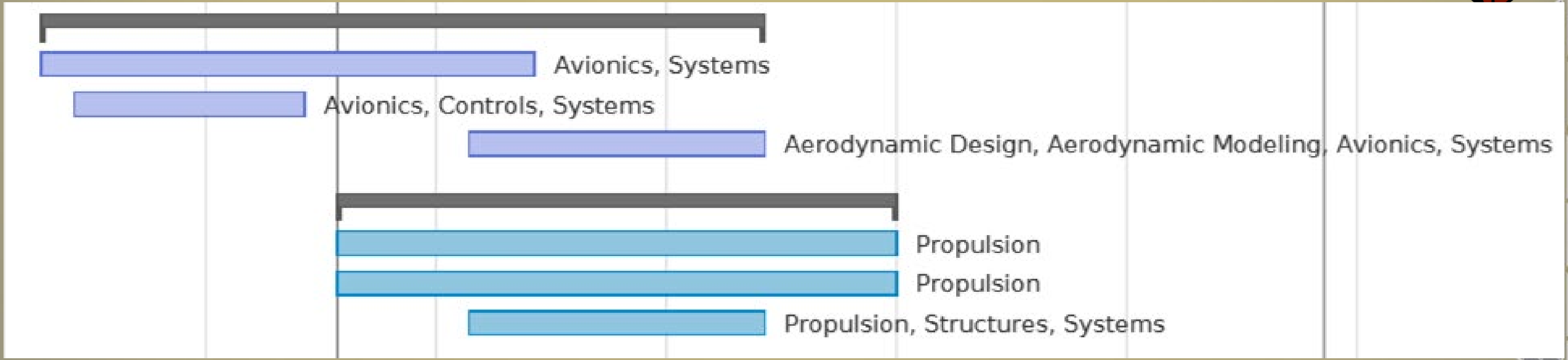
Schedule Close View




Flight

- Design Ground Station
- Size and Range of Control Surfaces
- Communication System Plan
- Determine Servos Needed for Control...
- Control Algorithm for PixHawk

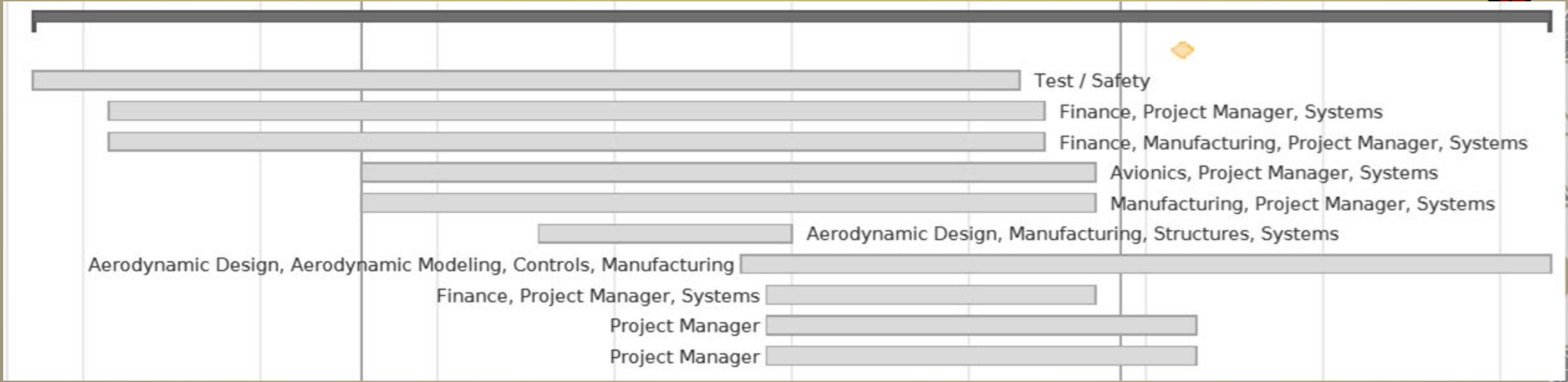
Schedule Close View

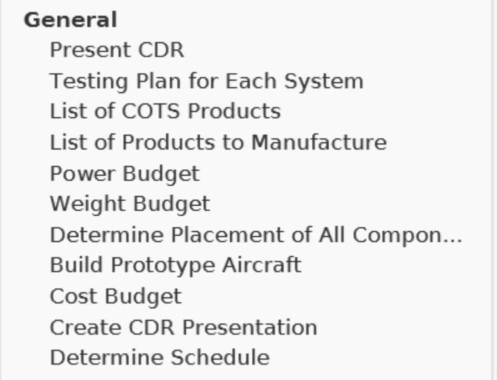


Science
- Design FADS Pressure Collection
- Design FADS Integration to Wing
- Calibration Plan for FADS Data

Propulsion
- Select Motor
- Select Propeller
- Determine Mounting Plan

Schedule Close View

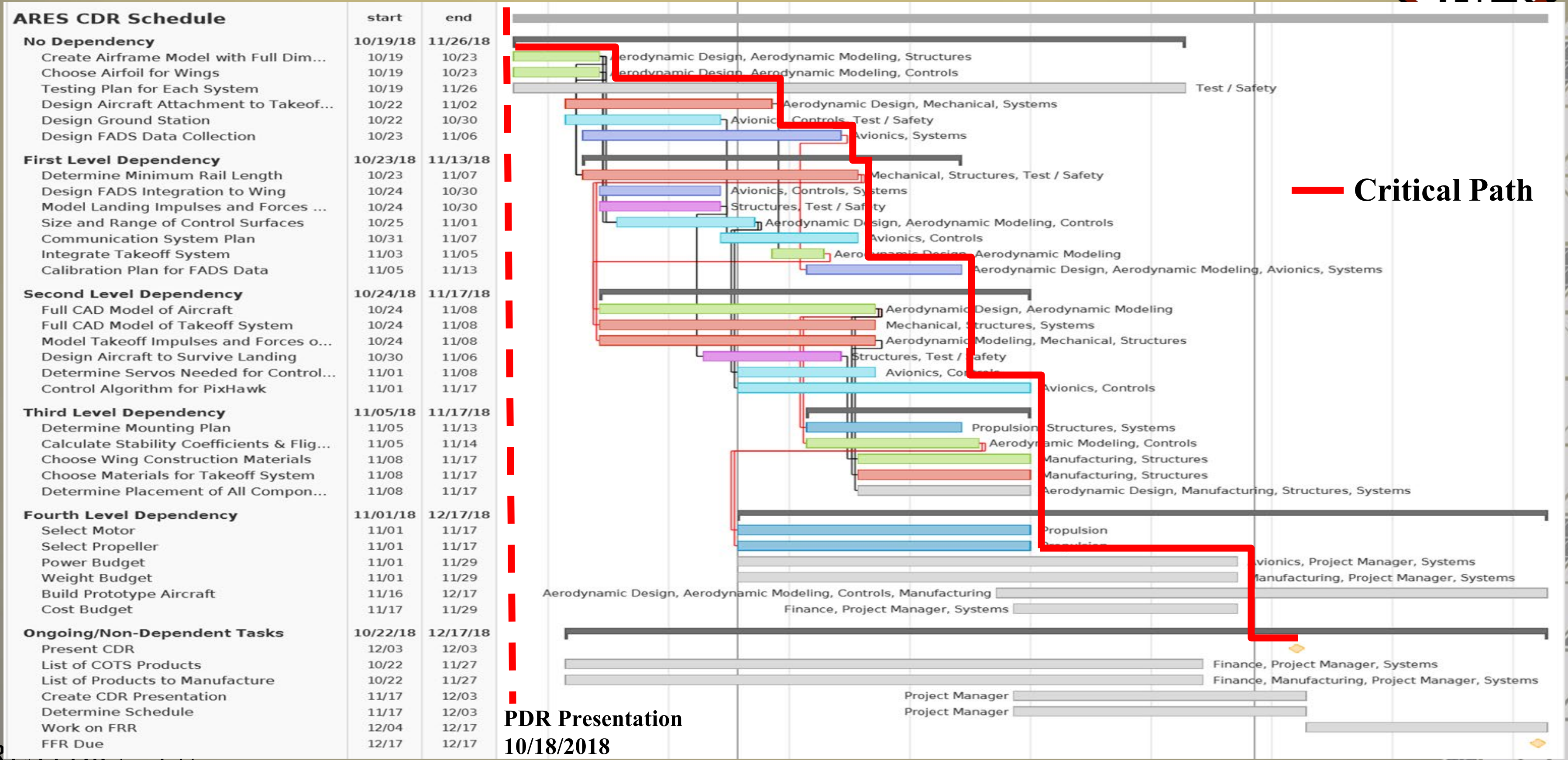




General

- Present CDR
- Testing Plan for Each System
- List of COTS Products
- List of Products to Manufacture
- Power Budget
- Weight Budget
- Determine Placement of All Compon...
- Build Prototype Aircraft
- Cost Budget
- Create CDR Presentation
- Determine Schedule

Schedule Dependency Organization



ARES CDR Schedule

	start	end
No Dependency	**10/19/18**	**11/26/18**
Create Airframe Model with Full Dim…	10/19	10/23
Choose Airfoil for Wings	10/19	10/23
Testing Plan for Each System	10/19	11/26
Design Aircraft Attachment to Takeof…	10/22	11/02
Design Ground Station	10/22	10/30
Design FADS Data Collection	10/23	11/06
First Level Dependency	**10/23/18**	**11/13/18**
Determine Minimum Rail Length	10/23	11/07
Design FADS Integration to Wing	10/24	10/30
Model Landing Impulses and Forces …	10/24	10/30
Size and Range of Control Surfaces	10/25	11/01
Communication System Plan	10/31	11/07
Integrate Takeoff System	11/03	11/05
Calibration Plan for FADS Data	11/05	11/13
Second Level Dependency	**10/24/18**	**11/17/18**
Full CAD Model of Aircraft	10/24	11/08
Full CAD Model of Takeoff System	10/24	11/08
Model Takeoff Impulses and Forces o…	10/24	11/08
Design Aircraft to Survive Landing	10/30	11/06
Determine Servos Needed for Control…	11/01	11/08
Control Algorithm for PixHawk	11/01	11/17
Third Level Dependency	**11/05/18**	**11/17/18**
Determine Mounting Plan	11/05	11/13
Calculate Stability Coefficients & Flig…	11/05	11/14
Choose Wing Construction Materials	11/08	11/17
Choose Materials for Takeoff System	11/08	11/17
Determine Placement of All Compon…	11/08	11/17
Fourth Level Dependency	**11/01/18**	**12/17/18**
Select Motor	11/01	11/17
Select Propeller	11/01	11/17
Power Budget	11/01	11/29
Weight Budget	11/01	11/29
Build Prototype Aircraft	11/16	12/17
Cost Budget	11/17	11/29
Ongoing/Non-Dependent Tasks	**10/22/18**	**12/17/18**
Present CDR	12/03	12/03
List of COTS Products	10/22	11/27
List of Products to Manufacture	10/22	11/27
Create CDR Presentation	11/17	12/03
Determine Schedule	11/17	12/03
Work on FRR	12/04	12/17
FFR Due	12/17	12/17

Critical Path

PDR Presentation
10/18/2018