ASPECT-RATIO REDESIGN OF EAGLE OWL FOR STORMCHASING

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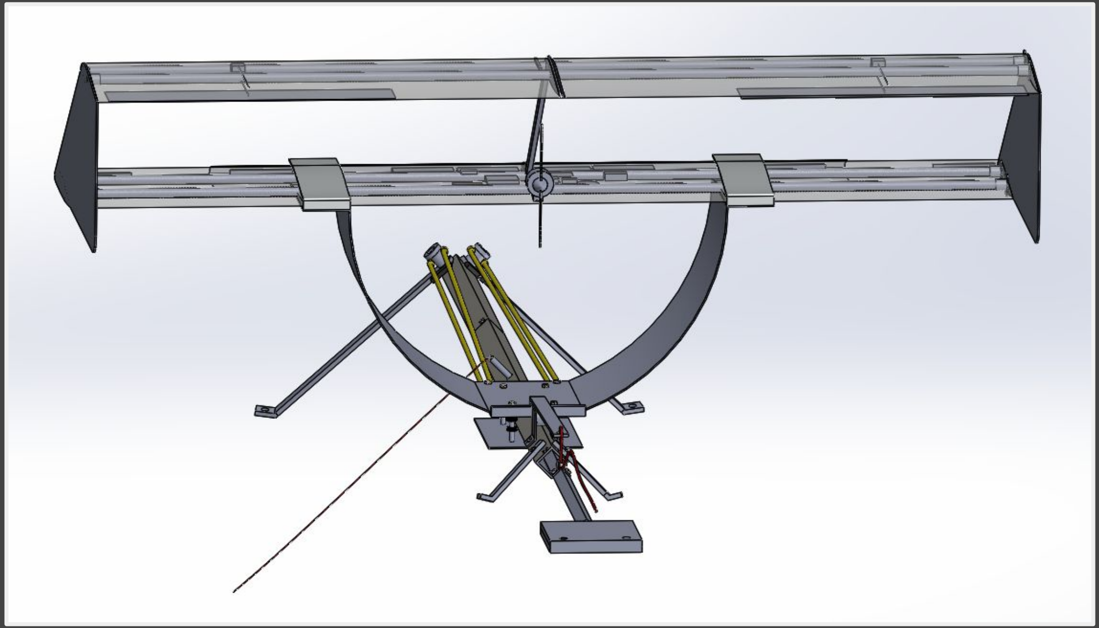
AGENDA

- Project Overview
- Scheduling
  - Test Overview
- Airframe Testing Status
- Avionics Testing Status
- Takeoff Testing Status
- Project Budget
- Backup Slides



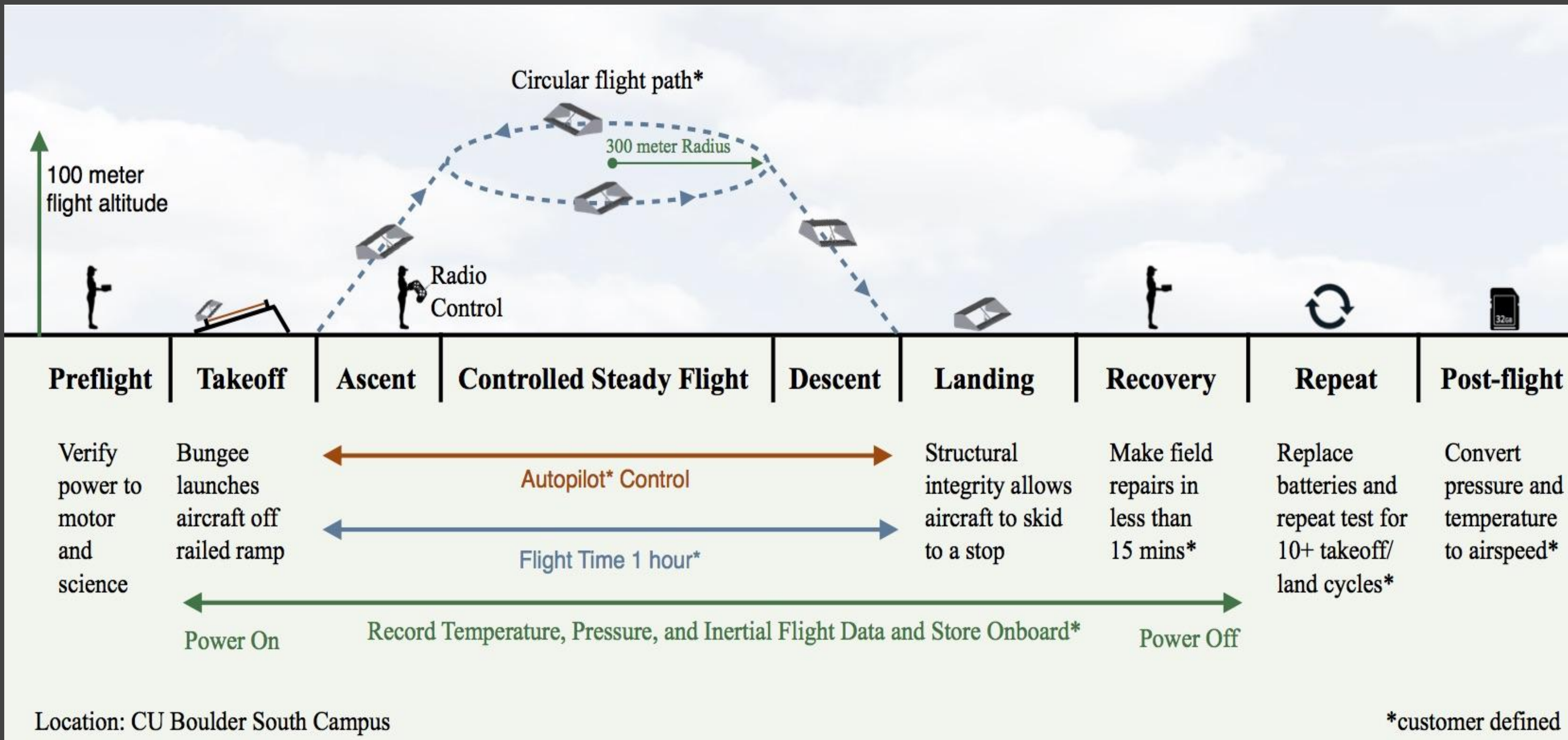
PROJECT OVERVIEW

PROJECT OBJECTIVES

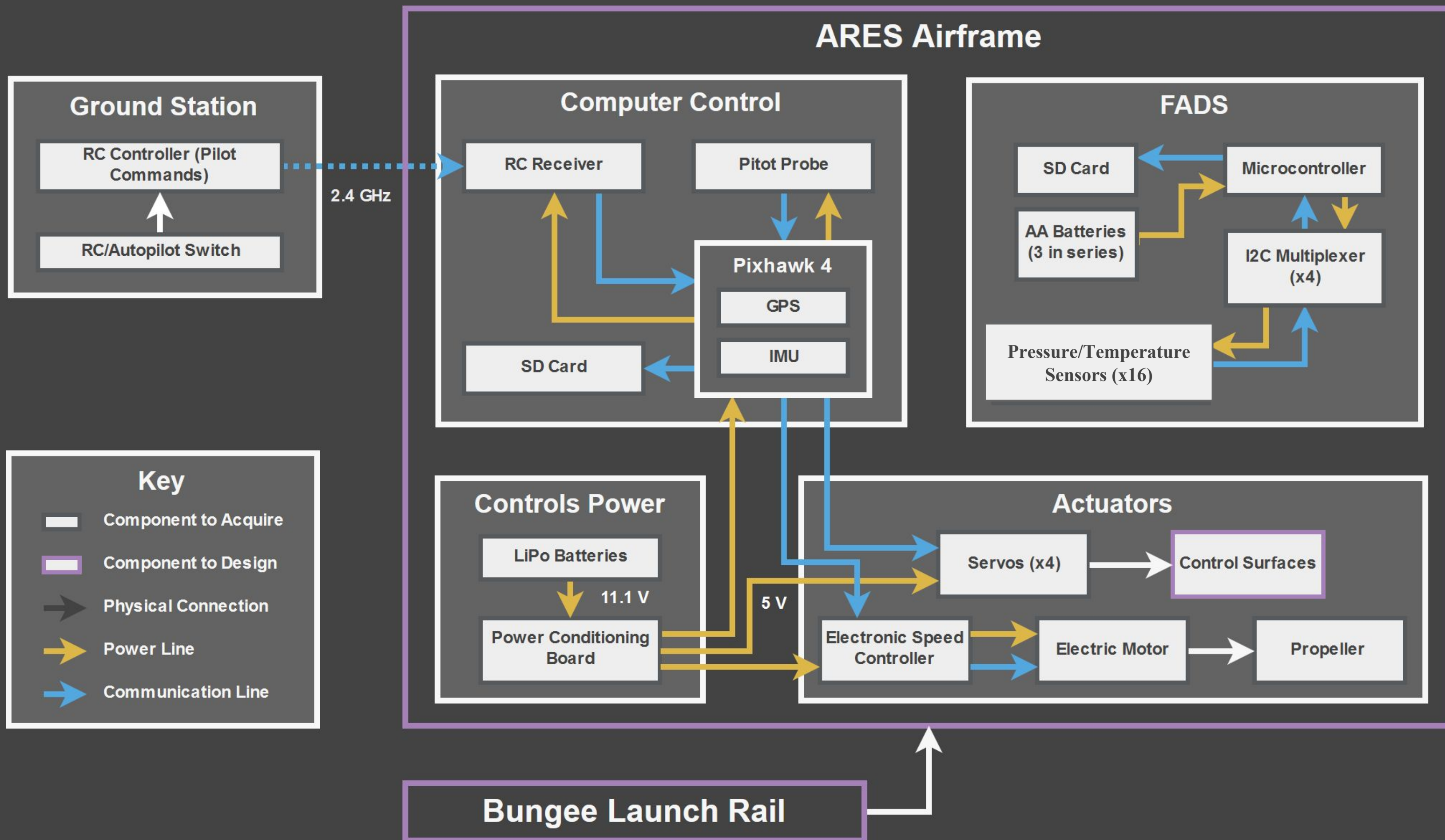
- **Aspect-ratio Redesign of Eagle-owl for Stormchasing (ARES)** will build upon the previous Eagle Owl project by designing, building, and testing a box-wing unmanned aircraft with a flush airdata sensing system (FADS) to measure relative wind velocity with the objective of creating a high endurance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

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

CONOPS

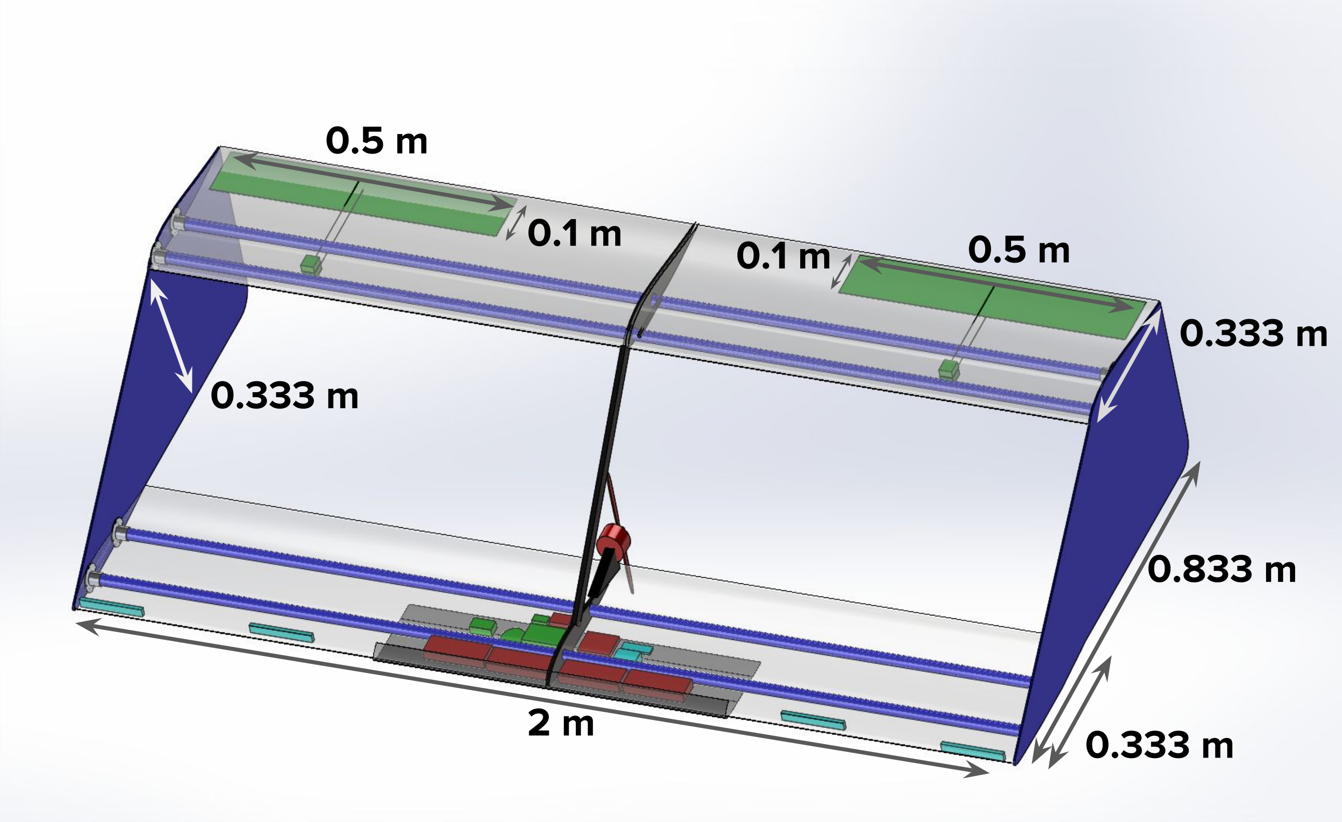

Circular flight path*
300 meter Radius
100 meter
flight altitude
Radio
Control
Preflight
Takeoff
Ascent
Controlled Steady Flight
Descent
Landing
Recovery
Repeat
Post-flight
Verify power to motor and science
Bungee launches aircraft off railed ramp
Autopilot* Control
Flight Time 1 hour*
Structural integrity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

FUNCTIONAL BLOCK DIAGRAM



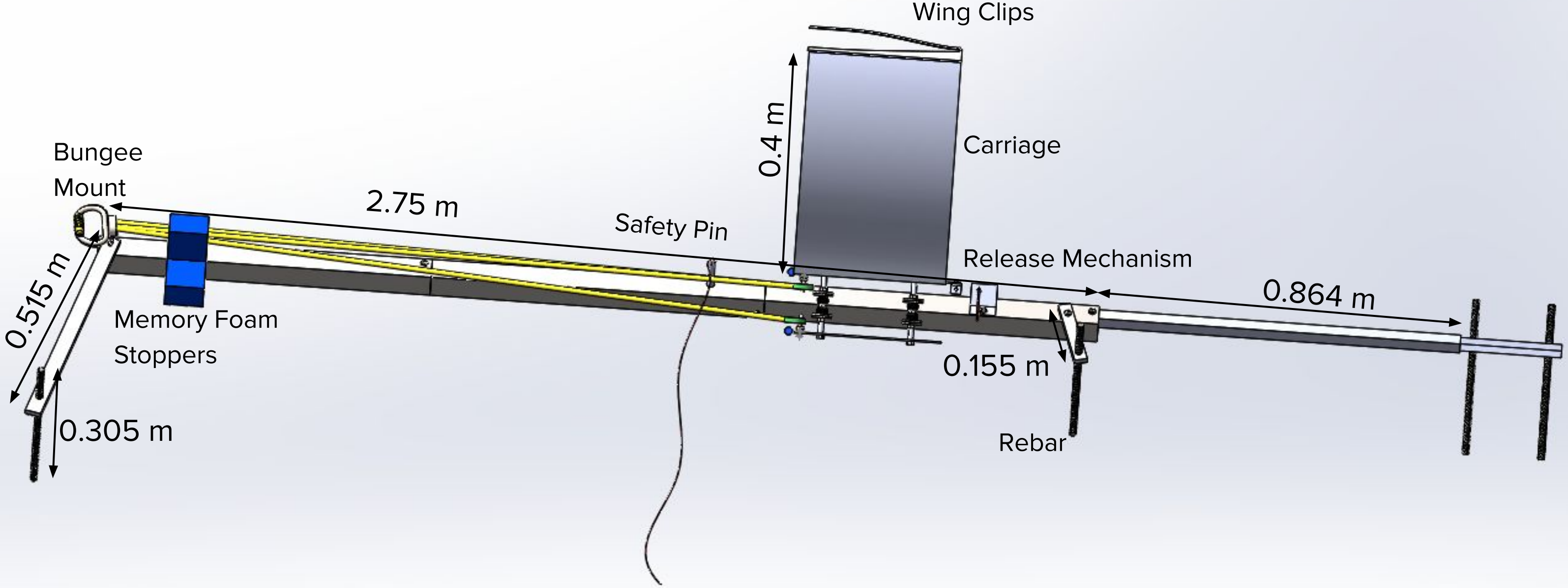
BASELINE DESIGN REVIEW

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



Structure Control Propulsion Science

Side View



Launch Direction

LEVELS OF SUCCESS

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

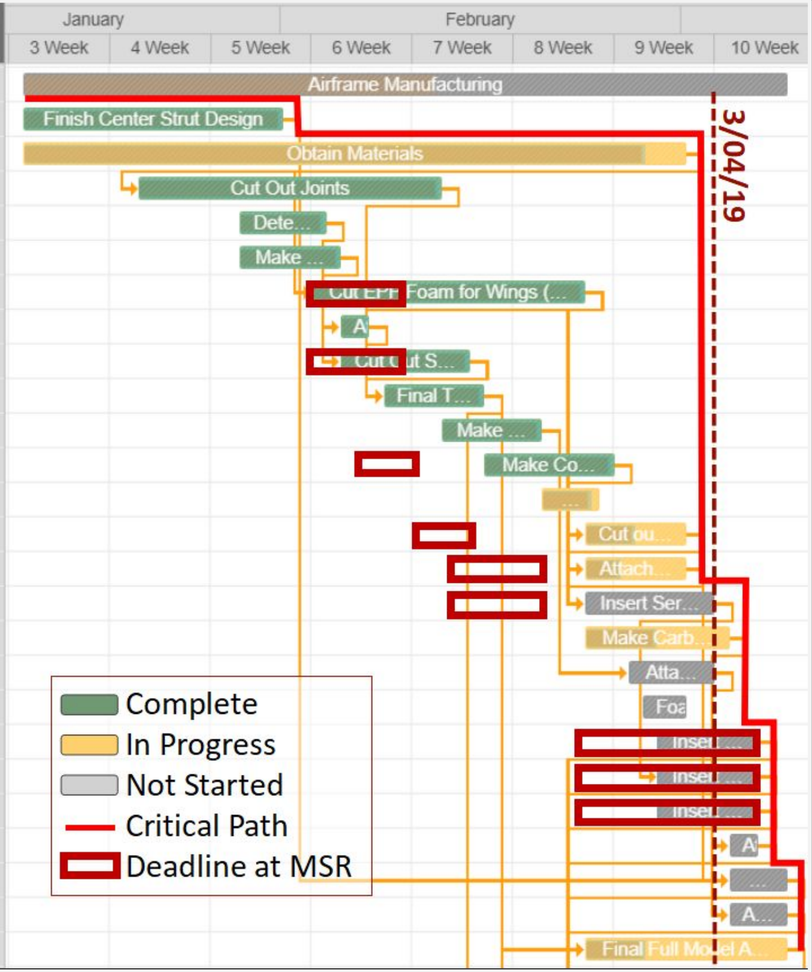
CRITICAL PROJECT ELEMENTS

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

SCHEDULING

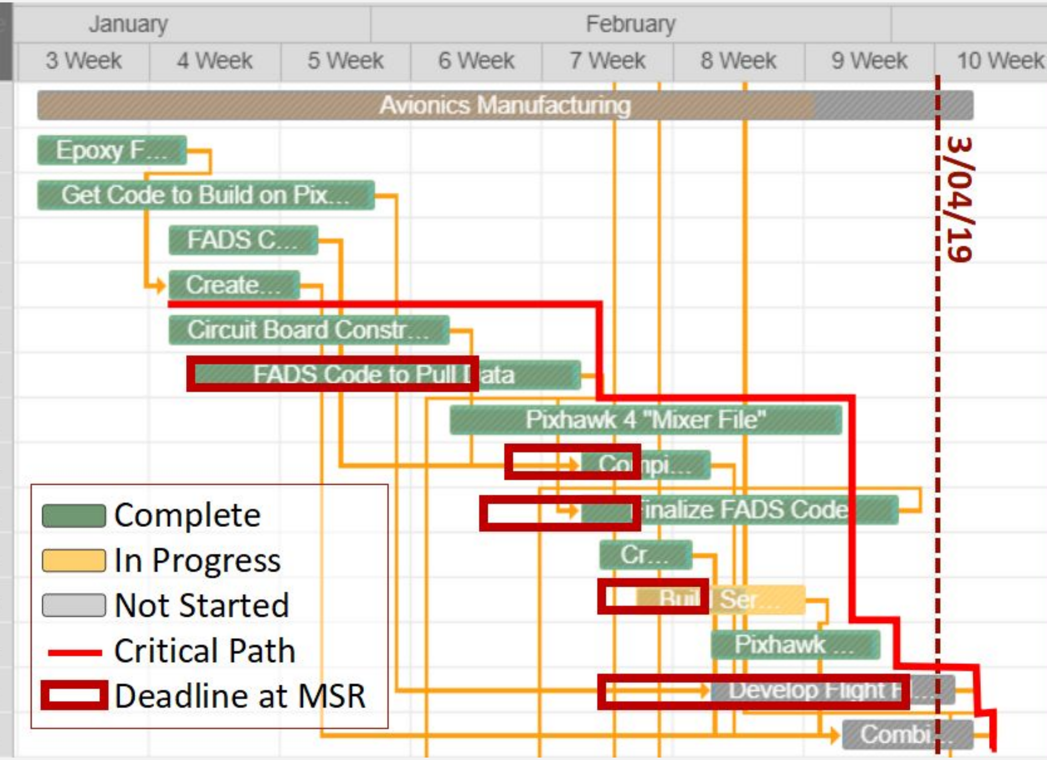
AIRFRAME SCHEDULE

Task name	Start date	End date
Airframe Manufacturing	01/14/...	03/08/...
Finish Center Strut Design	01/14/...	02/01/...
Obtain Materials	01/14/...	03/01/...
Cut Out Joints	01/22/...	02/12/...
Determine Material for Sidewalls (Test ...	01/29/...	02/04/...
Make Plastic Inserts for Joints	01/29/...	02/05/...
Cut EPP Foam for Wings (Both Models)	02/03/...	02/22/...
Attach Inserts to Rods	02/05/...	02/07/...
Cut Out Sidewalls (Test Model)	02/05/...	02/14/...
Final Test Model Assembly	02/08/...	02/15/...
Make Prop Motor Mount	02/12/...	02/19/...
Make Control Surfaces (Full Model)	02/15/...	02/24/...
Make Center Strut	02/19/...	02/23/...
Cut out Electronics Locations in Airfoil ...	02/22/...	03/01/...
Attach Control Surfaces (Full Model)	02/22/...	03/01/...
Insert Servos / Piano Wire (Full Model)	02/22/...	03/03/...
Make Carbon Fiber Plate	02/22/...	03/04/...
Attach Motor Mount (Full Model)	02/25/...	03/03/...
Foam cut mold foam	02/26/...	03/01/...
Insert Avionics Components (Full Model)	02/27/...	03/06/...
Insert Controls Components (Full Model)	02/27/...	03/06/...
Insert Propulsion Components (Full M...	02/27/...	03/06/...
Attach Motor/Spinner/Prop to Mount (F...	03/04/...	03/06/...
Cut Out Sidewalls and Strut (Full Model)	03/04/...	03/08/...
Attach Carbon Fiber Plate (Full Model)	03/04/...	03/08/...
Final Full Model Assembly	02/22/...	03/08/...



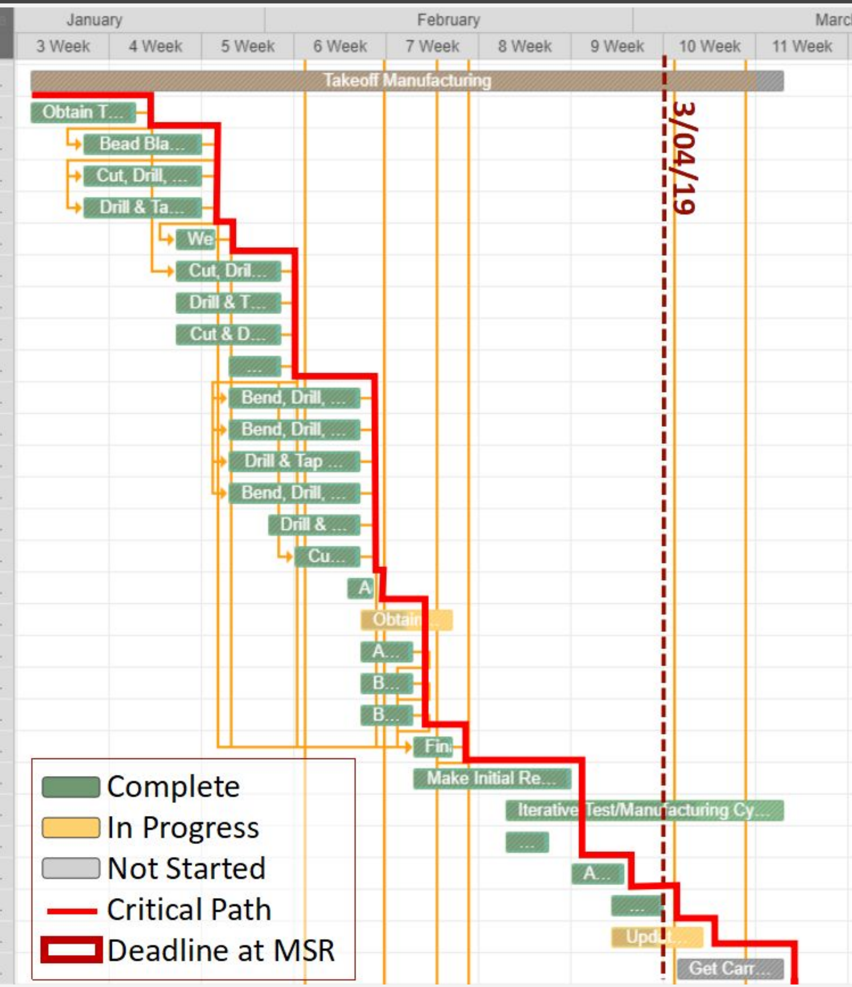
AVIONICS SCHEDULE

Task name	Start date	End date
Avionics Manufacturing	01/14/...	03/05/...
Epoxy FADS Boards and Add Tubing	01/14/...	01/22/...
Get Code to Build on Pixhawk4	01/14/...	02/01/...
FADS Code to Write to SD	01/21/...	01/29/...
Create Teensy / 9V Power Circuit	01/21/...	01/28/...
Circuit Board Construction	01/21/...	02/05/...
FADS Code to Pull Data	01/22/...	02/12/...
Pixhawk 4 "Mixer File"	02/05/...	02/26/...
Compile FADS Code on Teensy	02/12/...	02/19/...
Finalize FADS Code	02/12/...	03/01/...
Create Propulsion Power Circuit	02/13/...	02/18/...
Build Servo/Control Surface Connections	02/15/...	02/24/...
Pixhawk 4 R/C Flight Capable	02/19/...	02/28/...
Develop Flight Plans on Pixhawk4	02/19/...	03/04/...
Combine All Components and Prep for DITL	02/26/...	03/05/...

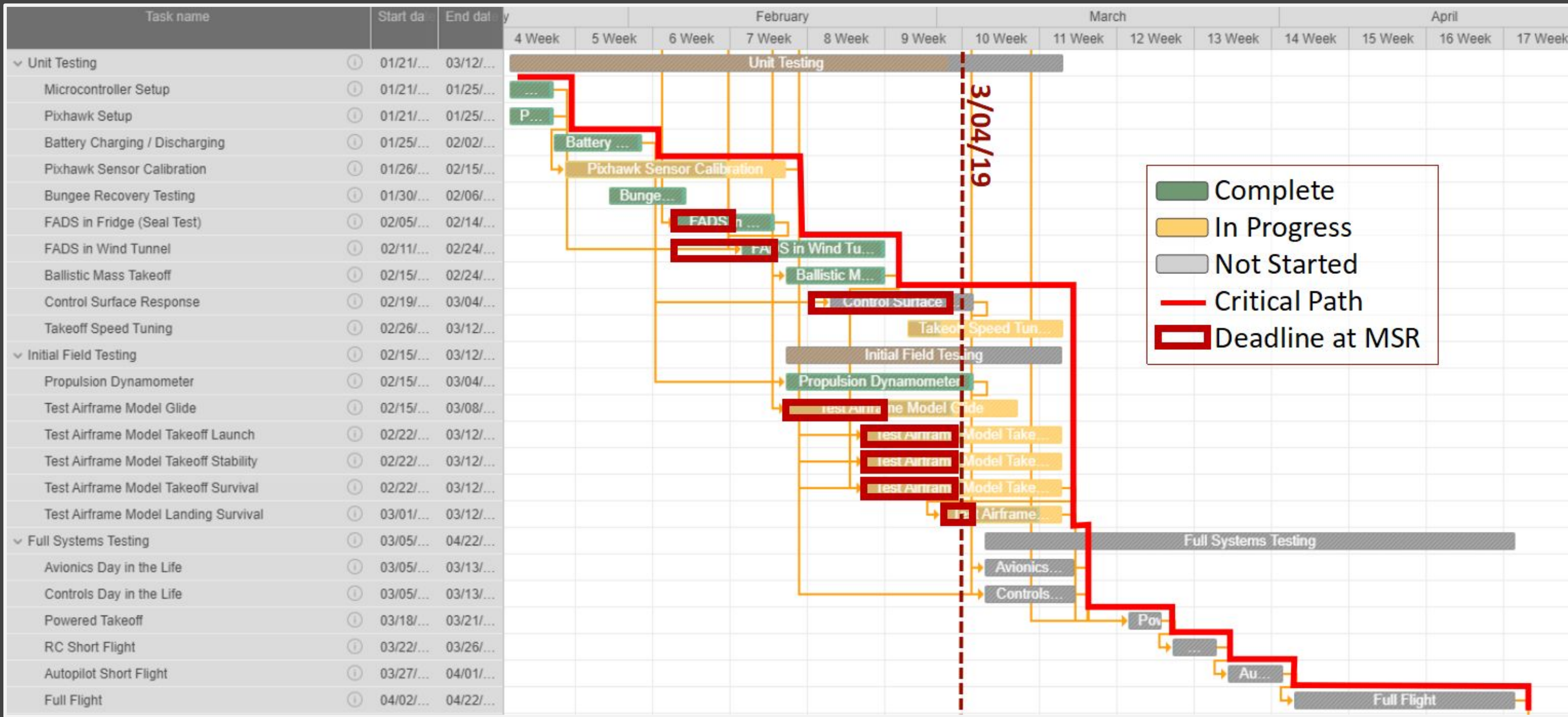


TAKEOFF SCHEDULE

Task name	Start date	End date
Takeoff Manufacturing	01/14/...	03/12/...
Obtain Takeoff Materials	01/14/...	01/22/...
Bead Blast, Drill, & Tap Center Rail	01/18/...	01/27/...
Cut, Drill, & Tap Center Support Rods	01/18/...	01/27/...
Drill & Tap Holes for Center Rail Clips	01/18/...	01/27/...
Weld Center Rail Clips	01/25/...	01/28/...
Cut, Drill, & Tap Legs	01/25/...	02/02/...
Drill & Tap Tail Post	01/25/...	02/02/...
Cut & Drill Rubber Stoppers	01/25/...	02/02/...
Obtain Scrap Metal for Release	01/29/...	02/02/...
Bend, Drill, & Tap Plate Metal for Release	01/29/...	02/08/...
Bend, Drill, & Tap Lever Arm	01/29/...	02/08/...
Drill & Tap Tube for Release	01/29/...	02/08/...
Bend, Drill, & Tap Carriage Clip for Release	01/29/...	02/08/...
Drill & Ream Standoffs	02/01/...	02/08/...
Cut, Drill, & Tap Carriage Plate Metal	02/03/...	02/08/...
Add Brackets to Support Rail	02/07/...	02/09/...
Obtain Additional Takeoff Materials	02/08/...	02/15/...
Attach Carriage Clip for Release	02/08/...	02/12/...
Bend, Drill, & Tap Sheet Metal for Carriage U	02/08/...	02/12/...
Bend, Drill & Tap Sheet Metal for Carriage Clips	02/08/...	02/12/...
Final Takeoff Assembly	02/12/...	02/15/...
Make Initial Repairs	02/12/...	02/24/...
Iterative Test/Manufacturing Cycle	02/19/...	03/12/...
Finalize Release Mechanism	02/19/...	02/22/...
Align Carriage on Rail	02/24/...	02/28/...
Redistribute Carriage Weight	02/27/...	03/03/...
Update Models for Bungee Length	02/27/...	03/06/...
Get Carriage Up to Speed	03/04/...	03/12/...



TESTING SCHEDULE

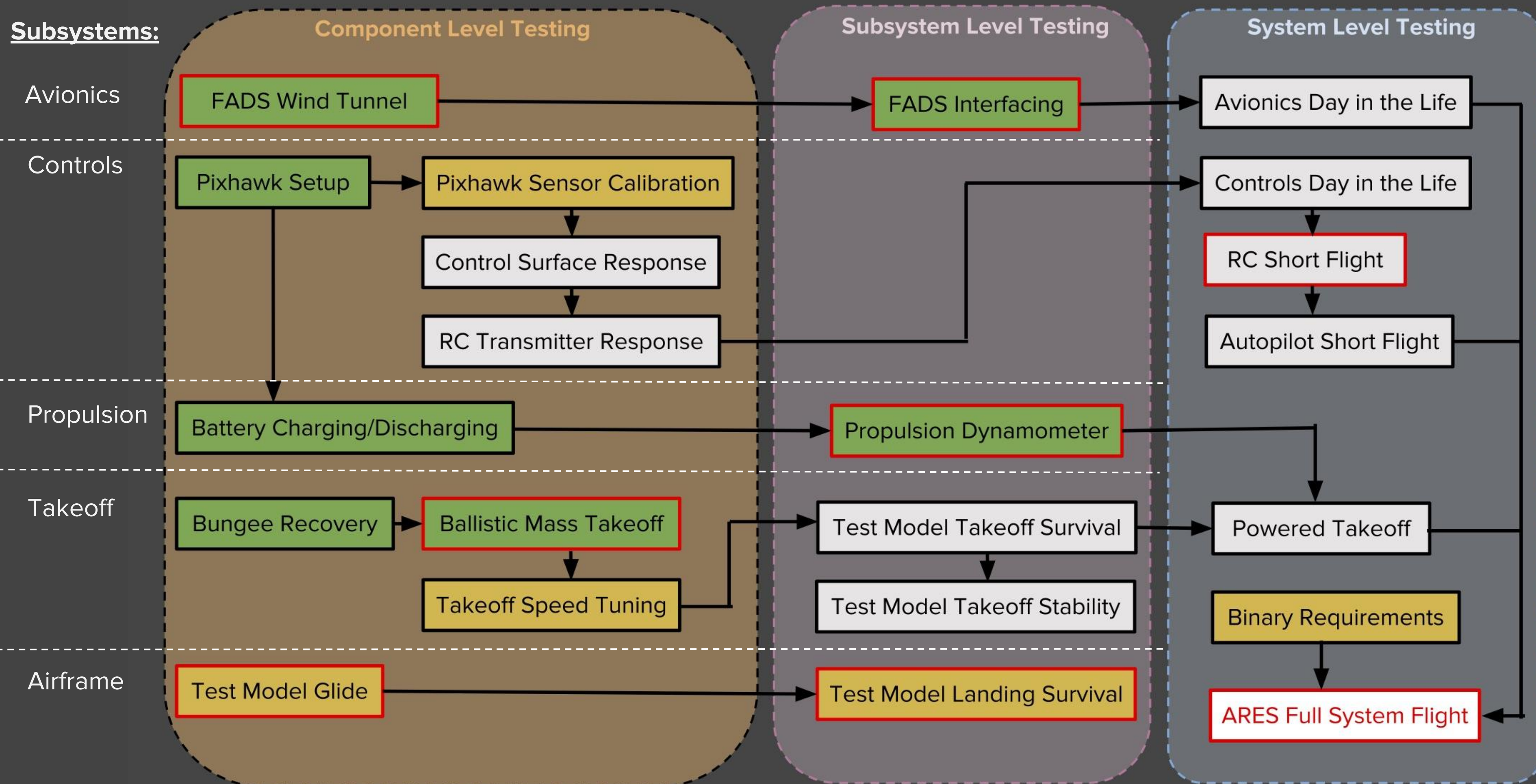


TEST OVERVIEW

Legend

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

TEST OVERVIEW



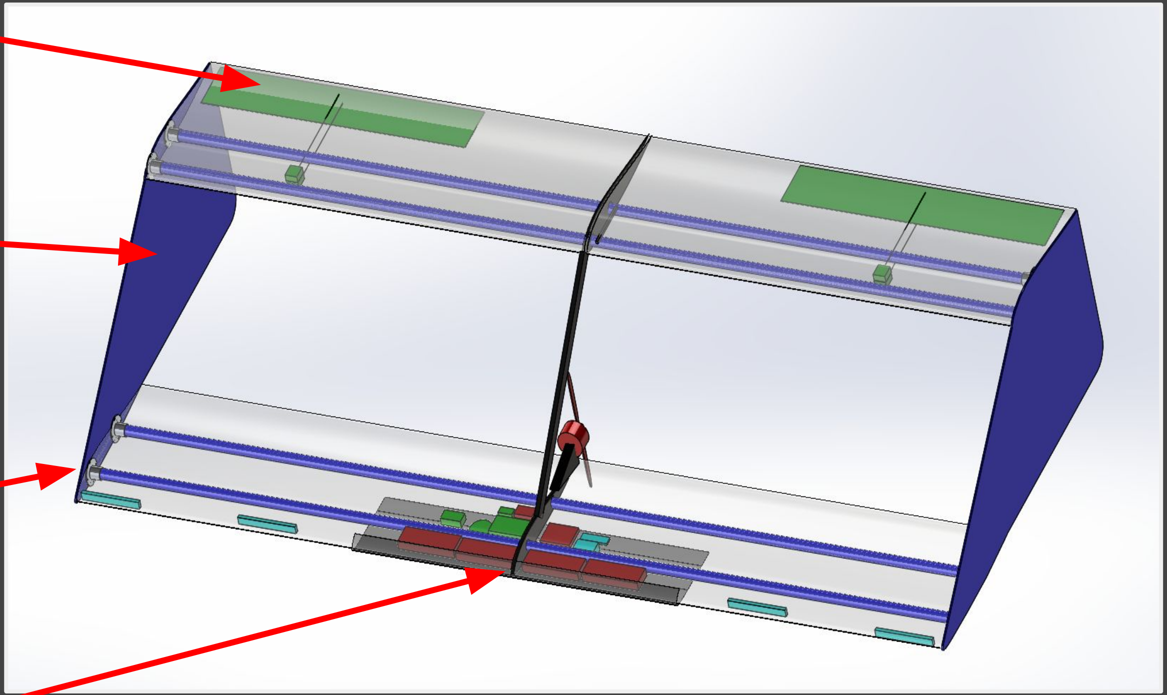
SAFETY PROCEDURES

- Mechanical
  - Takeoff System has safety procedures and documentation for launch procedure
    - **Safety Pin** on the rail has been proven to stop carriage
    - **Safety Glasses** are required to use
    - Hazard Tape to signify dangerous zones on the system
- Electrical
  - LiPo Batteries are **stored at recommended voltage** of 3.85V
  - **ABC Fire Extinguisher** owned by ARES in case of fire
  - Grounding wrist strap
- System
  - Team members have reviewed and understand ARES components that can cause harm and how to **avoid** them (Prop, LiPo's, Airframe, Takeoff Carriage)

AIRFRAME TESTING

CHANGES SINCE CDR

- Control surfaces resized (width 0.61 m to 0.50 m)
    - Manufacturing limitations
- Temporarily using corrugated plastic instead of honeycomb
    - Shipping delays
- Extension of honeycomb near joints
    - Helps prevent shear
- Sleeve on center strut screws into ribs



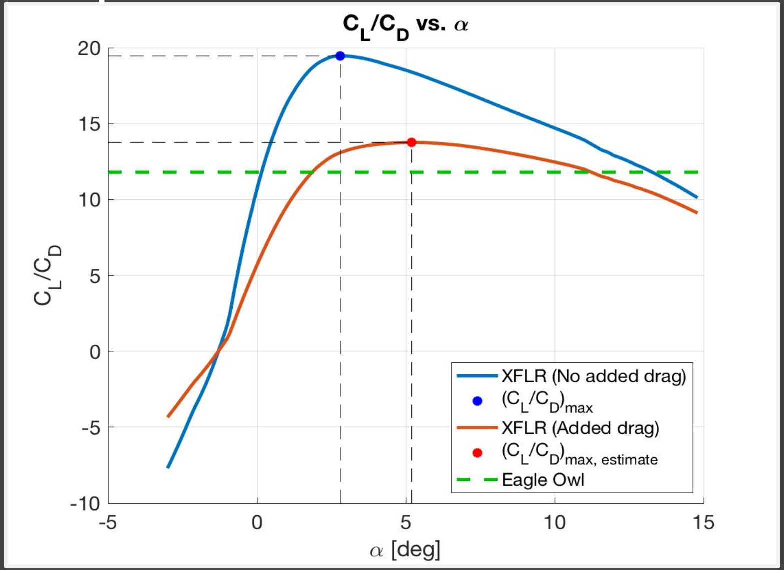
MODEL GLIDE TEST

Driving Requirements
D.R. 2.2: L/D ratio greater than the Eagle Owl (L/D > 12) **D.R. 2.1.3:** Stable flight without a tail boom

Status: 2/15 - 3/8 In progress

- **Test Fixtures/Facilities:** Takeoff system, Model plane, measuring tape
- **Procedures:** Clear landing area, launch plane, record video, postprocess data to calculate approximate L/D

Expected Results/Model Validation:



Device	Measurement	Accuracy
Measuring Tape	Inches	±1/8 in

Risk Reduction: Satisfy D.R 2.2, 2.1.3 without risking electronics or control surfaces

MODEL LANDING TEST

Driving Requirements

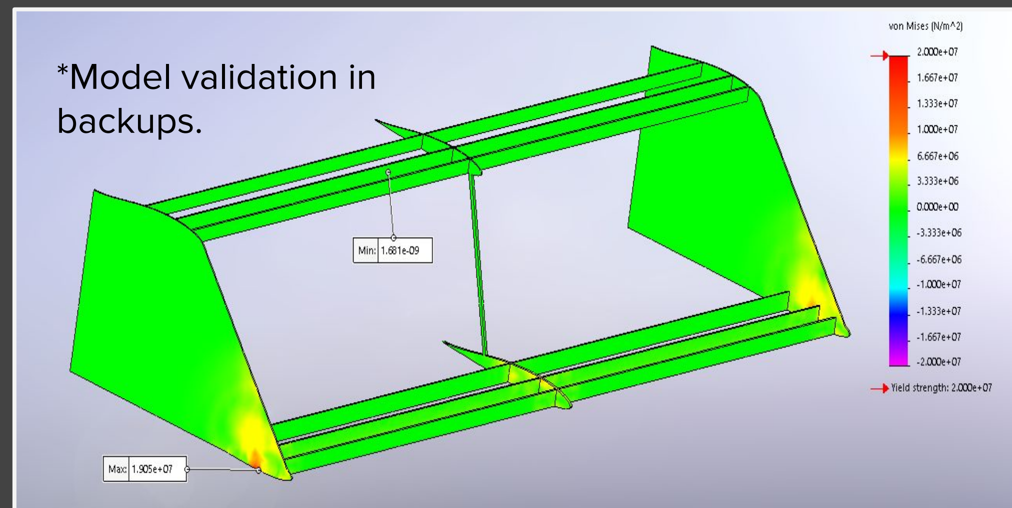
D.R. 6.1: Land so that it can take off in 15 minutes

D.R. 6.4: The landing system won’t put any person in danger

Status: 3/1 - 3/12
In progress

- **Test Facilities/Equipment:** Test performed in an open outdoor location with the model airframe and the takeoff system
- **Procedure:** Launch with takeoff system, land in open area, assess damage

Risk Reduction: Satisfy D.R 2.2, 2.1.3 without risking electronics or control surfaces



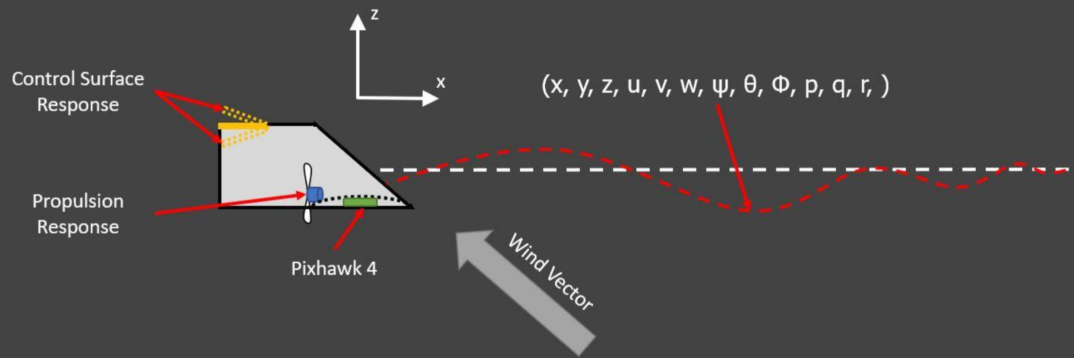
GLIDE/LANDING VIDEO

SHORT RC FLIGHT TEST

Driving Requirements
DR 2.1.3: Stable flight without a tail boom
DR 4.1: Autopilot demonstrates steady level flight for at least 2 minutes

Status: 3/22-3/26
Not Started

- **Test Fixtures/Facilities:** Takeoff system, ARES full airframe, trained pilot, CU Boulder South Campus
- **Procedures:** Launch aircraft, perform basic maneuvers, PixHawk 4 records performance to tune gains
- **Compare:** Gains modeled for CDR
- **Calculate:** Stability coefficients, PID control gains



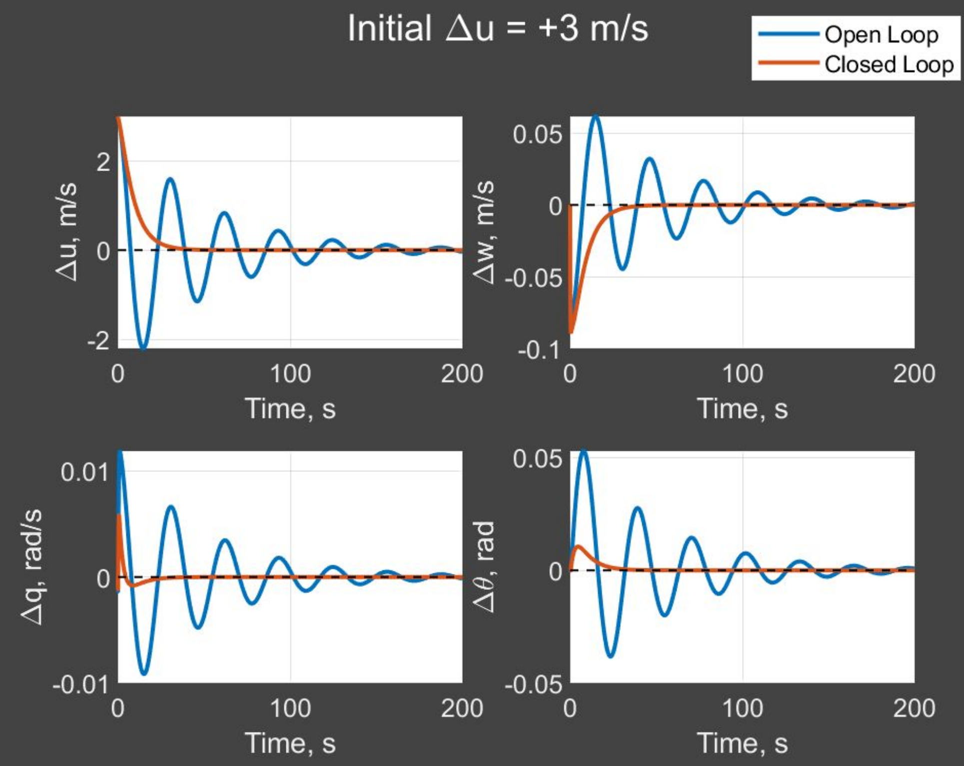
Device	Measurement	Accuracy
Pixhawk 4 ICM-20689 BMI055	x, y, z, ψ, θ, Φ u, v, w, p, q, r	± 2%, ± 0.04g's ± 1%, ± 0.164 °/s

Risk Reduction: Validate the airframe's response to wind disturbances and tune gains with ArduPlane

SHORT RC FLIGHT TEST

ARES flight models using aerodynamic data

- Stability matrix made in Athena Vortex Lattice (AVL)
- Use linear P-D control with MATLAB
- Perturbation inputs are different initial states

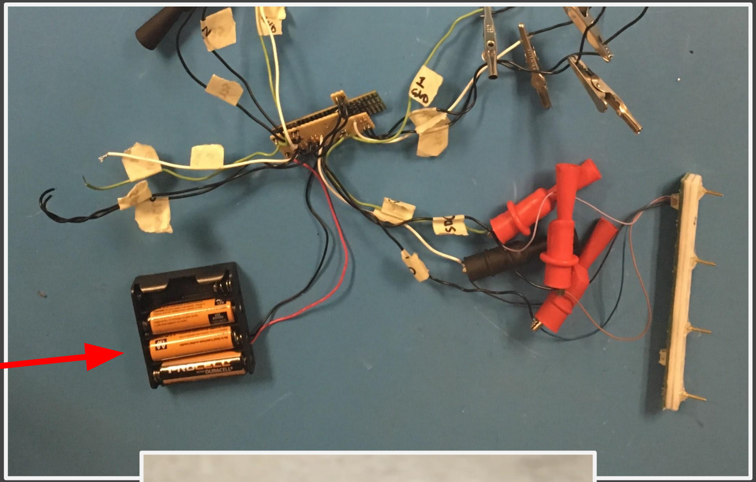


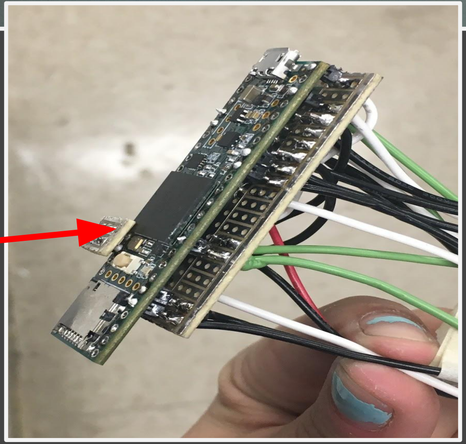
Response to a perturbation in cruise speed

AVIONICS TESTING

CHANGES SINCE CDR

- Autopilot software changed to ArduPlane from PX4
  - ArduPlane includes differential elevons and gain auto-tuning
- 9V and conditioning circuit changed to 3 AA's in series
  - Allows for addition of a switch, less components
- CircBoard added for I2c pull-up resistors
  - These were built in on Arduino used for testing





FADS INTERFACE TEST

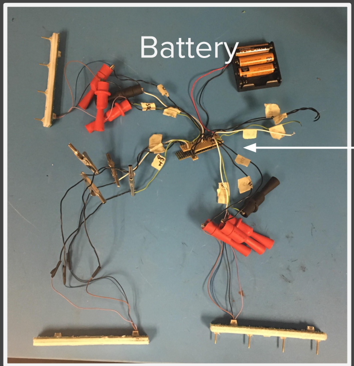
Driving Requirements

DR 5.3: Pressure and temperature sensors report at the same rate of 1 Hz

DR 5.5: The on-board computer communicates simultaneously with 12 sensors

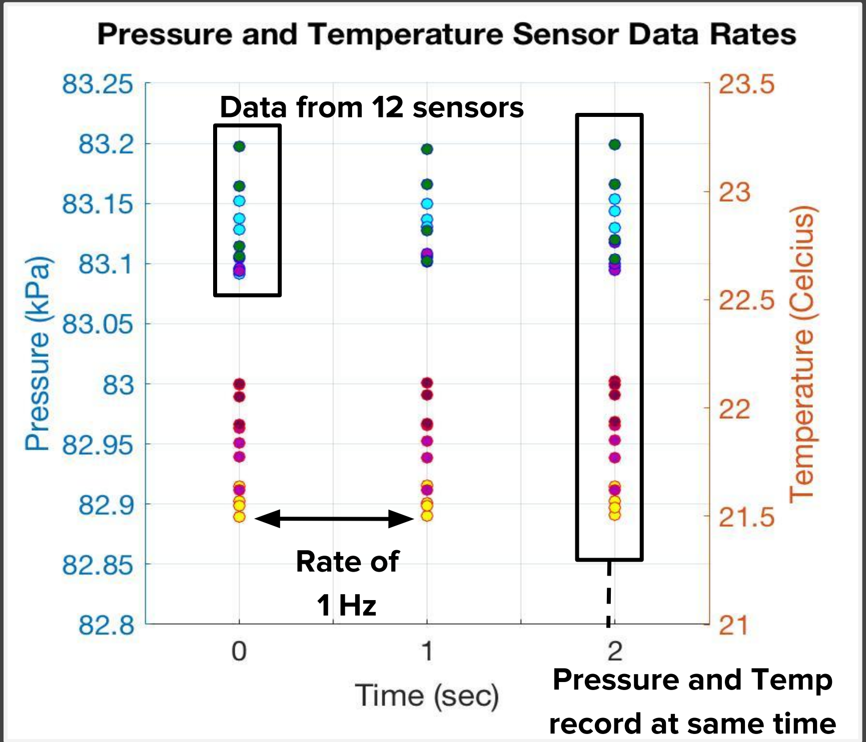
Status: Complete
2/25-2/28

- **Test Fixtures/Facilities:** Projects Room, FADS boards, microcontroller
- **Procedures:** Connect 12 sensors to microcontroller, power system, record pressure and temp, confirm data stored on SD card



FADS PCBs

Risk Reduction: Confirms capability of electronic interfaces prior to integration into airframe



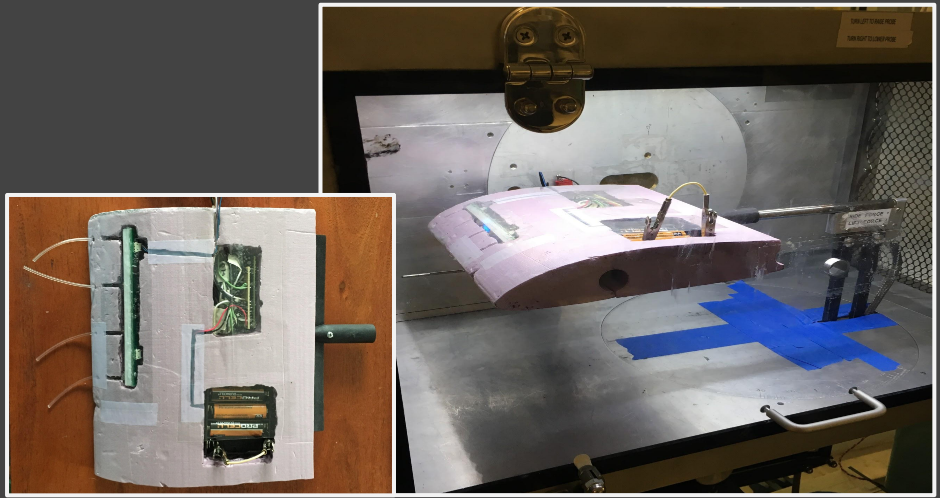
FADS WIND TUNNEL TEST

Driving Requirements
DR 5.1.3: Pressure sensors shall be accurate up to 200 Pascals

Status: In Progress
2/25-3/8

- **Test Fixtures/Facilities:** ITLL Wind Tunnel, FADS circuit, sting balance, scanivalve pressure sensor
- **Procedures:** Integrate FADS into wing section, insert in wind tunnel and vary airspeed, record data, pull FADS and pitot probe data, post-process to calculate P/T errors

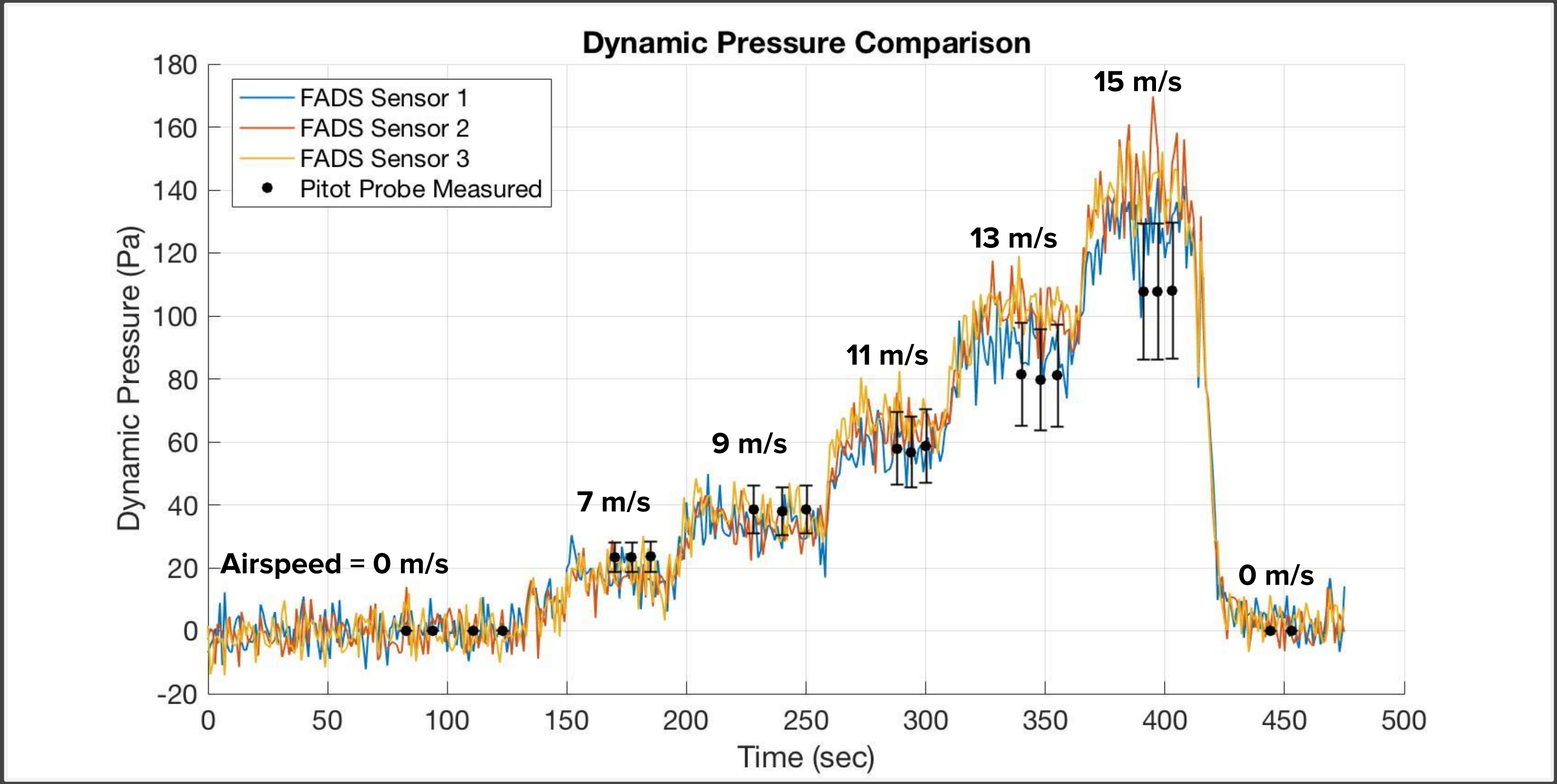
FADS in ITLL Wind Tunnel



Device	Measurement	Accuracy
Scanivalve	Press. [Pa]	± .20%, ± 5 Pa*

Risk Reduction: Verify requirement prior to integration to ensure accurate data collection

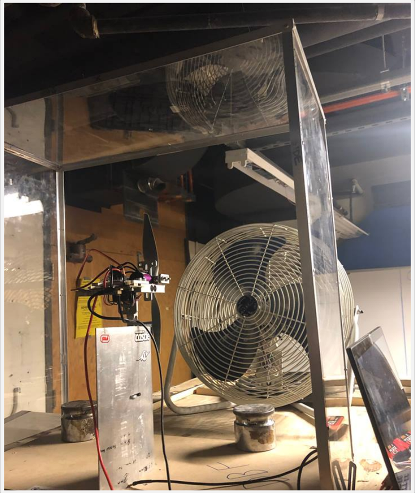
FADS WIND TUNNEL TEST



MOTOR DYNAMOMETER TESTING

Driving Requirements
DR 1.2: System produces enough thrust for flight **DR 1.2.1:** System capable of reaching between 10-30 [m/s]

Status:
Completed 1/30

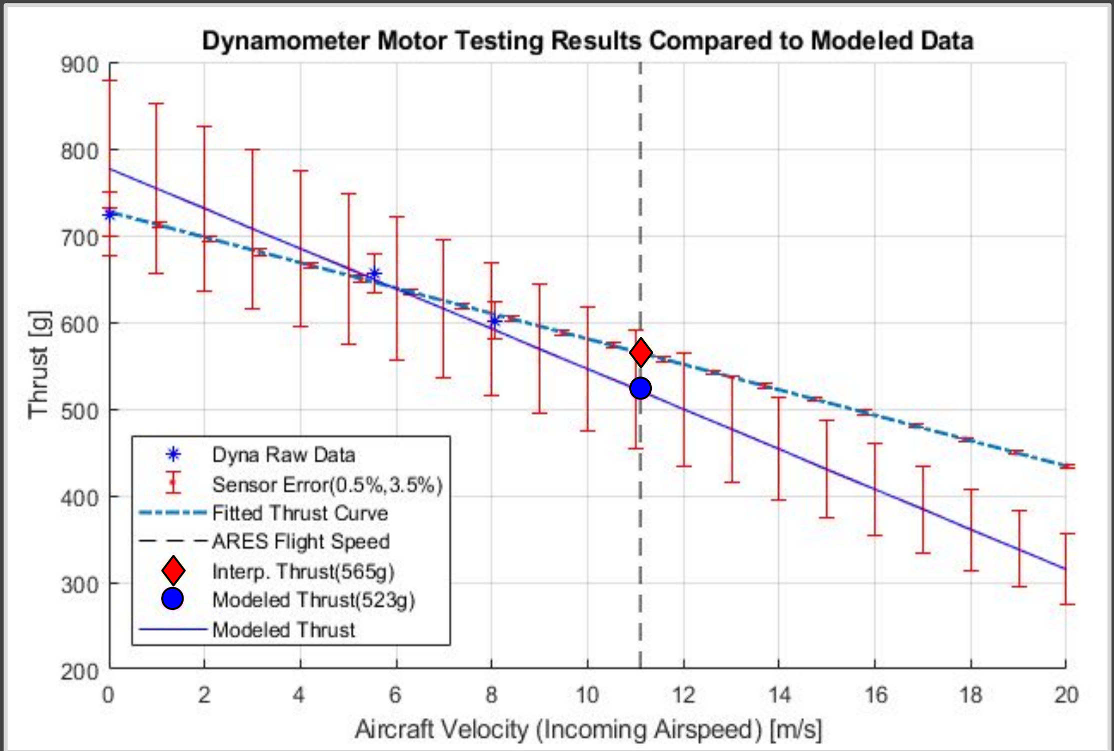


- **Test Fixtures/Facilities**: Testing in Composites Lab. Requires Dynamometer, thermal anemometer, optical tachometer
- **Procedures**: Place Dynamometer setup in test wind tunnel, record dynamic and static thrust, compare to eCalc and mathematical models and requirements

Device	Measurement	Accuracy
Dynamometer Load Cell	Thrust (g)	± 0.5%
Thermal Anemometer	Wind Speed (m/s)	± 3%
Optical Tachometer	Propeller RPM	± 0.3%

Risk Reduction: Collect motor thrust response to incoming wind and gain understanding of throttle requirements

DYNAMOMETER TEST RESULTS



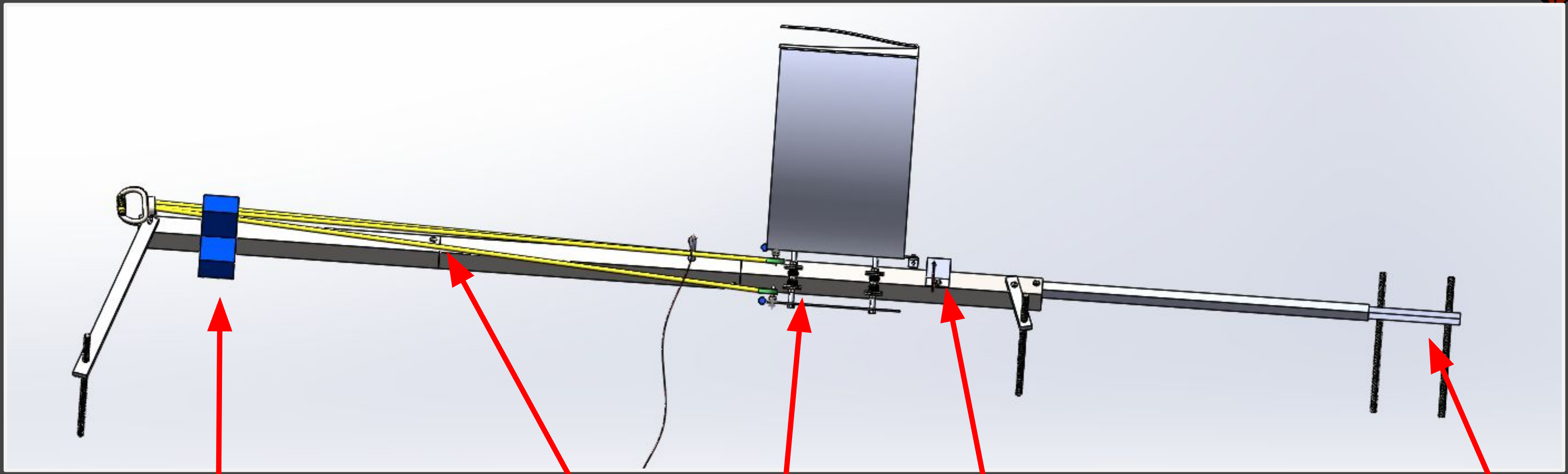
eCalc Data vs. Interpolated Test Results for 59% Throttle

Value	eCalc	Dyna Test	Error (%)
RPM	5622	6254	+10.1
Thrust (g)	513	576	+10.8

Conclusion: Our propulsion system satisfies DR 1.2 and DR 1.2.1. Able to establish flight settings based on test results and analysis

TAKEOFF TESTING

CHANGES SINCE CDR



- Pads added to stop carriage
- "L" brackets instead of clips on rail
  - Stronger connection prohibits sagging
- Torque Inhibitors to help guide carriage
  - Prevent carriage torque on rail
- Pin release instead of lever
  - Safer and more reliable release
- Base plate added with rebar stakes
  - Safety

LAUNCH VELOCITY TEST: AIRFRAME

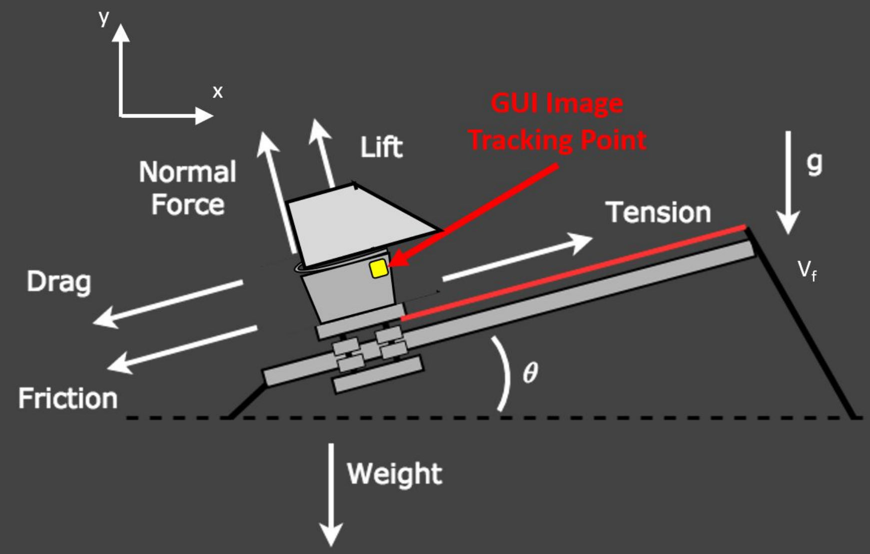
Driving Requirements
D.R. 3.2: Bring the aircraft to its desired initial velocity **D.R. 3.3:** Capable of 10 consecutive takeoffs

Status: 2/22 - 3/12 In progress

Expected Results: Achieve desired velocity and heading for consecutive takeoffs

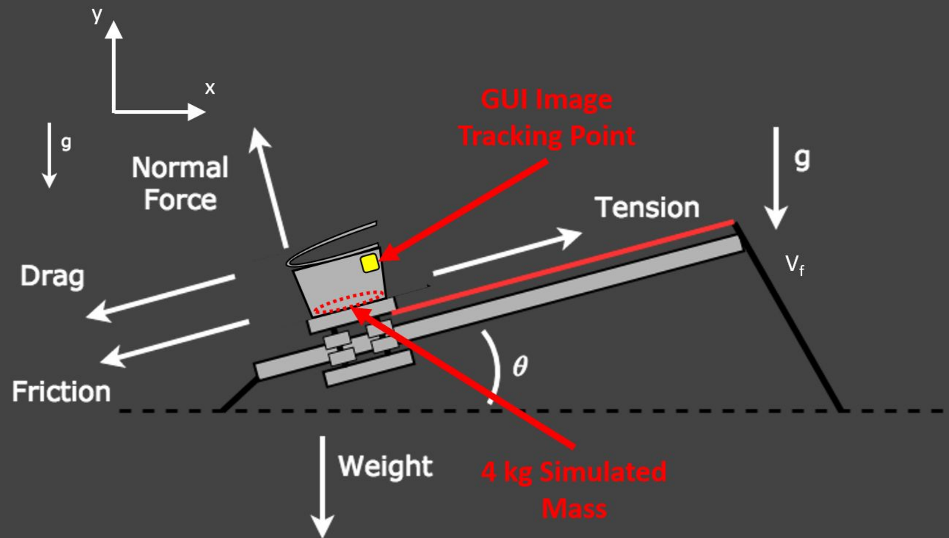
Validated Models: Launch Velocity Model

- **Test Fixtures/Facilities:** Launch system, test airframe, open space, slow motion camera
- **Procedure:** Follow safety guidelines, launch model using takeoff system, capture on video for speed analysis



Risk Reduction: Verify DR 3.2 and DR 3.3 prior to system use with ARES to reduce risk from damaging avionics components

LAUNCH VELOCITY TEST: MASS



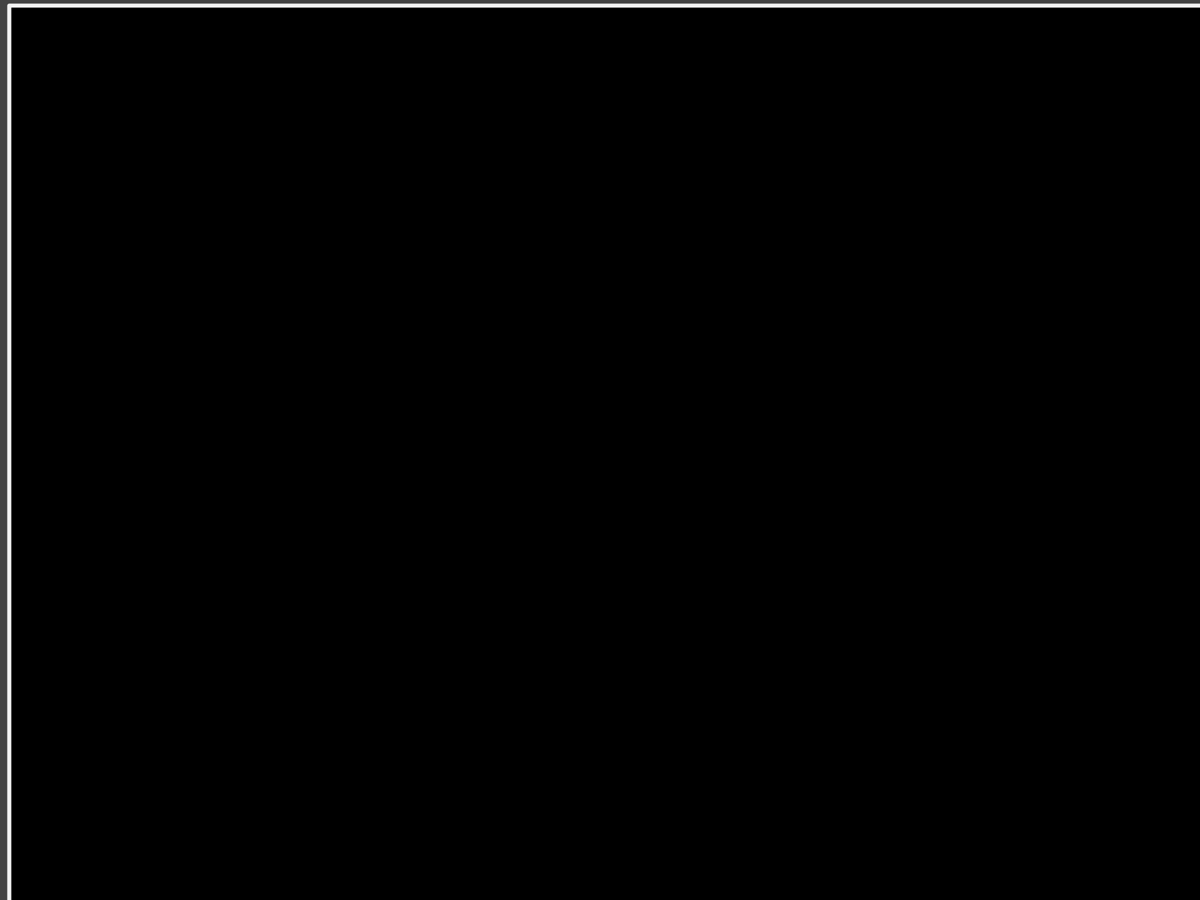
Status: 2/22 - 3/12
In progress

- **Test Fixtures/Facility:** Engineering Center Quad, Launch System, 4kg sandbag
- **Procedure:** Film each takeoff with connected mass, use GUI to determine takeoff velocity
- **Calculate:** Launch Velocity (V_f) and Launch Force (F)
- **Compare:** Ballistic Models to data recorded

Risk Reduction: Verify DR 3.2 and DR 3.3 prior to system use with ARES to remove risk from damaging avionics components

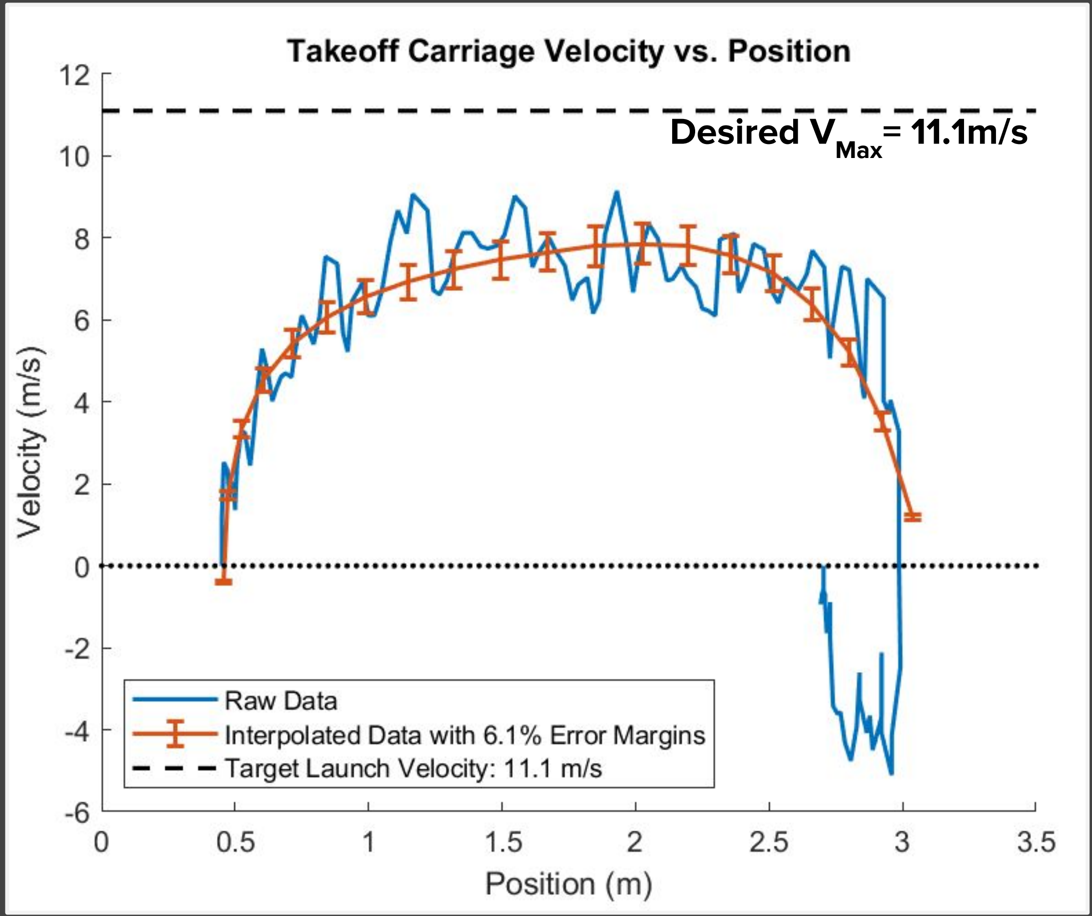
Device	Measurement	Accuracy
iPhone 10 Camera	Position on Rail [m]	± 6.1%

TAKEOFF TEST VIDEO



LAUNCH VELOCITY TEST RESULTS

- **Test Results:**
  - V_{Max} ≅ 7.86 m/s
  - Occurs at ≅ 0.429 s
- **Failure Analysis:** System not reaching needed speed, max speed not far enough along rail
  - Qualitative solution - shorten bungees, reduce carriage mass
  - Quantitative solution - retest with accelerometers
- **Model Inaccuracy:** Point mass assumption, inability to accurately predict friction, inaccurate carriage mass



FULL SYSTEM FLIGHT TEST

Driving Requirements
All Functional Requirements and Design Requirements

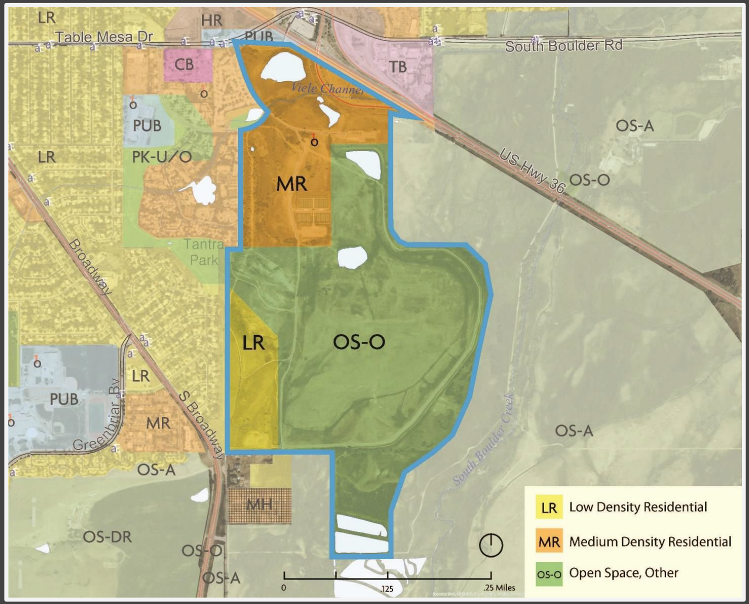
Takeoff/Ascent Path
1 hour Flight Circle
Landing/Descent Path

- Test Description (follows ConOps process):
  - Power on ARES Aircraft
    - Confirm recording of 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

FLIGHT TEST LOCATION

CU Boulder South Campus - Open Space

- Flight access requirements:
  - AMA card of pilot
  - FAA registration number of drone
  - Permission to fly from Director of Flight Operations, Dan Hesselius



PROJECT BUDGET

PROCUREMENT SUMMARY

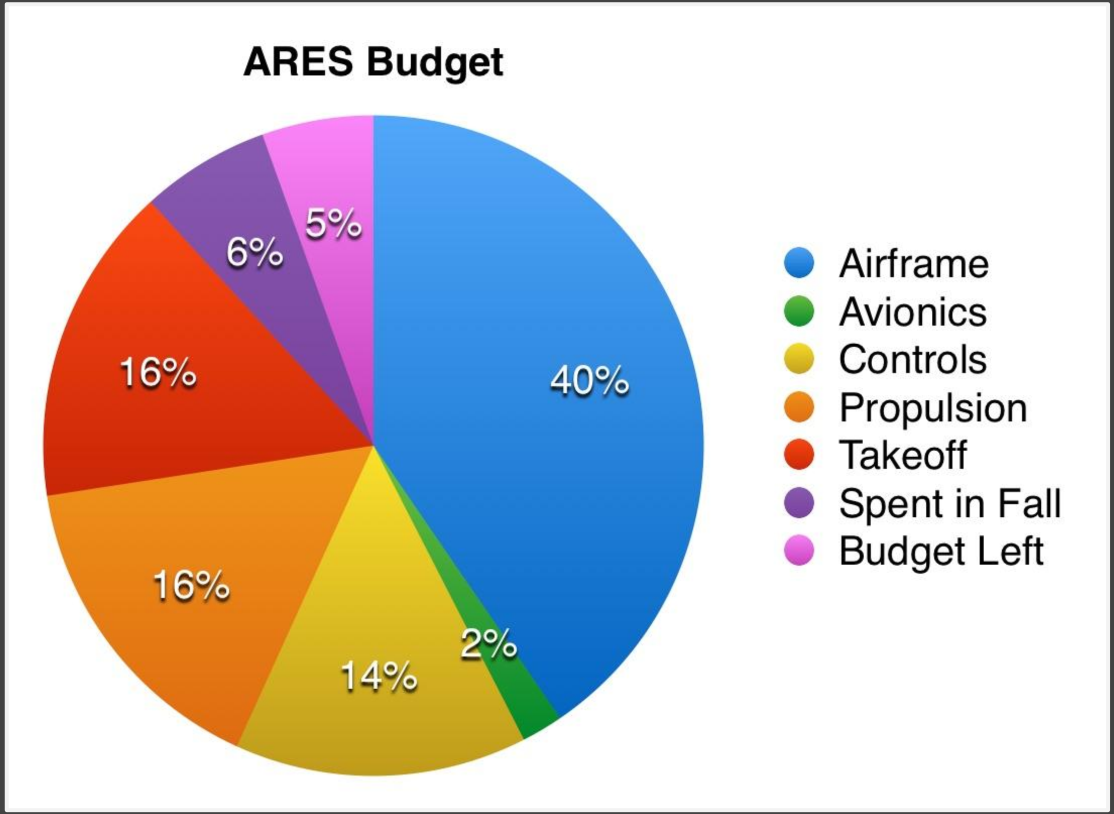
- CA Composites - Carbon Honeycomb
  - Expected delivery 3/4/19 (via tracking number)

- All other expected components and materials have been ordered and delivered
  - Enough material for 3 complete airframes
  - Unexpected items will be purchased as needed

BUDGET SUMMARY

Subsystem	Spent
Airframe	$2,021.91
Avionics	$101.42
Controls	$716.00
Propulsion	$789.04
Takeoff	$782.17
Spent in Fall	$316.41
Total	**$4726.95**

Left: $273.05



***Note: We have spent $302.48 since MSR.**

ACKNOWLEDGEMENTS

- Dr. Brian Argrow
- Dr. Donna Gerren
- Dr. Jelliffe Jackson
- Dr. Dale Lawrence
- Dr. Kathryn Wingate
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- John Mah
- Josh Mellin
- Ian Cooke
- Christine Reilly
- Dan Hesselius
- Ken Jochim
- Murray Lull
- Christopher Choate

QUESTIONS?

BACKUP SLIDES

BACKUP TABLE OF CONTENTS

AIRFRAME BACKUP

POWERED TAKEOFF TEST

Status: Unstarted

Driving Requirements

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

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.

Rationale: Satisfy D.R. 1.1, D.R. 1.2, and D.R. 1.2.1. Critical to mission success because a lack of power to the sensor and propulsion systems will result a mission failure.

Test Facilities/Equipment: Test will be performed in an open outdoor location with the integrated airframe/electronics system and the takeoff system.

Procedure: Perform takeoff procedure with motor on and producing thrust. Measure velocity through onboard instruments or visual observation.

Expected Results/Model Validation: Expect satisfaction of D.R.'s 1.1, 1.2, 1.2.1.

Model validation in backups.

Risk Reduction: Verify requirements without risking the aircraft in a lengthy flight cycle

POWERED 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)

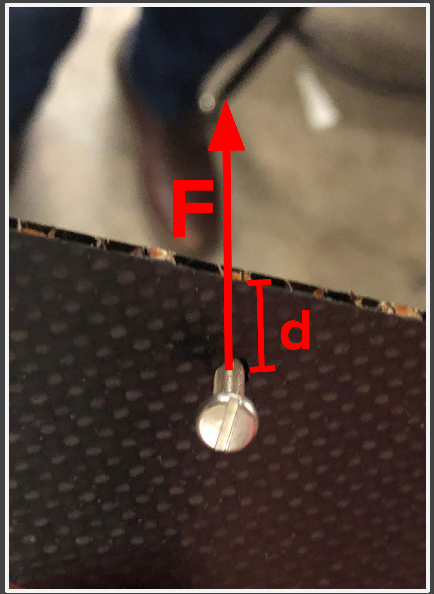
Device	Measurement	Accuracy
Measuring Tape	Distance [m]	± 1mm
iPhone 10 Camera	Height [m]	± 6.1%

Risk Reduction: Verify DR 3.1 without using ARES full flight model

STRUCTURE: JOINT SHEAR

Each joint can support at least 200lbs of shear force. A single screw supported 50lbs before failure. This is much less than our predicted forces on takeoff or landing.

- F - Shear force applied to screw
- d - Minimum distance from screw to edge of honeycomb



Test Setup

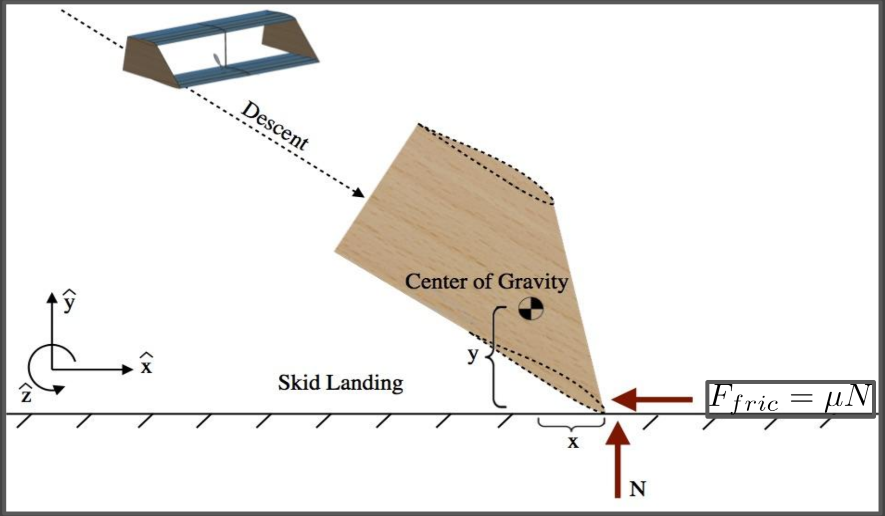
Result

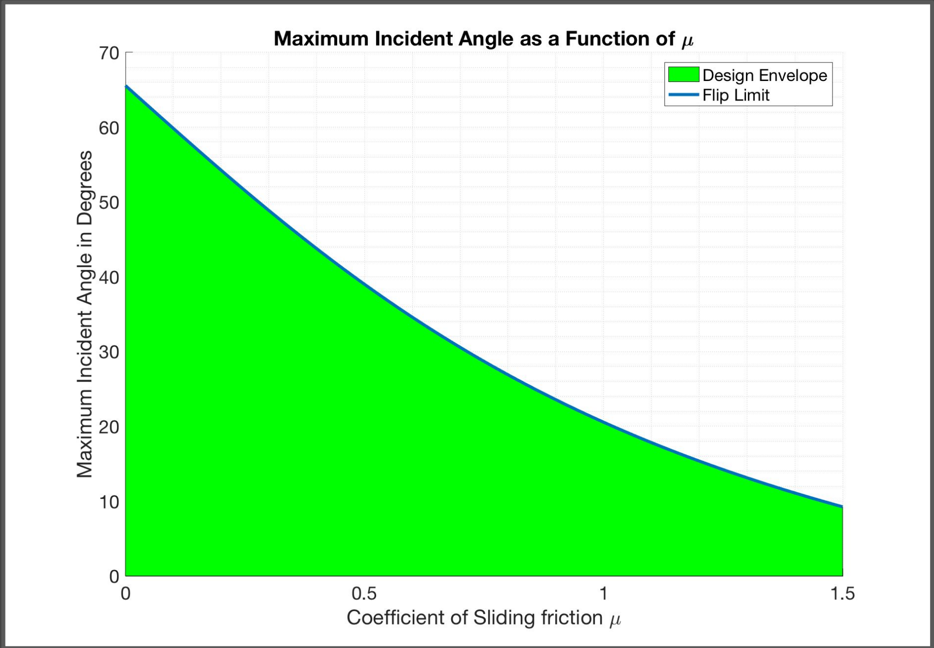
LANDING MODELS

Driving Requirements

D.R. 6.1: The aircraft shall land such that it can take off again within 15 minutes.

D.R. 6.4: The landing system shall not put any person in danger at any point. During landing, everyone involved will be a safe distance of 5 meters away.





LANDING MODELS

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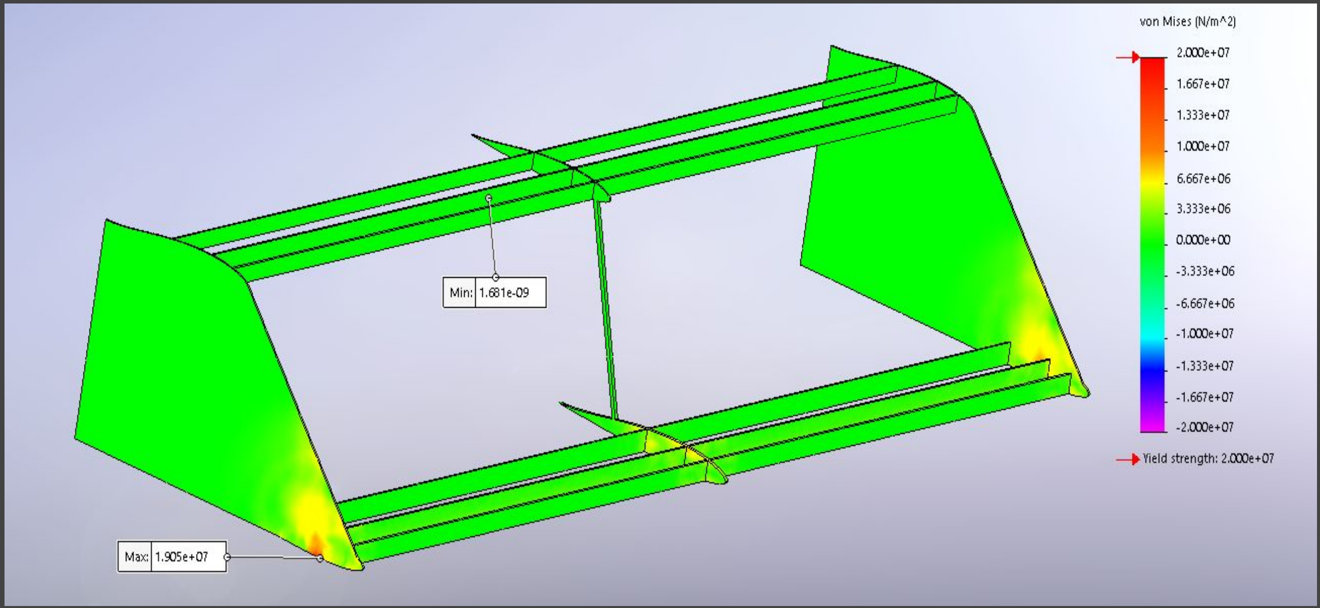
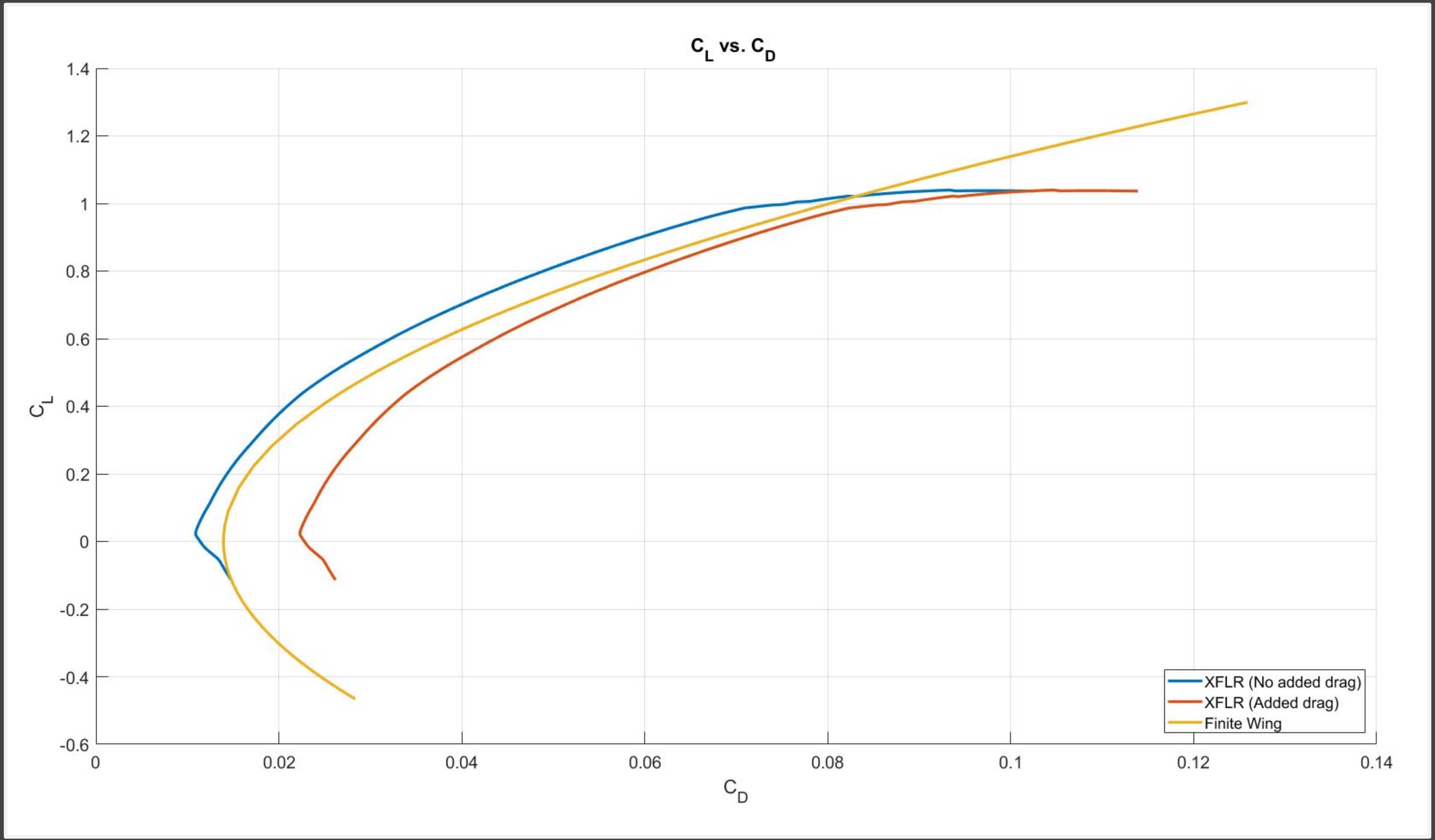
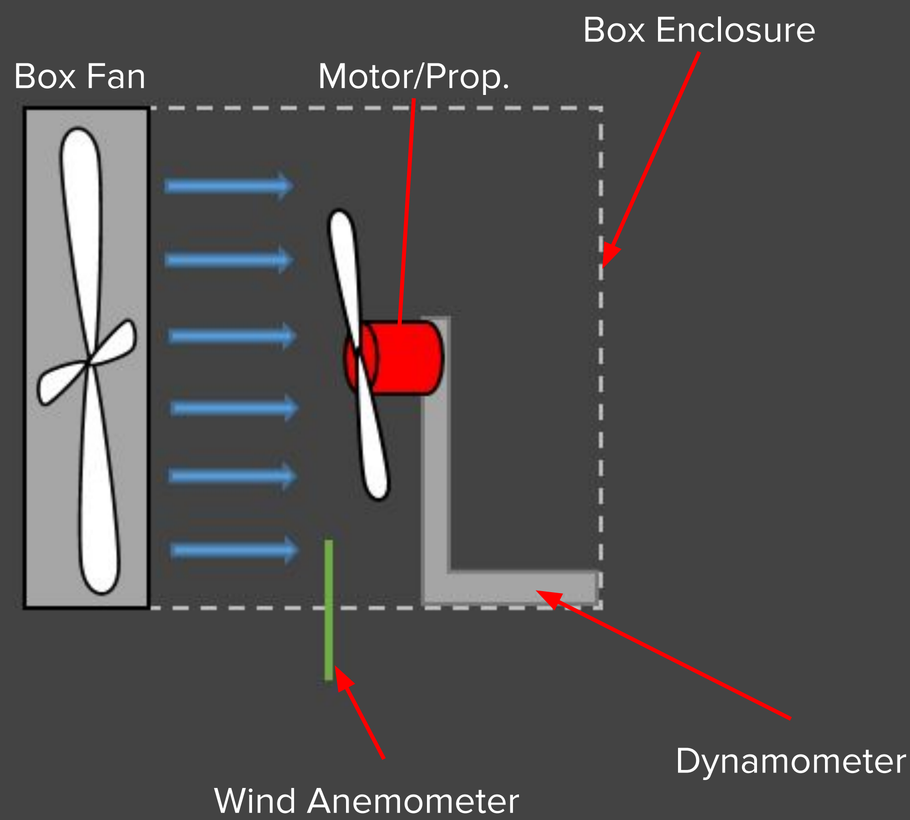


THEORETICAL DRAG POLAR



AVIONICS / PROPULSION BACKUP

MOTOR DYNAMOMETER TESTING



MOTOR DYNAMOMETER TESTING

- Pictures of test setup:

MOTOR DYNAMOMETER TESTING

- Main takeaways of tests:
  - Max throttle static thrust is **1140g**
  - Optimal Throttle is **59%** (test showed 724g on 100% charge and over hour of endurance)
  - Estimated Thrust at Flight Speed of 11.1 m/s is **576g**
  - Tests show motor performs better than expected but still agree with models' predictions.

MOTOR DYNAMOMETER TESTING

- Results Comparison

Value	eCalc			Static Experimental			Dynamic Experimental (Low)	Dynamic Experimental (Medium)
Thrust %	56	64	72	49.5	59	100	59	59
RPM	5400	6000	6600	6800	7989	-	-	7096
Thrust (g)	471	581	703	520	723	1140	656	600

- Note eCalc was verified using experimental data last semester and is very reputable among professionals here at CU

MOTOR DYNAMOMETER TESTING

- Possible Sources of Error:
  - Anemometer: Wind speed reading may not have been representative of what propeller actually experienced due to turbulent vortex produced from box fan.
    - Risk: Low
      - Localized velocity distribution did not vary by more than a few km/hr which equates to less than 1 m/s discrepancy
  - Dynamometer: Box fan produced heavy oscillations when turned on which may have affected readings.
    - Risk: Low
      - Dynamometer senses vibrations so their presence can be detected; vibrations were in the up/down direction - not axial.

MOTOR DYNAMOMETER TESTING

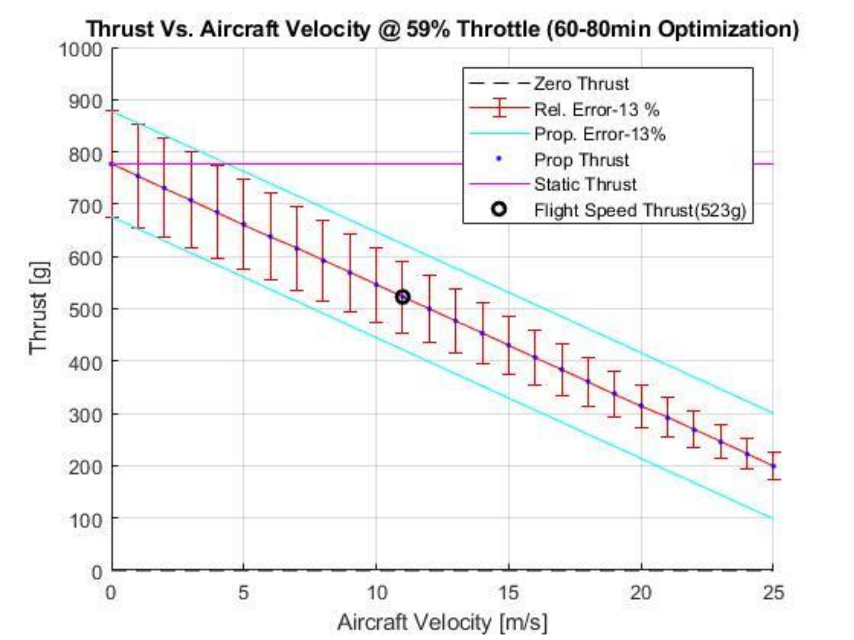
- Dynamic 'wind test' results

Wind Speed	Thrust	RPM
0m/s	700g	7941
5.56m/s	656g	-
8.06m/s	600g	7096

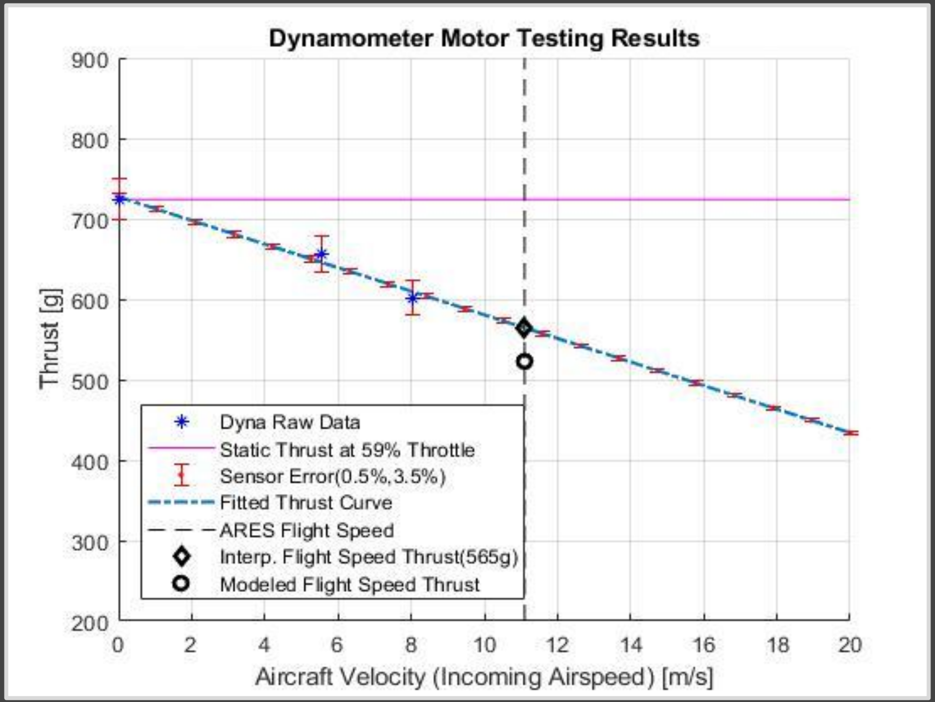
MOTOR DYNAMOMETER TESTING

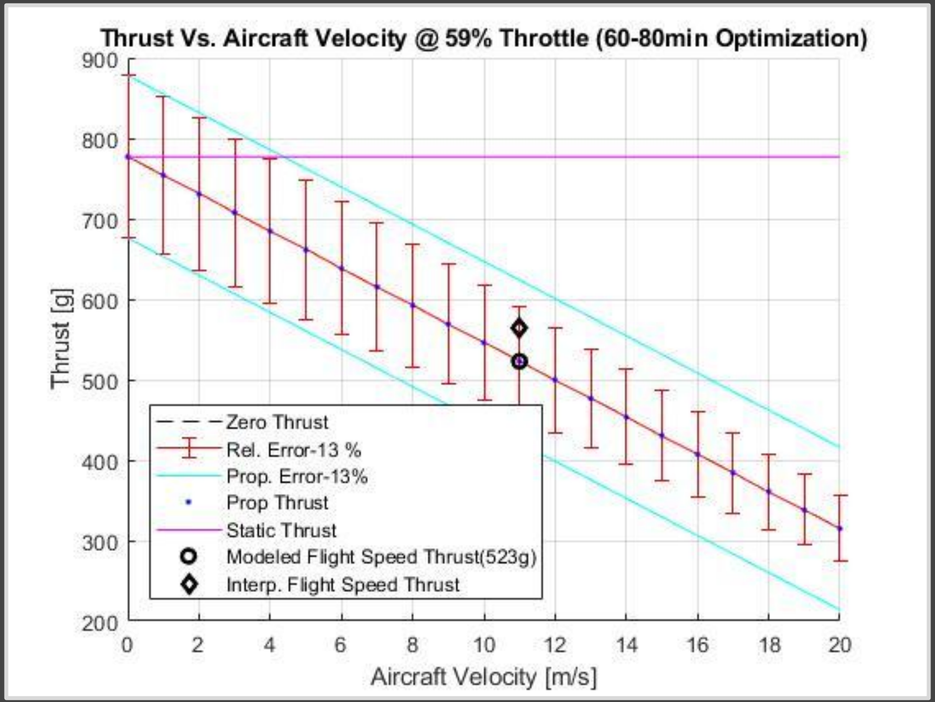
- Static versus Dynamic Model for Testing Comparison/Verification

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



MOTOR DYNAMOMETER TESTING





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

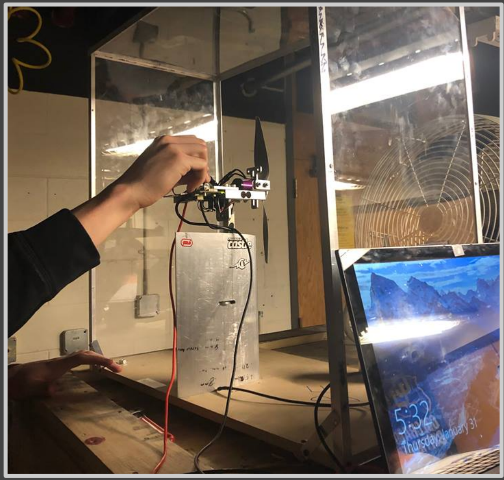
- Test Description:
  - Using Avionics and Propulsions subsystem components: 4 LiPo batteries (3200mAh), Power Management Board (PMB), ESC, and Propulsions Motor
  - Connect batteries to (PMB), then connect ESC to PMB, then Motor to ESC
  - Run the motor at a constant throttle
  - Record: the battery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

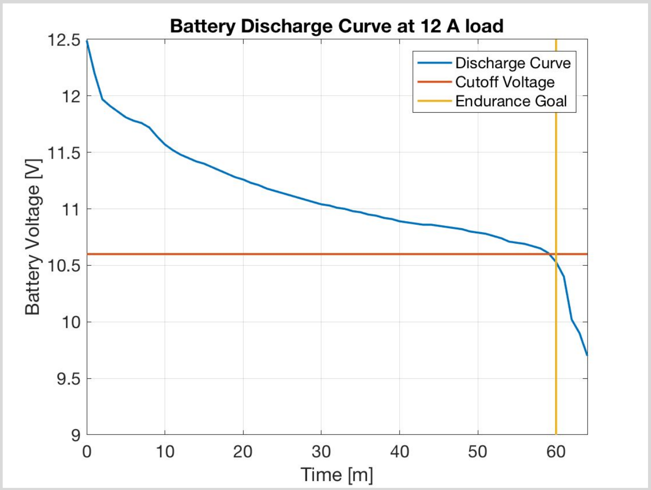
Device	Measurement	Accuracy
Fluke Multimeter	Voltage [V]	± 0.15%
Stopwatch	Time [s]	± .01s

Risk Reduction: Verify DR 1.1.1 prior to airframe integration to remove risk of power outage during flight

AVIONICS CHARGING/DISCHARGING

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





FADS FRIDGE TEST

Driving Requirement
DR 5.2.1: The temperature sensor shall be accurate to within 0.1 K.

Risk Reduction: Verify DR 5.1.3 and DR 5.2.1 prior to integration to ensure accurate data collection

Test Description:

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

Device	Measurement	Accuracy
Scanivalve	Press. [Pa]	± .20%, ± 5 Pa*
Thermometer	Temp. (*C)	?

AVIONICS AUTOPILOT POWER

Driving Requirements

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

- Test Description:
  - Controls and autopilot system wiring completed with all components: Pixhawk 4, Power Management Board, RC Receiver, Airspeed Sensor, Servos, ESC, Motor, and microSD card connected.
  - Plug in LiPo batteries to system in order to begin arming.
  - Turn on RC transmitter controller to finish autopilot arming cycle.
  - Use RC controller to test functionality of servos,
  - Record: voltage levels of ESC connector and servo rail using handheld multimeter.
  - Check microSD card after test to verify data was collected.

Risk Reduction: Verify that the autopilot system and its components can all be powered at the correct voltage using the components present on the aircraft

Device	Measurement	Accuracy
Fluke Multimeter	Voltage [V]	± 0.15%

A.P. RC TRANSMITTER TEST

Driving Requirements

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
  - Move autopilot system 300m away from Taranis X9D
  - Power on subsystem and provide RC inputs through Taranis X9D
  - Record: Response time of servos and propulsion motor and distance between transmitter and receiver

Device	Measurement	Accuracy
Taranis X9D	Res. Time [ms]	0-9ms
Rangefinder	Dist. [yard]	±0.5yards

Risk Reduction: Prove RC transmission distances for true flight operation and quantify delay (if any)

A.P. PITOT TUBE CALIBRATION

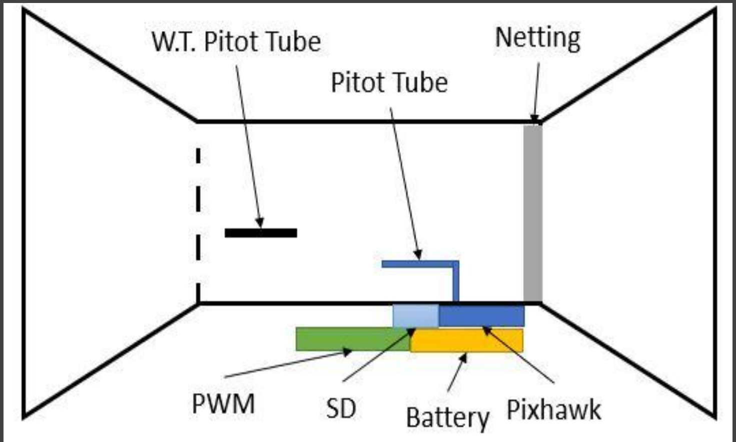
Driving Requirements

DR 4.6: The autopilot system shall be able to send commands to actuators and the propulsion system to move control surfaces and make speed adjustments.

Bernoulli's Equation

$\Delta p = 0.5\rho v^2$

- 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 to 15 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



Risk Reduction: Verify that airspeed sensor used to prevent stall will function properly

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

A.P. CONTROL SURFACE RESPONSE

Driving Requirements

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

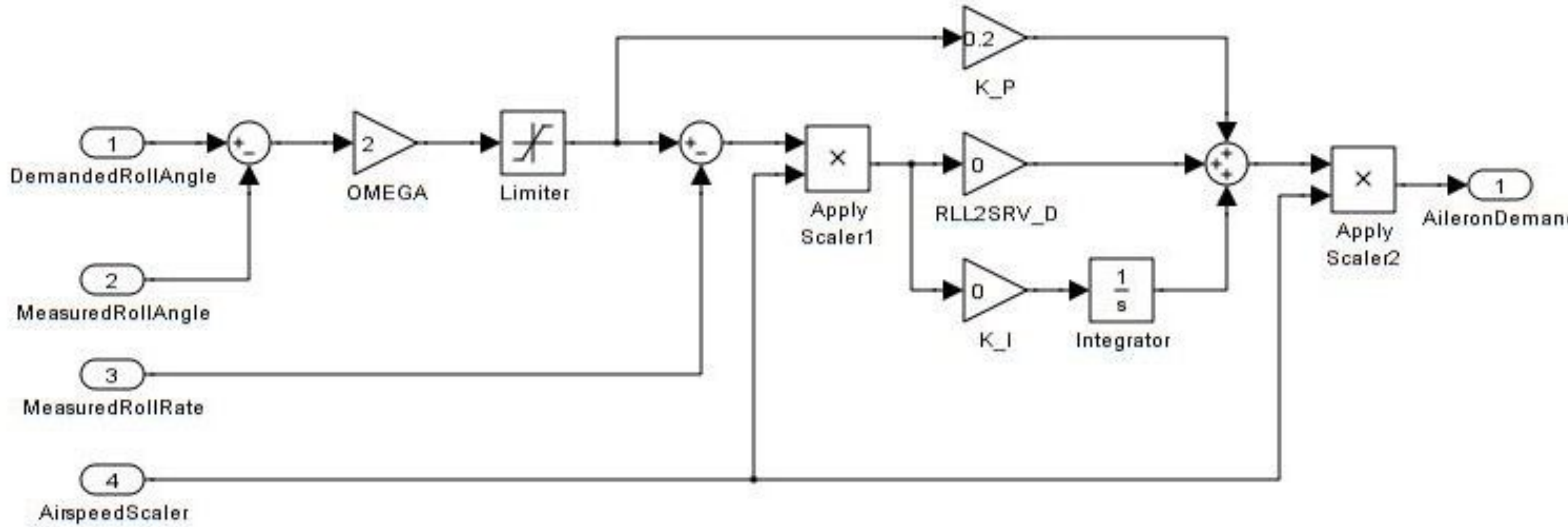
DR 4.6: The autopilot system shall be able to send commands to actuators and the propulsion system to move control surfaces and make speed adjustments.

- 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 motor.

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

Risk Reduction: Ensure desired control surface deflection prior to flight tests

ROLL CONTROL BLOCK DIAGRAM



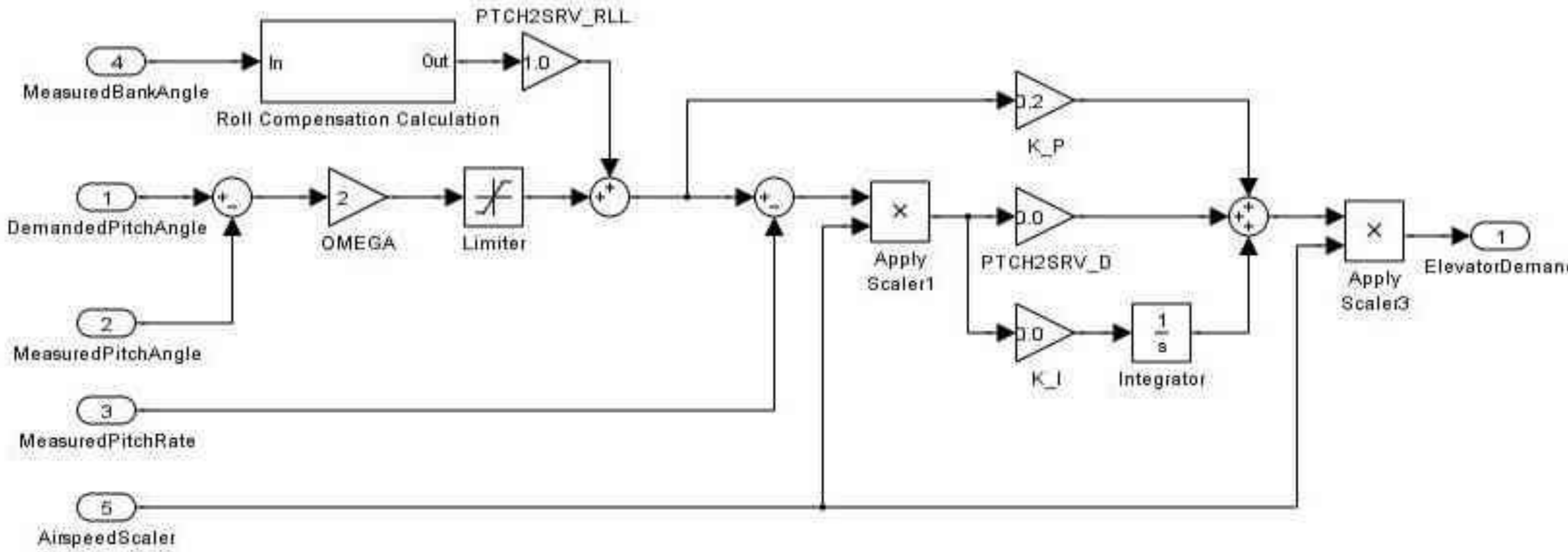
OMEGA = 1 / RLL2SRV_TCONST

K_P = (RLL2SRV_P - RLL2SRV_I * RLL2SRV_TCONST) * RLL2SRV_TCONST - RLL2SRV_D

K_I = RLL2SRV_I * RLL2SRV_TCONST

Limiter constrains signal between -RLL2SRV_RMAX and +RLL2SRV_RMAX

PITCH CONTROL BLOCK DIAGRAM



OMEGA = 1 / PTCH2SRV_TCONST

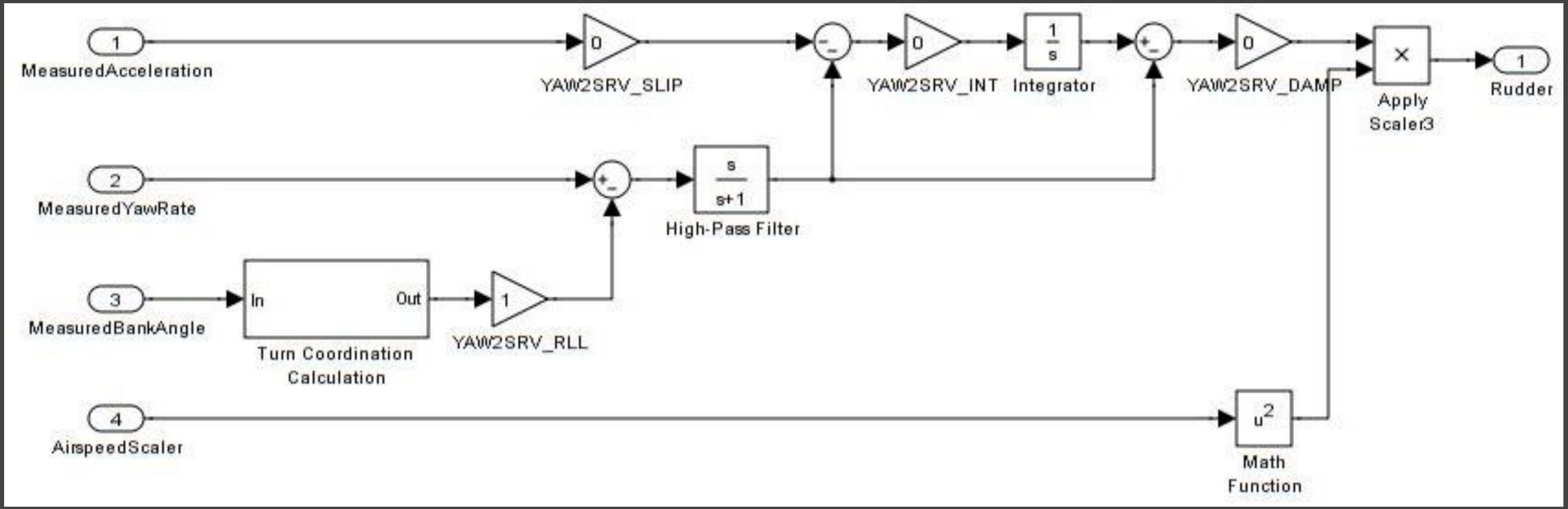
K_P = (PTCH2SRV_P - PTCH2SRV_I * PTCH2SRV_TCONST) * PTCH2SRV_TCONST - PTCH2SRV_D

K_I = PTCH2SRV_I * PTCH2SRV_TCONST

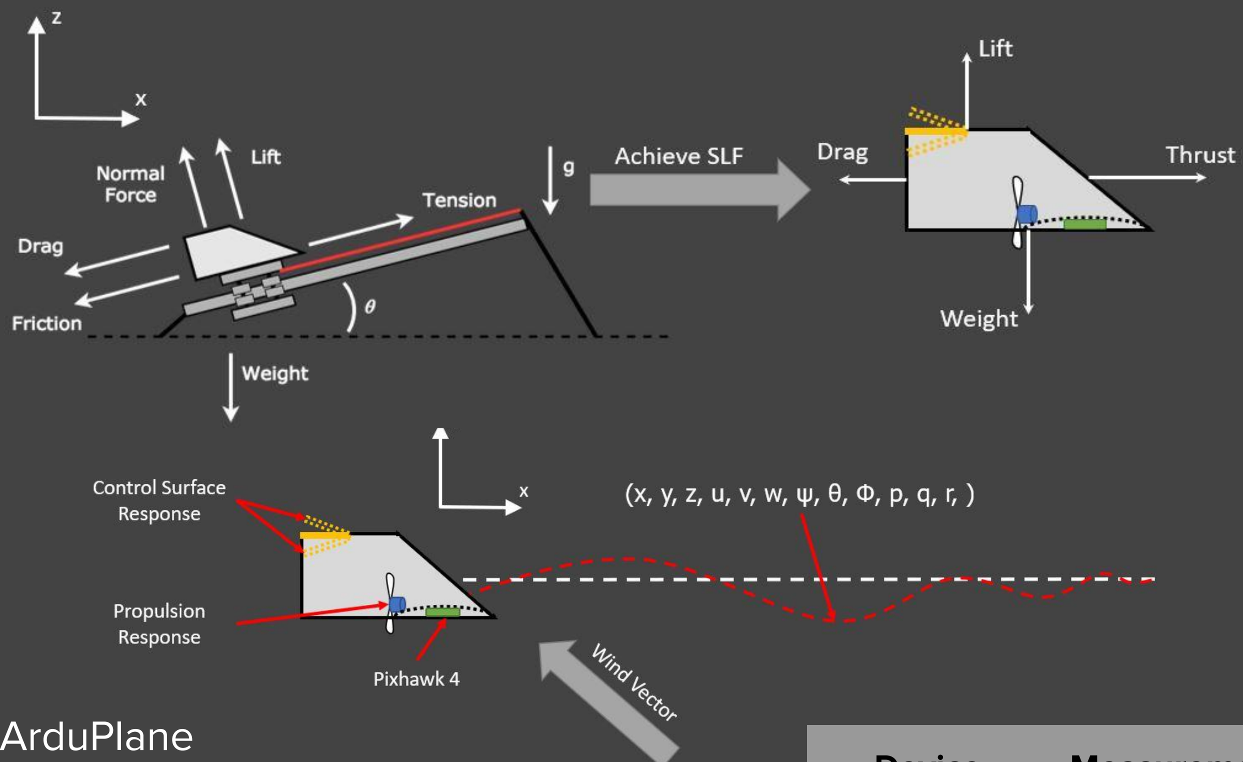
Limiter constrains signal between PTCH2SRV_RMAX_DN and PTCH2SRV_RMAX_UP

Roll Compensation = PTCH2SRV_RLL * gravity / (airspeed * tan(BankAngle) * sin(BankAngle))

YAW CONTROL BLOCK DIAGRAM



SHORT RC FLIGHT TEST



Conclusion: Use ArduPlane autotuning feature during RC flight test to get PID gains for stabilization

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

TAKEOFF BACKUP

CHANGES SINCE MSR

- 90° bend removed from legs
- New bungees
  - K band did not stretch
- 4 bungee connection points on carriage
- “L” brackets instead of clips on rail
  - Stronger connection prohibits sagging
- Torque Inhibitors to help guide carriage on rail
  - Carriage was torquing on rail and not sliding
- Pin release instead of lever
  - Safer and more reliable release
- Airfoil negatives in wing clips
  - To hold the aircraft more stable
- Base plate added with rebar stakes
  - For safety

BUNGEE RECOVERY TESTING

Driving Requirements

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

DR 3.3.1: The takeoff system shall accommodate 10 takeoffs without violating takeoff parameter constraints defined in DR 3.1 and DR 3.2.

Objective:

- Validate the degradation of the bungees after each simulated launch

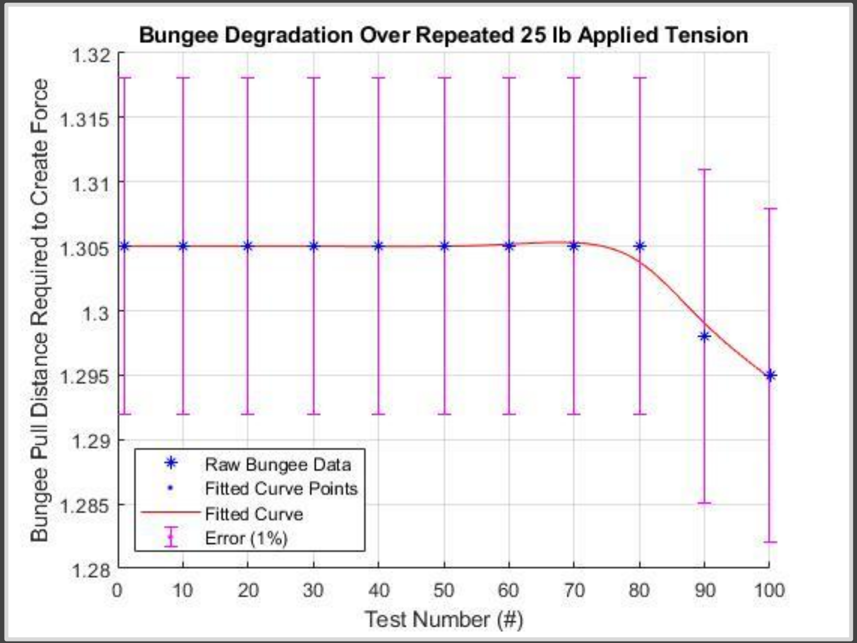
- Test Description:
  - Rationale: Quantify the reduction in bungee strength over their use to verify that DR 3.3 will not have failure due to the bungees
  - Test Fixtures/Facilities: The bungees will be tied to a fixed surface in the ASEN Senior Projects Lab and tested for force of stretch using a spring scale
  - Procedure: Tie Bungee to fixed surface, measure out a length of 1.305m on the bungee, measure out a pull distance of 2m, pull the bungee 100 times recording distance required to create 25lbs of force

Risk Reduction: Ensure bungees response to operation is nominal and will not impact takeoff system

Device	Measurement	Accuracy
Spring Scale	Weight [lbs]	± 1%

BUNGEE RECOVERY TEST RESULTS

- Test Results:
  - The Bungee shows little to no degradation over 100 tests
    - Reduction of 0.01m (0.77%)
    - Loss of 0.843 N

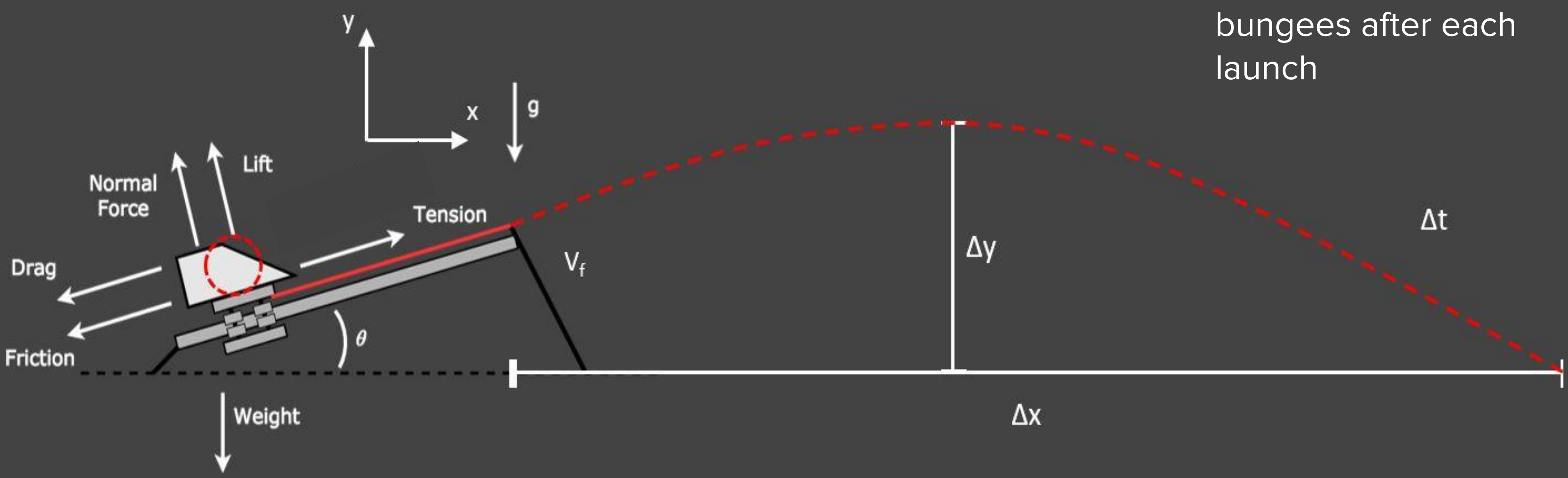


LAUNCH VELOCITY TEST

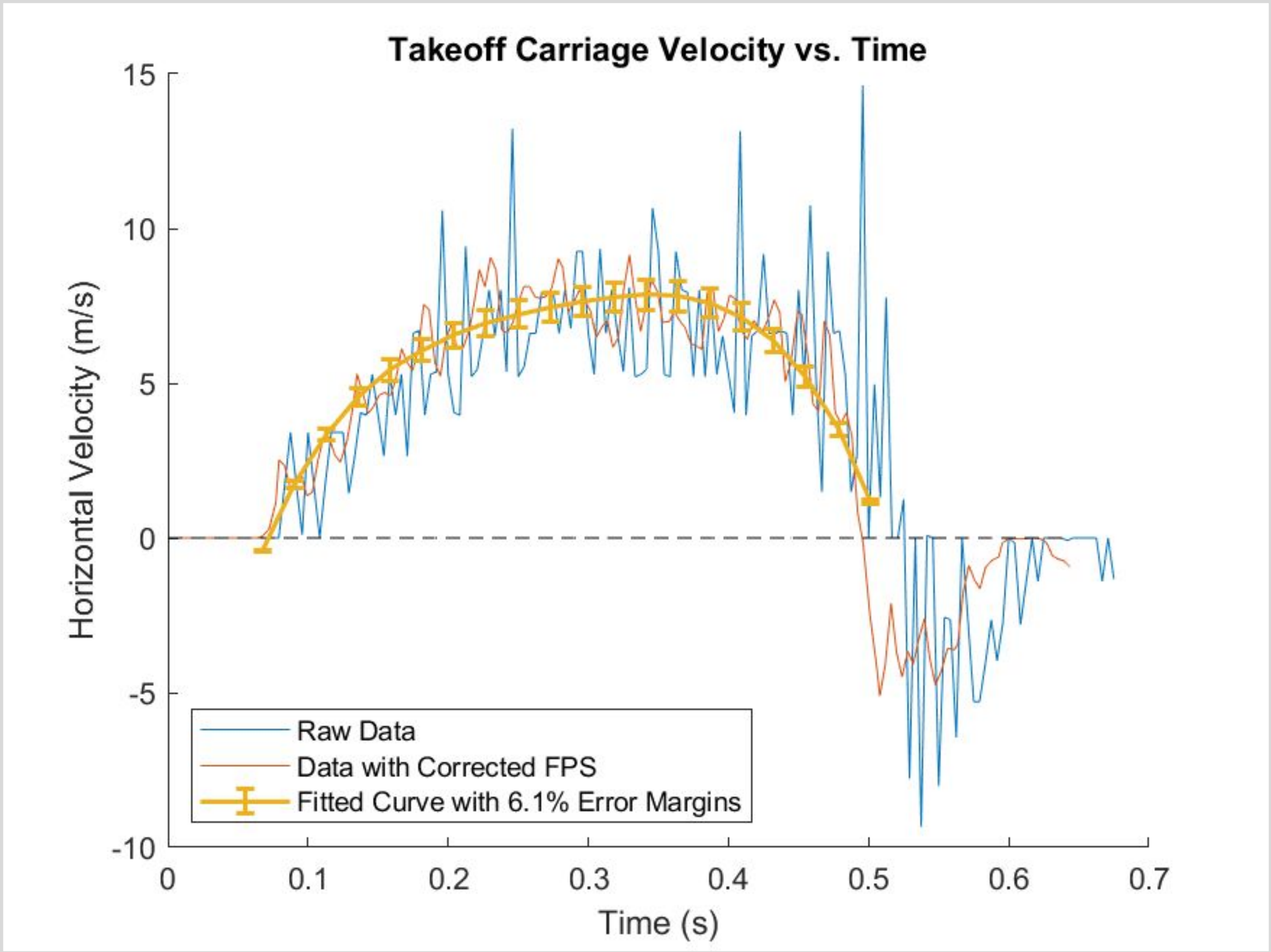
Driving Requirements

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} = 11.1m/s
- Validate the degradation of the bungees after each launch



Takeoff GUI Data vs Time

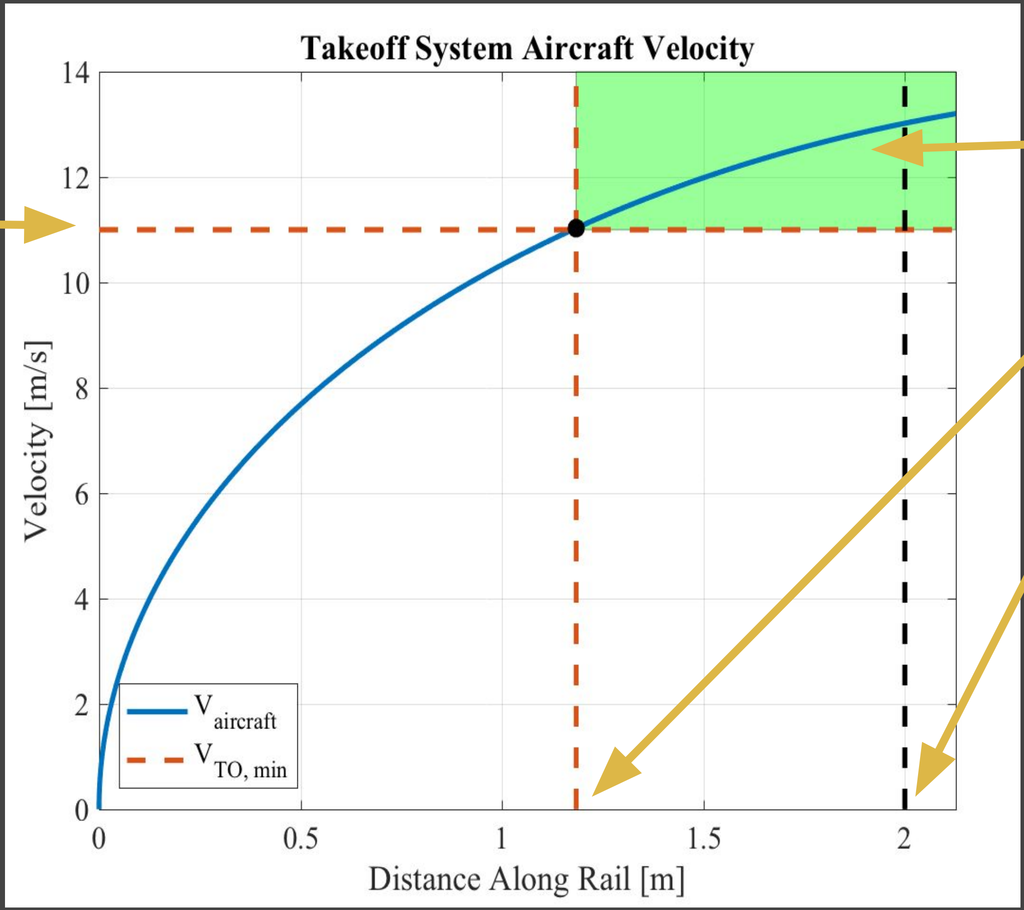


CDR LAUNCH VELOCITY MODEL

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

Outputs:

Rail = 2 m
F_{bungee} = 399 N

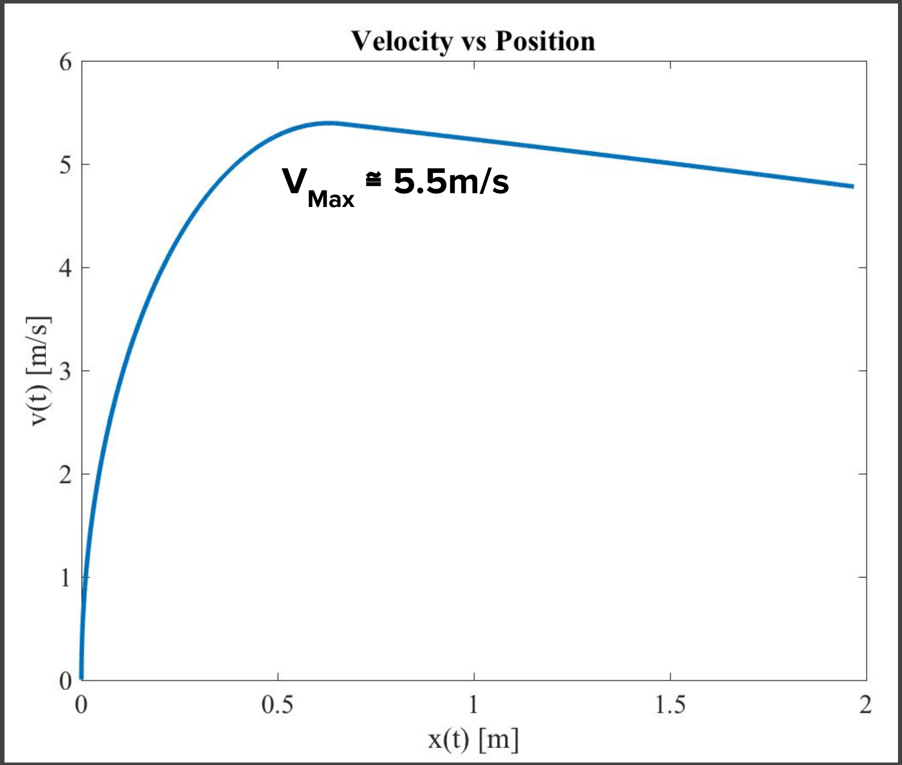


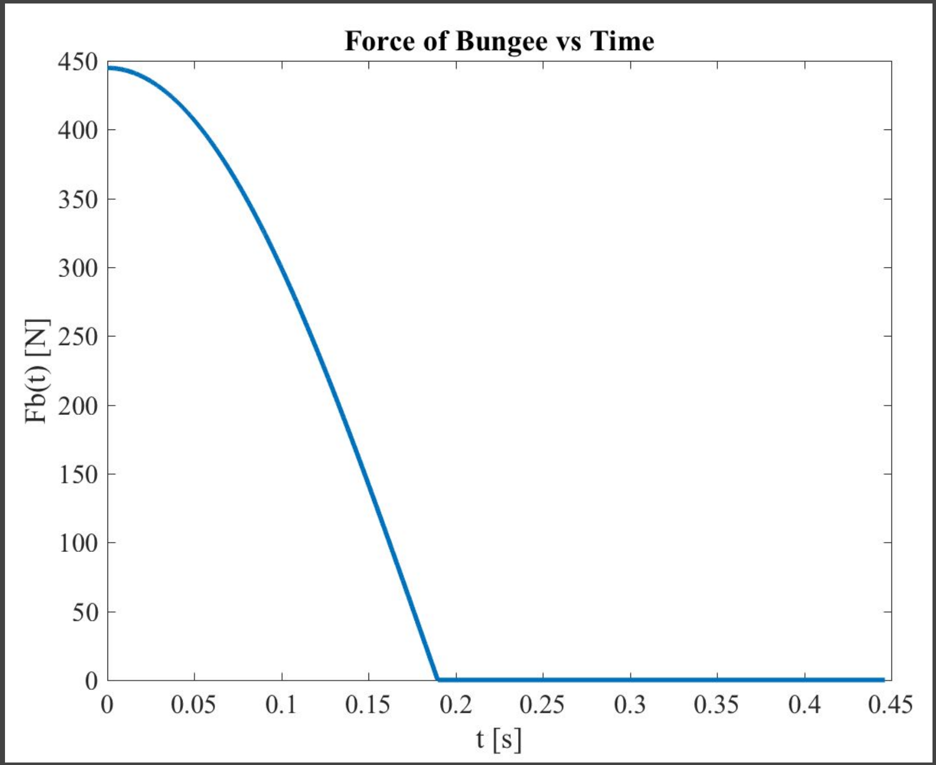
Design Space

Min rail length: 1.18 m

Design rail length: 2.00 m

NEW LAUNCH VELOCITY MODEL

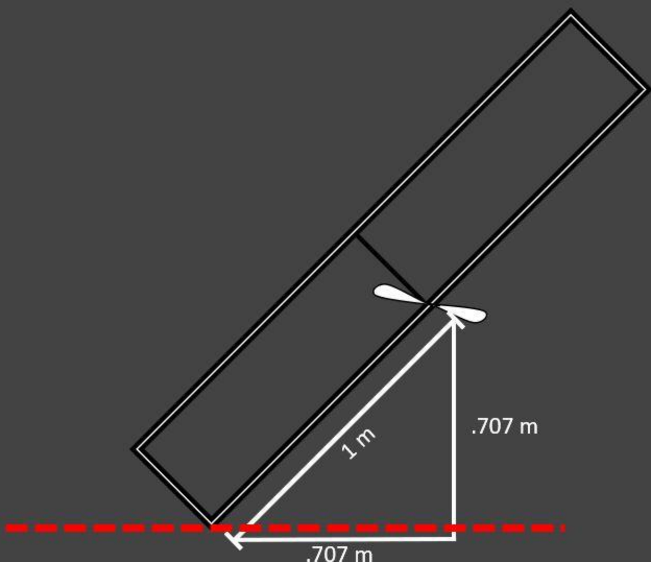


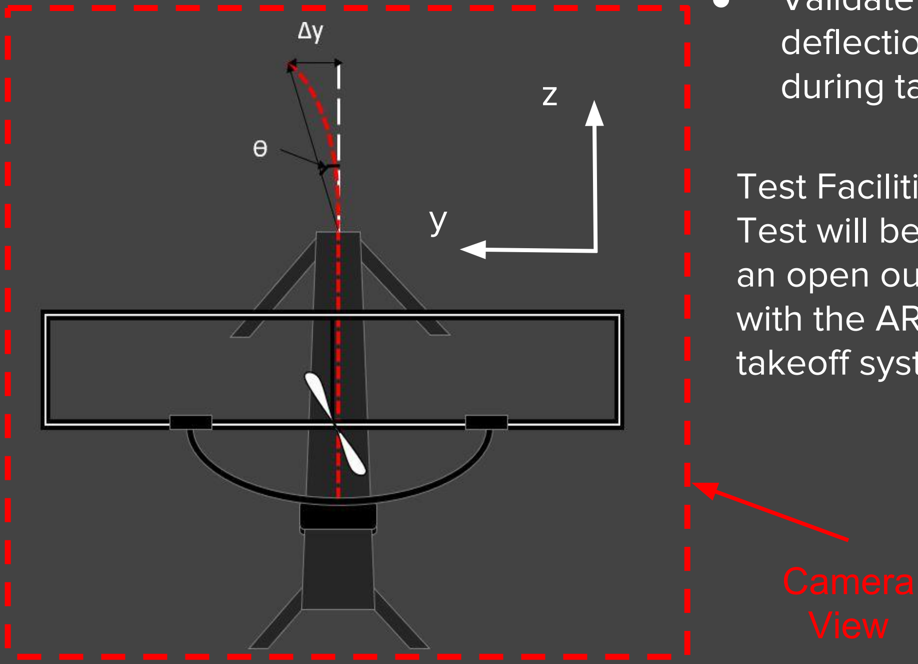


STABLE TAKEOFF TEST

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

Test Facilities/Equipment: Test will be performed in an open outdoor location with the ARES airframe and takeoff system.

SYSTEM TEST BACKUP

AIRFRAME TESTING SUMMARY

Test	Driving Req.	Date	Method	Location/ Facility	Level of Success
Airframe - Model Glide	DR 2.1.3 & DR 2.2	02/15/19	Testing	CU ECCR Courtyards	Flight 1
Airframe - Model Takeoff Launch	DR 3.1 & DR 3.2.1	02/22/19	Testing	CU South Campus	Flight 1
Airframe - Model Takeoff Survival	DR 3.4	02/22/19	Testing	Boulder Aeromodeling Society	Flight 1
Airframe - Model Landing Survival	DR 6.1 & DR 6.4	02/22/19	Testing	CU South Campus	Landing 1
Airframe - Powered Takeoff Test	DR 1.1 & DR 1.2 & DR 1.2.1	03/18/19	Testing	CU South Campus	Flight 2
Airframe - Short RC Flight Test	DR 2.1.3 & DR 4.4	03/22/19	Testing	CU South Campus	N & C - 1 Flight - 2

AVIONICS TESTING SUMMARY

Test	Driving Req.	Date	Method	Location/ Facility	Level of Success
Av. - Autopilot Power	DR 4.3	01/21/19	Testing	ASEN Electronics Lab	-
Av. - Battery Charging/ Discharging	DR 1.1.1 & DR 1.1.2	01/25/19	Testing	ASEN Senior Projects Lab	-
Av. - Autopilot Sensor Calibration	DR 4.6	01/26/19	Testing	ITLL Wind Tunnel	-
Av. - Autopilot RC Transmission	DR 4.3 & DR 4.4	NEED DATE	Testing	ASEN Senior Projects Room	Navigation/Control 1
Av. - FADS in Fridge	DR 5.1, DR 5.2.1, DR 5.3, DR 5.5.2, DR 5.5.3, DR 5.6	02/22/19	Testing	Team Member Home	Data Capture 1
Av. - FADS in Wind Tunnel	DR 5.1.3, DR 5.3, DR 5.5.2, DR 5.5.3	02/25/19	Testing	ITLL Wind Tunnel	Science 1 & 3

AVIONICS TESTING SUMMARY

Test	Driving Req.	Date	Method	Location/ Facility	Level of Success
Av. - Dynamometer	DR 1.2 & DR 1.2.1	02/25/19	Testing	CU ASEN Composites Lab	-
Av. - Control Surface Response	DR 4.4 & DR 4.6	03/3/19	Testing	CU Business Field	Navigation/Control 1
Av. - Avionics Day in the Life	FR 5.0 & All 5.0 DR's	03/13/19	Testing	ASEN Senior Projects Lab	Data Capture 1 & 2
Av. - Autopilot Day in the Life	FR 4.0 & All 4.0 DR's	03/13/19	Testing	ASEN Senior Projects Lab	N & C - 1 Flight - 1

TAKEOFF TESTING SUMMARY

Test	Driving Req.	Date	Method	Location/ Facility	Level of Success
T.O. - Bungee Recovery	DR 3.3 & DR 3.3.1 & DR 3.4.3	01/30/19	Testing	ASEN Senior Projects Room	-
T.O. - Launch Velocity	DR 3.2 & DR 3.3	02/22/19	Testing	Boulder Aeromodeling Society	-
T.O. - Stable Takeoff/ Wing Deflection	DR 3.0 & DR 3.1	02/22/19	Testing	CU South Campus	Flight 2

OBSERVATION TESTING 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	-

FULL SYSTEM TESTING SUMMARY

Test	Driving Req.	Date	Method	Location/ Facility	Level of Success
ARES Autopilot Short Flight	All Functional & Design Requirements	03/27/19	Testing	CU South Campus	-
ARES Full System Flight	All Functional & Design Requirements	04/1/19	Testing	CU South Campus	All Success Criteria 2 & 3

FADS DAY IN THE LIFE

Driving Requirements

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. **(All 5.0 Related DR's)**

- Test Description (follows ConOps process):
  - With components integrated onto airframe, AA batteries are connected and FADS power is turned on.
  - Assure Teensy and board LEDs are lit
  - Leave the sensors on to take data for the hour flight time
  - After the hour is completed, check to assure LEDs are still lit
  - Remove the SD card and analyze the data

Risk Reduction: Verify FADS subsystem is capable of running for mission time and confirm subsystem prior to flight

AUTOPILOT DAY IN THE LIFE

Driving Requirements

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

All 4.0 Related DR's

- Test Description:
  - With components integrated onto airframe, LiPo batteries are connected to begin system arming.
  - RC controller is turned on and the pairing is verified.
  - GPS fix is verified with flashing blue LED on module.
  - Servo and motor control verified with simple commands.
  - Triple switch changed to alter between full manual, stabilized, and mission autopilot control.
  - Takeoff, loiter circling, and landing cycles are tested.

Risk Reduction: Verify Autopilot subsystem is capable of running for mission time and confirm subsystem prior to integration

ARES AUTOPILOT SHORT FLIGHT

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:
  - Power on ARES Aircraft
    - Confirm recording of 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 3 Autopilot flight circles, descend, and land
  - **Validate:** Conditionally met all Design and Functional Requirements

Risk Reduction: Conditionally Validate system operation and response to auto-piloted flight prior to Full System Flight Test

Takeoff/Ascent Path
Single Flight Circle
Landing/Descent Path