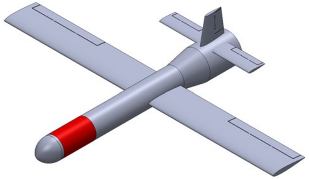
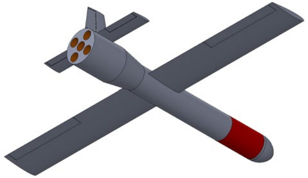
RAPTR



In Partnership with LOCKHEED MARTIN



Rapid Aerial Photographic Target Recognition

Preliminary Design Review Outline

1. Project Overview
2. Critical Project Elements
3. Baseline Design
4. Feasibility Analysis
5. Summary
6. Backup Slides/References

RAPTR Organization – Aerospace Team

Project Manager – AJ McKelvy
Systems Engineer – Logan Thompson

Mechanical and Structures	Propulsion	Aerodynamics	Controls and Electronics	Software
Austin Abraham	Anna Tiberi	Thad Gleason	Logan Thompson	Jeremiah Lane
Nick Carvo	Greg Clements	AJ McKelvy	Zach Donovan	Everett Hale
			Tyler Faye	

Project Motivation

- Need for Real Time Surveillance
- Military Context
  - Threat Detection
  - Threat Identification
- Search and Rescue Context
  - Situational Awareness

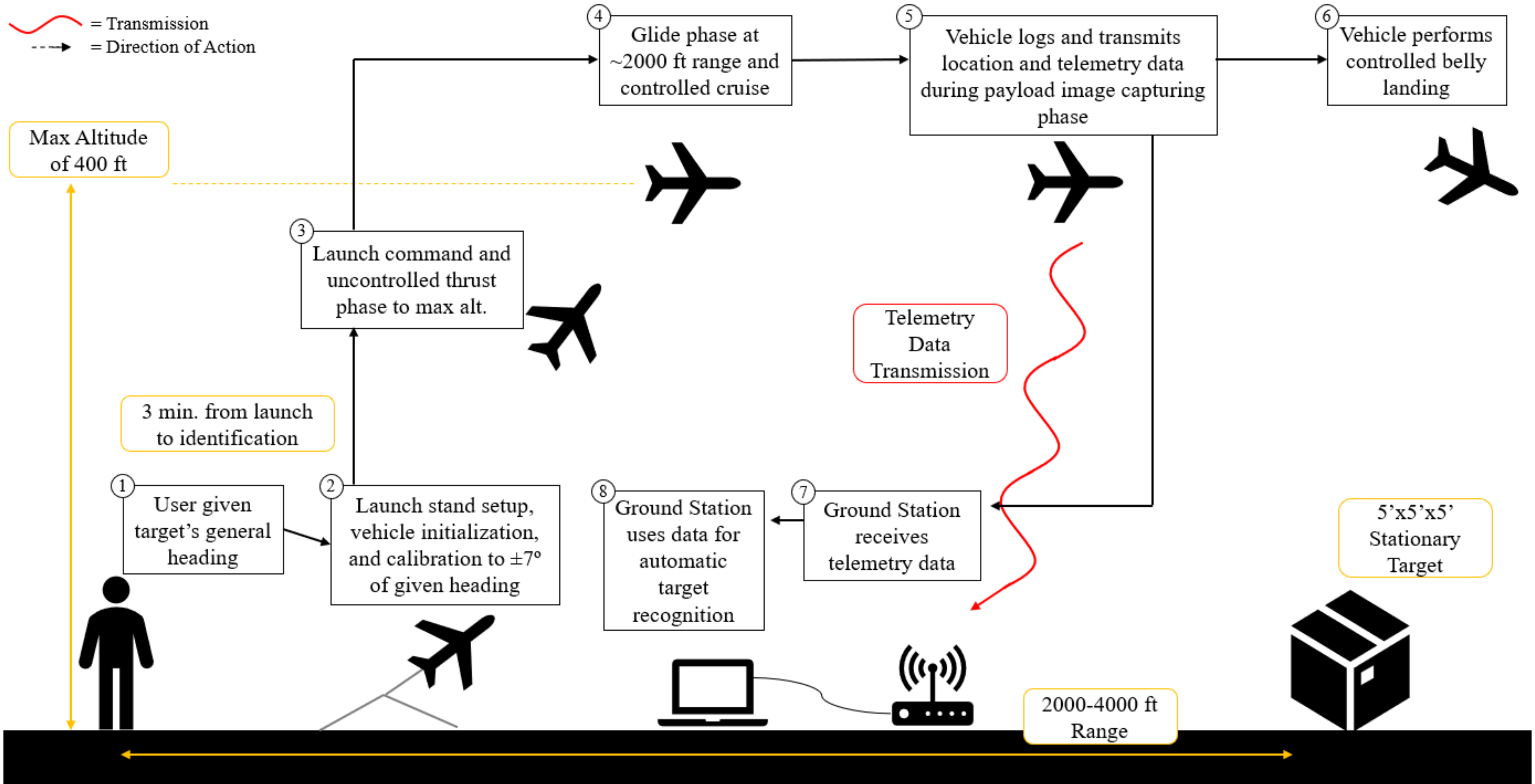
Project Statement

The purpose of this project is to design, manufacture, and test a portable, user-deployable system that can image and identify ground targets of interest and provide real time threat location and classification of said targets to a ground station within three minutes of initial system deployment.

Functional Requirements

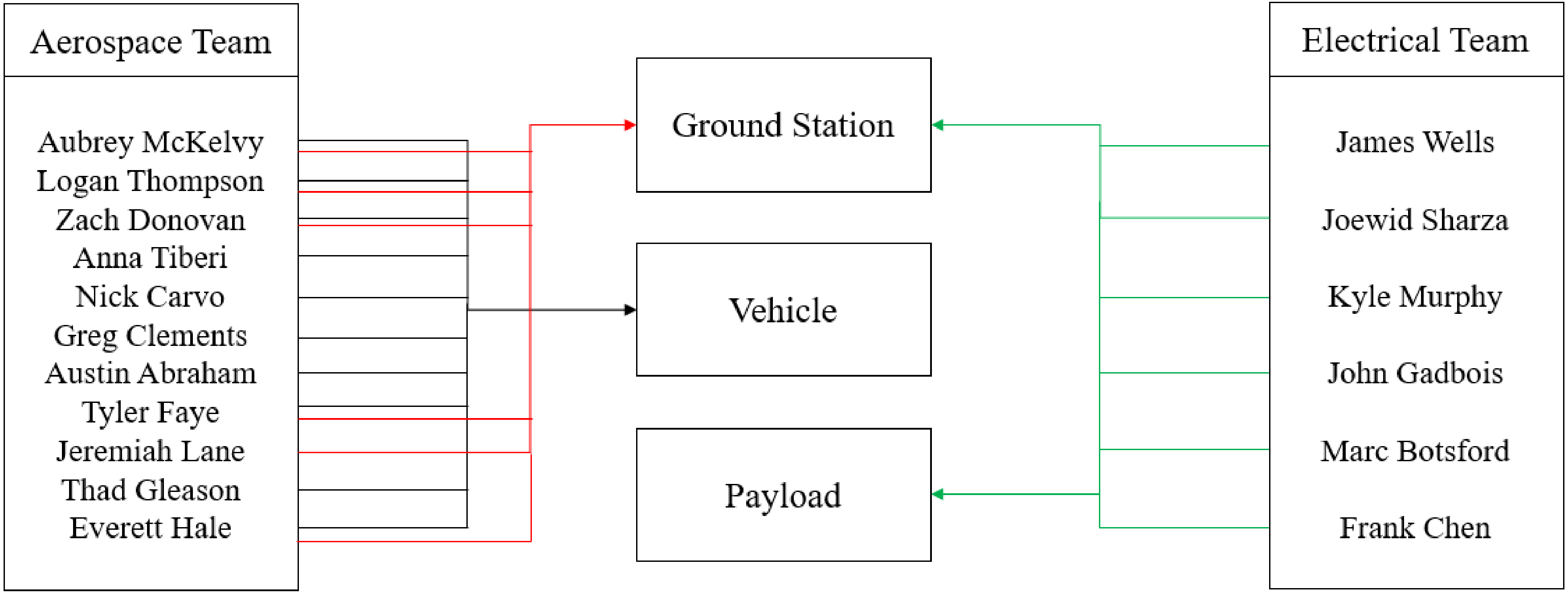
Requirement	Description
1	The system shall utilize image processing to detect a 5'x5'x5' stationary ground target that is 2000 feet downrange from the user and from an altitude of 400 feet.
2	The system shall be man portable and deployable on up to a 10 percent grade.
3	The system shall transmit images to a ground station.
4	The system shall identify a distinctly colored target and determine the unique target shape and relay the target's latitude and longitude.
5	The system shall complete its mission (deployment to processed images) within 3 minutes.
6	The system shall comply with all federal and state laws regarding testing and functionality of the system.

RAPTR – Aerospace Team Mission

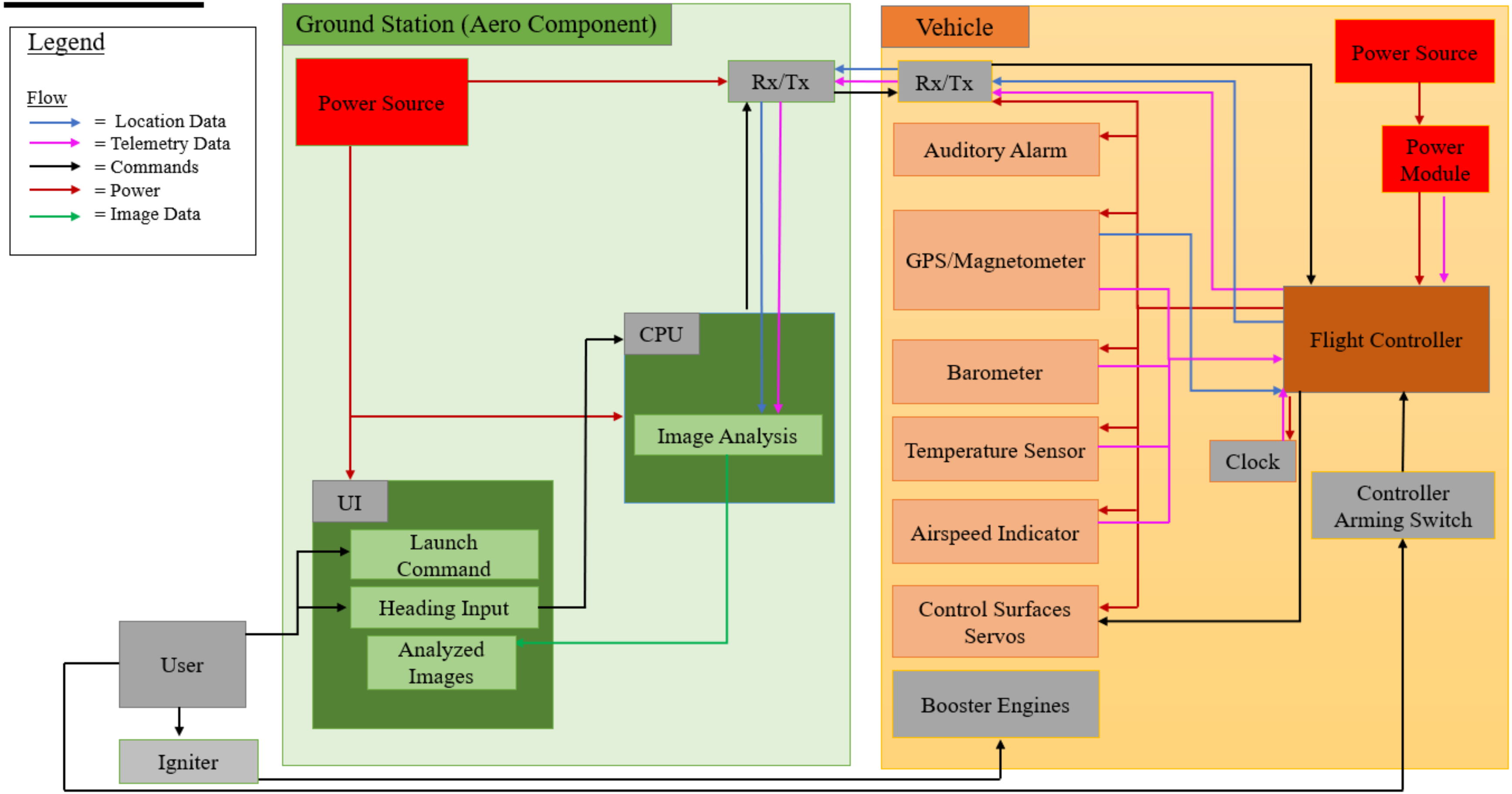


RAPTR Organization Chart

RAPTR Mission Components



RAPTR


Legend
Flow
= Location Data
= Telemetry Data
= Commands
= Power
= Image Data
Ground Station (Aero Component)
Power Source
Rx/Tx
CPU
Image Analysis
UI
Launch Command
Heading Input
Analyzed Images
User
Igniter
Vehicle
Rx/Tx
Power Source
Power Module
Auditory Alarm
GPS/Magnetometer
Flight Controller
Barometer
Temperature Sensor
Clock
Controller Arming Switch
Airspeed Indicator
Control Surfaces Servos
Booster Engines

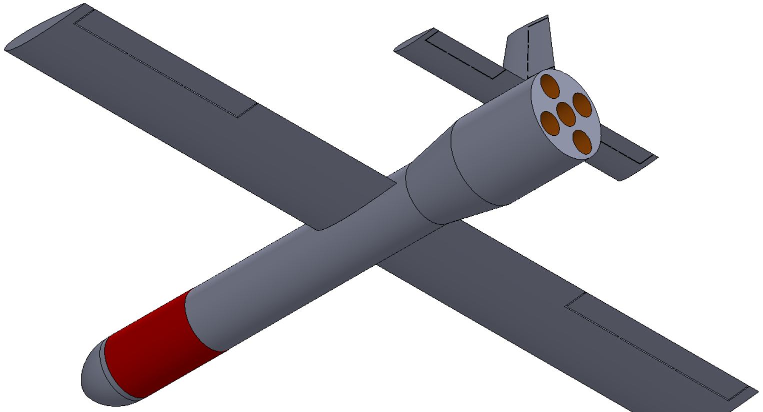
Critical Project Elements

CPE1	Control
CPE2	Power Needs
CPE3	Structural Integrity
CPE4	Manufacturability
CPE5	Size Constraint
CPE6	Vehicle Design
CPE7	Thrust Phase Performance
CPE8	Image Processing

Overview of Baseline Design

Component	Weight Estimate
Magnetometer/Gyroscope/Accelerometer/ Transceiver	0.35 oz
PixHawk	0.56 oz
Servo x4	7.05 oz (1.76 oz ea.)
Antenna	1.41 oz
Structures (Wing/Tube/Nosecone)	35.27 oz
Battery	14.11 oz
Camera	2.12 oz
Misc.	3.53 oz
Motors x5	10.95 oz (2.19 oz ea.)
Total	**75.34 oz / 4.71 lb**

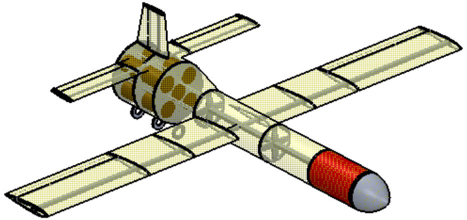
- Rocket Powered Glider
- Rib and Spar Wing Structure
- Pixhawk Autopilot Running Ardupilot Software
- Variable Elevation Tripod Launch Rail
- 5 "F-10-6" COTS motors

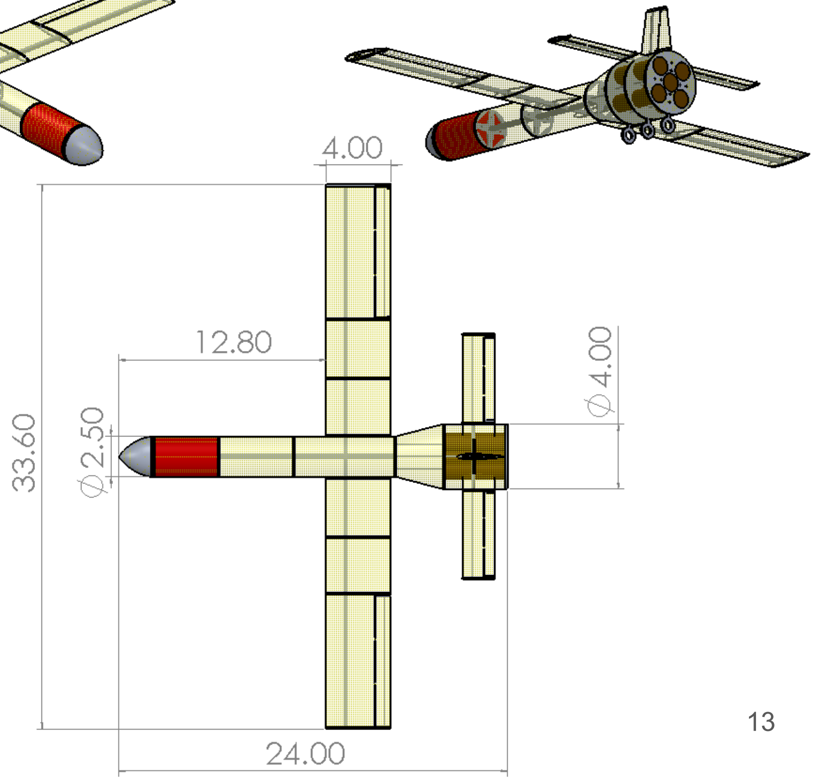


Feasibility Analysis

Mechanical and Structures: Design

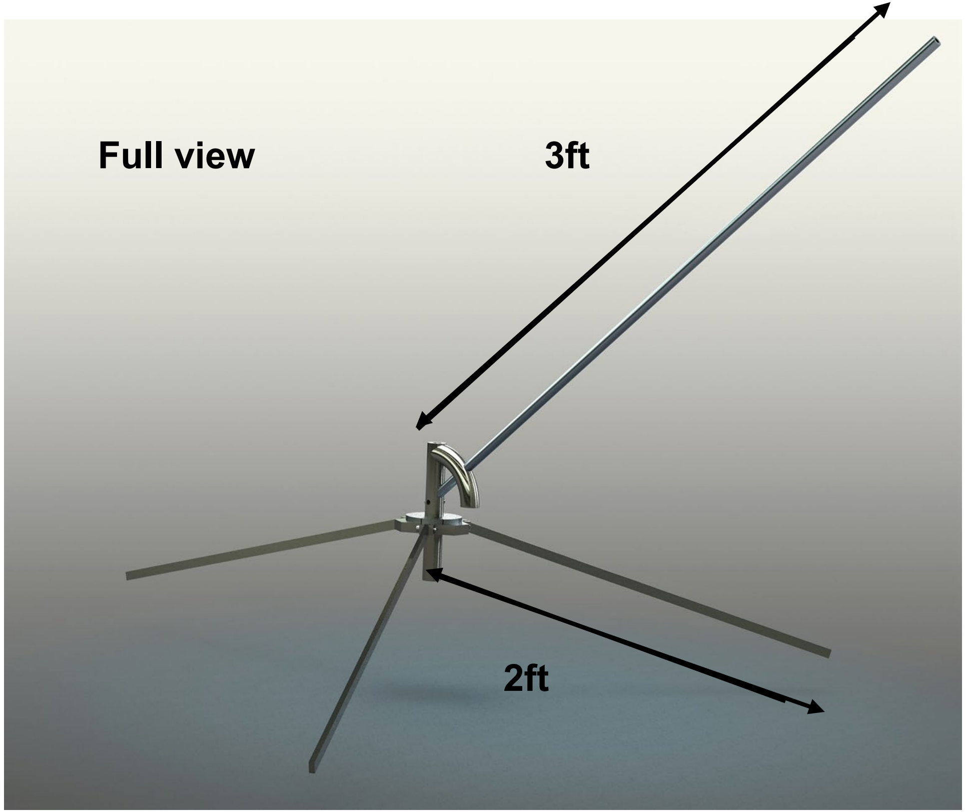
- Aluminum rib and spar design
- Monokote skin
- EE payload accommodation
  - 2.5" diameter by 4" length
  - 0.25 lb mass
- Approximate weight: 1.869 pounds





Mechanical and Structures: Launch Pad

- Deployment method: variable tripod launch rail
- Launch possible on variable terrain
- Ability to measure and adjust launch angle and azimuth angle

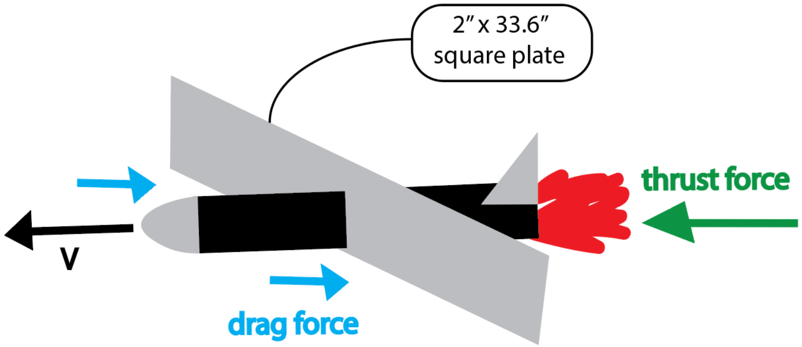


Mechanical and Structures: Wing Integrity

- Square plate wing drag assumption (shown below) → NASA gives $C_d = 1.28$
- Assume the vehicle experiences V_{max} during $T_{max} = (5 \text{ x } 4.5 \text{ lbf})$ → then $\sum F = (2 \text{ x } F_D) + T_{max}$
- Which gives shear stress $\tau_{model} = \sum F \div (2A_{CS,\ spar})$
- Can find factor of safety for different materials with $FOS = \tau_{max} \div \tau_{model}$
- From calculations:

$\longrightarrow \tau_{model}$ @ v = 100 ft/s = 236.78 psi

$\longrightarrow \tau_{model}$ @ v = 200 ft/s = 407.12 psi



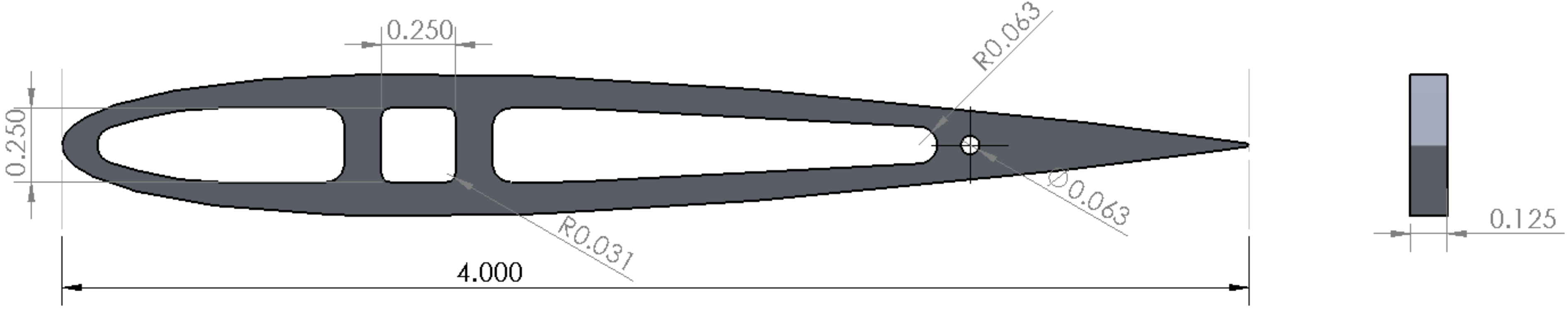
@ v = 100 ft/s ⟶ $\boxed{FOS_{Al} = 101.35}$ ⟶ $\boxed{FOS_{Balsa} = 0.675}$

@ v = 200 ft/s ⟶ $\boxed{FOS_{Al} = 58.95}$ ⟶ $\boxed{FOS_{Balsa} = 0.393}$

Based on data from www.matweb.com

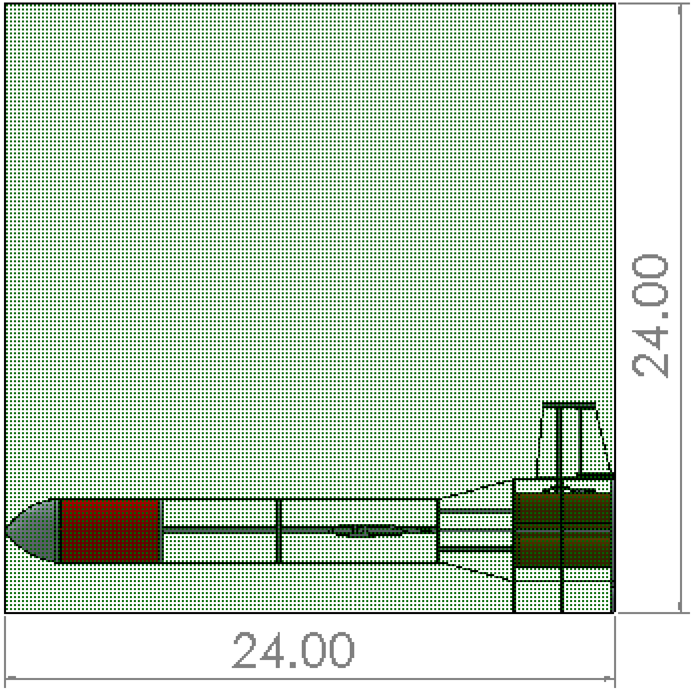
Mechanical and Structures: Manufacturability

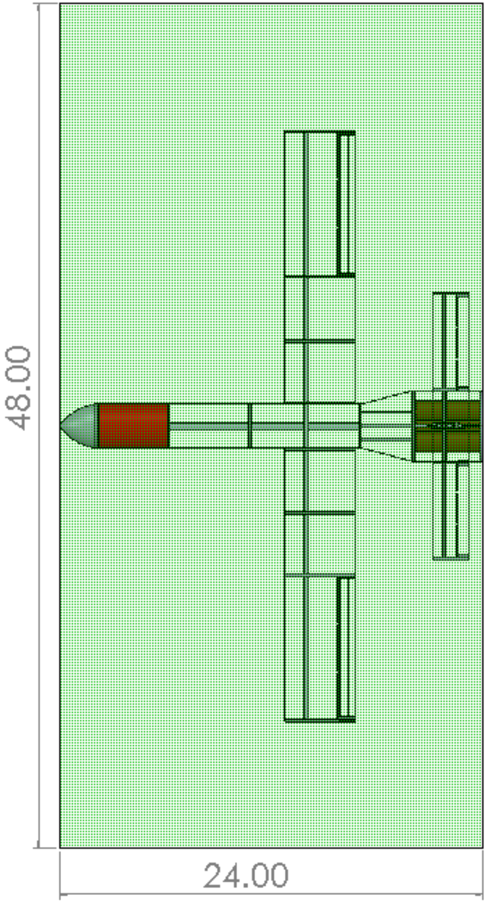
- All custom parts can be manufactured with on campus CNC mills and lathes
- Can be assembled with off the shelf fasteners or adhesive
- Homogenous structure of aluminum makes for simpler milling



Mechanical and Structures: Storage Volume

- Vehicle fits in the storage volume of 4'x 2' x 2'



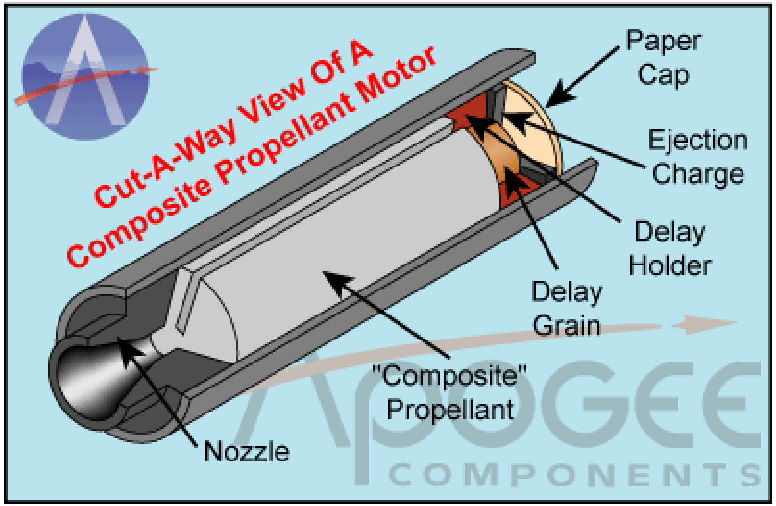


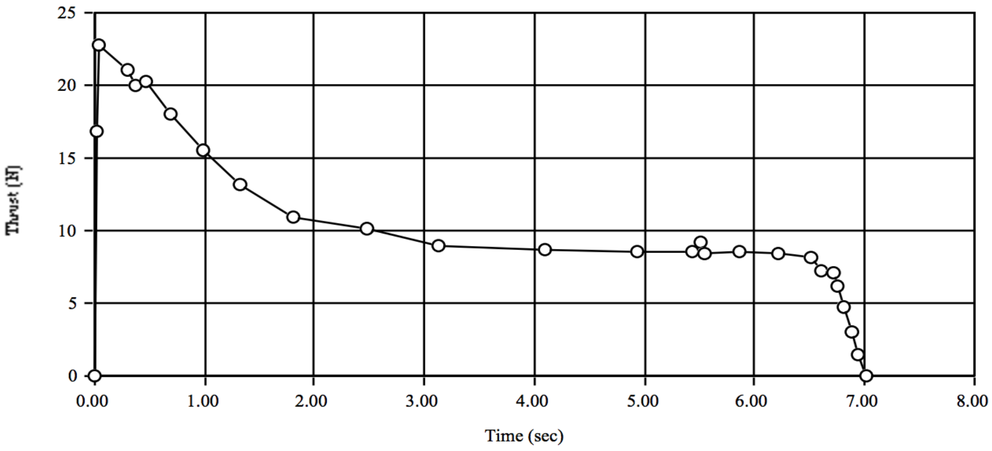
Mechanical and Structures: Feasibility

Requirement	Description	Feasibility Analysis
FR.2	The system shall be man portable and deployable on up to a 10 percent grade.	√Feasible
DR.2.1	The deployment system shall collapse to a fit within a 4'x2'x2' envelope and weigh no more than 10 pounds.	√Feasible
FR.5	The system shall complete its mission (storage to processed images) within 3 minutes.	√Feasible
DR.5.3.1	The vehicle shall be built to exhibit negligible electromagnetic interference.	√Feasible
FR.6	The system shall comply with all federal and state laws regarding testing and functionality of the system.	√Feasible
DR.6.1	Vehicle must comply with 14 CFR part 107.	√Feasible
DR.6.1.1	The vehicle must weigh less than 55 pounds.	√Feasible

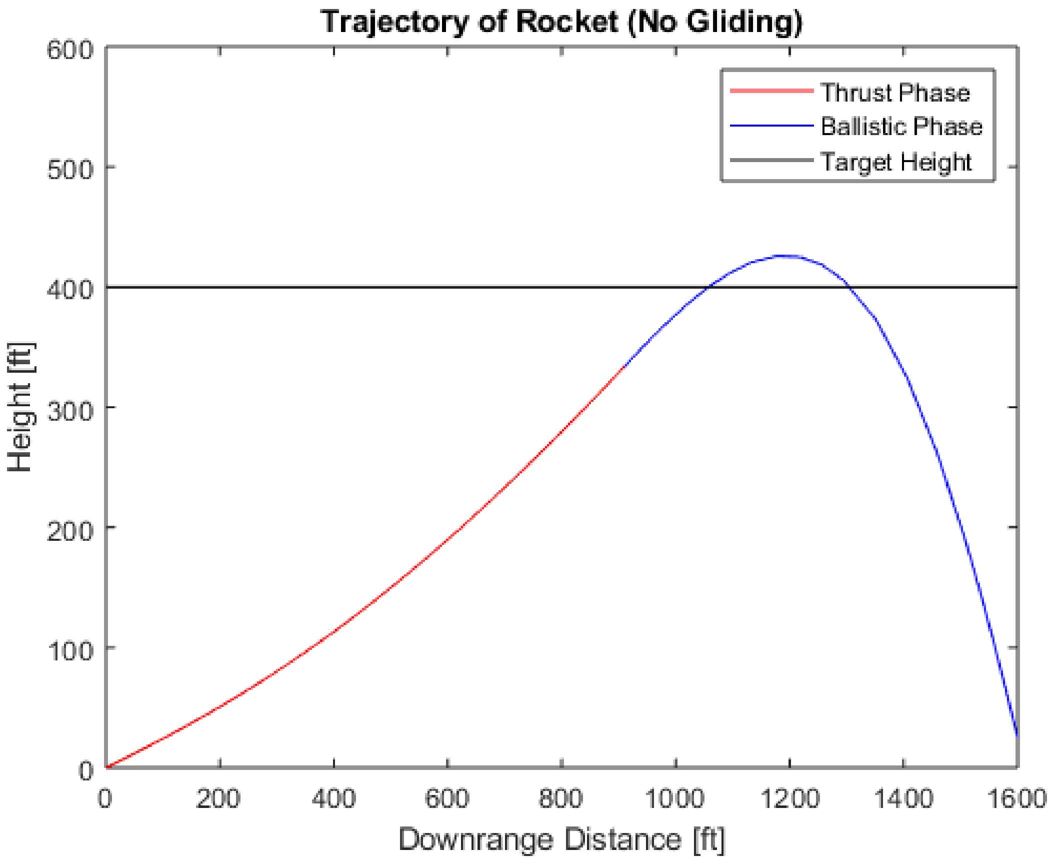
Propulsion: Model Rocket Booster

- 5x "F-10-6" COTS motors





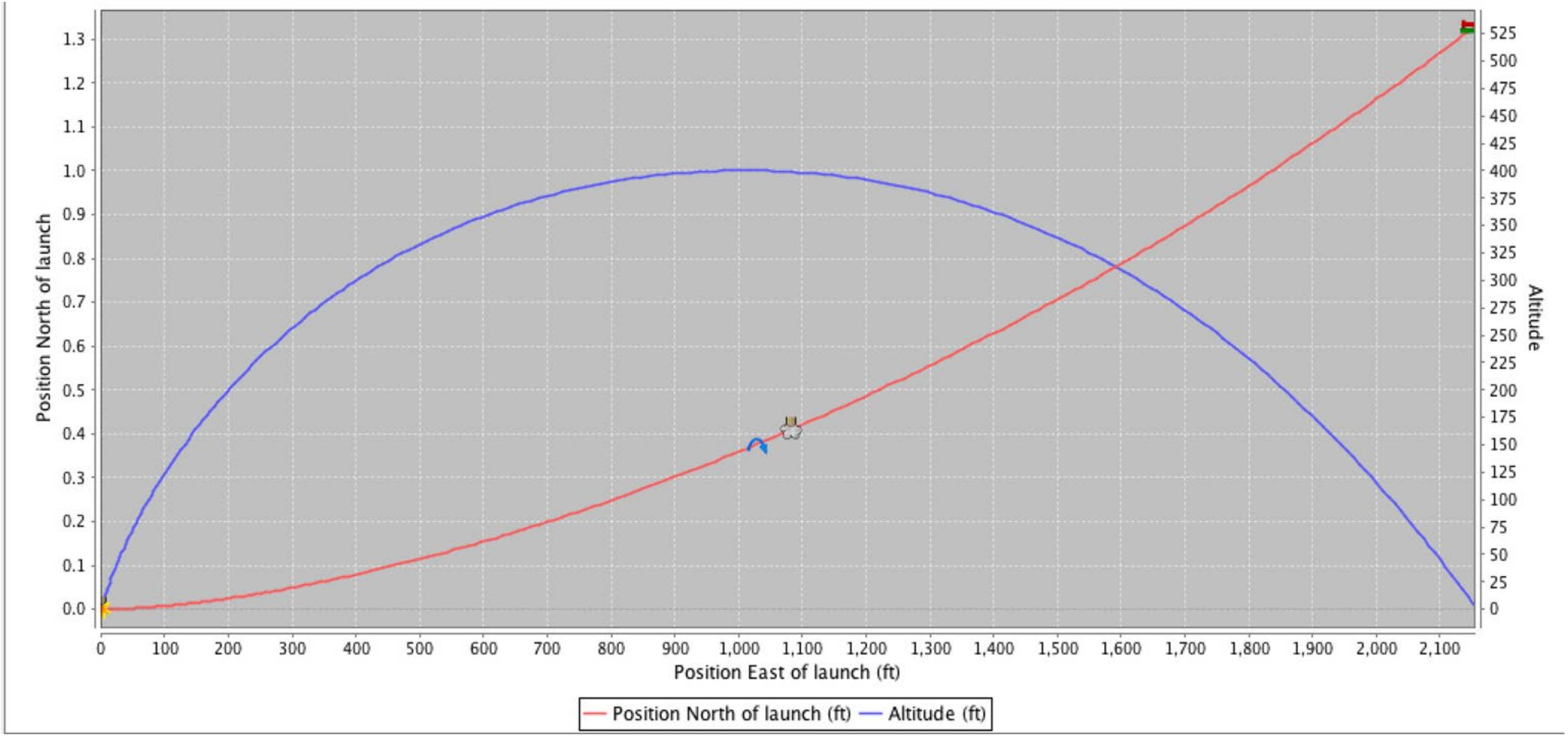
Propulsion: MATLAB Simulation



Propulsion: OpenRocket Design

Apogee: 400 feet
Max. Velocity: 265 ft/s
Max. Acceleration: 129 ft/s^2
Time to Apogee: 6.84 s
Flight Time: 12.2 s
Ground Hit Velocity: 221 ft/s

Propulsion: OpenRocket Simulation Ground Track



Propulsion: Feasibility

Requirement	Description	Feasibility Analysis
FR.5	The system shall complete its mission (storage to processed images) within 3 minutes.	✓Feasible
DR.5.2	The vehicle shall take less than 20 seconds to travel 2000 ft laterally and 400 ft vertically.	✓Feasible
DR.5.2.2	The vehicle shall achieve a horizontal speed of at least 100 ft/s.	✓Feasible

Aerodynamics: Design

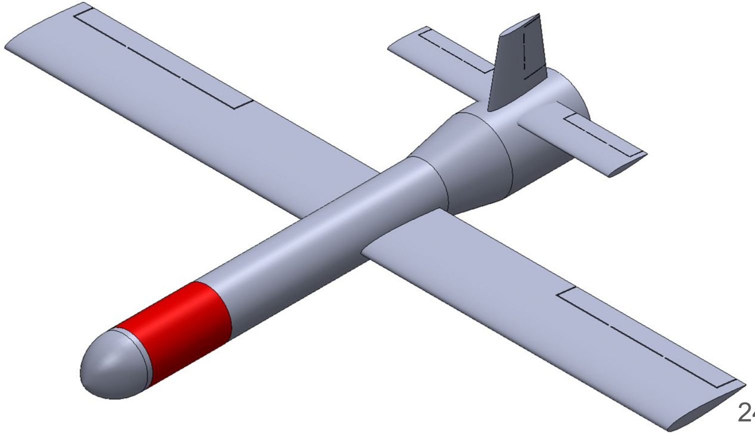
<u>Purpose:</u> Enable the vehicle to glide over the target area.

<u>What's Required:</u>

- Sustain uncontrolled boost to 400' AGL with 140 ft/s horizontal velocity
- Glide 2000' down range with < 100 ft altitude loss

<u>Design:</u>

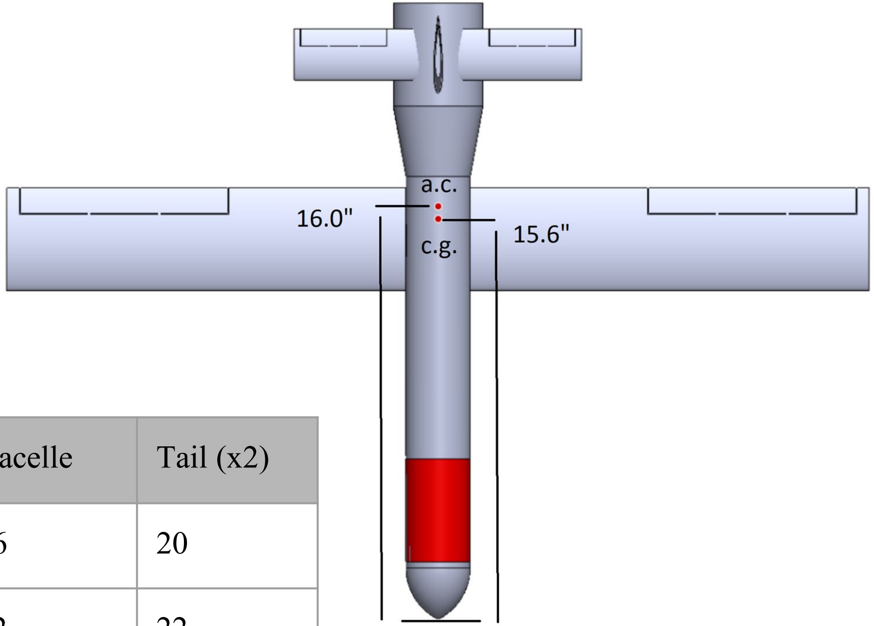
- Fixed High AR wing
- Symmetric Airfoil



Aerodynamics: Thrust Phase Stability

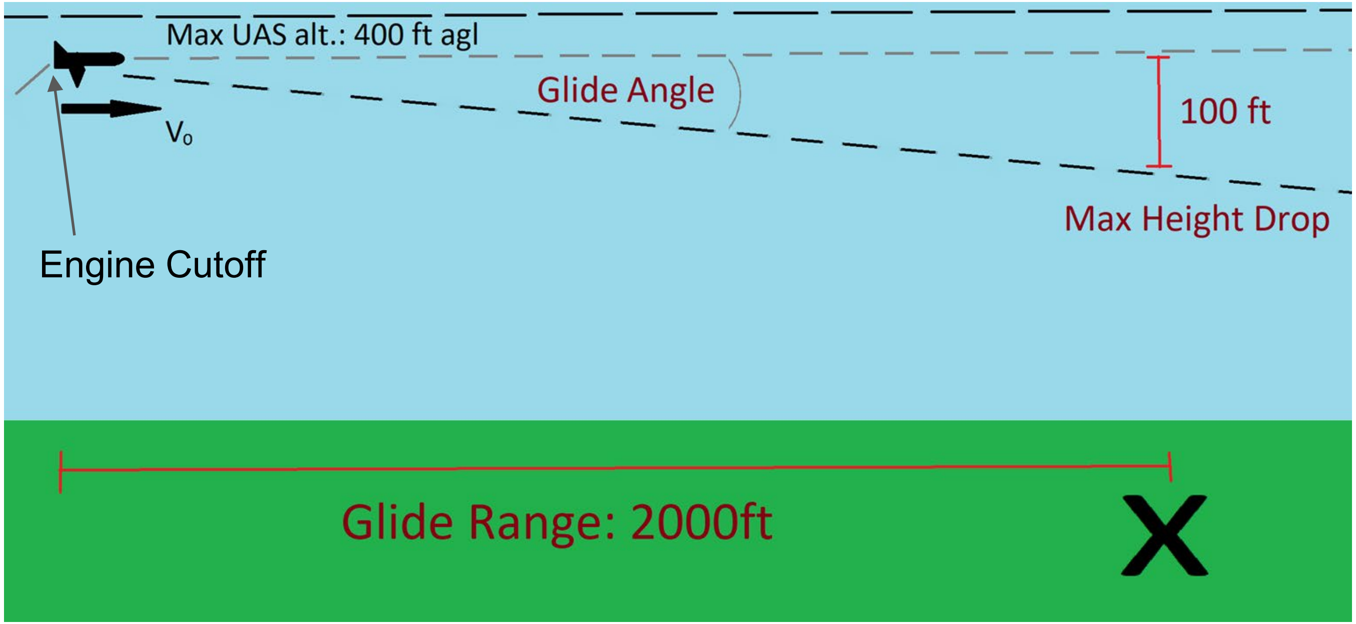
Requirements for Stability:
- a.c. aft of c.g. for negative static margin
- Zero Lift and Moment at trim state

How this will be achieved:
- Wing/Empennage configuration
- Symmetric Airfoil



	Nose	Fuselage	Wing (x2)	Taper	Nacelle	Tail (x2)
Area [in^2]	4	28	64	12	16	20
X [in]	2	9	15	19	22	22

Aerodynamics: Glide Performance Requirements



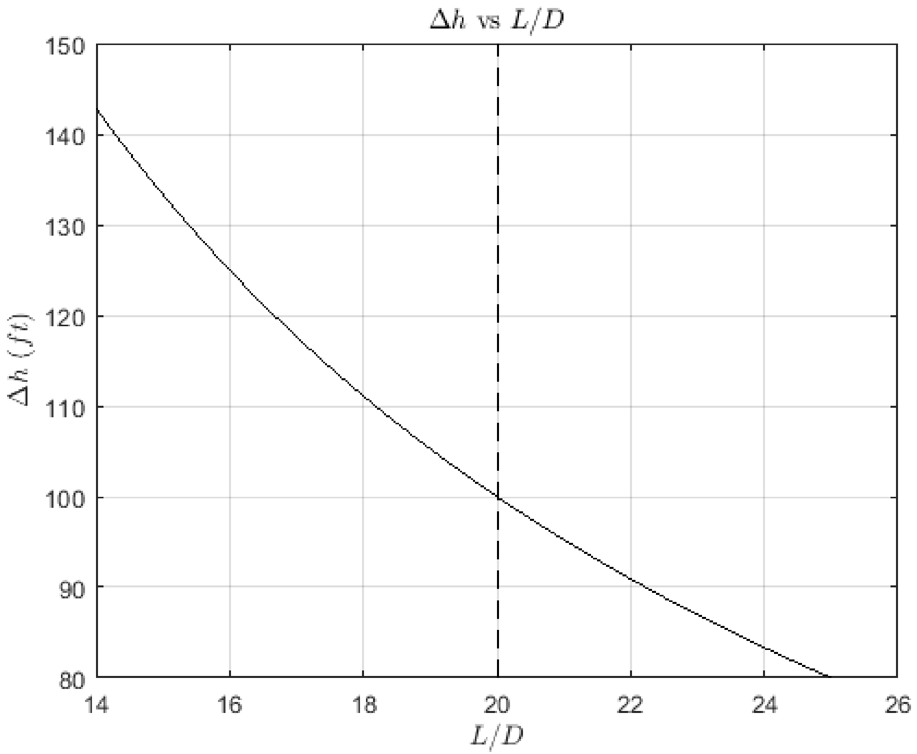
Aerodynamics: Glide Capability

Required L/D:

- R = 2000 ft
- < 100 ft altitude loss

$$\tan\gamma = \frac{\Delta h}{R} \qquad \tan\gamma = \frac{1}{\frac{L}{D}}$$

$$R = \frac{L}{D}\Delta h$$



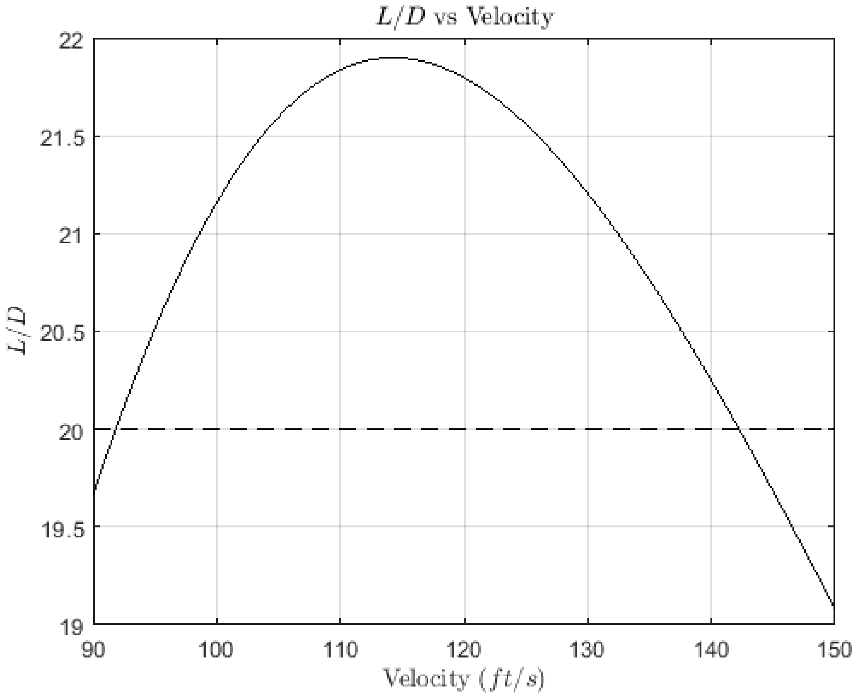
Aerodynamics: Lift-to-Drag Ratio

- Vary velocity from 90-150 ft/s
- Assume weight of 6 lb
- Assume span of 2.85 ft
- Use following equations to calculate L/D

$$C_f = \frac{1.328}{\sqrt{Re}} \qquad C_D = C_{D,0} + \frac{C_L^2}{\pi e AR}$$

$$e = 1.78(1 - 0.045AR^{0.68}) - 0.64$$

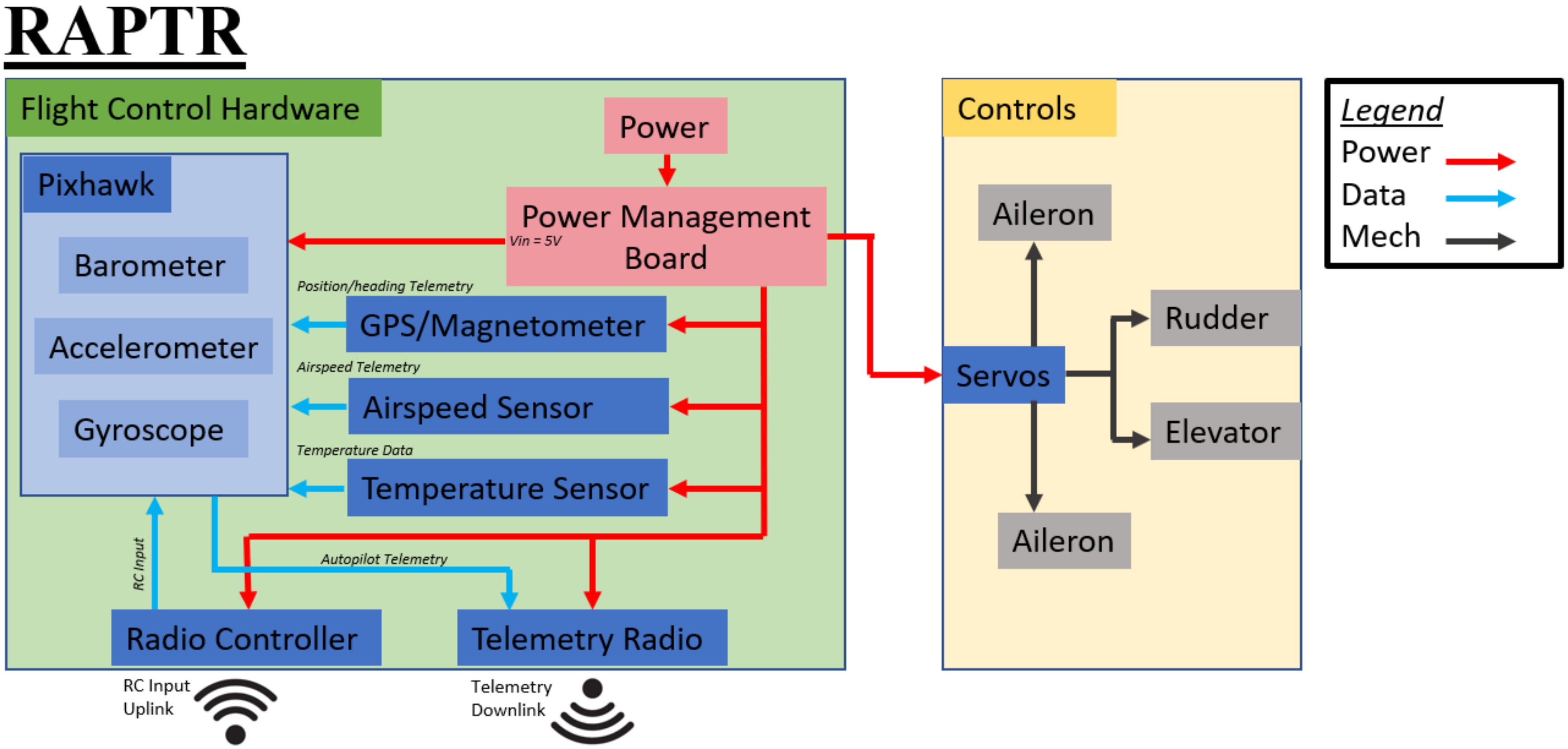
$$L \approx W$$



Aerodynamics: Feasibility

Requirement	Description	Feasibility Analysis
FR.1	The system shall utilize image processing to detect a 5'x5'x5' stationary ground target that is 2000 feet downrange from the user and from an altitude of 400 feet.	✓Feasible
DR.1.2	The vehicle shall be capable of entering and enduring a glide of 2000' with less than 100' of altitude loss.	✓Feasible

Controls and Electronics: Design



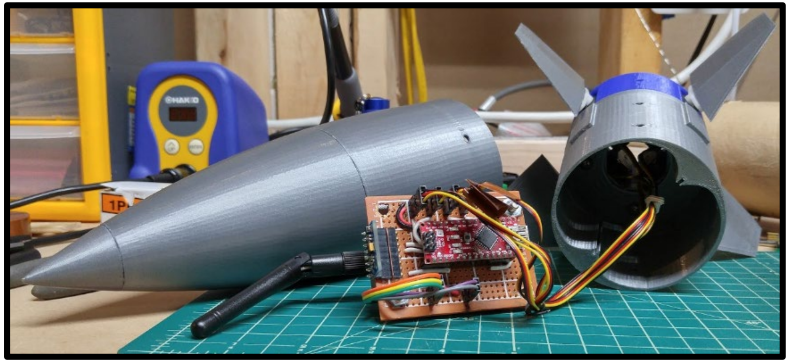
Controls and Electronics: Pixhawk Vehicle Adaptation

Autopilot software: Ardupilot

Aircraft adaptation

1. Common airframe configuration values
2. Simulation tuning
3. Flight test tuning

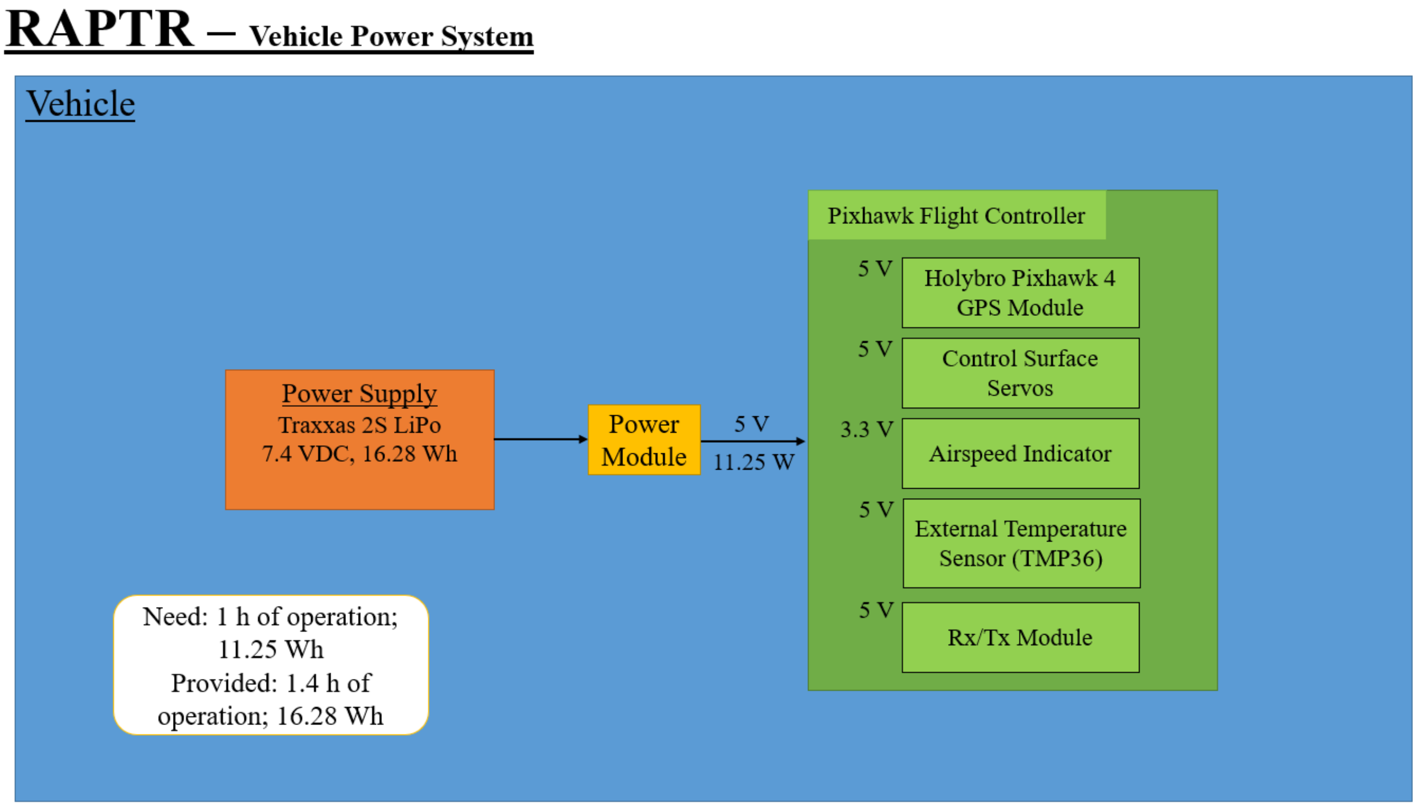
Controlled Rocket Adaptation



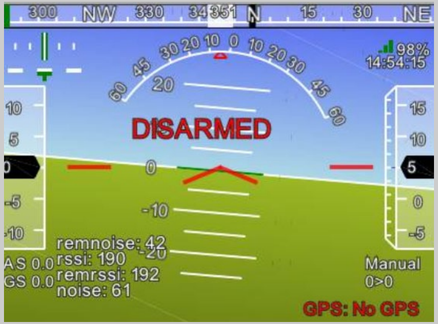
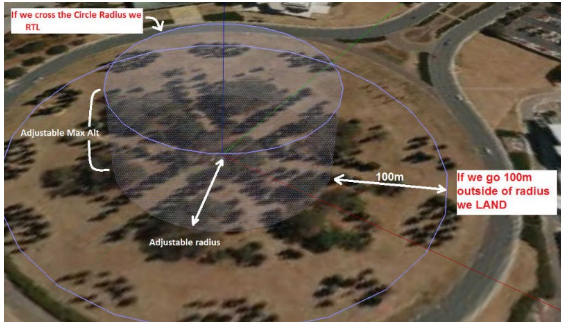
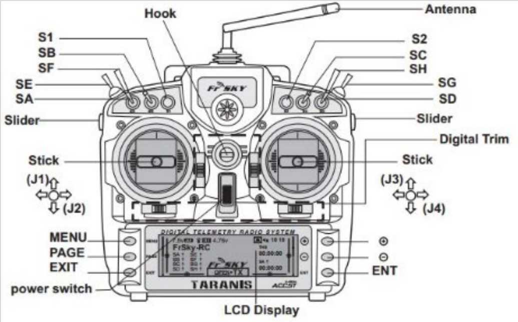
Ardupilot Mission Planner

FR. 1 "...detect target 2000-4000ft downrange at 400ft altitude." ✓

Controls and Electronics: Power Distribution



Controls and Electronics: Controls Override

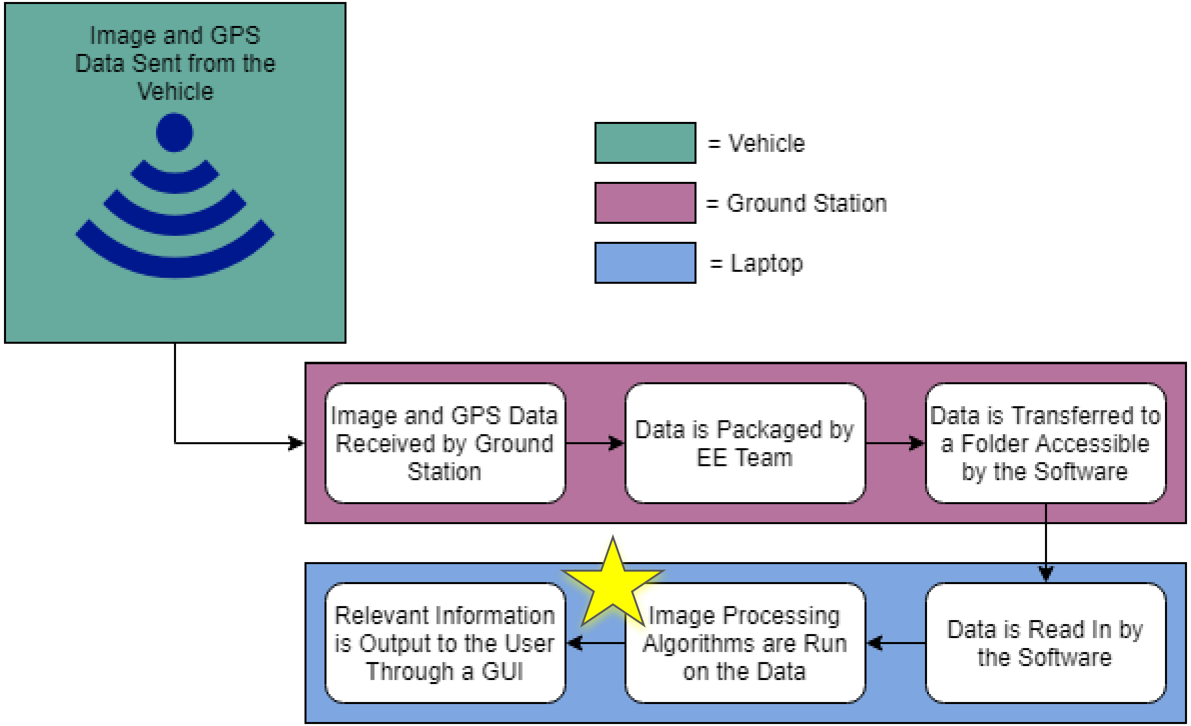
Tertiary Autopilot Override Capabilities		
#1 Arming Switch	**#2 Autopilot Geofence**	**#3 Manual Override**
A throttle arming switch must be tripped before any controls are initiated.	A waypoint defined geometric shape and an altitude confine the vehicles flight.	User intervention ceases autopilot and returns control to the user. *(AMA 2b)*
		

FR. 6 "System shall comply with all federal and state laws." ✓

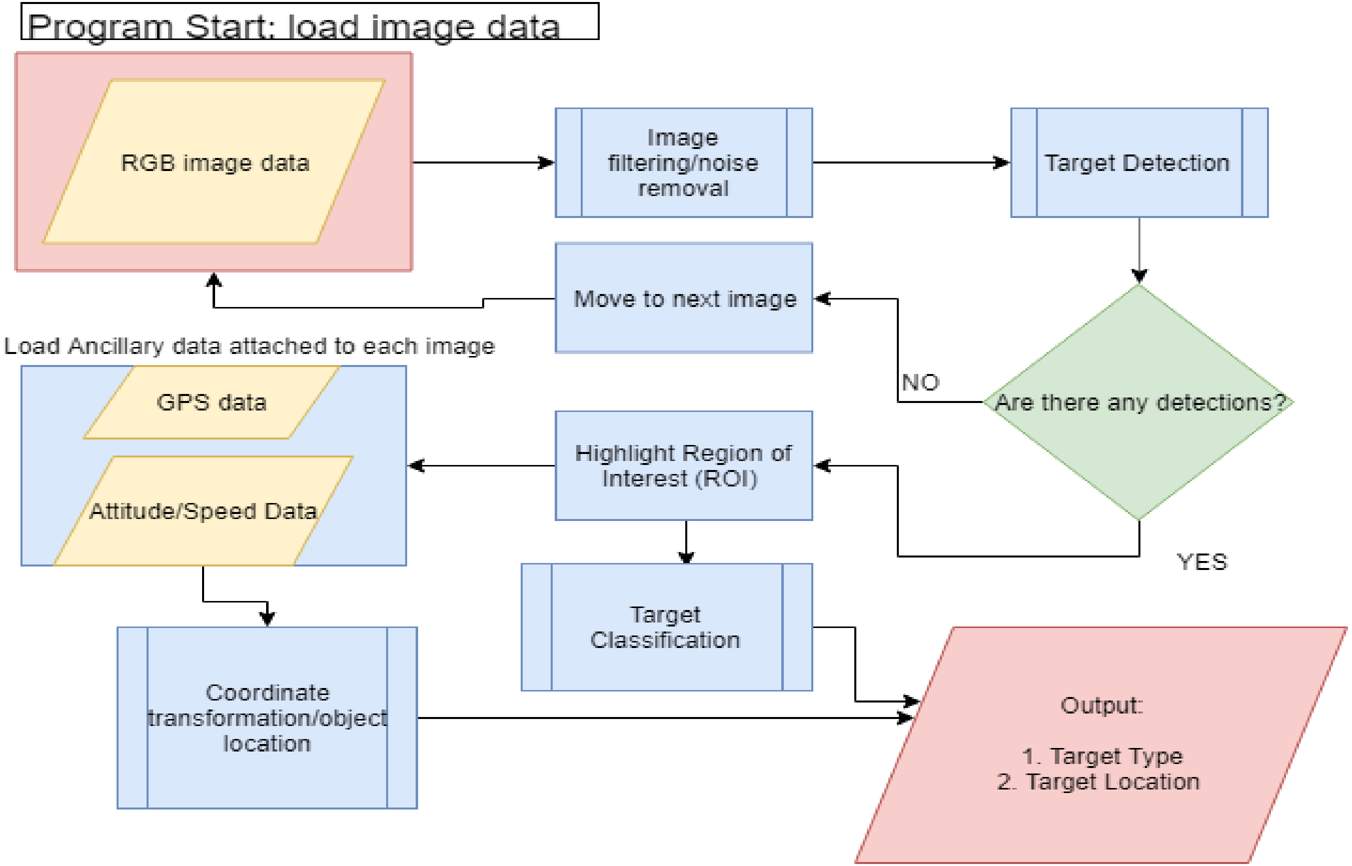
Controls and Electronics: Feasibility

Requirement	Description	Feasibility Analysis
FR. 1	The system shall utilize image processing to detect a 5'x5'x5' stationary ground target that is 2000 feet downrange from the user and from an altitude of 400 feet.	✓Feasible
DR. 1.1	The vehicle shall be capable of imaging the target if launched within ±7.5° of the target relative to the user for a constant vehicle ground path.	✓Feasible
FR. 4	The system shall identify a distinctly colored target and determine the unique target shape and relay the target's latitude and longitude.	✓Feasible
DR. 4.2	The ground station shall output the location of the target relative to the ground station/user.	✓Feasible
DR. 4.2.1	The vehicle/payload shall use a sensor suite to quantify its location.	✓Feasible
FR. 6	The system shall comply with all federal and state laws regarding testing and functionality of the system.	✓Feasible
DR. 6.1	The vehicle must comply with 14 CFR part 107.	✓Feasible
DR. 6.4	The vehicle shall remain controlled until landing.	✓Feasible

Software: Ground Data Path

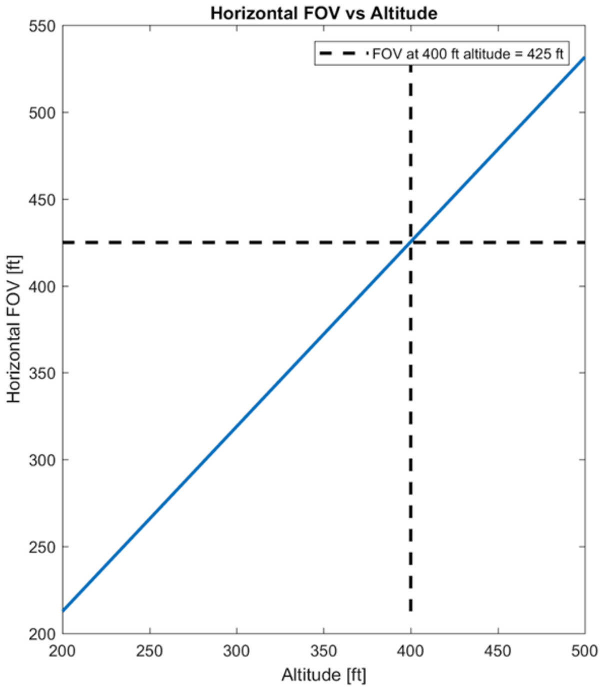


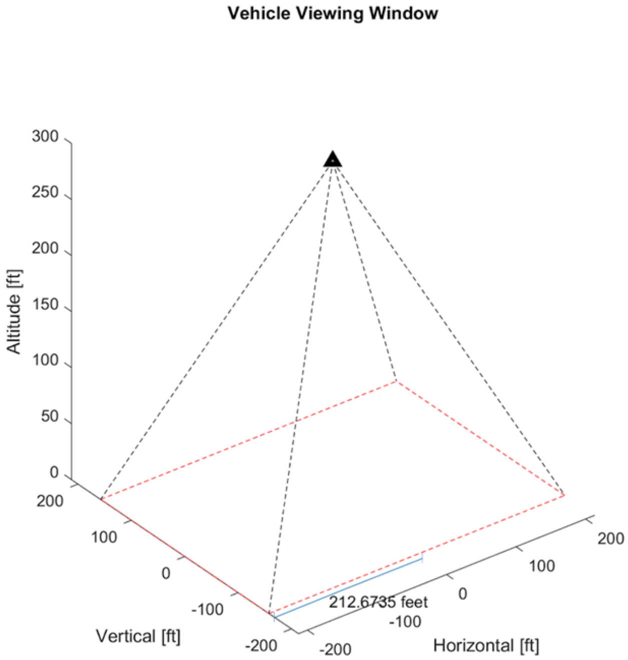
Software: Target Recognition Software



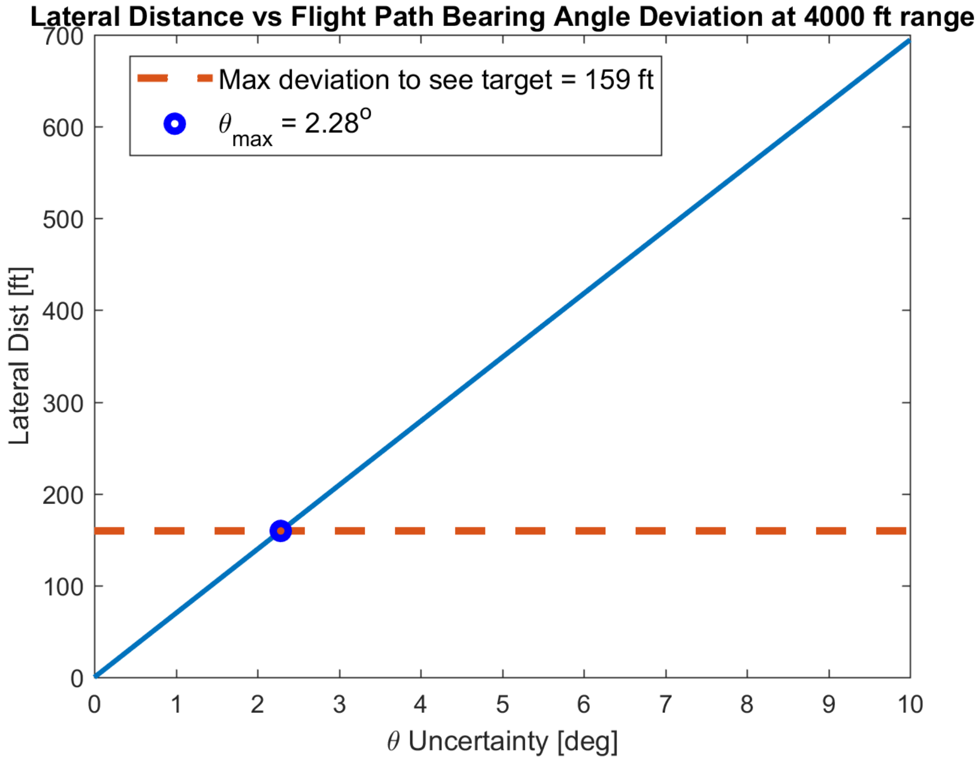
Software: Automatic Target Recognition

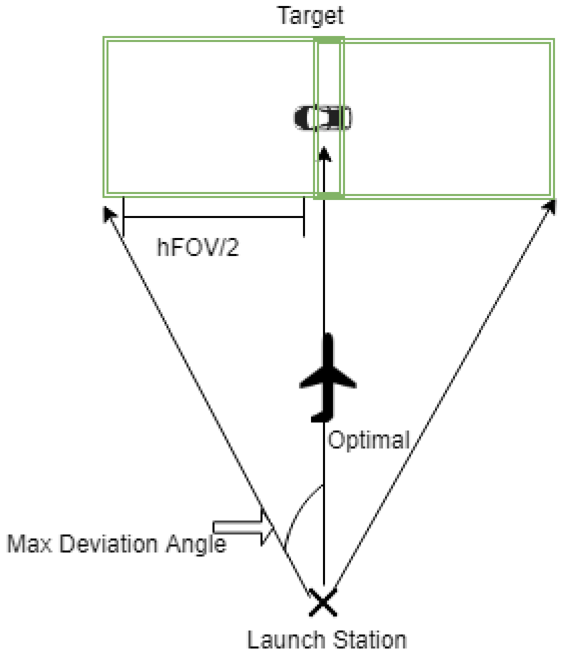
Must be able to see the target before processing can begin





Software: Launch Window Uncertainty

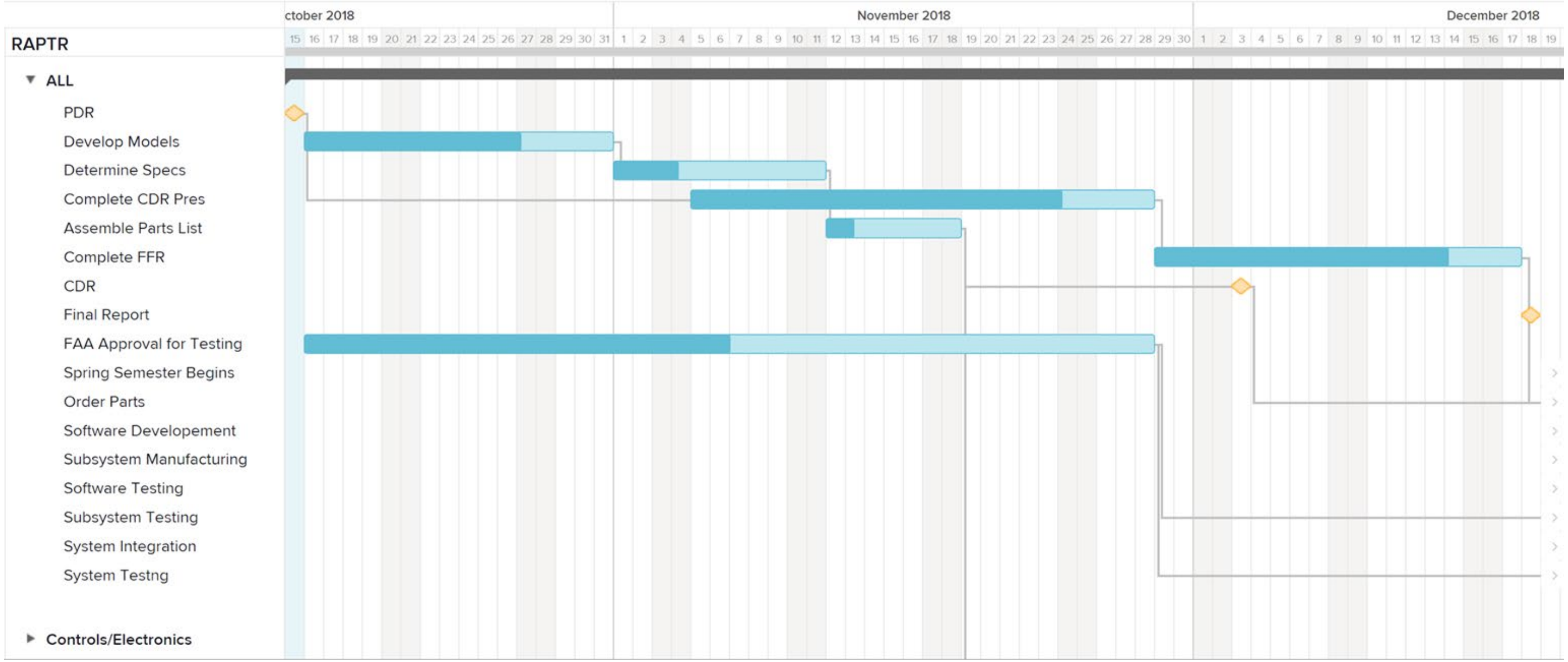




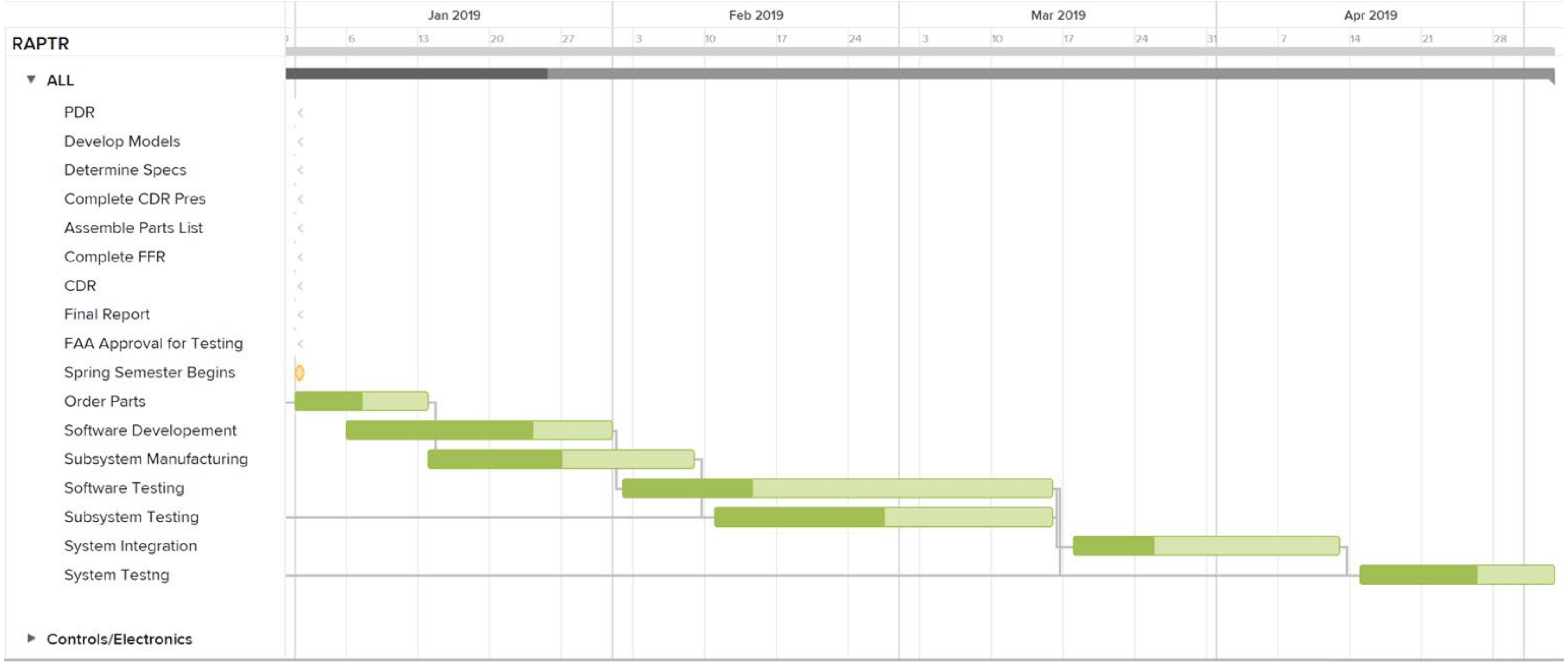
Software: Feasibility

Requirement	Description	Feasibility Analysis
FR.1	The system shall utilize image processing to detect a 5'x5'x5' stationary ground target that is 2000 feet downrange from the user and from an altitude of 400 feet.	✓Feasible
DR.1.1	The vehicle shall be capable of imaging the target if launched within ±7.5° of the target relative to the user for a constant vehicle ground path.	✓Feasible
DR.1.1.1	The imaging system shall be able to capture images at 0.1282 ft/pixel resolution with a max horizontal field of view of 540 ft and max vertical field of view of 400 ft.	✓Feasible

Fall Semester Gantt Chart



Spring Semester Gantt Chart



Budget

	Element	Estimated Cost [$]
CPE1-2	Power and Control	505
CPE3-5	Structures	650
CPE6	Vehicle Design	N/A
CPE7	Thrust Phase Performance	560
CPE8	Image Processing	N/A

Total Cost: $1715

Summary

CPE1	Control	✓Feasible
CPE2	Power Needs	✓Feasible
CPE3	Structural Integrity	✓Feasible
CPE4	Manufacturability	✓Feasible
CPE5	Size Constraint	✓Feasible
CPE6	Vehicle Design	✓Feasible
CPE7	Thrust Phase Performance	✓Feasible
CPE8	Image Processing	✓Feasible

Acknowledgments

Dr. Dennis Akos

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Team GHOST

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Tim Moon

Theresa Brown

Eileen Liu

Dan Hesselius

Questions?

References for Main Presentation

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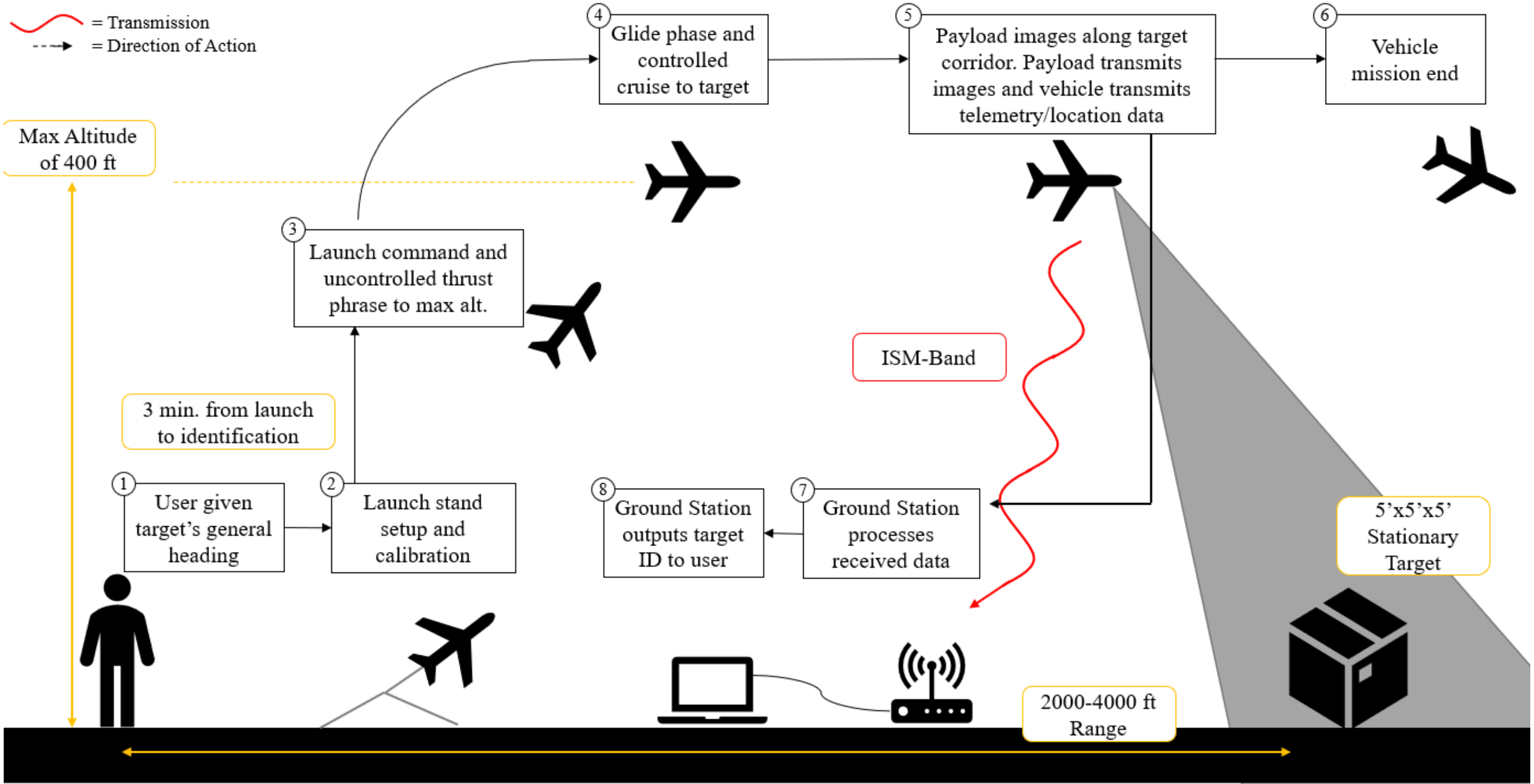
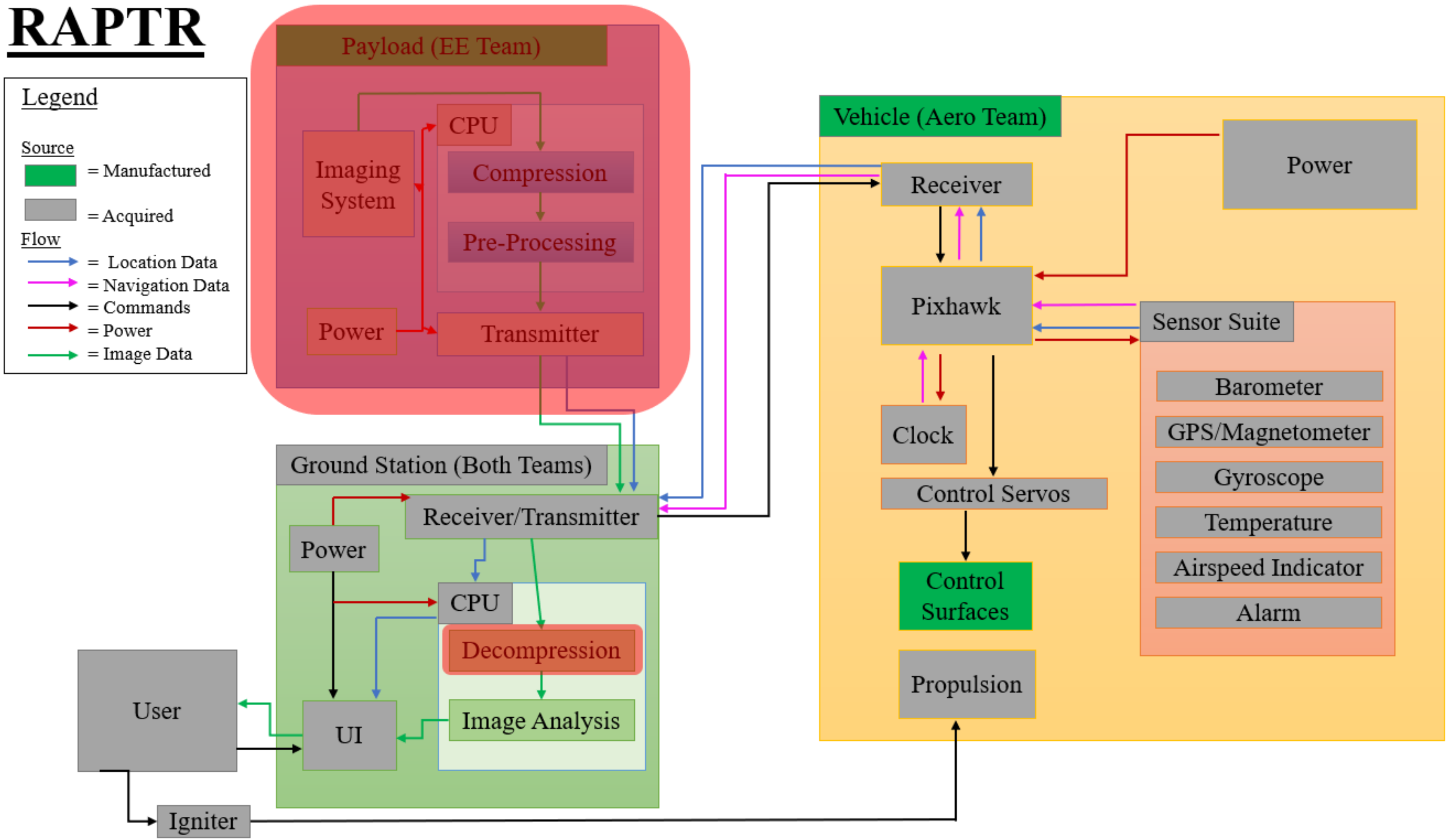
Backup Slides

Backup Slides
Project Overview

RAPTR – Overall Mission




RAPTR
Legend
Source
= Manufactured
= Acquired
Flow
= Location Data
= Navigation Data
= Commands
= Power
= Image Data
Payload (EE Team)
Imaging System
CPU
Compression
Pre-Processing
Power
Transmitter
Vehicle (Aero Team)
Receiver
Power
Pixhawk
Sensor Suite
Barometer
GPS/Magnetometer
Gyroscope
Temperature
Airspeed Indicator
Alarm
Clock
Control Servos
Control Surfaces
Propulsion
Ground Station (Both Teams)
Receiver/Transmitter
Power
CPU
Decompression
Image Analysis
UI
User
Igniter

Overview: FAA Regulations

SEC. 336. SPECIAL RULE FOR MODEL AIRCRAFT.

(a) IN GENERAL.—Notwithstanding any other provision of law relating to the incorporation of unmanned aircraft systems into Federal Aviation Administration plans and policies, including this subtitle, the Administrator of the Federal Aviation Administration may not promulgate any rule or regulation regarding a model aircraft, or an aircraft being developed as a model aircraft, if—

(1) the aircraft is flown strictly for hobby or recreational use;

(2) the aircraft is operated in accordance with a community-based set of safety guidelines and within the programming of a nationwide community-based organization;

(3) the aircraft is limited to not more than 55 pounds unless otherwise certified through a design, construction, inspection, flight test, and operational safety program administered by a community-based organization;

(4) the aircraft is operated in a manner that does not interfere with and gives way to any manned aircraft; and

(5) when flown within 5 miles of an airport, the operator of the aircraft provides the airport operator and the airport air traffic control tower (when an air traffic facility is located at the airport) with prior notice of the operation (model aircraft operators flying from a permanent location within 5 miles of an airport should establish a mutually-agreed upon operating procedure with the airport operator and the airport air traffic control tower (when an air traffic facility is located at the airport)).

(b) STATUTORY CONSTRUCTION.—Nothing in this section shall be construed to limit the authority of the Administrator to pursue enforcement action against persons operating model aircraft who endanger the safety of the national airspace system.

(c) MODEL AIRCRAFT DEFINED.—In this section, the term "model aircraft" means an unmanned aircraft that is—

(1) capable of sustained flight in the atmosphere;

Overview: AMA Regulations

AMA ACADEMY OF MODEL AERONAUTICS

Radio-Controlled small/micro Unmanned Aircraft Systems/Model Aircraft (m/sUAS) Operations Utilizing Failsafe, Stabilization, Autopilot, Ground-Station, Cameras/Sensors

1. Definition of terms

Please refer to Page 3, section 7, which contains an alphabetical listing of the definitions of the terms that are used in this document.

2. Operations, requirements, and limitations

a) AMA pilots should first be capable of manually flying their sUAS without utilizing GPS or Intelligent Orientation Control (IOC).

b) AMA pilots, when flying sUAS utilizing an autopilot system, must be able to deactivate the autopilot automated flight at any time to resume manual control of the sUAS.

c) AMA pilots should perform preflight inspections of their sUAS electronic and navigational control, and power and mechanical systems before each flight.

d) AMA pilots must perform a manual RC test flight of their sUAS before activating a newly installed stabilization or autopilot system and/or after any repairs or replacement of the sUAS essential flight systems.

e) sUAS exceeding 55 pounds cannot use an autopilot for automated flights, except for a failsafe-activated emergency landings or a "return to launch" (RTL).

f) AMA pilots may control the flight path of an sUAS with a standard gimbal RC transmitter or a smartphone, tablet, smartwatch, laptop, and/or proprietary controller with mission software using radio frequency telemetry modules for the control link.

g) sUAS must operate on frequencies approved by the FCC for wireless video, radio control, and ground station telemetry systems. Some systems, because of power output or Amateur Band frequencies, will require FCC licensing (AMA documents #580 & 590).

Academy of Model Aeronautics
National Model Aircraft Safety Code

Effective January 1, 2018

A model aircraft is a non-human-carrying device capable of sustained flight within visual line of sight of the pilot or spotter(s). It may not exceed limitations of this code and is intended exclusively for sport, recreation, education and/or competition. All model flights must be conducted in accordance with this safety code and related AMA guidelines, any additional rules specific to the flying site, as well as all applicable laws and regulations.

As an AMA member I agree:

- I will not fly a model aircraft in a careless or reckless manner.
- I will not interfere with and will yield the right of way to all human-carrying aircraft using AMA's *See and Avoid Guidance* and a spotter when appropriate.
- I will not operate any model aircraft while I am under the influence of alcohol or any drug that could adversely affect my ability to safely control the model.
- I will avoid flying directly over unprotected people, moving vehicles, and occupied structures.
- I will fly Free Flight (FF) and Control Line (CL) models in compliance with AMA's safety programming.
- I will maintain visual contact of an RC model aircraft without enhancement other than corrective lenses prescribed to me. When using an advanced flight system, such as an autopilot, or flying First-Person View (FPV), I will comply with AMA's Advanced Flight System programming.
- I will only fly models weighing more than 55 pounds, including fuel, if certified through AMA's Large Model Airplane Program.
- I will only fly a turbine-powered model aircraft in compliance with AMA's Gas Turbine Program.
- I will not fly a powered model outdoors closer than 25 feet to any individual, except for myself or my helper(s) located at the flightline, unless I am taking off and landing, or as otherwise provided in AMA's *Competition Regulation*.
- I will use an established safety line to separate all model aircraft operations from spectators and bystanders.

Overview: NAR Regulations

Level 1 allows the purchase and use of H and I impulse class motors; solid and hybrid. Certain F and G motors may also require Level 1 certification for purchase and use.

Level 2 allows the purchase and use of J, K, and L impulse class motors; solid and hybrid.

Level 3 certification allows the purchase and use of M, N, and O impulse class rocket motors; solid and hybrid.

Who Needs HPR Certification?A person needs High Power certification if they:

1. Launch models containing multiple motors with a total installed impulse of 320.01 Newton-seconds or more, or
2. Launches models containing a single motor with a total installed impulse of 160.01 Newton-seconds or more, or
3. Launches rockets that weigh more than 53 ounces (1500 grams), or
4. Launches models powered by rocket motors not classified as model rocket motors per NFPA 1122, e.g.:
    1. Average thrust in excess of 80.0 Newtons
    2. Contains in excess of 125 grams of propellant
    3. Hybrid rocket motors

Level 1 high power certification (160.01 to 640.00 Newton-seconds impulse)

1. Certification at this level permits single or multiple motor rocket flights with motors having a maximum total impulse of 640.00 Newton seconds.

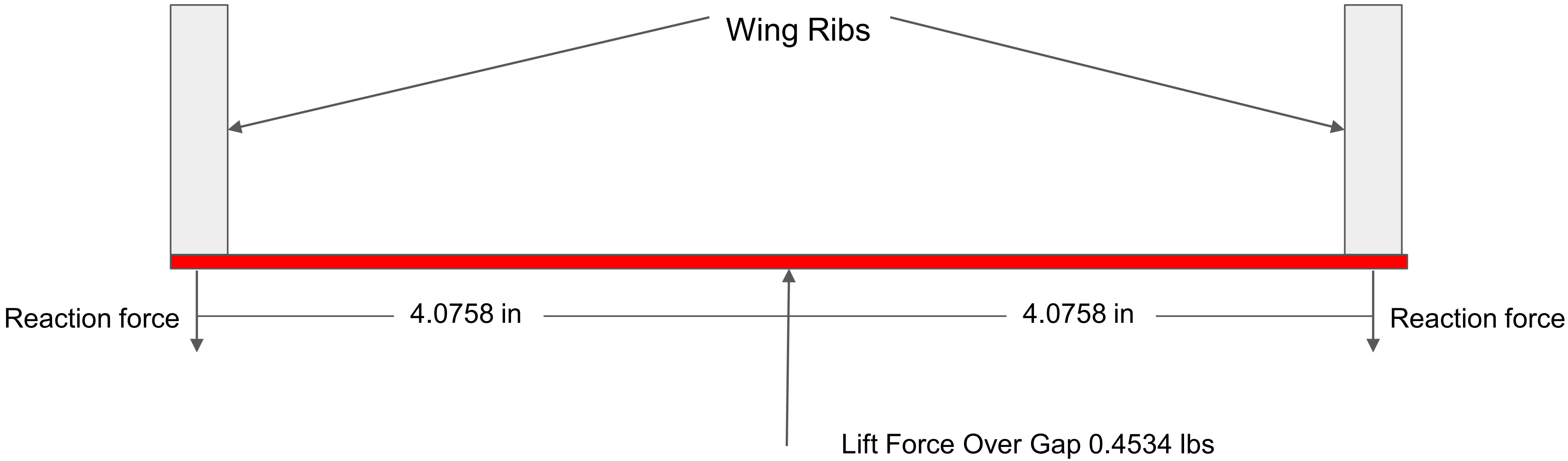
Backup Slides
Mechanical and Structures

Mechanical and Structures: EE Payload Requirements

- Electronic Component integration (volume and plate area we provide)
  - Payload volume is 2.5” diameter cylinder 4” in length giving a volume of 19.63 cubic inches
  - Gives electronics mounting plate size of 2.25” x 4”

Mechanical and Structures: Monokote Strength Analysis

- Monokote strength analysis
  - Maximum deflection: 0.0039 inches
  - Used Young's Modulus of Mylar (7.6e5 psi) and thickness of 0.01 inches



Mechanical and Structures: Monokote Information

- Monokote Information
  - Density: 0.2 oz/ft^3
  - Tensile Strength: 25,000 psi
  - Approximate surface area: 681.557 in^2
  - Approximate weight for 0.01 thickness: 7.888e-4 lbs
  - Application to aluminum
    - Sand and clean the entire surface.
    - Apply a thin coat of LustreKote Primer. Wait 2-3 minutes and apply a second, heavier coat.
    - Wait at least three hours before wet-sanding the primer with #320 grit or finer sandpaper.
    - Using a light, inspect the surface at an angle. Make sure that all deep scratches are filled. If not, repeat Steps 2-3 until the surface is smooth and scratch-free.

Mechanical and Structures: Material Properties

- Properties of 6061-T4 aluminum
  - Density: 0.0975 lb/in^3
  - Shear Strength: 24,000 psi

http://www.matweb.com/search/DataSheet.aspx?MatGUID=d5ea75577b1b49e8ad03caf007db5ba8

- Properties of balsa wood
  - Density: 0.00578 lb/in³
  - Shear Strength: 160 psi

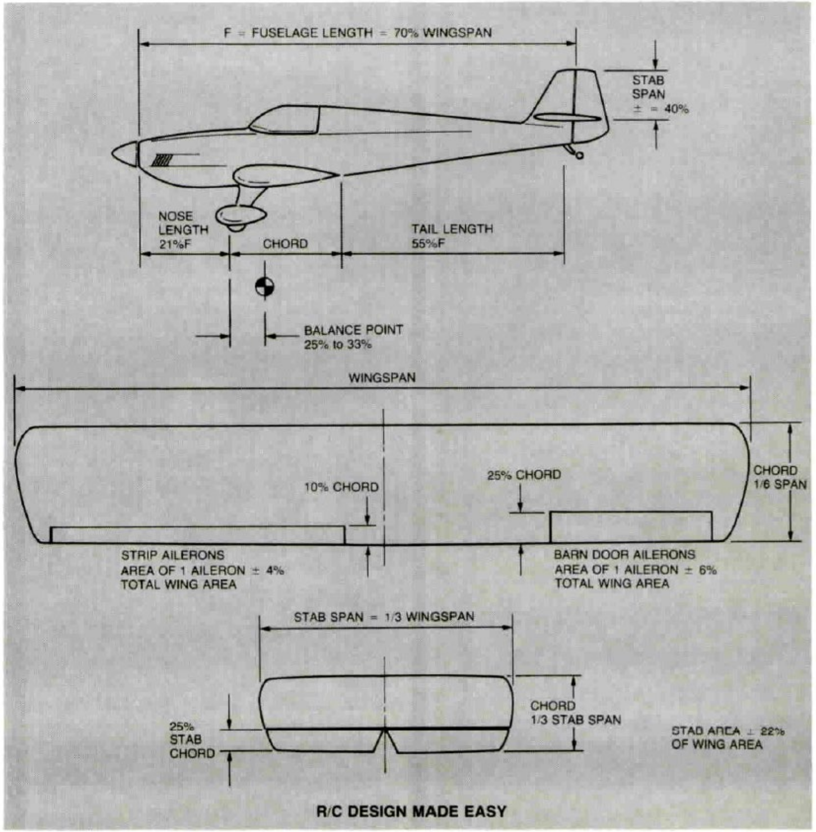
http://www.matweb.com/search/datasheet.aspx?matguid=368427cdadb34b10a66b55c264d49c23&ckck=1

Mechanical and Structures: General

- Worst case landing: Traveling 140.175 ft/s and a deceleration to zero over 0.1 seconds
- Look at wing cross section like during launch
- F = 2619.86 lbf
- Tau = F/2A = 2619.86/(2*0.25*0.25) = 20,958.88 psi
- Tensile strength of aluminum: 24,000 psi
- FOS = 1.14

Mechanical and Structures: Sizing Refrence

375621556



Mechanical and Structures: Custom Launch Rail

- Slide about launch system and the type of moment that the variable launch rail might have to support
  - Weight of launch stand assembly: 6.87 lbs
  - Center of mass: slightly below middle of base plate, shifts slightly to side of rod.

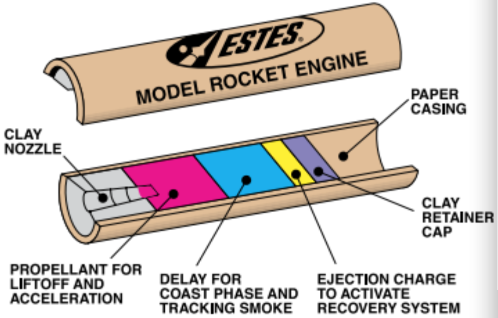
Backup Slides
Propulsion

Propulsion: Model Rocket Engines

ESTES MODEL ROCKET ENGINES

The famous model rocket engines that made model rocketry the great activity it is today. Estes model rocket engines have been proven consistent and reliable in more than 275,000,000 launches.

- The concept of a factory assembled model rocket engine is the foundation of this scientific and educational activity!
- 3% of all Estes engines are static-tested at the factory for reliability and adherence to performance specifications.
- All engines comply with the code requirements of the National Fire Protection Association and are certified by the National Association of Rocketry.

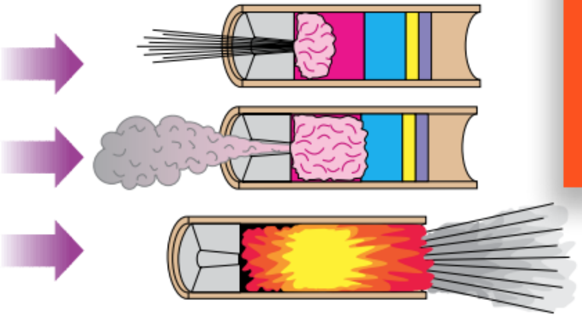


HOW DOES A MODEL ROCKET ENGINE WORK?

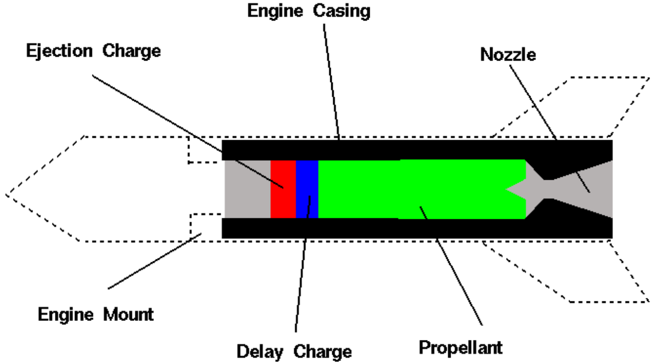
1. When engine is ignited, it produces thrust and boosts rocket into sky.

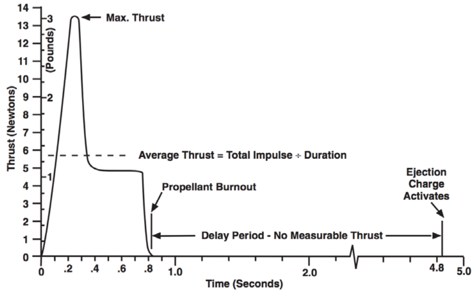
2. After propellant is used up, delay is activated, producing tracking smoke and allowing rocket to coast.

3. After delay, ejection charge is activated, deploying recovery system.



Model Solid Rocket Engine

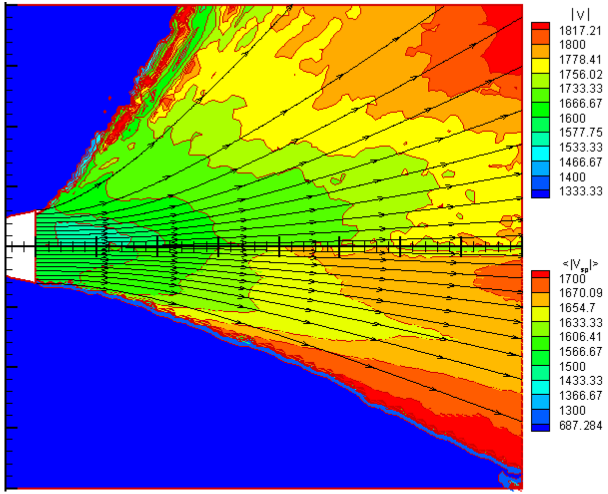




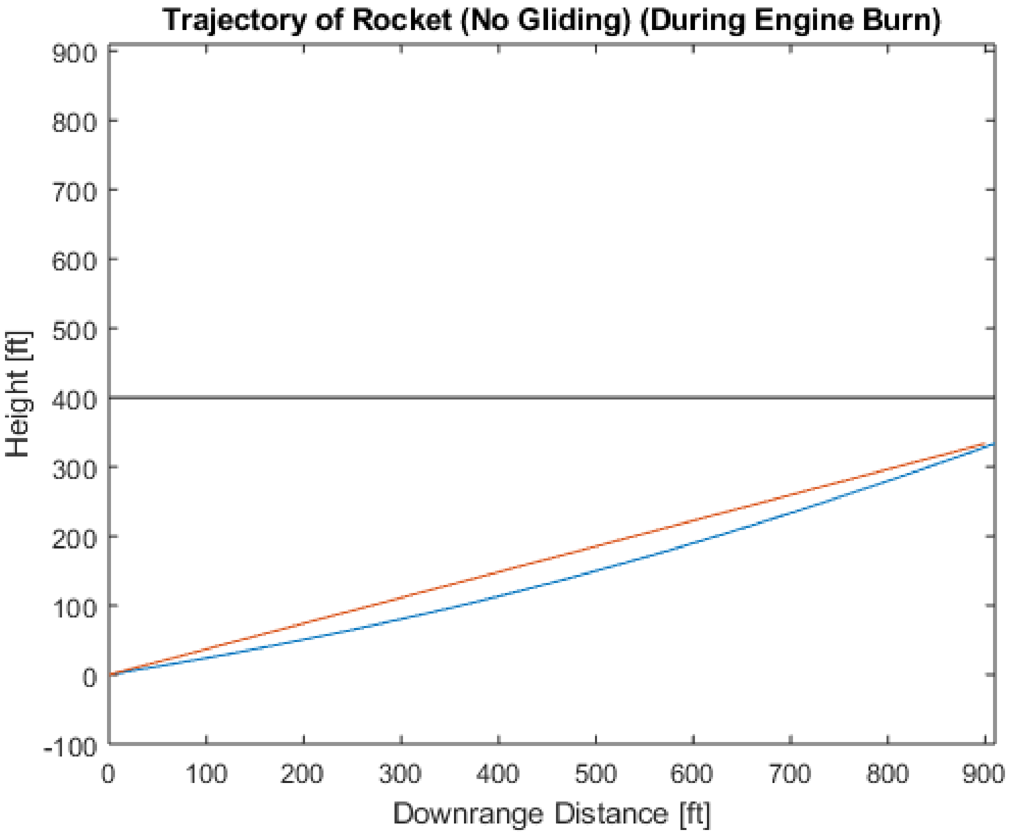
www.estesrockets.com

Propulsion: Thermodynamics

- The given paper covers computed results SE induced effects in the plume at T = 2565 K
- *Modeling of Thermal Radiation of Heterogeneous Combustion Products in the Model Solid Rocket Engine Plume*
  - "The paper contains the description of both the technique and calculation results on the thermal radiation of heterogeneous combustion products in the model solid rocket engine plume. The technique's testing has been done through comparative analysis against the data obtained by Nelson. The influence of gaseous and condensed phases, "spotlight" effect, and particles sizes upon radiation characteristics (coefficients of the attenuation, absorption and scattering) and emission characteristics (flux densities, emissivity factors) has been analyzed through mathematical modeling."
- Model rocketeers do this all the time, structures stay intact



Propulsion: MATLAB Trajectory During Burn



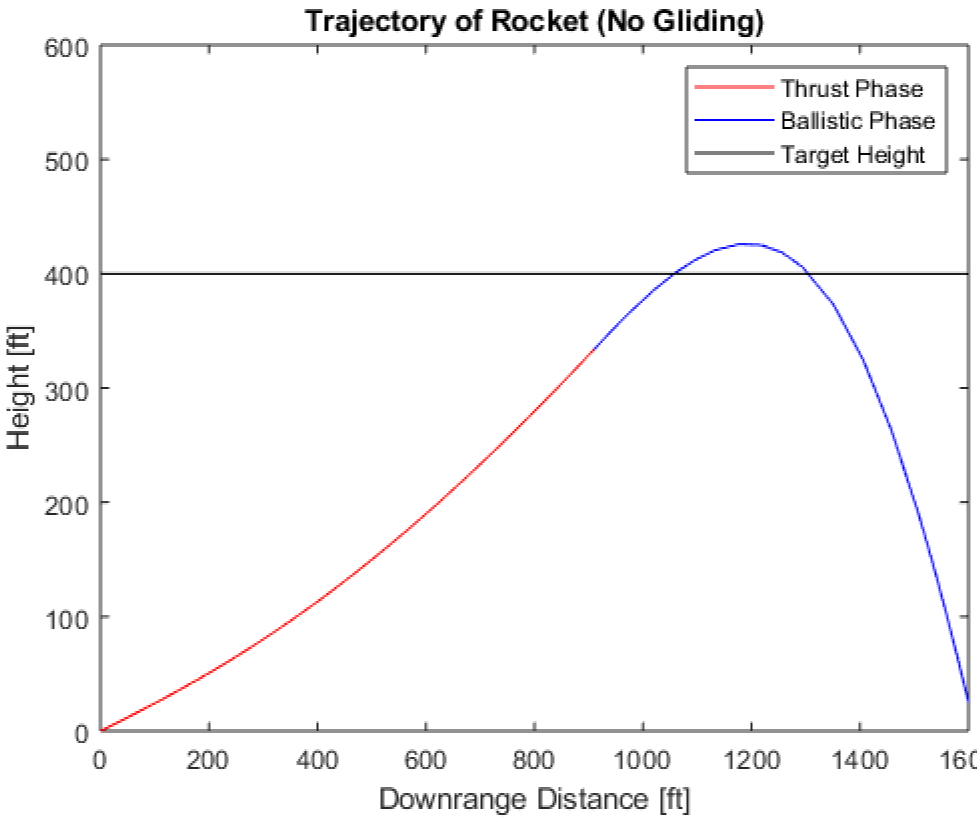
Propulsion: MATLAB Simulation

Baseline Performance Values:

- Weight = 4.4 lb
- Launch Angle = 41 deg.
- Average Thrust = 2.3 lbf
- Burn Time = 7.8 s
- Number of Motors = 4
- Cd = 0.1

Performance Results:

- Max Height = 425.6 ft
- Downrange Distance at Apogee = 1177 ft
- Max Speed = 171.4 ft/s
- Apogee Speed = 98.22 ft/s
- Time to Reach Apogee = 9.98 s



Propulsion: MATLAB Simulation

Equations/Functions:

Ode45

State Variables: x,y,z,vx,vy,vz

$$\frac{dV}{dt} = a = \frac{F_{total}}{m_{total}}$$

$$F_{total} = F_{motor} - D_f - F_{gravity}$$

$$F_{motor} = \frac{I_{sp}}{t_{burn}} n_{motor}$$

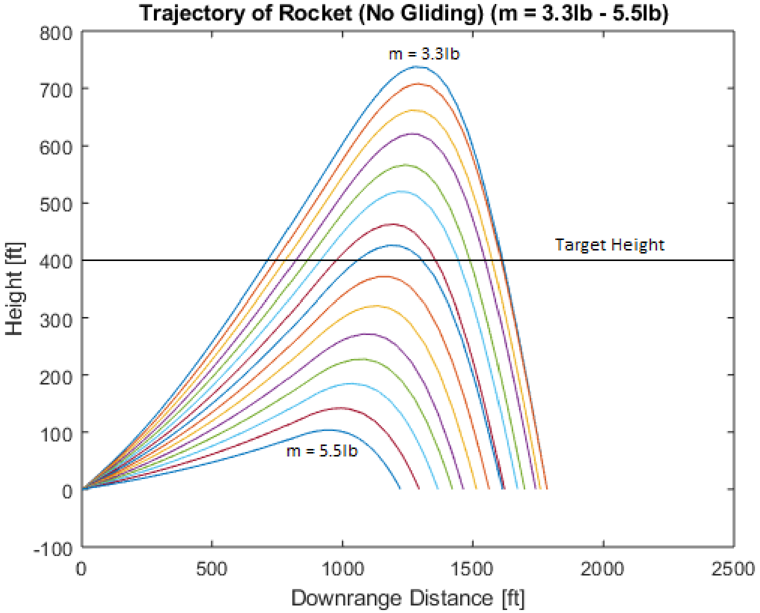
$$D_f = \frac{1}{2} \rho_{air} V^2 C_d A_{cross}$$

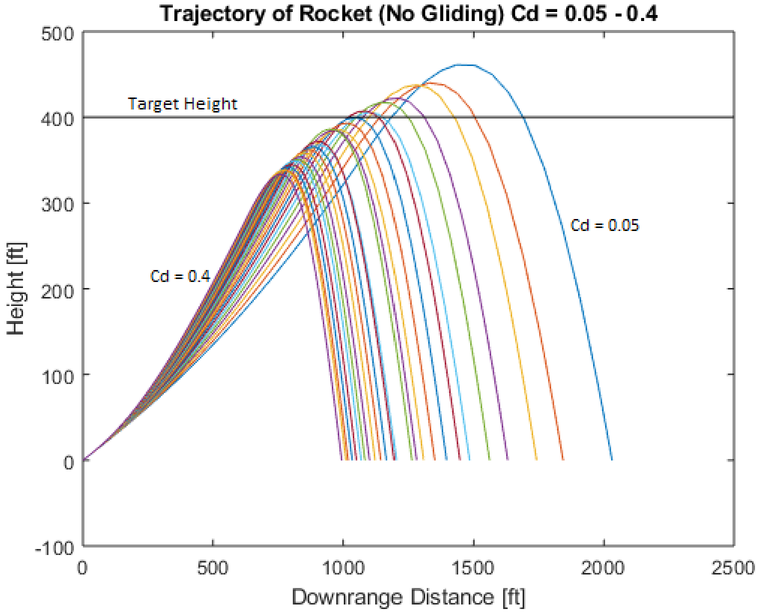
$$F_{gravity} = m_{total} * g$$

Assumptions:

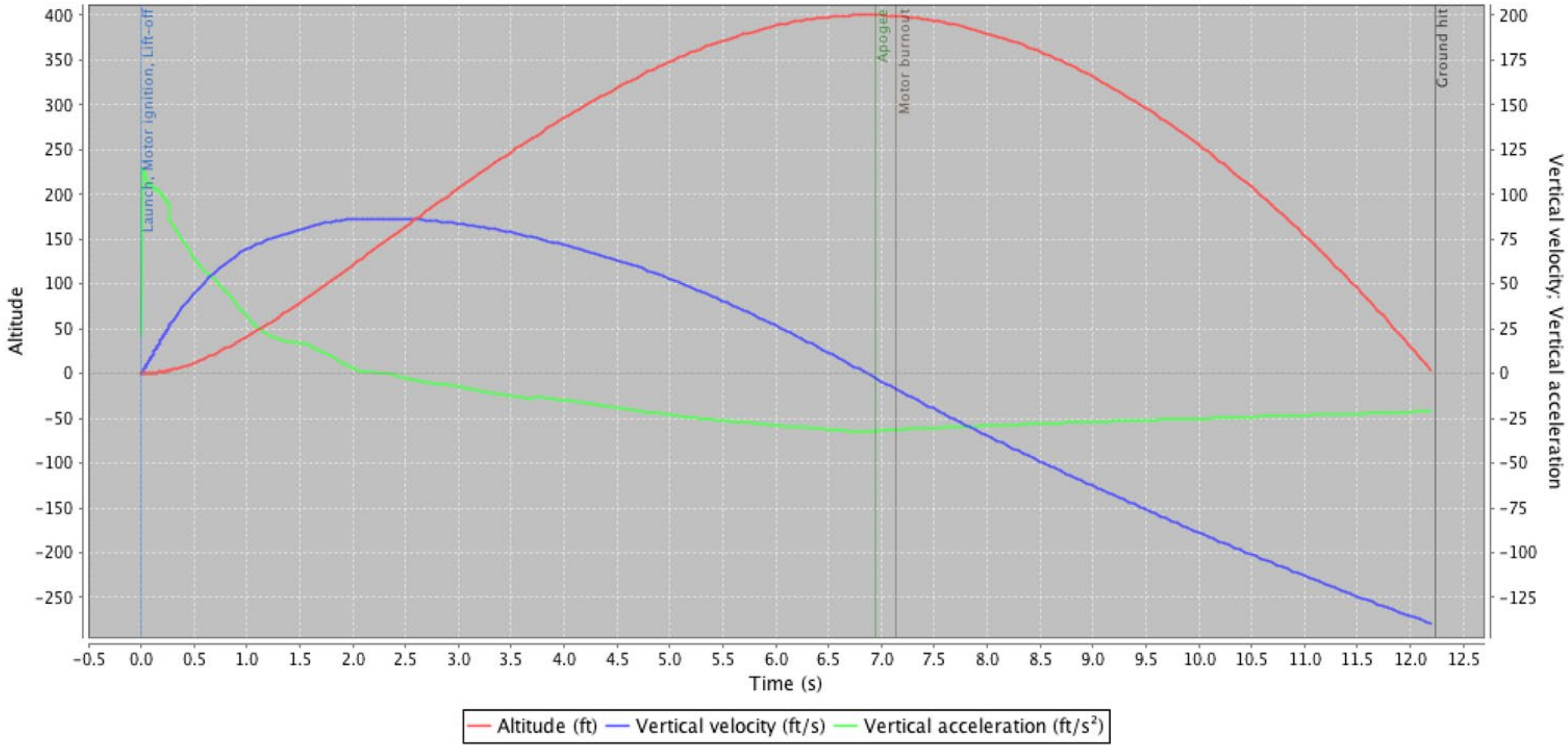
- Constant average thrust during burn
- No lift generated from wing
- No gliding after apogee
- No wind
- Point mass
- Thrust vector directed along launch angle during entire burn

Propulsion: MATLAB Simulation

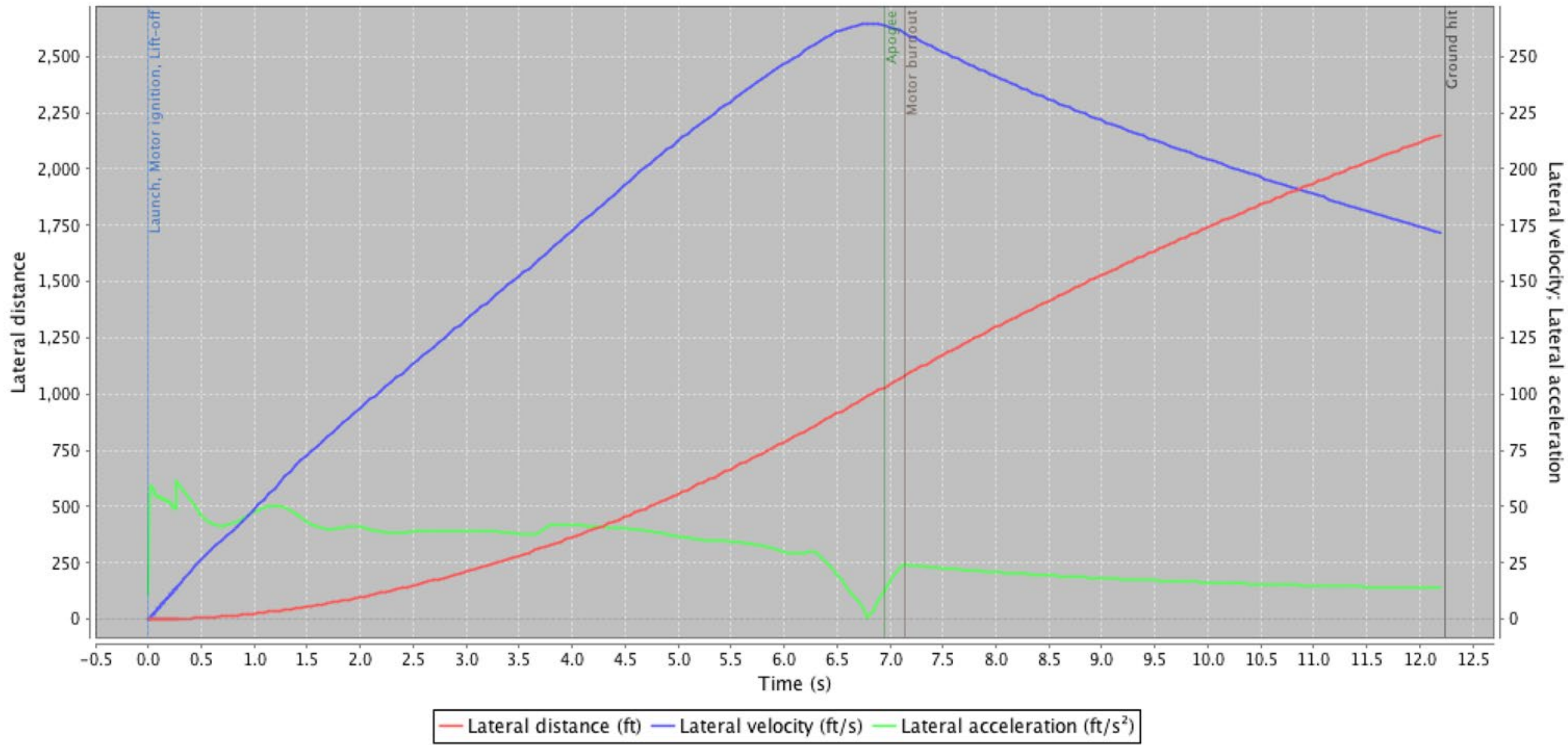




Propulsion: OpenRocket Vertical Motion



Propulsion: OpenRocket Lateral Motion



Propulsion: OpenRocket Design

Stages: 1
Mass (with motor): 102 oz (6.38 lbs)
Stability: 0.447 cal
CG: 13.171 in
CP: 14.961 in

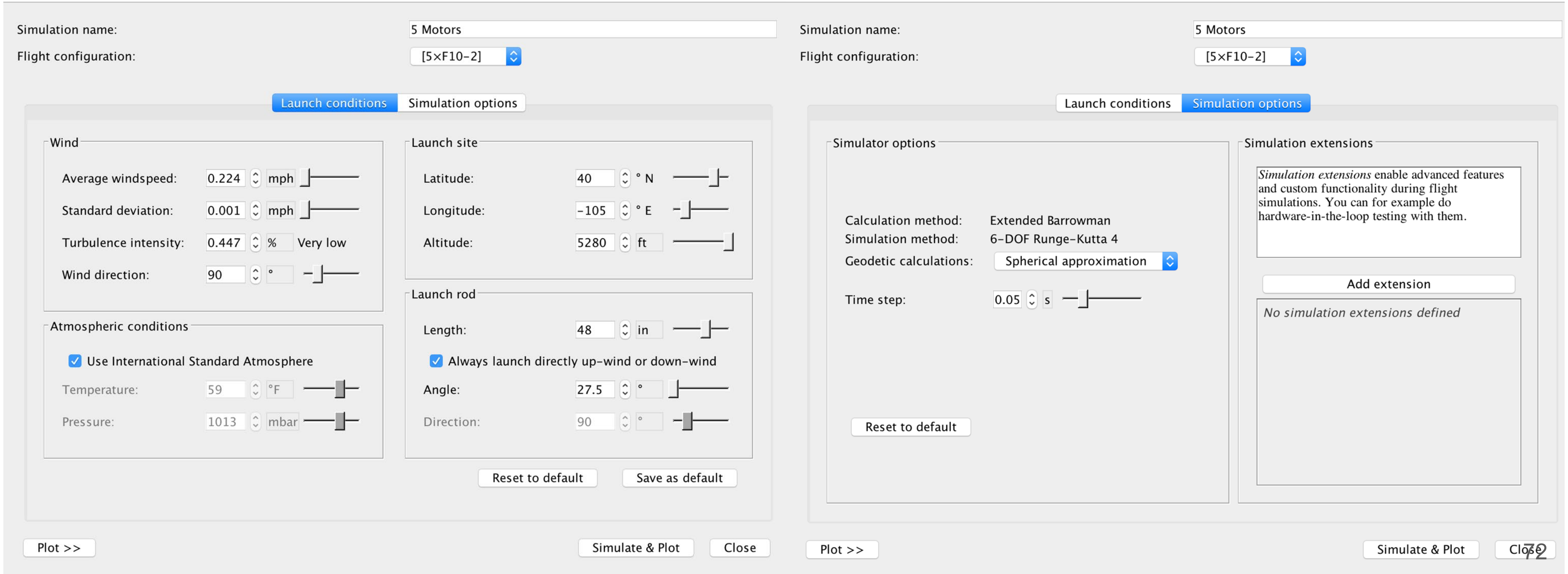
5×F10-2

Altitude	400 ft
Flight Time	12.2 s
Time to Apogee	6.84 s
Optimum Delay	-0.2 s
Velocity off Pad	30.4 ft/s
Max Velocity	265 ft/s
Velocity at Deployment	N/A
Landing Velocity	221 ft/s

Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
F10 (×5)	10.9 N	7.02 s	28.2 N	76.3 Ns	0.38:1	1.44 oz	1.14/3.66 in
Total:				382 Ns	1.91:1	7.18 oz	

Propulsion: OpenRocket Parameters

Simulation Parameters



Propulsion: OpenRocket SW Reliability

"OpenRocket is an opensource model rocket simulation software. It was originally developed by Sampo Niskanen in 2009 as part of his master thesis at the *Helsinki University of Technology*."

Thesis Abstract: "Model rocket simulation is a powerful tool allowing rocketeers to design and simulate the flight of rockets before they are actually built...In this thesis a step-by-step process was developed for calculating the aerodynamic properties of model rockets and simulating rocket flight. These methods were implemented in the OpenRocket software package, which includes an easy-to-use user interface for designing and simulating model rockets. The software has been published as Open Source software. The methods for calculating the aerodynamic properties of rockets follow primarily those presented by James Barrowman in his Master's thesis. Several extensions were made to allow for computation at large angles of attack and to estimate the aerodynamic properties of free-form fins. Additionally methods for simulating atmospheric properties such as wind turbulence are presented, and a process for a six degree of freedom flight simulation. The simulated results were validated against experimental rocket flights and wind tunnel data. **The validation indicates that the altitude of a subsonic rocket is simulated with an accuracy of approximately 10–15%**. This is on par with the commercial model rocket simulators. While access to flight data of supersonic rockets was unavailable, it is expected for the simulation to be reasonably accurate up to Mach 1.5."

Propulsion: OpenRocket SW Reliability

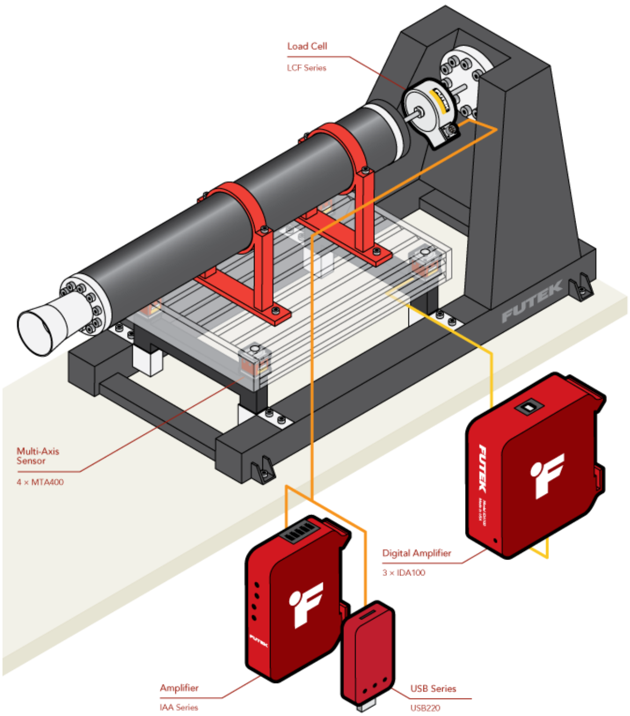
Java Program

"Intended to be used by all model-rocketeers who intend to test the performance of a model rocket before actually building and flying it. In fact the software computes accurately the aerodynamic properties of model rockets and simulates their flight, returning a wide range of technical results."

"**Rocket design**, where you can design the model rocket you intend to build, choosing from a wide range of **body components**, **trapezoidal**, **elliptical** and **free-form fins**, **inner components**, and **mass objects**. During this phase you will see a 2D representation of the rocket you are building and various technical information (**size**, **mass**, **apogee**, **max. velocity**, **max. acceleration**, **stability**, **centre of gravity** (**CG**), **centre of pressure** (**CP**)) about your rocket, so you can have already a good idea of its performance even before running any simulation. "

"**Flight simulation**, where you can run one or more simulations of your rocket's flight, choosing from one or more **motor configurations**. Each simulation (calculated using the Runge-Kutta 4 simulator) returns a wide range of data about the rocket's flight. Unfortunately, for the moment a graphical visualisation of the rocket's flight is not available."

Propulsion: Engine Thrust Test Bench

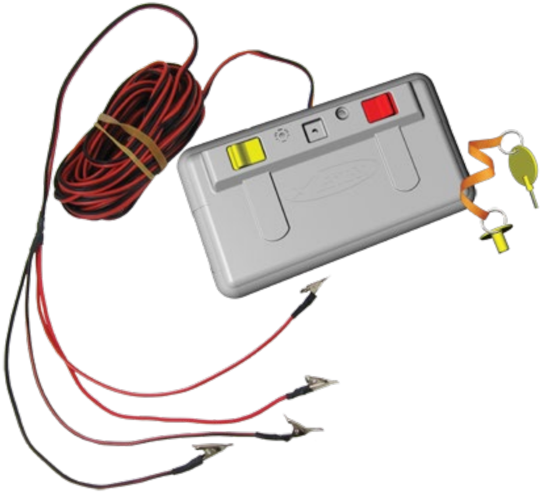


How it Works

1. In this application, the rocket engine is threaded into the LCF series universal load cell.
2. The engine mount prevents any side loading on the cell, ensuring the load cell is only receiving axial loads.
3. The load cell assembly is mounted to a fixed test stand securing the engine.
4. In line with the base supports, MTA400/MTA600 multi-axis load cells are installed.
5. As the engine is operating, thrust is measured with the LCF series load cells.
6. Mass flow and Drag(aka "kick") are captured with MTA400/MTA600 load cells.
7. Thrust data can be live streamed and logged for monitoring and later review and comparison against simulated models with USB220 and SENSIT.
8. Mass flow data from all 4 multi-axis load cells are captured, streamed and logged with USB220 and SENSIT.
9. Each axis of the MTA400/MTA600 is captured with a separate USB220.
10. Load cell output can also be amplified via the IAA series for capture by pre-existing DAQs.

Propulsion: Launch Safety

COTS options are reliable and very commonly used.



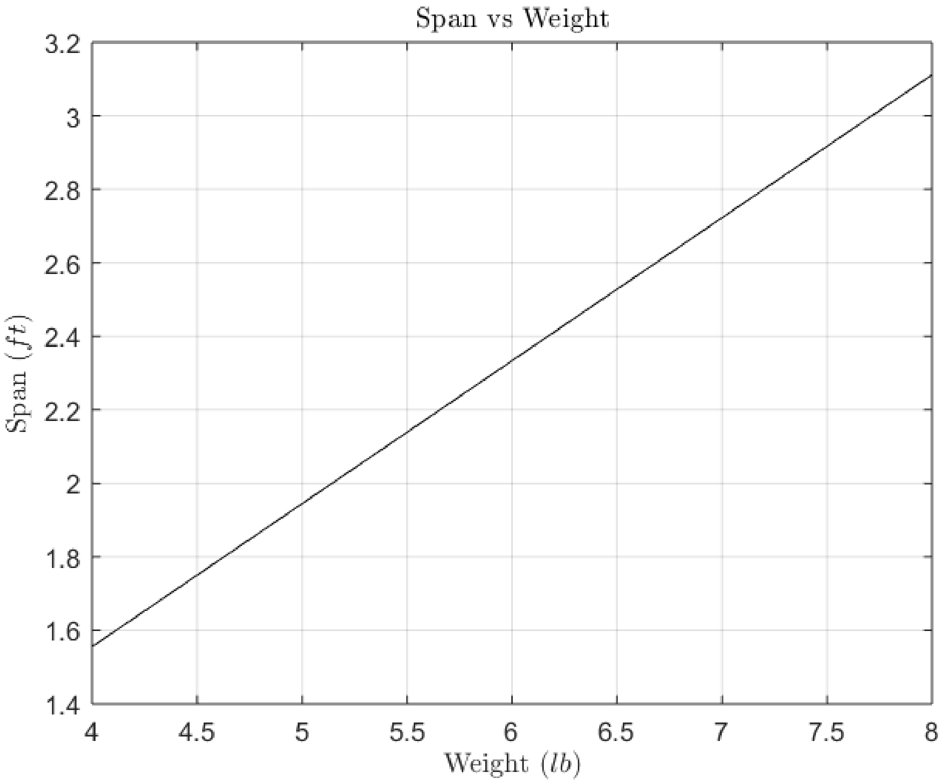
- "Estes Sonic Igniter"
- Bridge wire in contact with propellant
- Charge sent by ground station
- Use a given handheld launch device like a normal rocket launcher
- Resistance = 1.6 Ω
- Min. fire-current = 3.8 A

Backup Slides
Aerodynamics

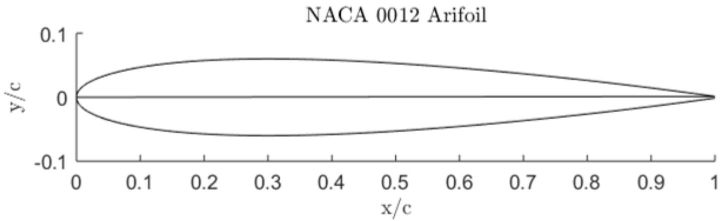
Aerodynamics: Wingspan

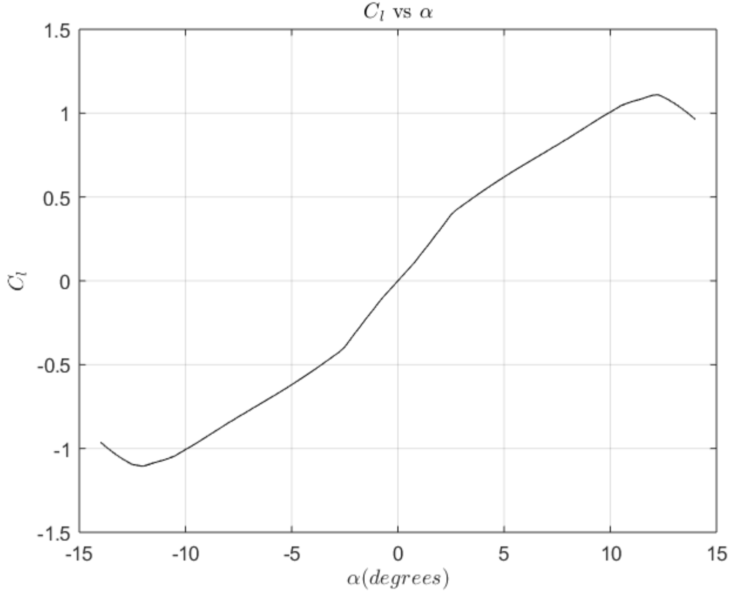
Mission requirements:

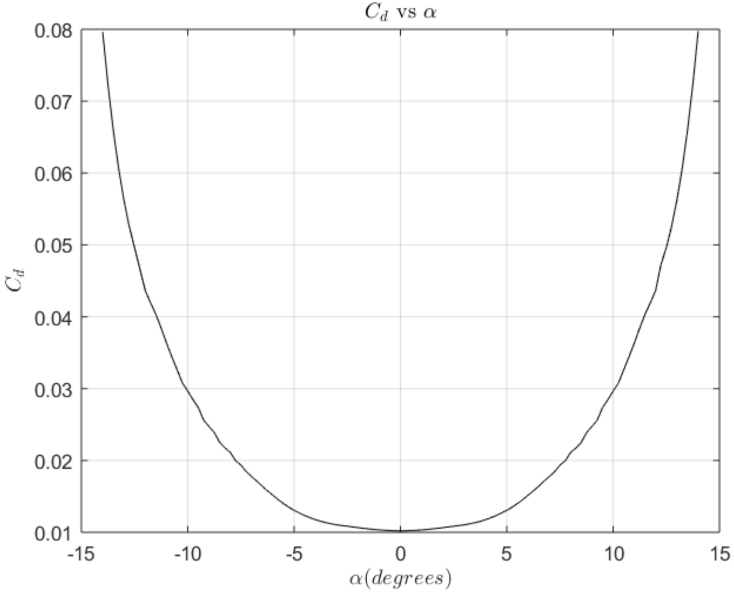
- Cannot be greater than our largest dimension (4 ft)
- Span must lie above line in order to be feasible
- Assume chord of 0.33 ft (4 in)



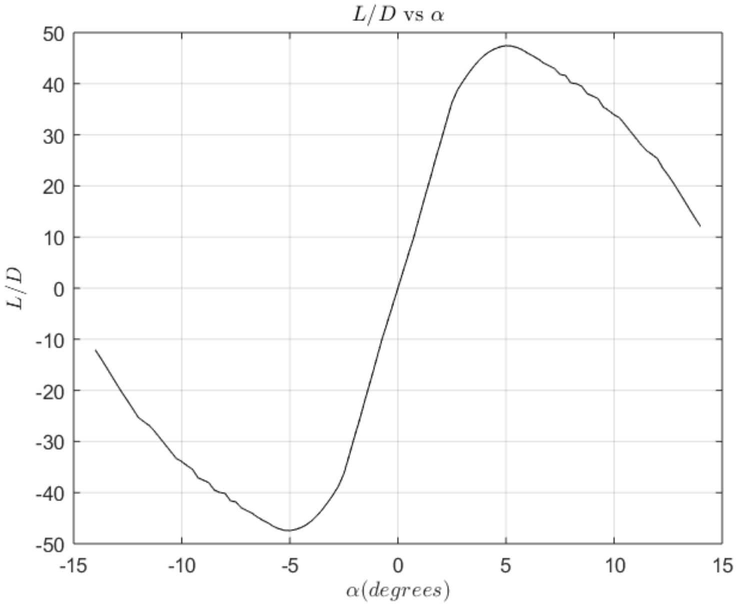
NACA 0012 - Lift and Drag

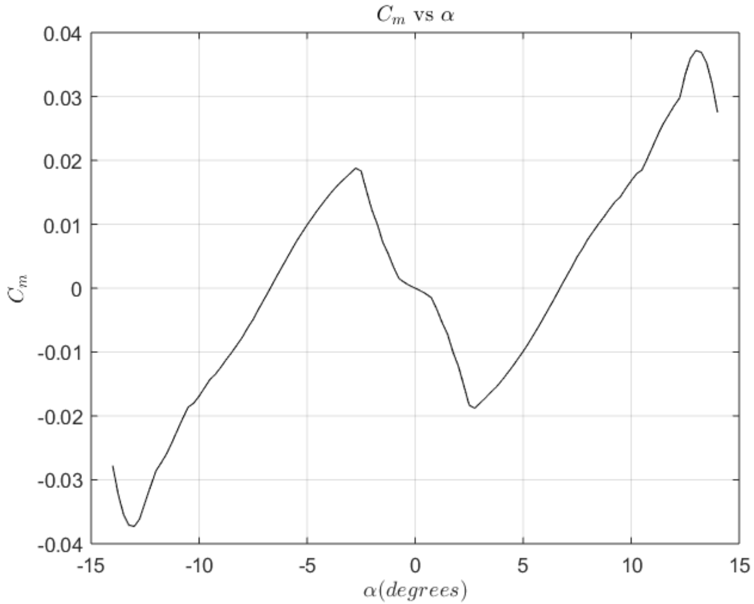






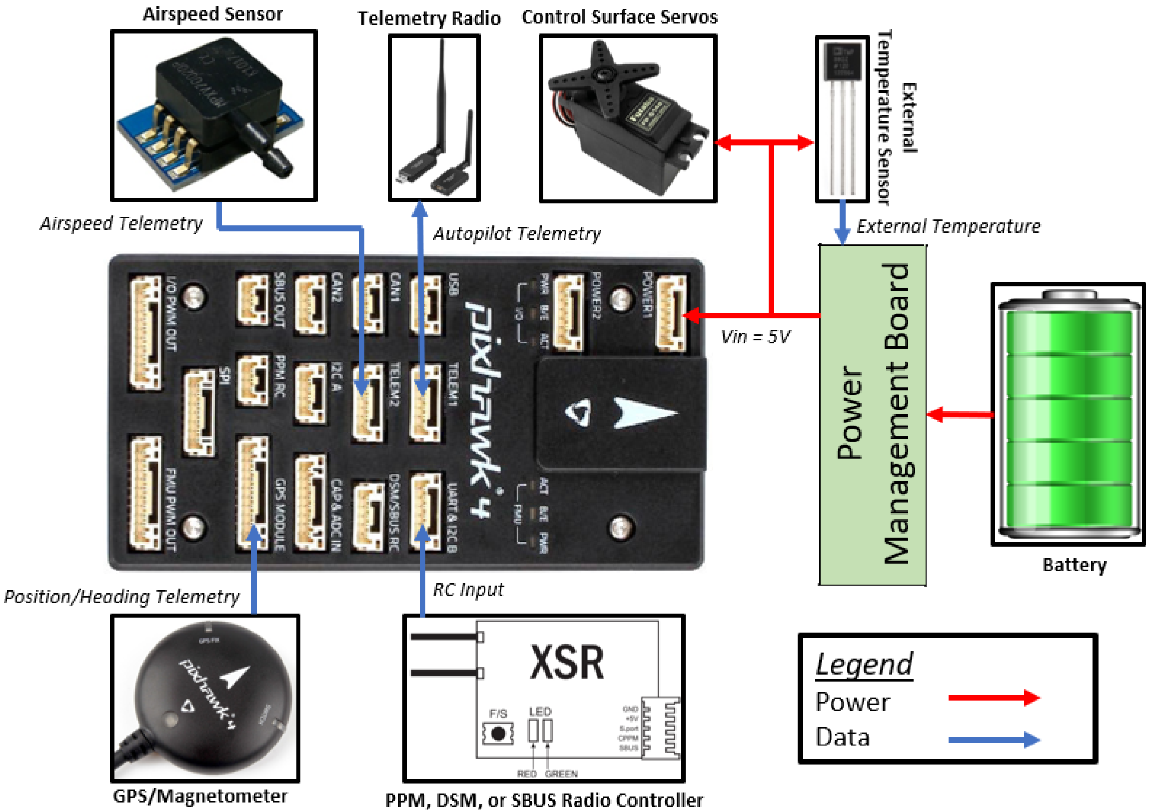
NACA 0012 - L/D and Moment





Backup Slides
Controls and Electronics

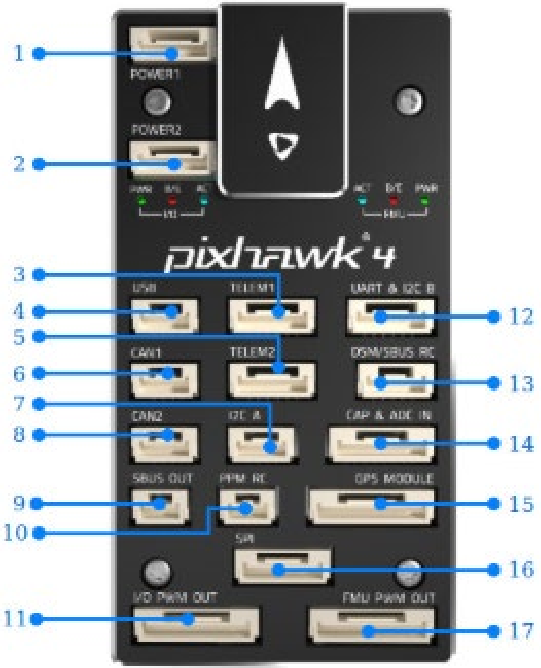
Controls and Electronics: FBD



Controls and Electronics: Pixhawk Flight Controller

FMU Processor	Sensors	Interfaces
• 32bit core with FPU • 216 MHz • 512KB RAM • 2 MB Flash	• Micro 16 bit gyro • Mico 12 bit accel • 3-axis accel/gyro • Barometer	• 8-16 PWM outputs • 3 PWM inputs • CPPM input • DSM, SBUS, RSSI input • SBUS servo output • 5 serial ports • 3 I2C ports • 4 SPI buses • 2 CAN buses • Analog voltage input

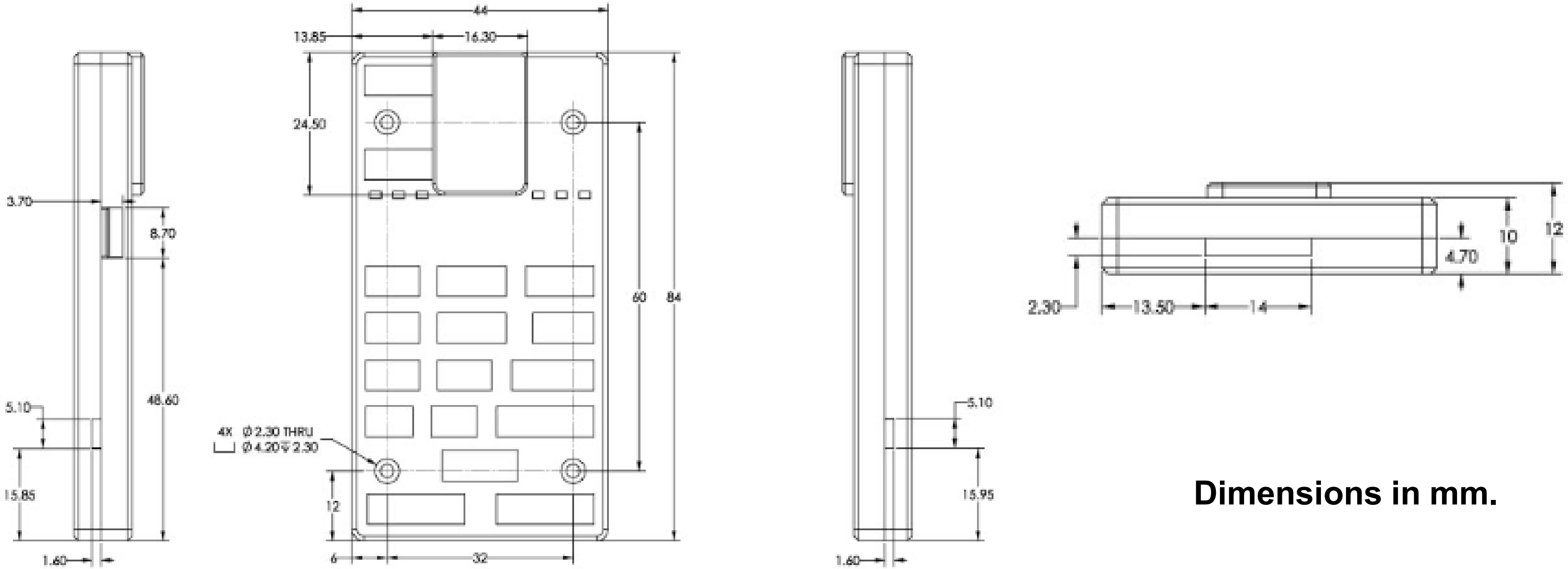
Controls and Electronics: Pixhawk Flight Controller



1. Power module 1
2. Power module 2
3. Telemetry 1 (radio telemetry)
4. USB
5. Telemetry 2 (companion computer)
6. CAN1 (controller area network) bus
7. I^2C (for I^2C splitter to use additional sensors)
8. CAN2 (controller area network) bus
9. S.BUS out for S.Bus servos
10. Radio Control Receiver Input (PPM)
11. Main outputs (I/O PWM out)
12. UART and I2C (for additional GPS)
13. Radio Control Receiver Input (DSM/SBUS)
14. Input Capture and ADC IN
15. GPS module
16. SPI (serial peripheral interface) bus
17. AUX outputs (FMU PMU out)

1. Micro-USB Port
2. IO Reset button
3. SD card
4. FMU Reset button

Controls and Electronics: Pixhawk Flight Controller



Dimensions in mm.

Controls and Electronics: Servos

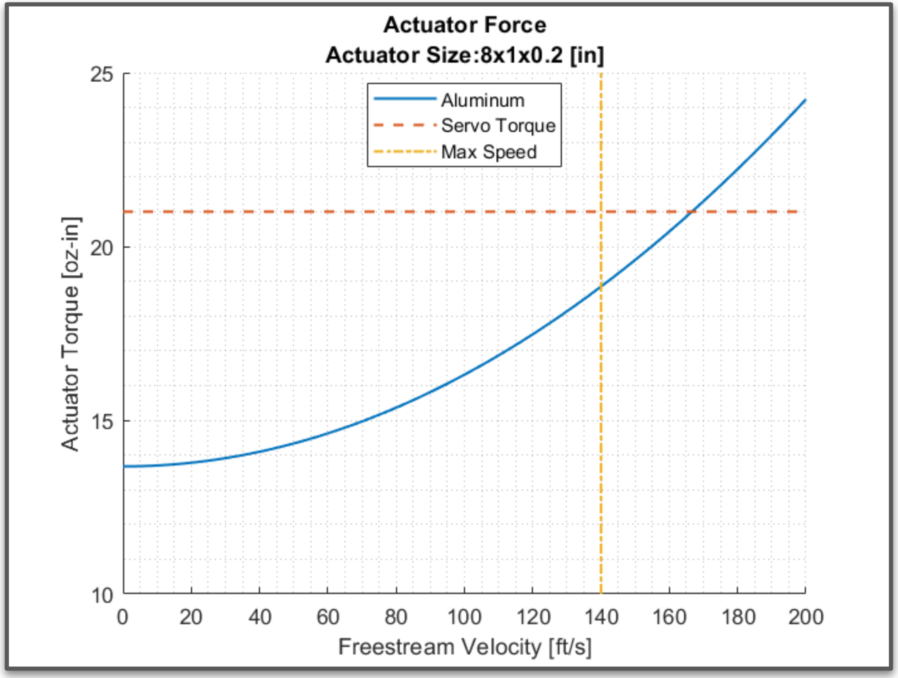
Worst case analysis using

- Smallest sized servo
- Maximum velocity
- Maximum density control surface

$\rho_{Al} = 169\ [lbm/ft^3]$

S3154 High-Torque/High-Speed Micro

FUTM0654		
Volts	**Torque**	**Speed**
4.8V	21 oz-in (1.5 kg-cm)	0.10 sec/60°
6.0V	24 oz-in (1.7 kg-cm)	0.09 sec/60°
Dimensions		**Weight**
7/8 x 7/16 x 13/16 in (22 x 11 x 20 mm)		0.28 oz (7.9 g)
		3P



Assume: Actuator is flat plate, gravity and air mass flow are only opposition forces, maximum 45° actuator cant, forces act on the center of the actuator

Controls and Electronics: Interference

Interference Prevention:

1. Place compass away from high current wires
2. Place gps unit with unobstructed view of sky
3. Construct with non-magnetic materials
4. Isolate PWM signal wires from low current DC wires
5. High frequency or current wires should not be laid parallel
6. Twist wires and use ground shielding
7. Communicate on different radio bands than payload

GPS Module

Telemetry Radio Set

Controls and Electronics: Sensor Sampling Rate

GPS 4 GPS Module

- Cold start time: 26s
- Baud rate: 38400 bps at 5Hz
- Navigation sensitivity: -167 dBm
- Includes GPS, compass, safety switch, and buzzer
- http://www.holybro.com/manual/Pixhawk4-GPS-Quick-Start-Guide.pdf

Micro FPV Radio Telemetry set

- Range: ~1 mile
- Band: 915 or 433 MHz
- Receiver sensitivity: -117 dBm
- Max output power: 100 mW
- http://www.holybro.com/product/17

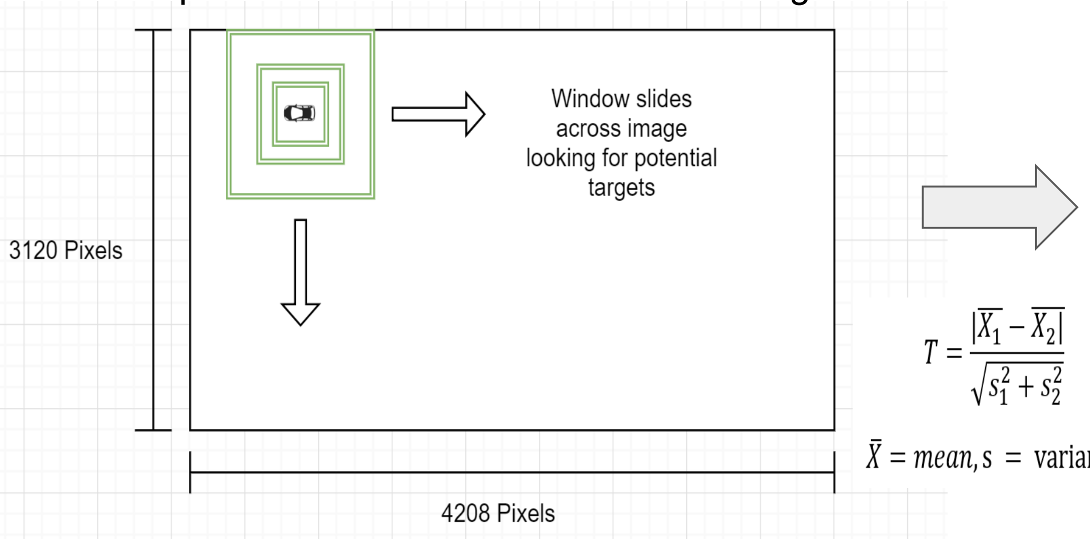
Controls and Electronics: Instrument Accuracies

- Holybro Pixhawk 4 GPS Module
  - $\leq$ 25.6 ft of real target location (95% confidence)
- Airspeed Indicator
  - $\mp$0.0475 kPa
- TMP36 Temperature Sensor
  - $\mp$2 C

Backup Slides
Software

Software: Target Detection

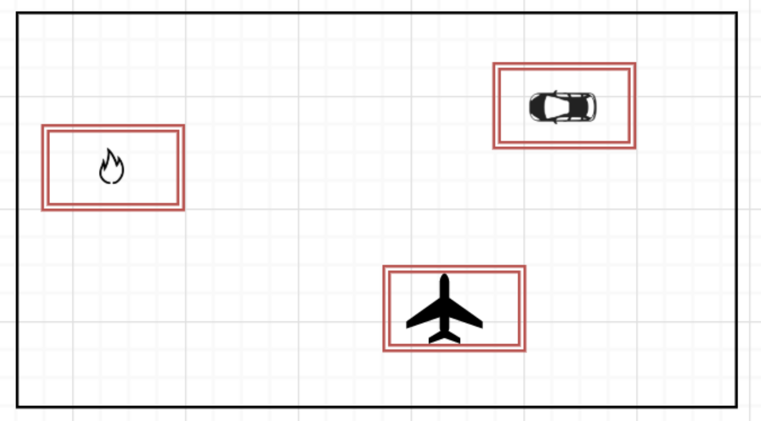
Compare statistics between windows using T-test:



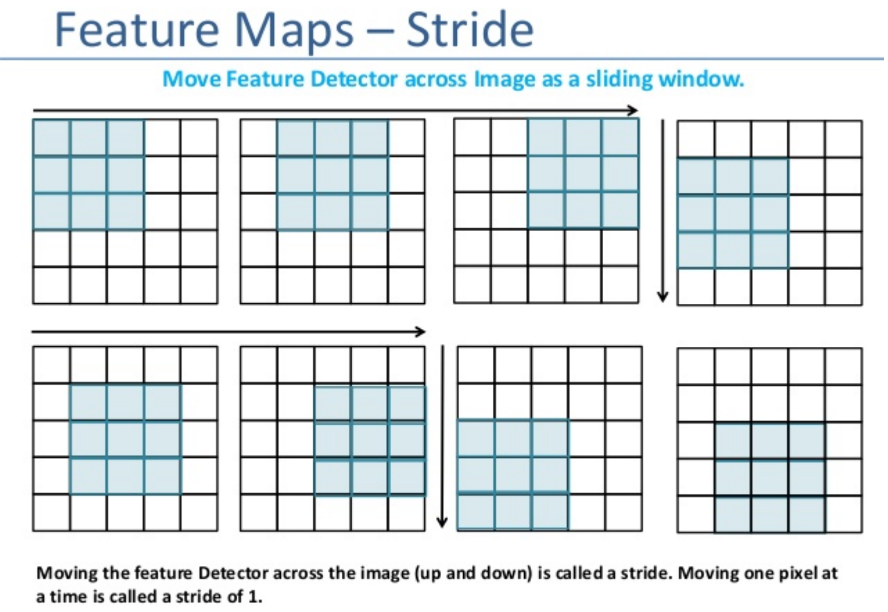
$$T = \frac{|\bar{X}_1 - \bar{X}_2|}{\sqrt{s_1^2 + s_2^2}}$$

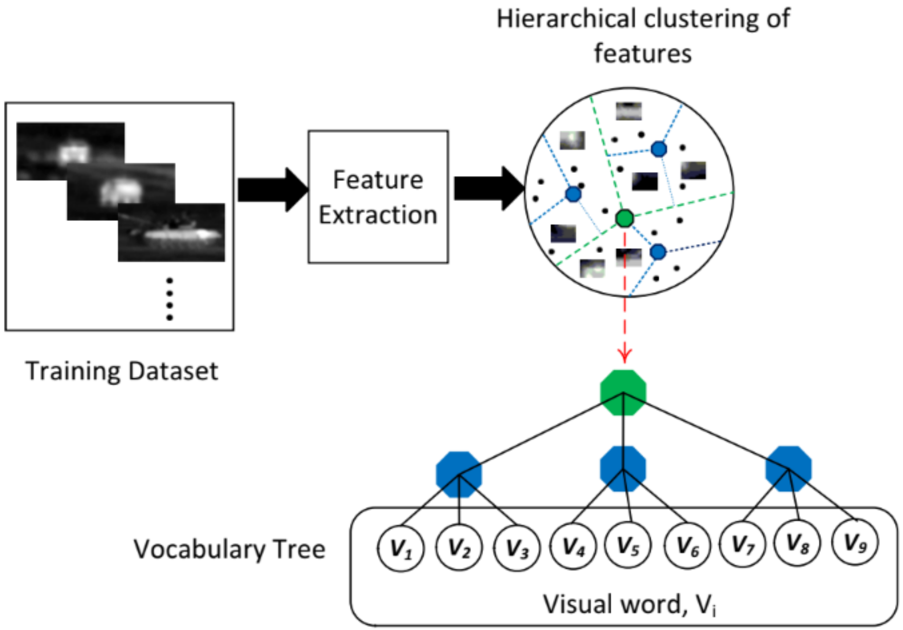
$\bar{X} = mean, s = \text{variance}$

Highlight regions of interest for classification and geolocation

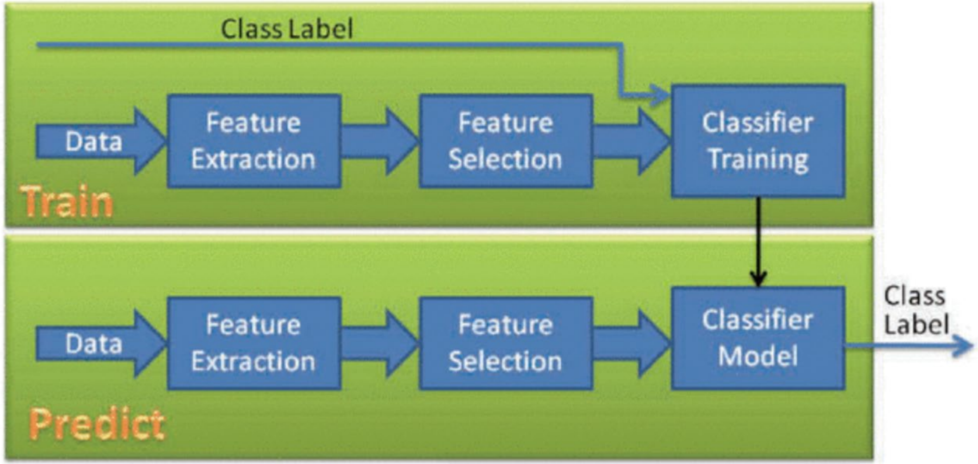


Software: Feature Extraction





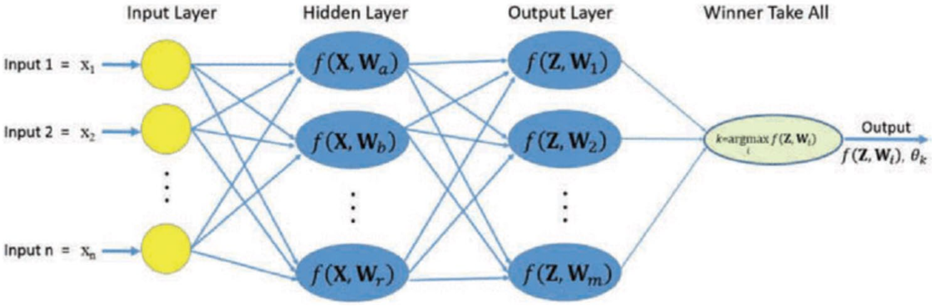
Software: Target Classification



Training data:

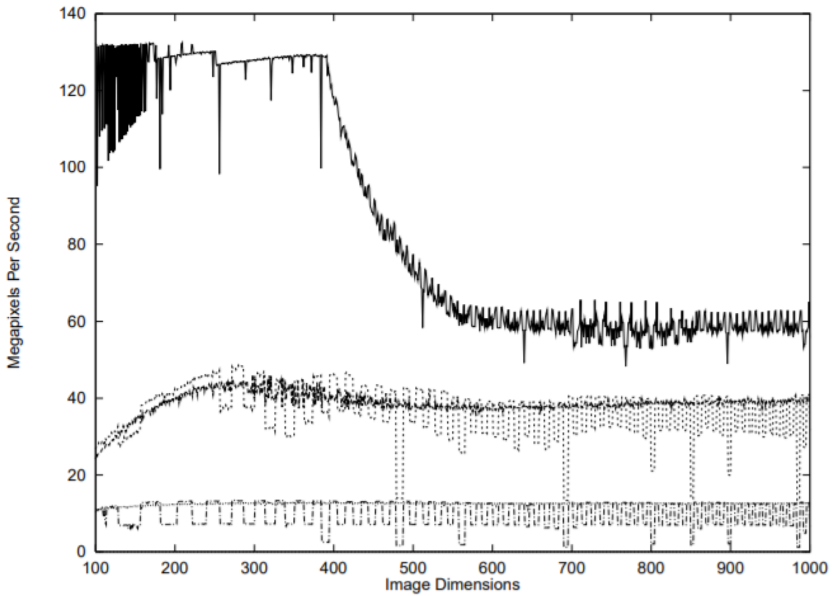
- Size and complexity depends on customer input
- Use images taken from quadcopter with similar camera
- Use online databases of images

Train with open source Neural Network: TensorFlow



Software: Processing Power Feasibility Backup

- Military Standard Dell Laptop
  - Comparable to what would be used by military p
  - 4GB RAM with support of up to 32GB RAM
  - 2.3GHz Processor
- Image Processing Speed
  - From a master's thesis at UC Berkeley: Process megapixels/second using a machine with 96MB powerful than what we are designing for



Software: Automatic Target Recognition

- Resolution requirement needs and what's common in practice
- Single camera field of view: chances target will fall in image plane
- SNR, target contrast, image quality at night, through fog, etc.
- Machine learning/computer vision - finding training images for identification
- Target location accuracy and error propagation
- Success probabilities - certainty of target vs. non-target

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