Final Design Package

S.U.A.S.

Student Unmanned Aerial System

Senior Design Team# 14

Team Members

Antwon Blackmon, ME

Walker Carr, ME

Alek Hoffman, EE

Ryan Jantzen, ME

Eric Prast, EE

Brian Roney, CpE

Introduction

Primary Objectives:

- Systems Engineering approach for the design and manufacture of an Unmanned Aerial System (UAS)
- System must be designed for:
  - Waypoint Navigation
  - Autonomous Area Search for Ground Targets
  - Image Recognition of Ground Targets
- System must comply with the 2012 AUVSI Student UAS Competition requirements.

Introduction

- Budget = 3000$
  - Electronics = 1500$
  - Aircraft Materials = 800$
  - Surplus = 700$

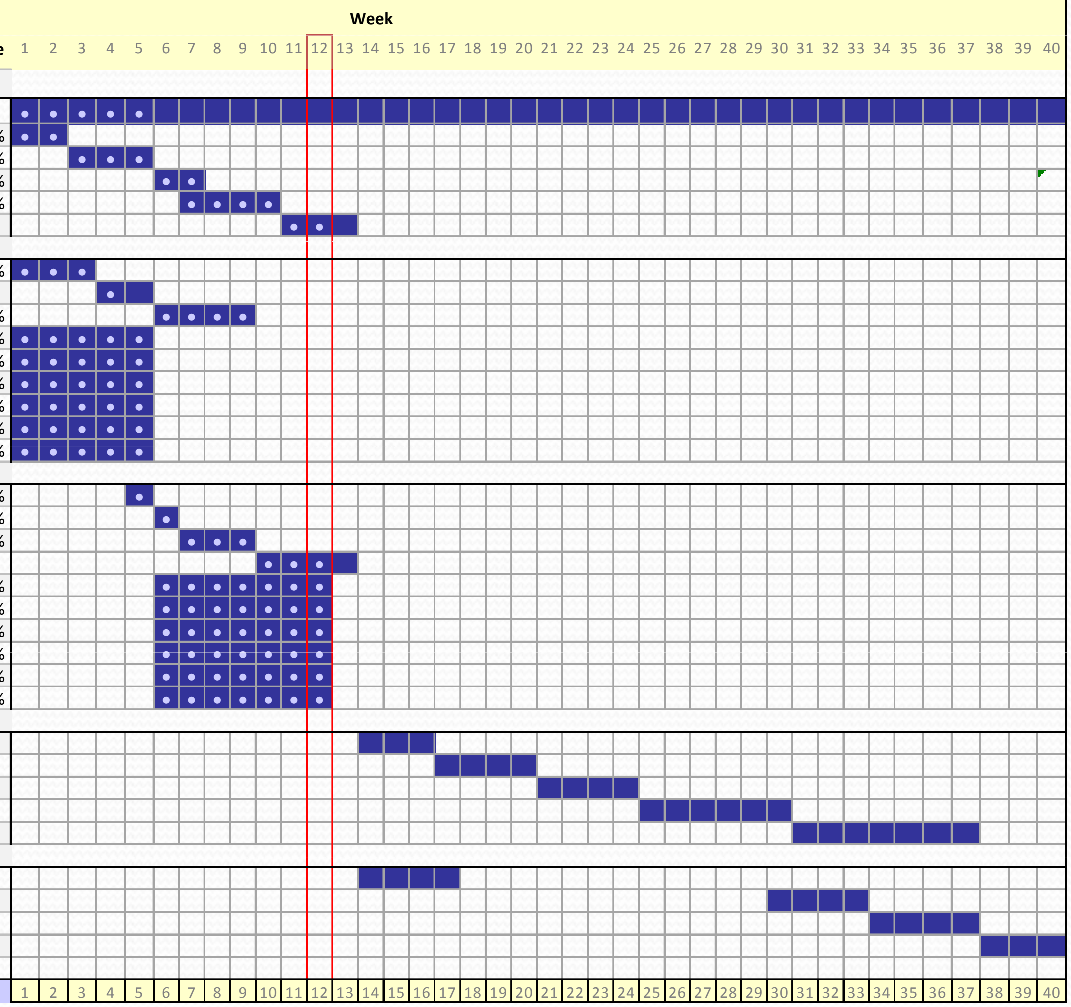
- To accomplish our primary objectives, our UAS must be comprised of several subsystems:
  - Aircraft Subsystem
  - Avionics Subsystem
  - Imagery Subsystem
  - Ground Station Control (GSC) Subsystem

Project Plan

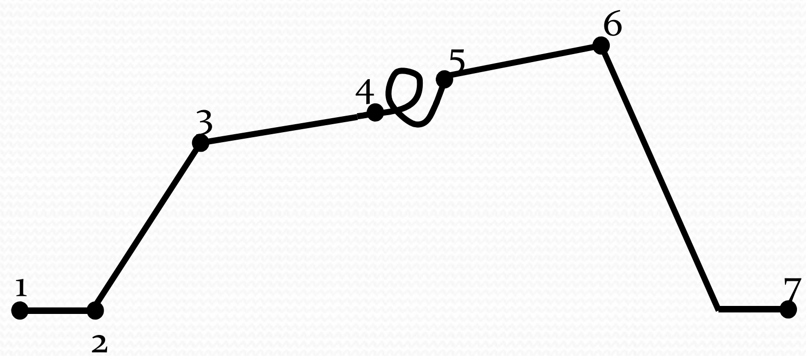
Team 14 Gannt Chart

Completion: • | Current Week: 12

#	Activity	Begins	Ends	Planned Start	Dur	% Done
	Management					
1	Project Management	11-Sep-11	11-Jun-12	1	40	12%
2	NAPS	11-Sep-11	29-Sep-11	1	2	100%
3	Project Specifications	30-Sep-11	13-Oct-11	3	3	100%
4	CDR Presentation	14-Oct-11	27-Oct-11	6	2	100%
5	IDR Presentation	28-Oct-11	17-Nov-11	7	4	100%
6	FDR Presentation	18-Nov-11	8-Dec-11	11	3	50%
	Research					
7	Blanket Research	11-Sep-11	2-Oct-11	1	3	100%
8	Specified Research	3-Oct-11	16-Oct-11	4	2	50%
9	Design Research	10-Oct-11	7-Nov-11	6	4	100%
10	Structure Research	11-Sep-11	16-Oct-11	1	5	100%
11	Propulsion Research	11-Sep-11	16-Oct-11	1	5	100%
12	Materials Research	11-Sep-11	16-Oct-11	1	5	100%
13	Power Research	11-Sep-11	16-Oct-11	1	5	100%
14	Controller Research	11-Sep-11	16-Oct-11	1	5	100%
15	Sensor Research	11-Sep-11	16-Oct-11	1	5	100%
	Design					
16	Concept Generation	11-Oct-11	16-Oct-11	5	1	100%
17	Concept Selection	17-Oct-11	23-Oct-11	6	1	100%
18	Design Refinement	24-Oct-11	6-Nov-11	7	3	100%
19	Final Design	7-Nov-11	5-Dec-11	10	4	75%
20	Structure Design	17-Oct-11	4-Dec-11	6	7	100%
21	Propulsion Design	17-Oct-11	4-Dec-11	6	7	100%
22	Materials Design	17-Oct-11	4-Dec-11	6	7	100%
23	Power Design	17-Oct-11	4-Dec-11	6	7	100%
24	Controller Design	17-Oct-11	4-Dec-11	6	7	100%
25	Sensor Design	17-Oct-11	4-Dec-11	6	7	100%
	Prototype					
26	Part Ordering	12-Dec-11	31-Dec-11	14	3	0%
27	Initial Testing	2-Jan-12	22-Jan-12	17	4	0%
28	Intermediate Testing	23-Jan-12	19-Feb-12	21	4	0%
29	Final Testing	20-Feb-12	31-Mar-12	25	6	0%
30	Final Prototype	2-Apr-12	10-Jun-12	31	7	0%
	Competition					
31	Application	12-Dec-11	8-Jan-12	14	4	0%
32	Clearance	2-Apr-12	2-May-12	30	4	0%
33	Journal	1-May-12	24-May-12	34	4	0%
34	Compete	13-Jun-12	17-Jun-12	38	3	0%
35				0	0	0%



Mission Profile



Mission Profile:

1. Warm-up & Take-off
2. Climb
3. Waypoint Navigation
4. Autonomous Area Search
5. Waypoint Navigation
6. Descent
7. Landing

Constraint Analysis

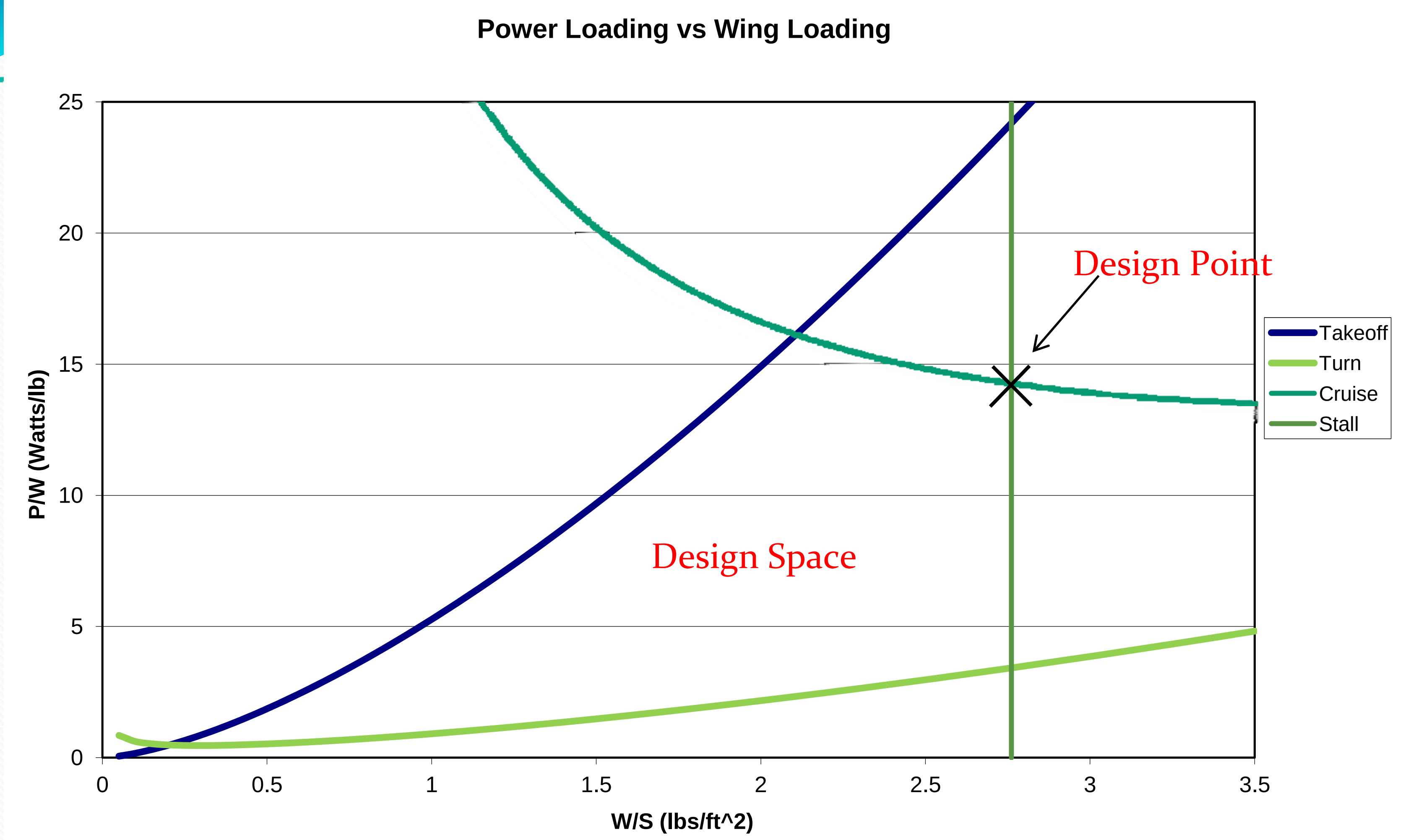
- Used to determine the initial power loading $\left(\frac{P}{W}\right)$ and wing loading $\left(\frac{W}{S}\right)$for our design.
- $\frac{P}{W} = fnc\left(\frac{W}{S}\right)$
- Example: Cruise Requirements

$$\left(\frac{P}{W}\right)_{cruise} = \frac{V}{\eta}\left(\frac{qC_{D_o}}{\left(W/S\right)} + \left(\frac{W}{S}\right)\frac{K}{q}\right)$$

Constraint Analysis

These quantities are held constant for the current analysis:

Cl_max	1.5
C_Do	0.025
Oswald Efficiency Factor	0.8
Lift to Drag Ratio	16
Propeller Efficiency	0.7



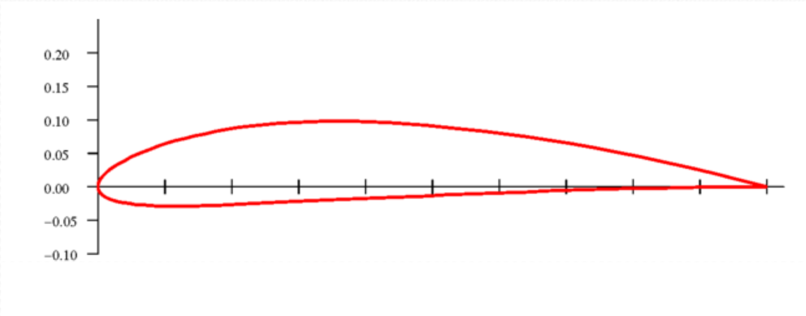
Design Point:

$$\frac{P}{W} = 14.25 \ \frac{Watts}{lb}$$

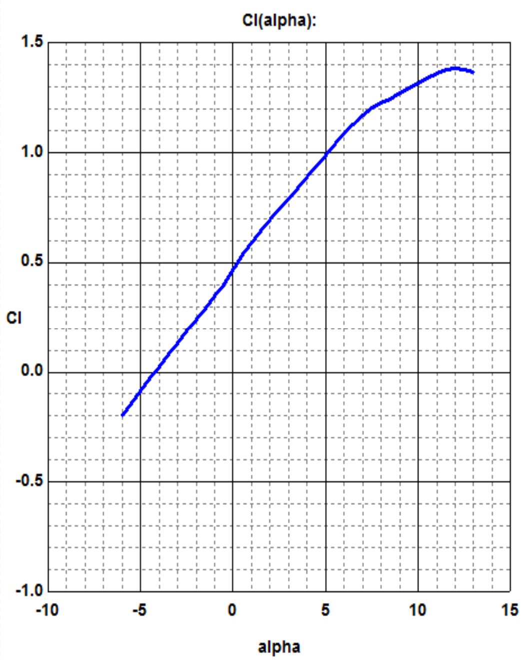
$$\frac{W}{S} = 2.72 \ \frac{lb}{ft^2}$$

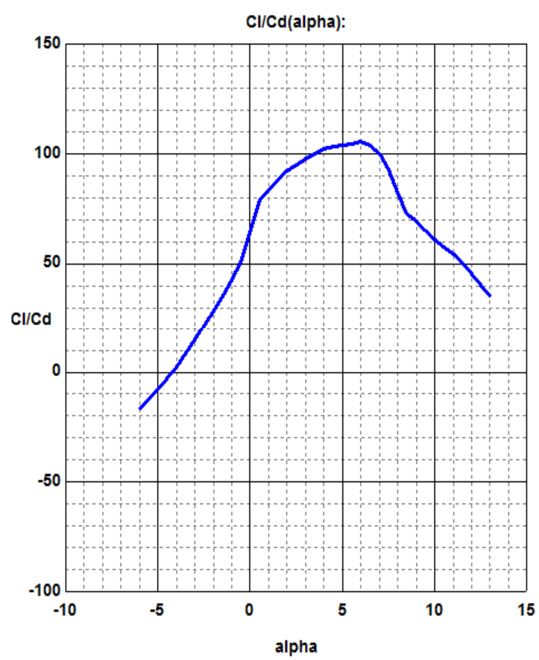
Airfoil Selection

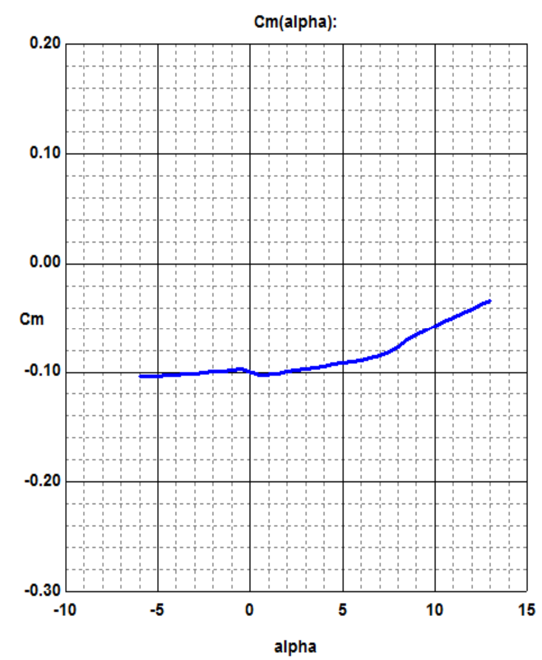
NACA 4412



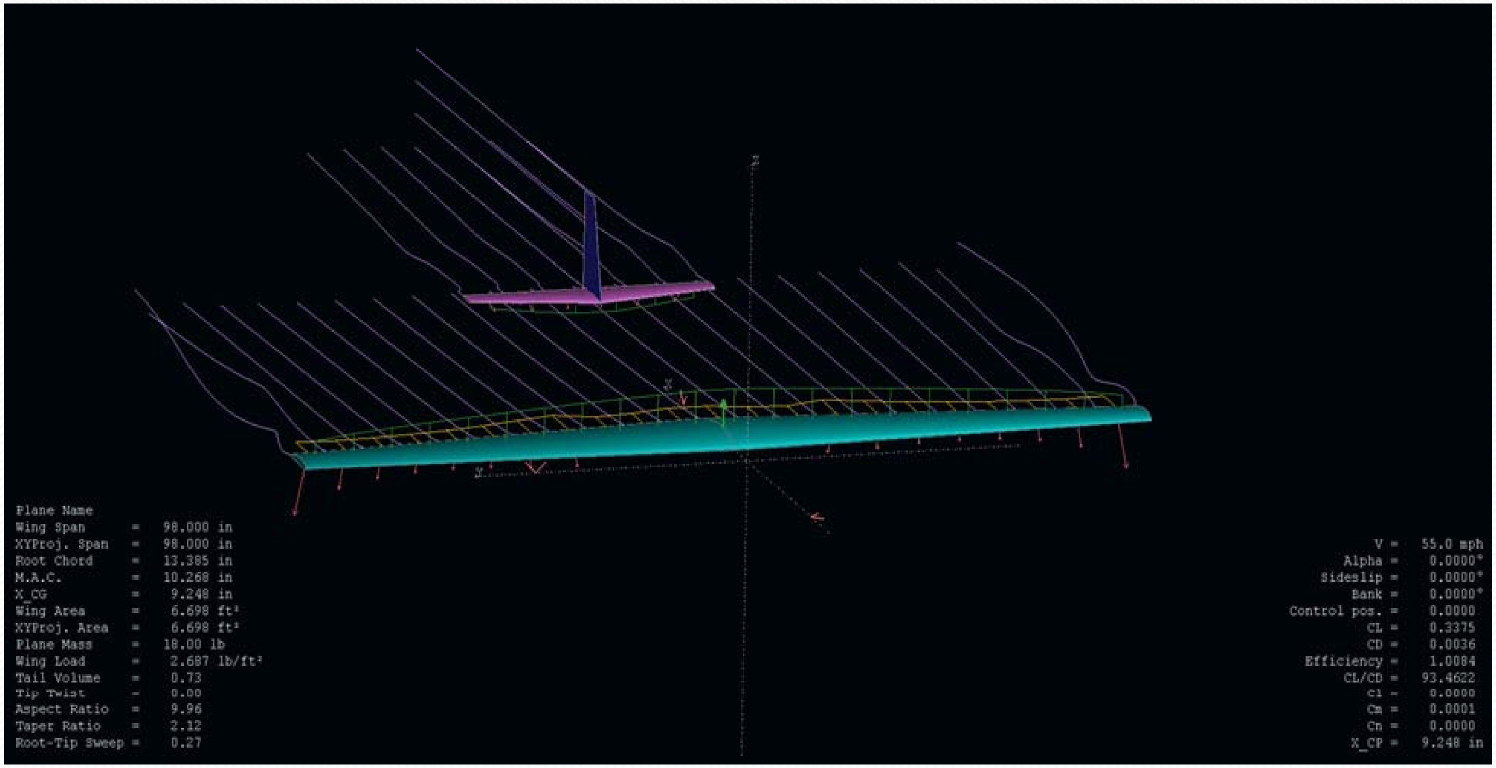
Max C_L:	1.51
Max C_L angle:	11.0
Max L/D:	57.2
Max L/D angle:	5.50
Max L/D C_L:	1.19
Stall angle:	6.00
Zero-lift angle:	-4.00





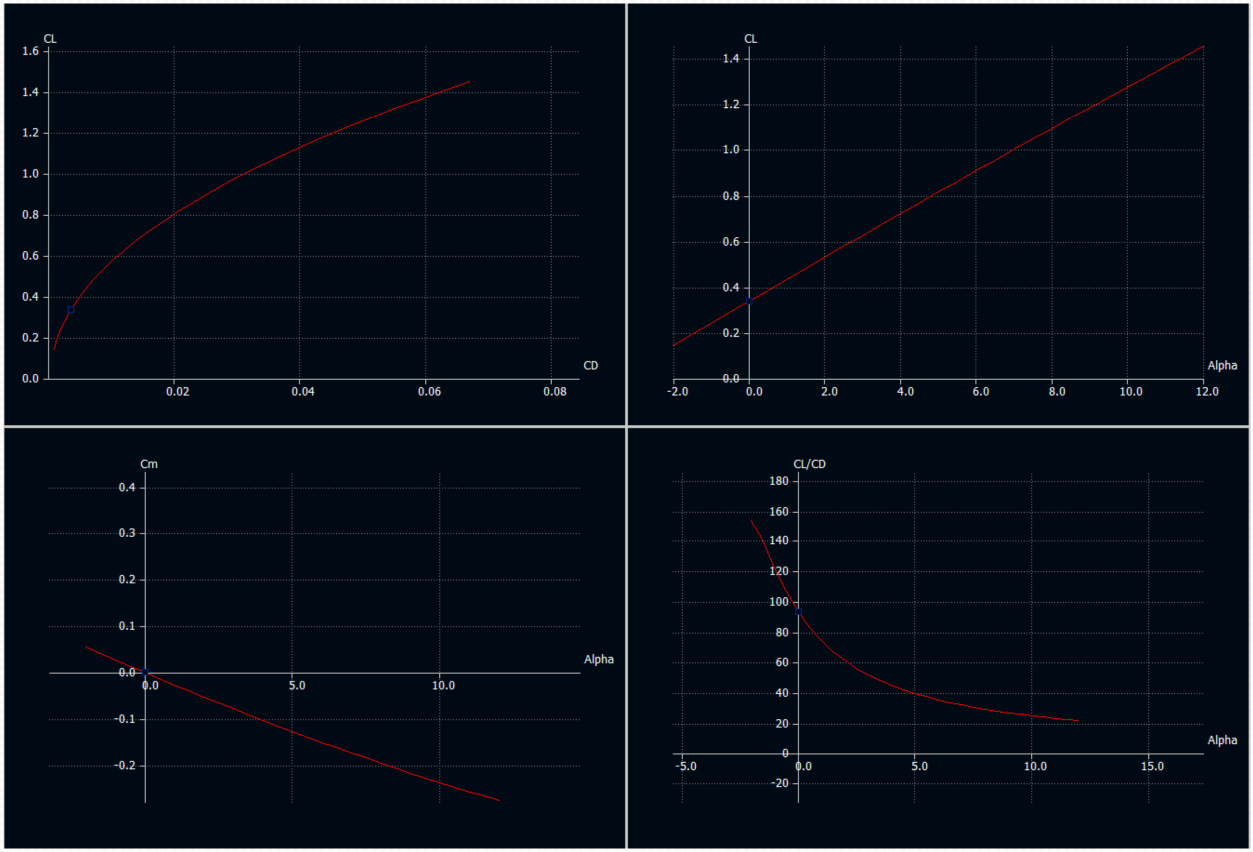


Wing Planform and Empennage Design



XFLR5 Analysis

Wing Planform and Empennage Design



XFLR5 Analysis

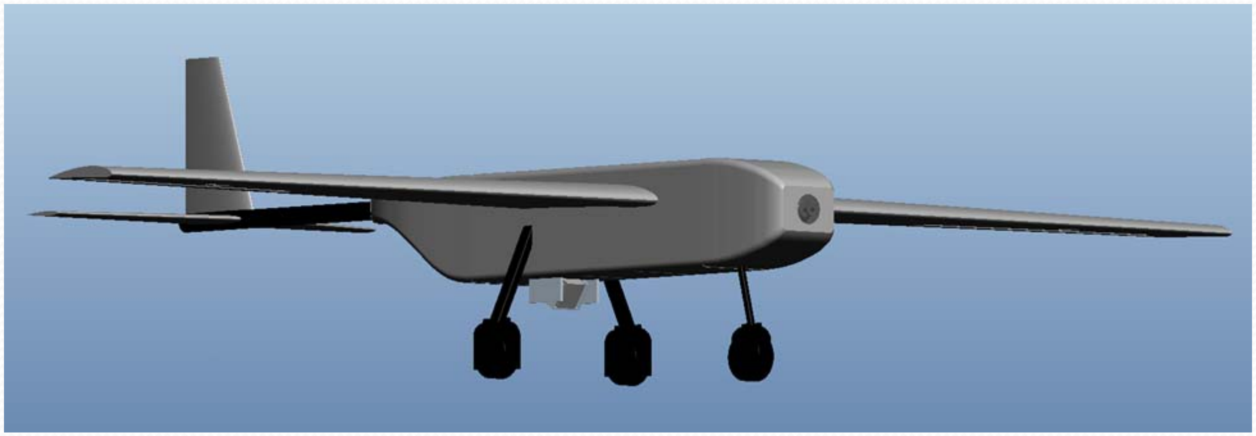
Final Design

Wing	
Span	98 in
Area	6.7 ft-^{2}
Root Chord	13.4 in
Tip Chord	6.3 in
Aspect Ratio	10
Taper Ratio	0.47
Sweep	0.27^{o}
MAC	10.3 in
MAC Location Span-wise	2.5^{o}
Wing Loading	2.7 lb/ft^{2}
Cruise C_L	0.34
Airfoil	NACA 4412
Ailerons	
Span	55-95% Half Span
Chord Percentage	20%
Max Deflection	±30^{o}

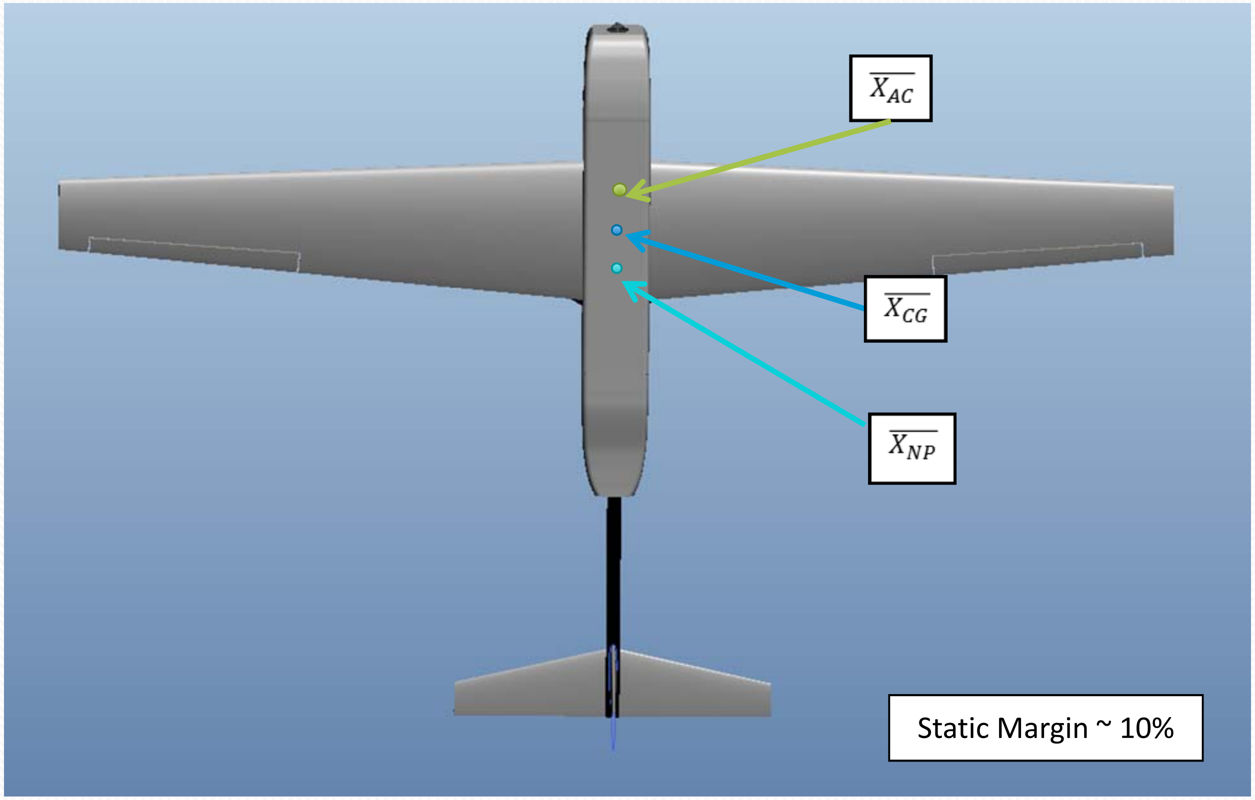
Horizontal Tail	
Span	28.3 in
Area	0.93 ft^{2}
Root Chord	6.3 in
Tip Chord	3.15 in
Aspect Ratio	6
Sweep	9.4^{o}
Taper Ratio	.5
Airfoil	NACA 0012
Elevator	
Span	Full Span
Chord Percentage	20%
Max Deflection	±30^{o}

Vertical Tail	
Span	20.7 in
Area	0.37 ft^{2}
Root Chord	6.9 in
Tip Chord	3.45 in
Aspect Ratio	4
Sweep	14.04^{o}
Taper Ratio	.5
Airfoil	NACA 0012
Rudder	
Span	Full Span
Chord Percentage	20%
Max Deflection	±30^{o}

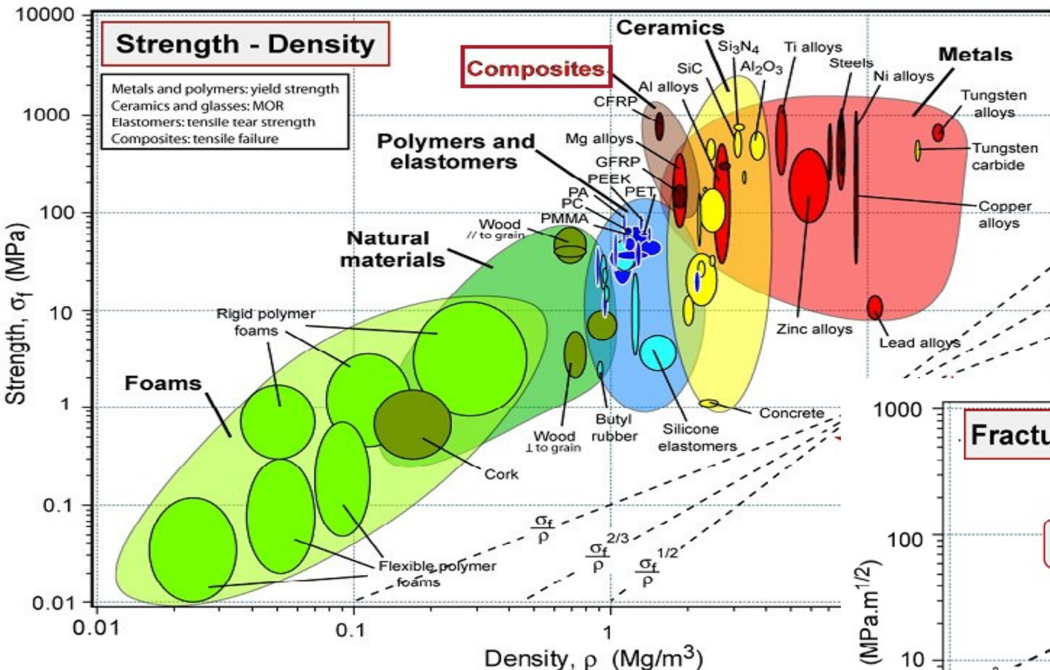
Final Design

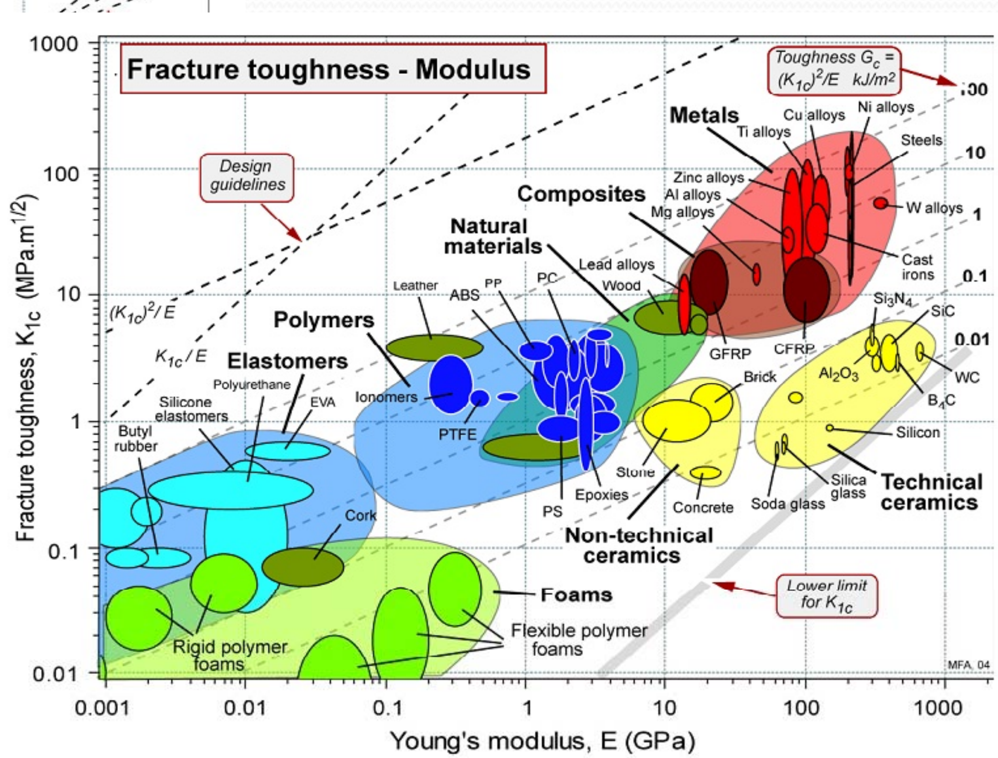


Final Design



Material Selection





Material Selection

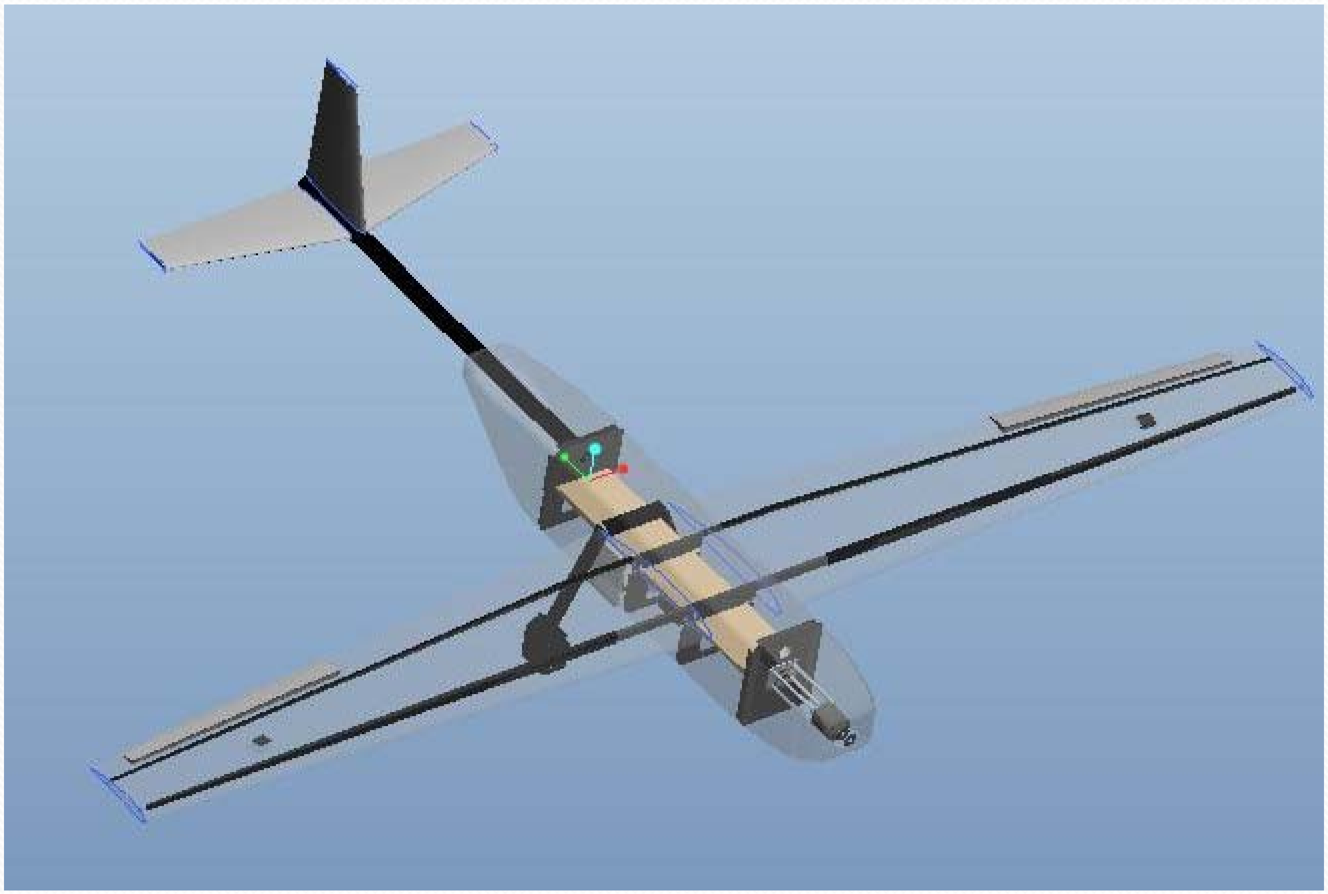
Material	T. Strength 0° (KSI)	T. Strength 90° (KSI)	T. Modulus 0° (MSI)	T. Modulus 90° (MSI)	In-Plane Shear (KSI)	Poisson's Ratio
Carbon Fiber	87	87	10.1	10.1	13	0.11
Fiberglass	23	23	2.18	2.18	3.95	0.1

Material	Density (lb/ft³)	Compressive strength (psi)
EPS Foam	2	25
Balsa	8	1750
Plywood	32	2320

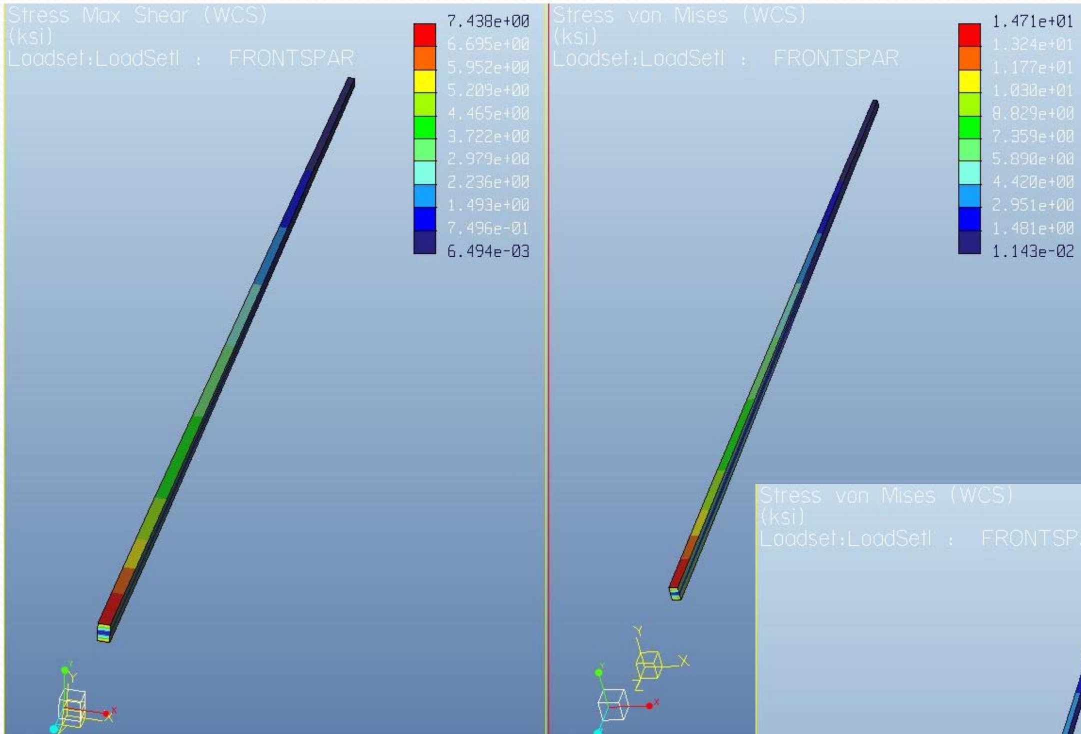
Resin System:

West Systems 105 epoxy resin and 206 slow cure hardening system

Structure



Spar Structural Analysis



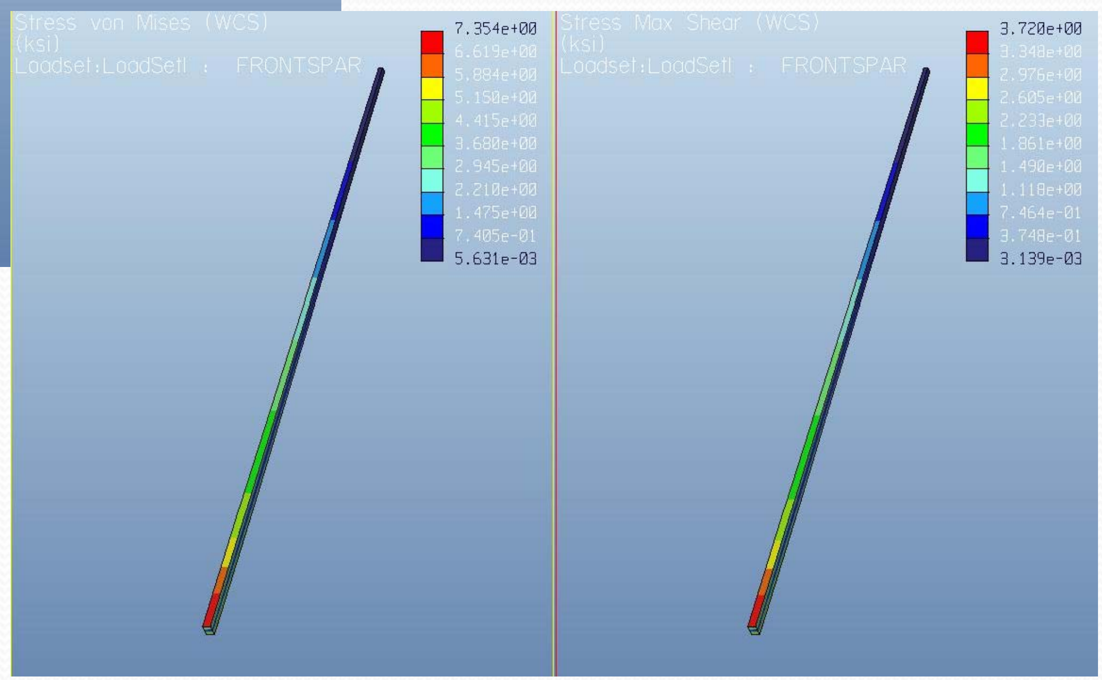
38lbf top load:

Shear Stress (ksi): 7.44

Von Mises (ksi): 14.7

FOS Shear: 1.75

FOS: 5.92

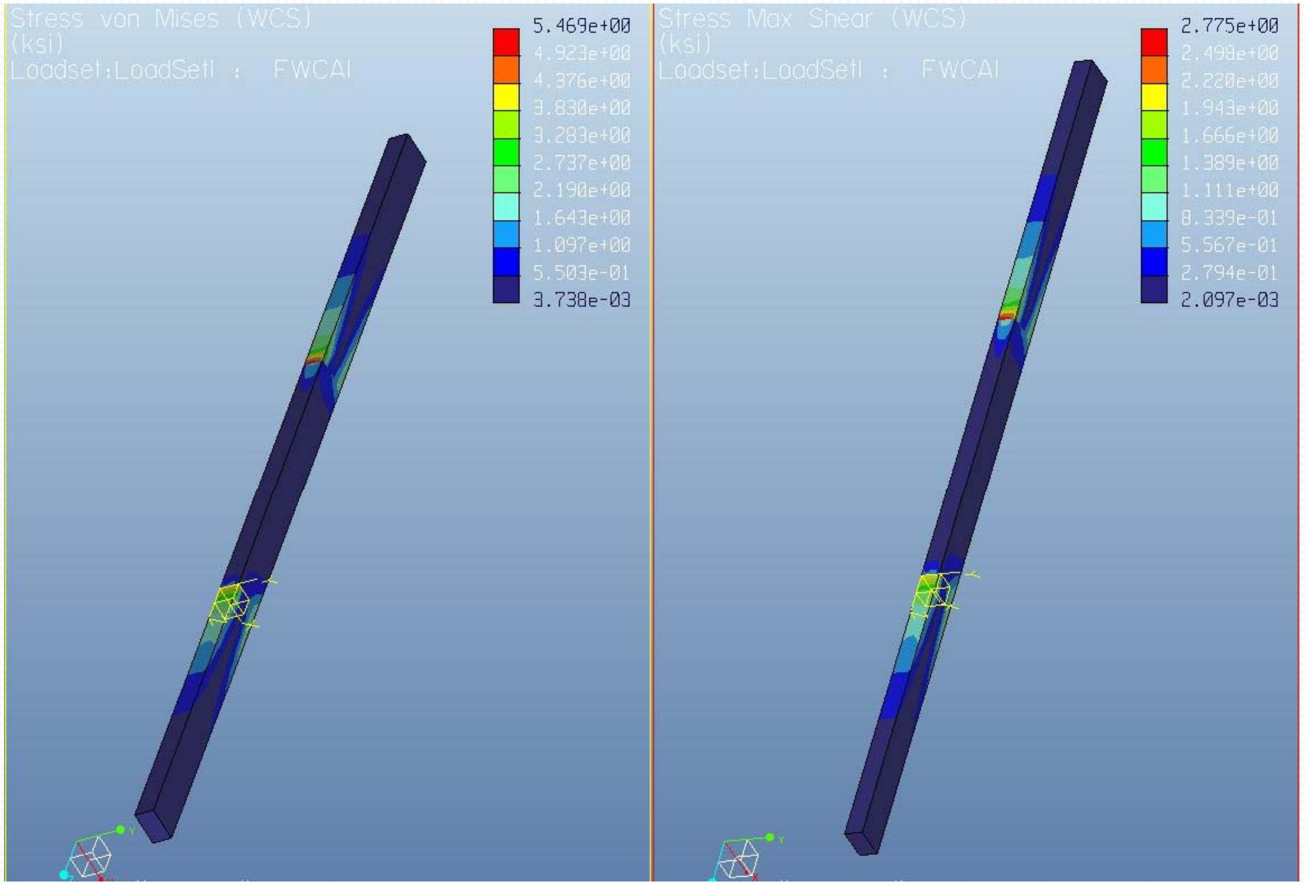


19lbf bottom load:

Shear Stress (ksi): 3.72

Von Mises (ksi): 7.35

Wing Connection Analysis

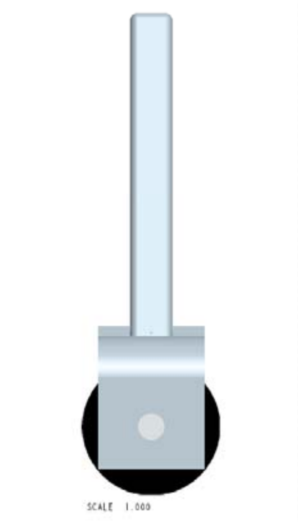


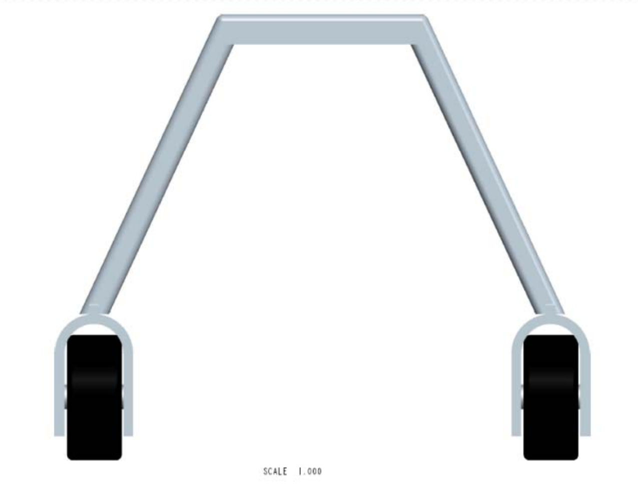
Shear (ksi): 2.78
Von Mises (ksi): 5.47

FOS shear: 4.77
FOS: 16

Landing Gear

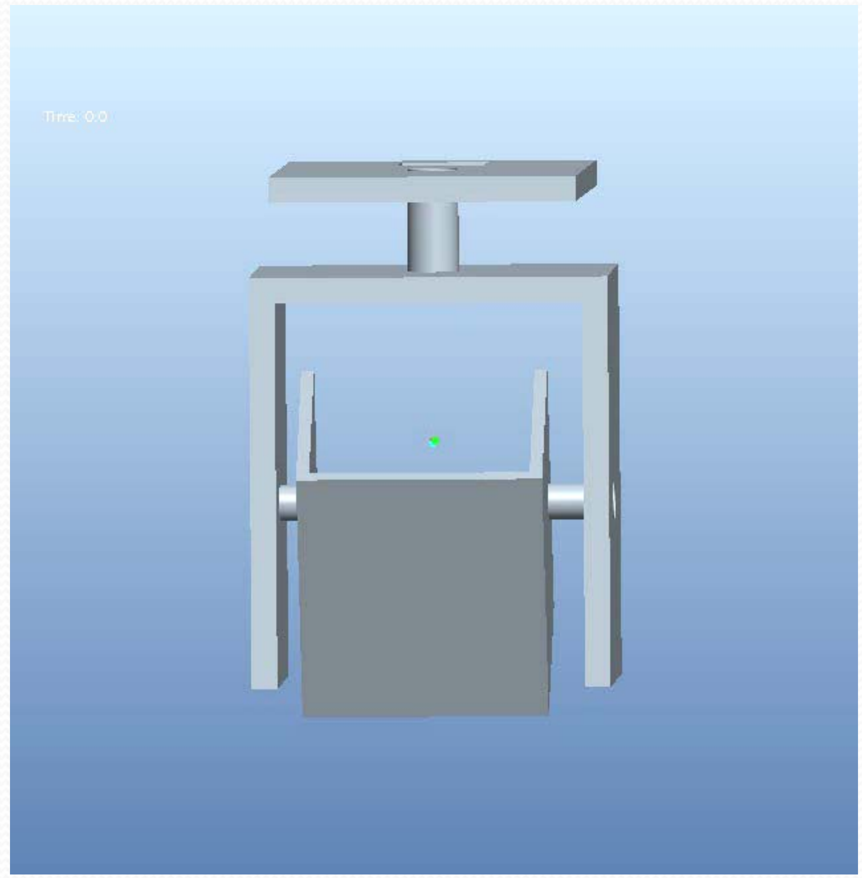
- Tricycle gear
- Front wheel angled
- Rear wheels angled
- Placed near center of gravity



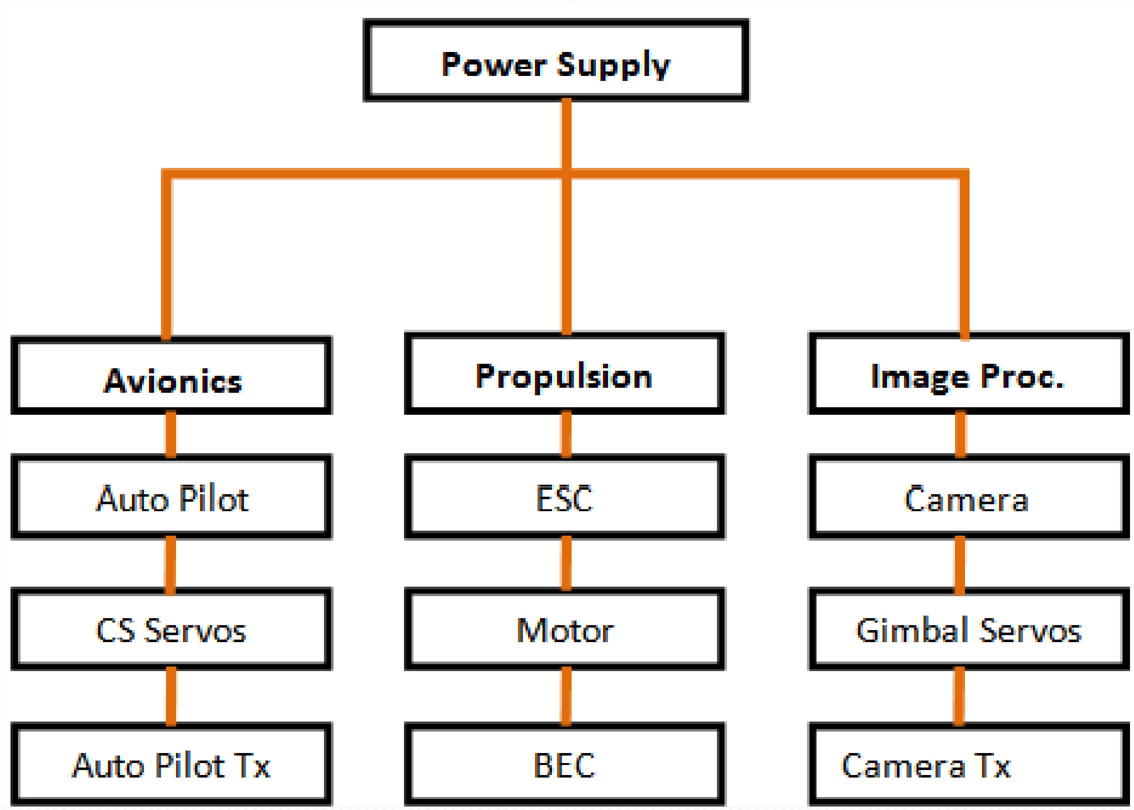


Gimbal

- Spin about 2 axis
- Servo controlled
- Hold camera
- Imagine recognition
- Stabilization



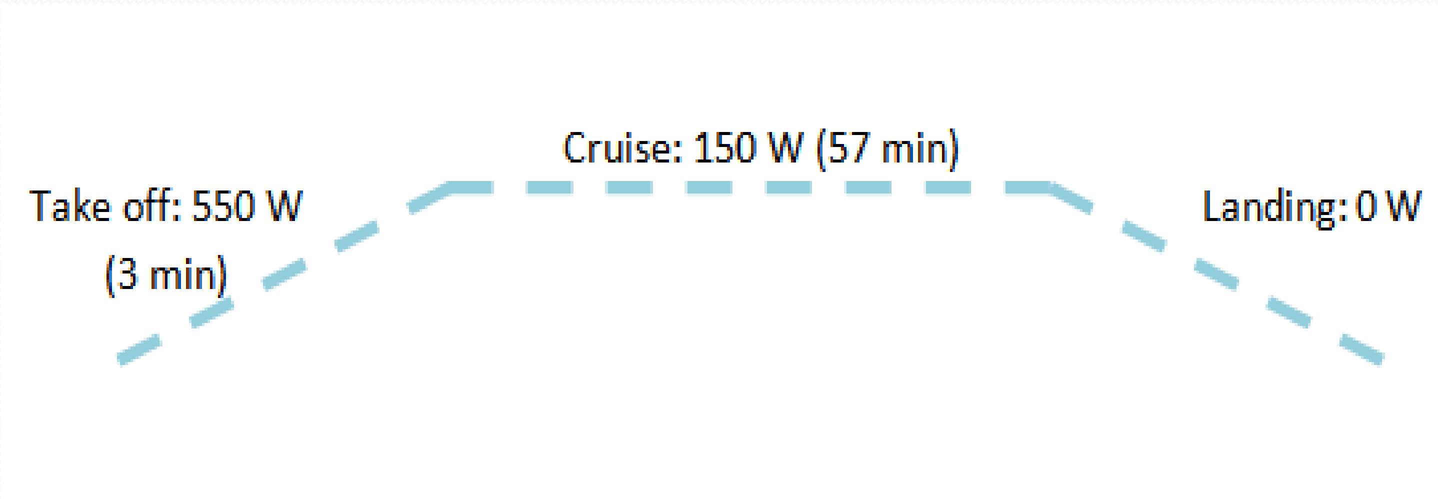
Power Supply System



- Analysis of SUAS Electronic Components

Propulsion System Analysis

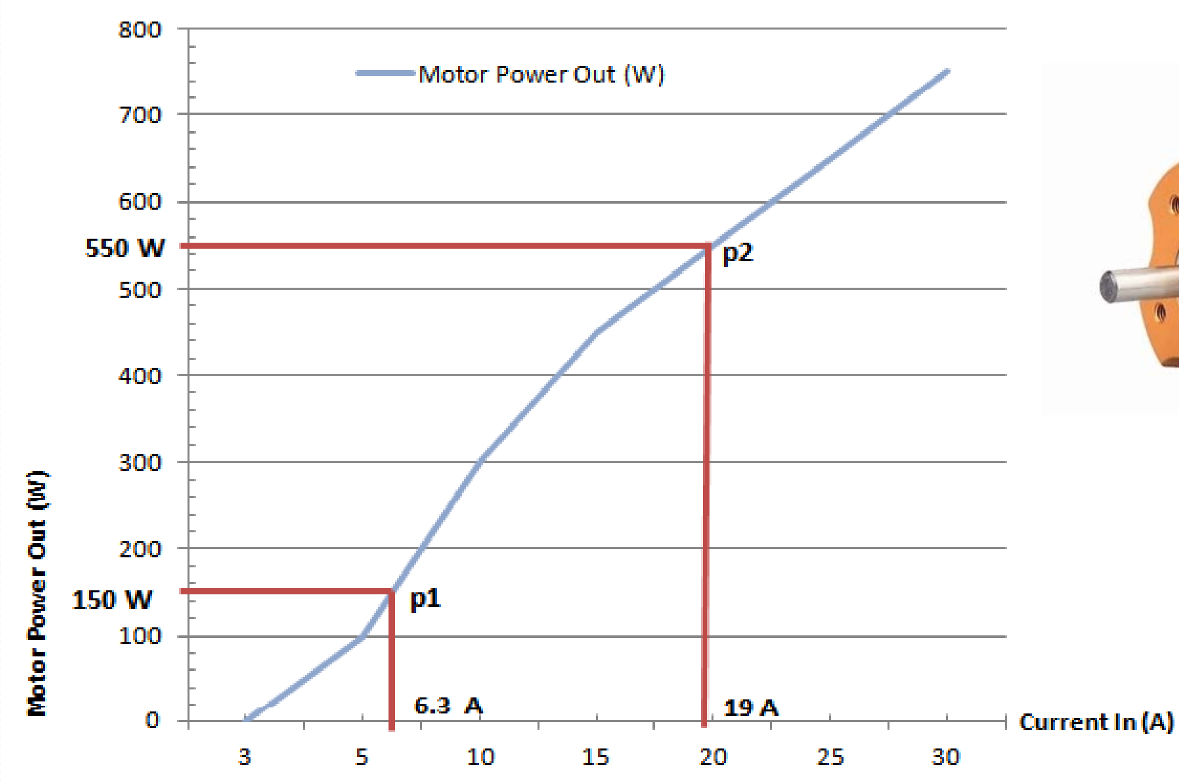
- Mission Power Requirements Profile
- Required Maximum Power Required = 550 W

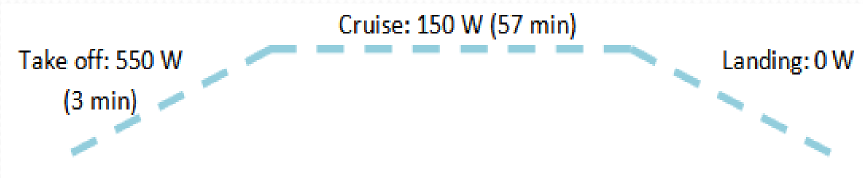


Propulsion System Analysis

Motor Decision Matrix			AXI 5320/28			Elite Power 60			AXI 4130/20	
Criteria	weight		Grade	Weighted G		Grade	Weighted G		Grade	Weighted G
Weight	0.2		2.00	0.40		4.00	0.80		3.00	0.60
Cell # (LiPo)	0.25		3.00	0.75		4.00	1.00		4.00	1.00
KV (RPM/V)	0.15		3.00	0.45		4.00	0.60		4.00	0.60
Max Power	0.1		4.00	0.40		3.00	0.30		4.00	0.40
Efficiency	0.1		5.00	0.50		4.00	0.40		4.00	0.40
Cost	0.2		3.00	0.60		3.00	0.60		4.00	0.80
Total	1		15.00	**3.10**		18.00	**3.70**		19.00	**3.80**

Propulsion System Analysis





Propulsion System Analysis

The total current consumption of the motor for the entire mission can then be calculated as:

$$C_{tot}(t) = \sum I_{req} * t_{total} = (I_{cruise} * t_{cruise} + I_{takeoff} * t_{takeoff})$$

Where C_{tot} is the total current capacity required by the motor in Amp hours (Ah), calculated as the sum of the required currents multiplied by the respective times. For a capacity in Ah, the time is inputted in hours. The equation is then:

$$C_{tot}(t) = 6.3A * 0.95h + 19A * 0.05h = 6.935\ Ah$$

Propeller Considerations

- Overloading the motor using an unsuitable propeller can damage the motor severely
- Manufacturer recommend 16” diameter by 10” pitch

Electronic Speed Control (ESC) Battery Eliminator Circuit (BEC)

Phoenix ICE 100 Specifications	
Cell # (LiPo)	8
Max Voltage	34 V
Max Current Output	100 A
BEC Output	5-7 V
Weight	56.7 g

Phoenix ICE 100 Brushless for 8 cell Lipo ESC by Castle Creations

Avionics System Analysis

Avionics Component	Supplied Voltage (v)	Current Consumption (mAh)
Paparrazi AP Board	11.1	20
Nav/Ori Sensors	N/A	30
CS Servos	5	160
Xbee Pro Transmitter	3.3	221
Total Current Consumption		431

By estimating the individual supply voltage required and the current consumption of each component, the entire avionics system can be analyzed as a whole. The total current consumption for the avionics system can be calculated as:

$$C_{tot}(t) = \sum I_{Avionics} * t = \left(I_{autopilot} + I_{servos} + I_{Tx} + I_{sensors}\right) * t$$

Solving with estimated values and a t = 1 hour.

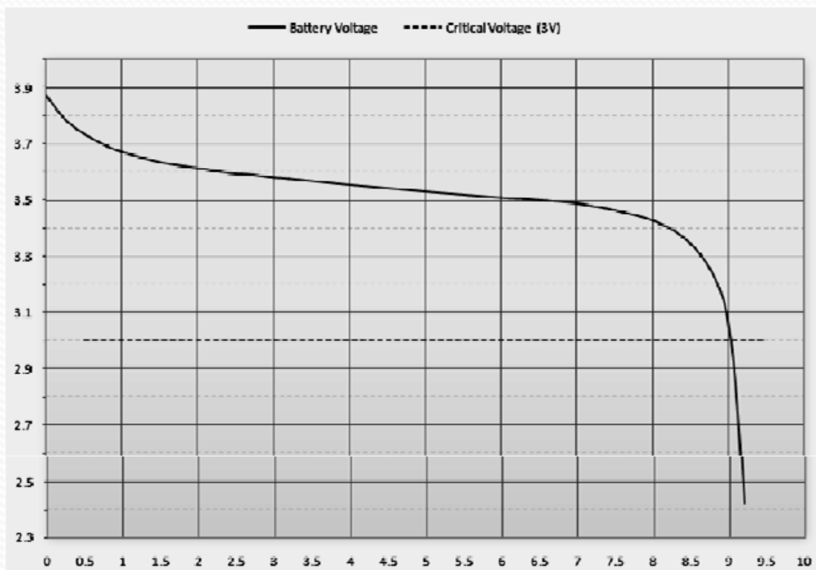
$$C_{tot}(t) = (.02 + .16 + .221 + .03) * 1 = .431Ah = 431\ mAh$$

Image Processing System Analysis

Image Processing Component	Supplied Voltage (v)	Current Consumption (mAh)
Sony FCB-IX11A	11.1	200
Lawmate 2.4GHz	11.1	500
Gimbal Servos	5	50
Total Current Consumption		750

Battery Selection

Battery Decision Matrix		NiMH Battery		LiPO Battery	
Criteria	weight	Grade	Weighted G	Grade	Weighted G
Performance	0.2	4	0.8	5	1
Weight	0.25	3	0.75	4	1
Size	0.25	1	0.25	5	1.25
Cost	0.1	5	0.5	1	0.1
Safety	0.2	5	1	3	0.6
Total	1	18	**3.3**	18	**3.95**



Power Supply System Design

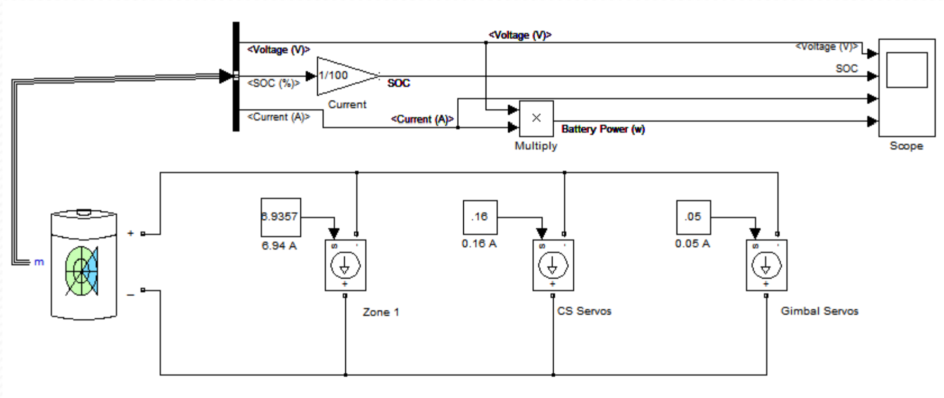
Component	Required Voltage (v)	Supplied Voltage (v)	Voltage Zone	Current Consumption (mAh)
Voltage Regulator (BEC)	29.6	29.6	1	0.5
Motor ESC	29.6	29.6	1	0.2
AXI 4130/20 motor	29.6	29.6	1	6935
CS Servos	3 - 6	5	2	160
Paparazzi board (Complete)	6 - 18	11.1	3	40
CCD BlockCamera	6 -12	11.1	3	200
Lawmate Video Tx	10.5 - 13	11.1	3	500
Xbee AP Tx	3 - 3.6	3.3	4	210
Gimbal Servos	3 - 6	5	2	50

Zone	Supplier	Voltage (v)	Total Capacity Required (mAh)
1	8-Cell Lipo (7700 mAh)	29.6	7145.7
2	ESC integrated BEC	5	N/A
3	3-Cell Lipo (1300 mAh)	11.1	950
4	Autopilot Board	3.3	N/A

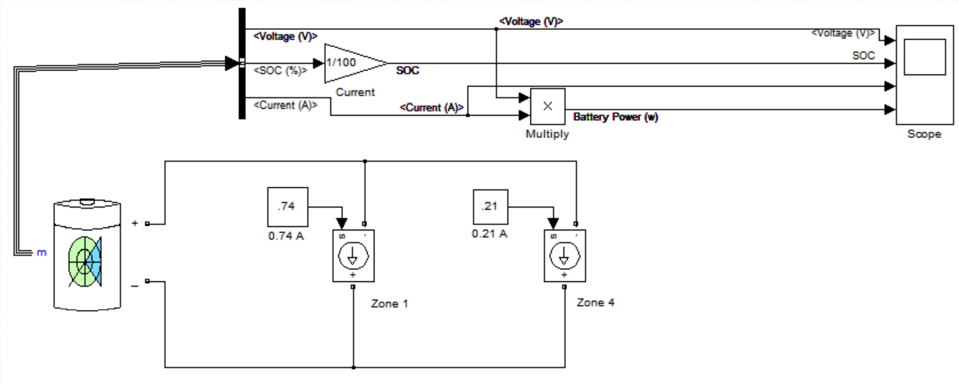
Total Battery Capacity = 9 Ah

Battery Analysis

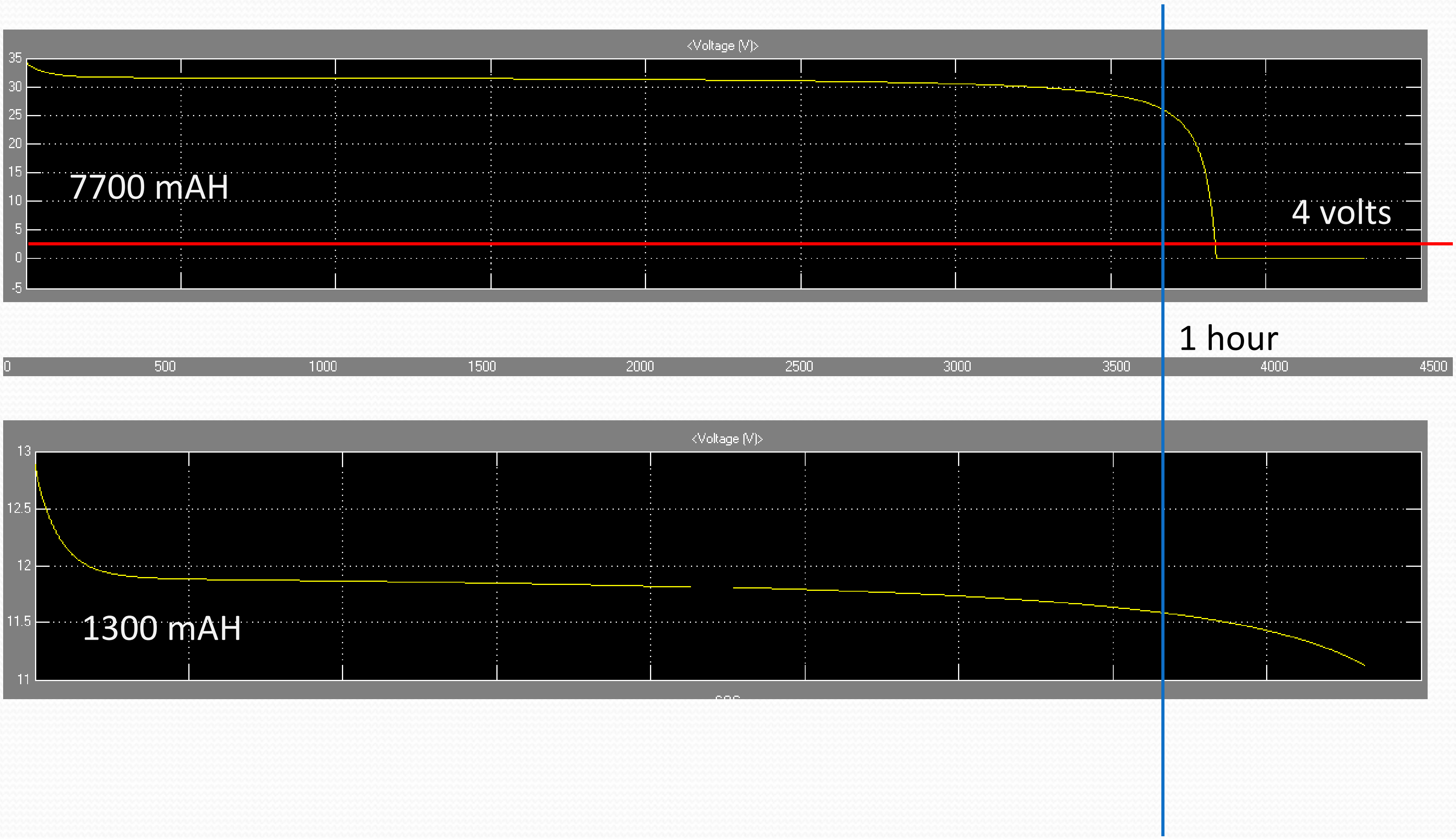
7700 mAH



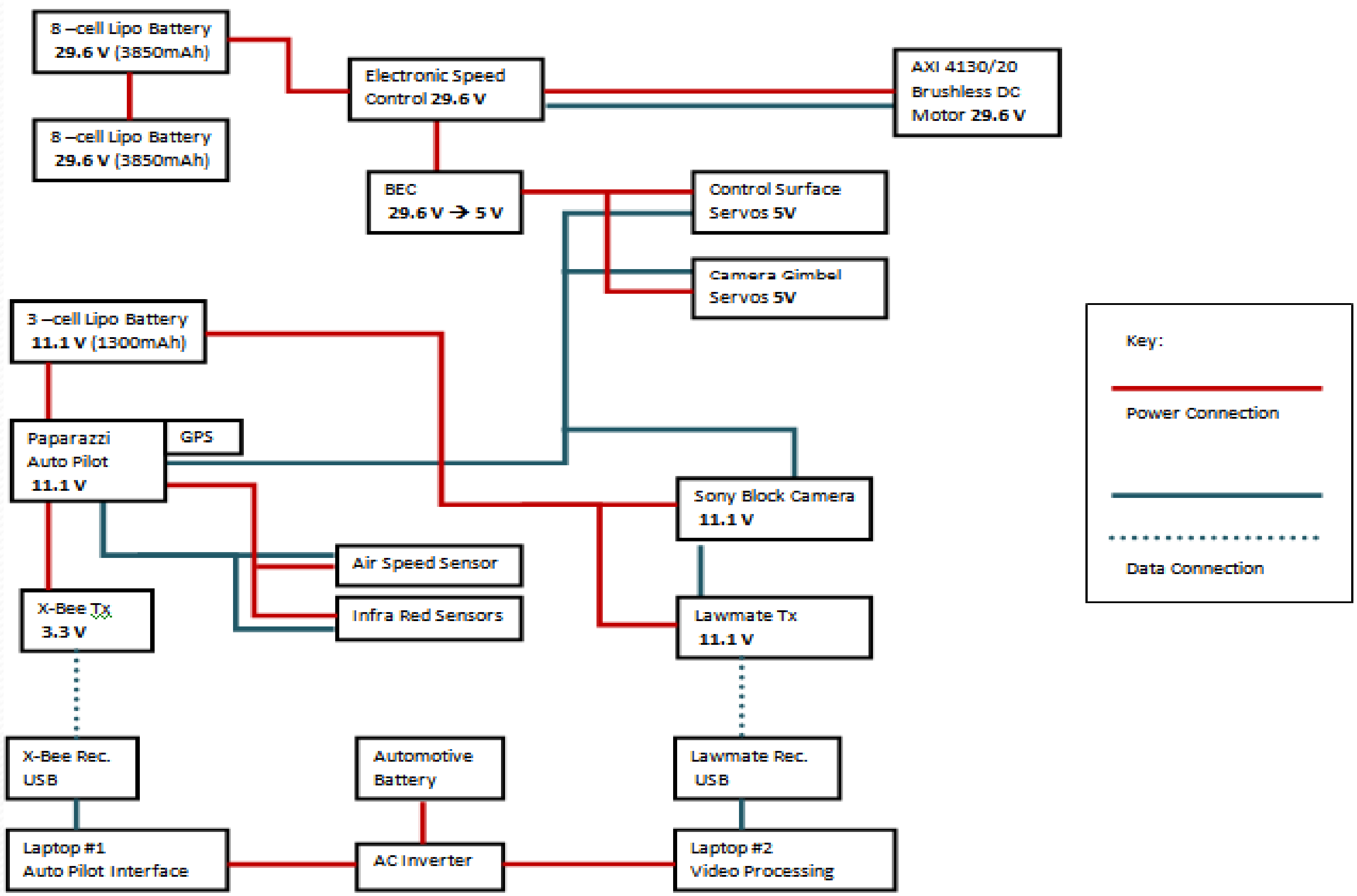
1300 mAH



Battery Analysis



Power Supply System Design



Autopilot System Final Design

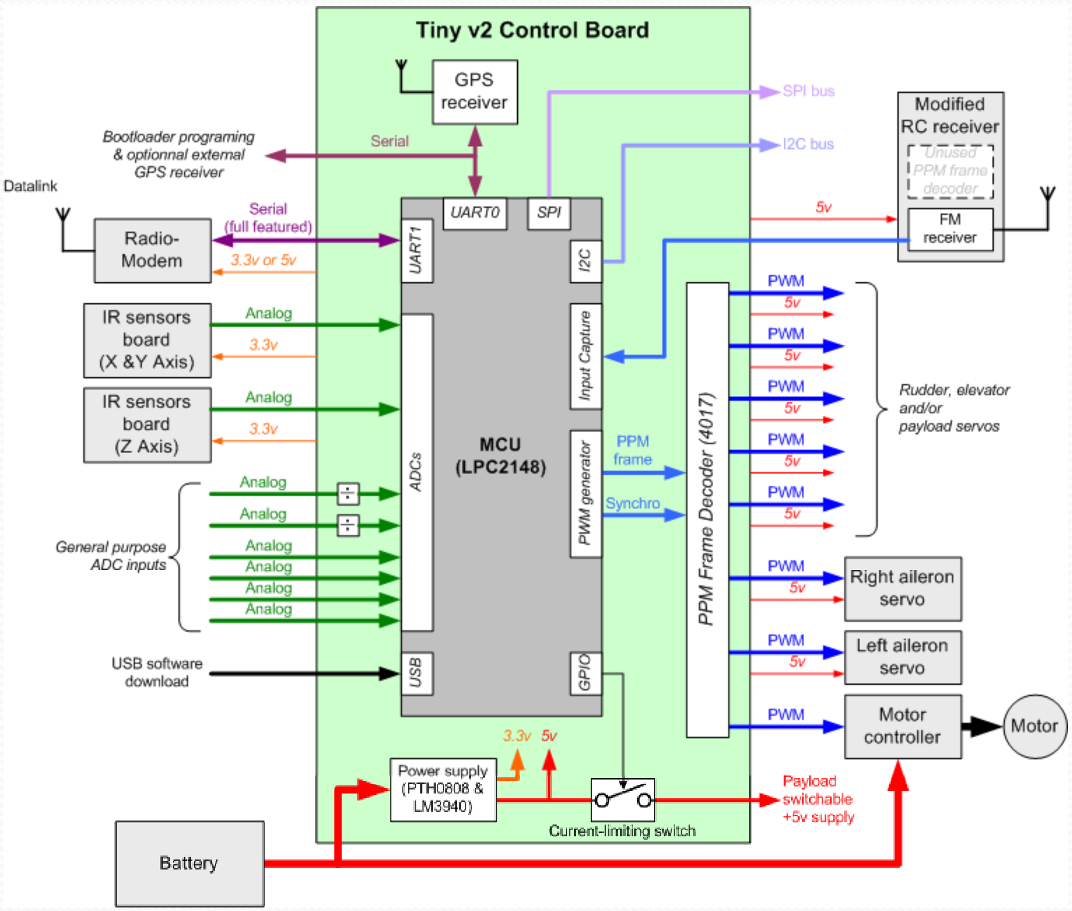
- Capabilities
  - Autonomous waypoint navigation and area search
- Modules
  - Autopilot board & software
  - Sensors
  - Communication

Autopilot System Final Design

- Autopilot Board & Software: Paparazzi Tiny v2.11 autopilot
- Battery: 5-18V, 2.5A max
  - Has built in power supply for 5V lines
- Weight: 24g (with GPS on), dimensions: 70.8 mm x 40 mm
- Has extra ports for camera gimbal
- Source code downloadable and can be modified
- Interfaces with most sensors, has preferred list

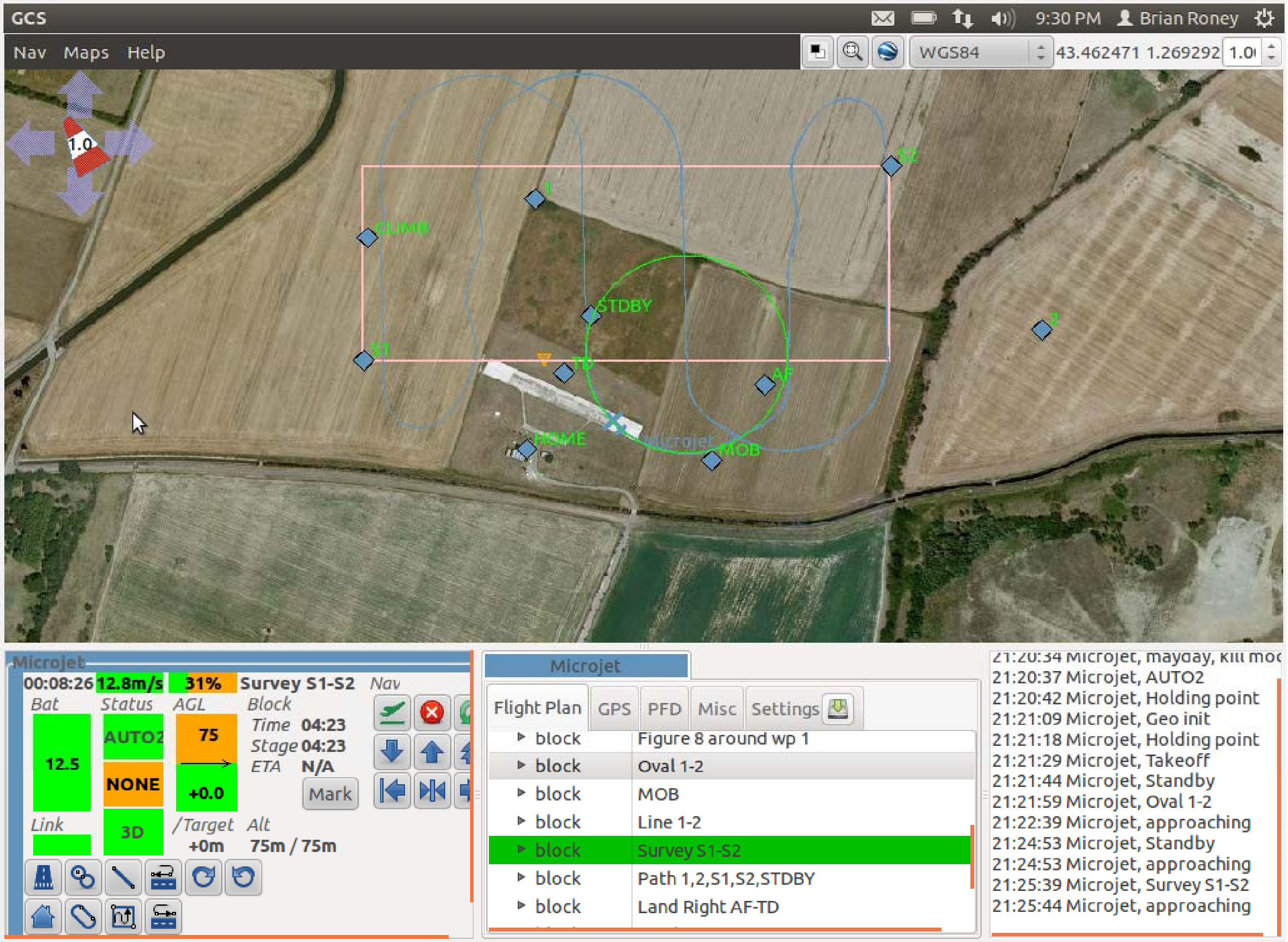
Autopilot System Final Design

- Paparazzi Tiny v2.11 autopilot – Board Layout



Autopilot System Final Design

- Autopilot Software: Ground Control Station (GCS)

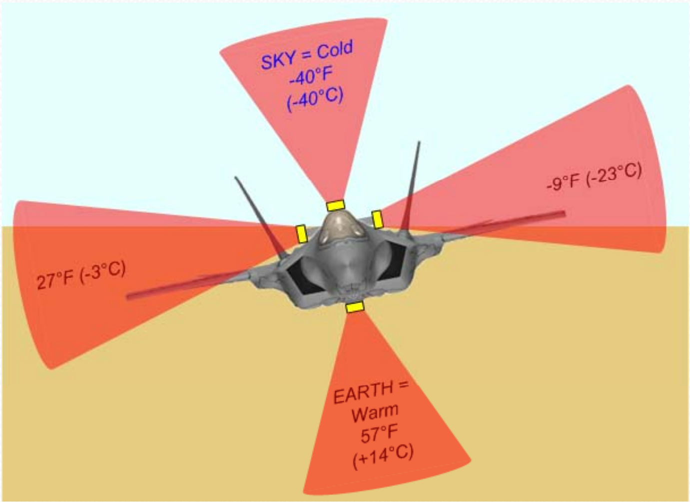


Autopilot System Final Design

- Autopilot Sensors-GPS: uBlox LEA-4P
- Details
  - Size: 17 x 24 mm, Weight: 2.1 g
  - Power: 36mA @ 3.0V
  - Up to 4Hz position update rate
  - Module is built into Tiny v2.11 and configuration file already in Paparazzi software

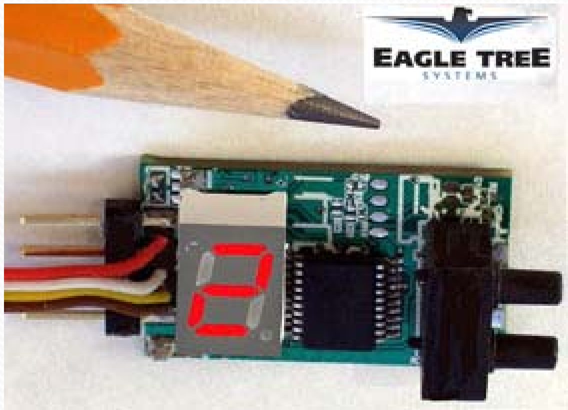
Autopilot System Final Design

- Autopilot Sensors-Orientation: IR
- Details
  - Use thermopiles to use difference in temperature of sky and ground to calculate orientation.



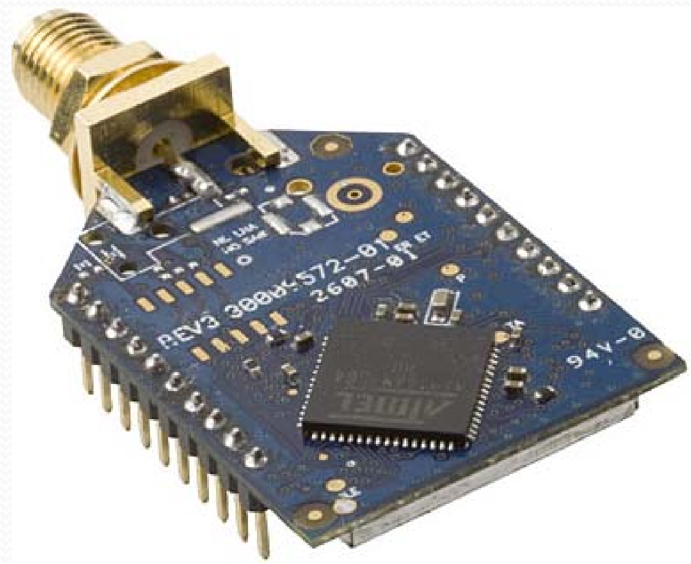
Autopilot System Final Design

- Autopilot Sensors-Airspeed: Eagle Tree Airspeed Microsensor V3
- Details
  - Size: 28 x 16 x 10 mm, Weight: 4 grams
  - Resolution: 1 mph
  - Configuration file already in Paparazzi autopilot software.



Autopilot System Final Design

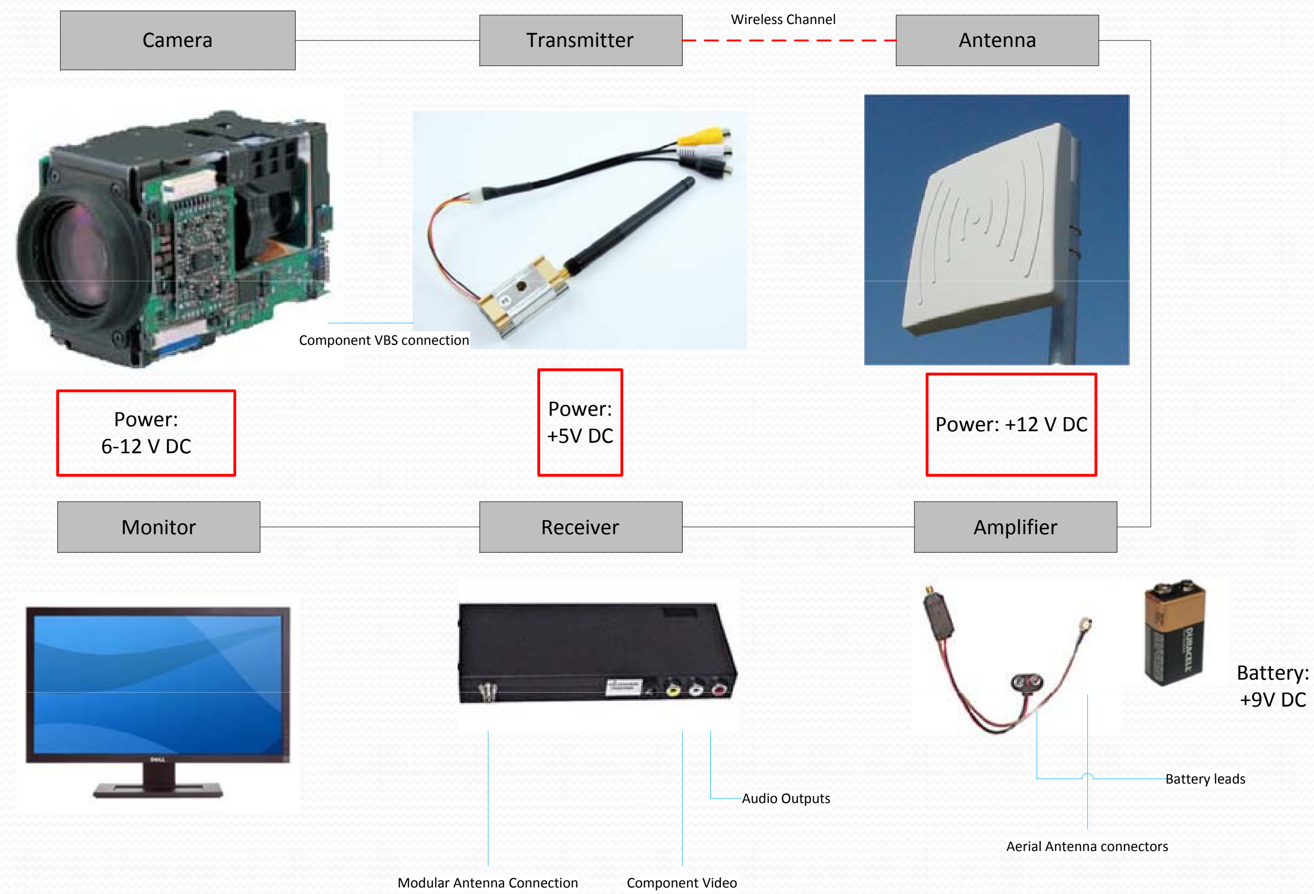
- Autopilot Communication – Data: Xbee Pro 900 module
- Details
  - Operates at 900MHz
  - Data rate: 156 Kbps
  - Range: up to 6 miles
  - Configuration file exists for Paparazzi



Autopilot System Final Design

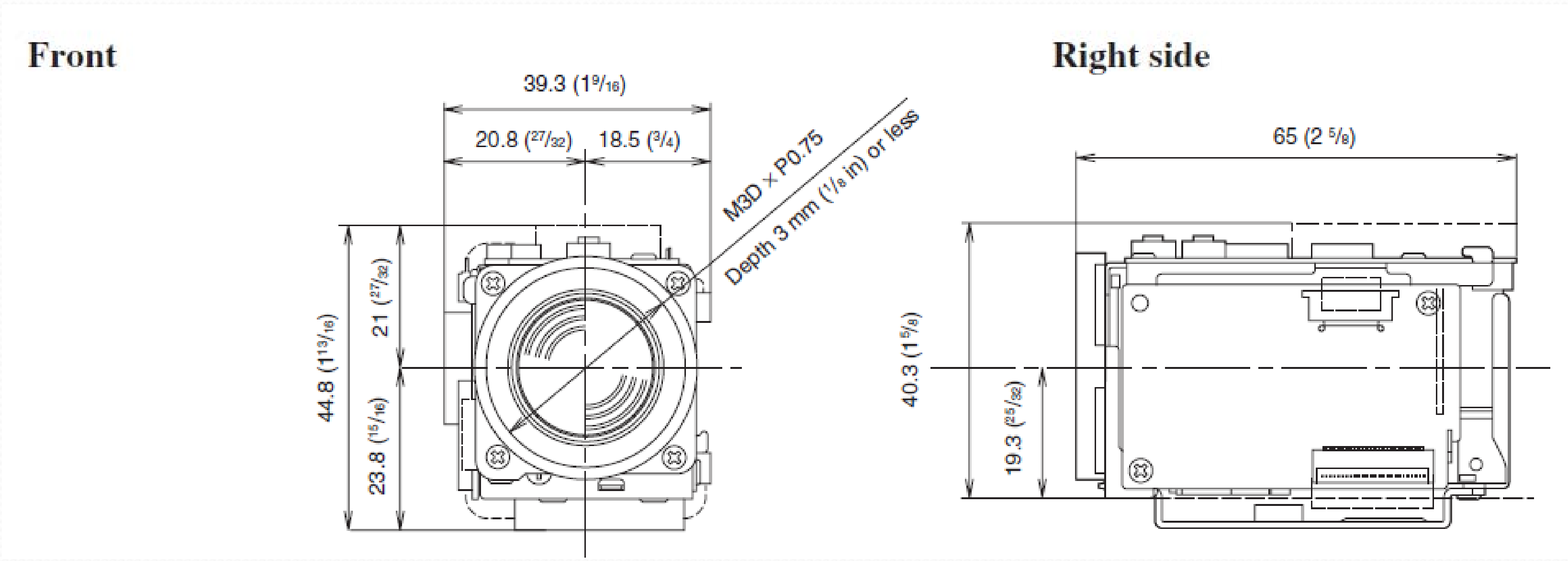
- Autopilot Communication – R/C: Futaba 7CAP
- Details
  - Operates at 72MHz
  - 7 Channels
  - 3 position switch for kill switch
  - Already available for team

Imagery System Architecture



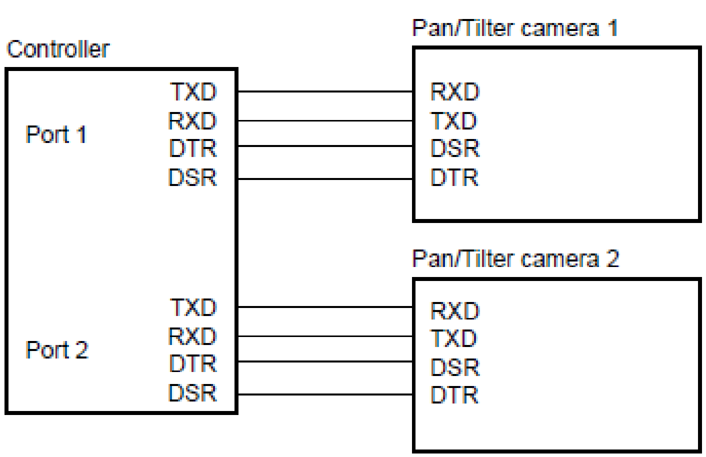
Camera Selection

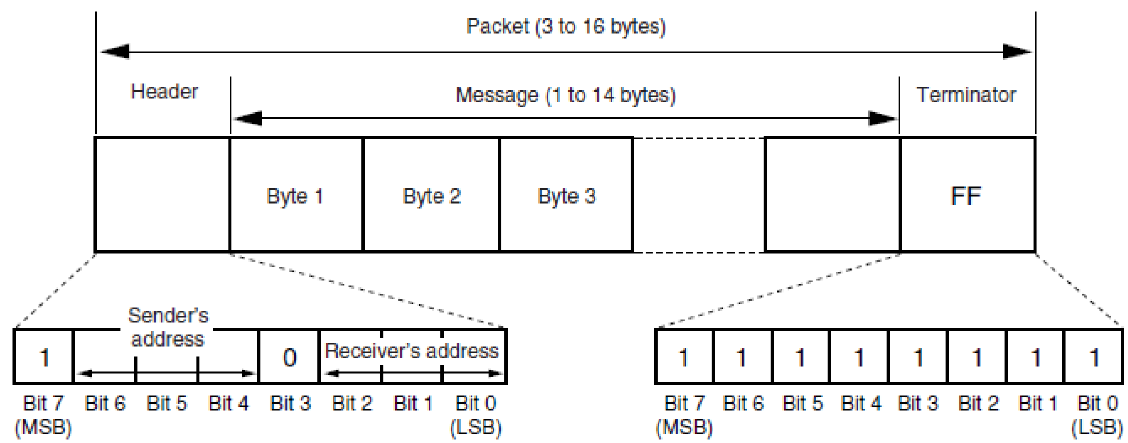
- Sony FCB IX11A Block Camera
- ¼ Exview HAD CCD
- 40x zoom (10x optical, 4x digital)
- NTSC: 470 TV lines, PAL: 460 TV lines
- Controlled through rs-232 serial cable
- Powered by 11.1 LiPolymer battery
- Customizable OSD
- Ultra light and compact



Camera Control

- Sony FCB Block utilizes Video-Integrated System Control Architecture (VISCA) RS-232C interface TTL serial port
- VISCA protocol sends a bit sequence to the camera to control it's functionality.
  - ON/OFF, PAN/TILT, SLOW/FAST ZOOM, & IMAGE INVERSION





Analog vs. Digital

- Digital Transmissions

  Advantages:
  - Data is already converted if using Image Processing software
  - Doesn’t require signal amplification
  - Less chance of transmission error

  Disadvantages:
  - Requires RF modem on board the aircraft
  - If error occurs entire signal will be lost
  - Image data could require compression

- Analog Transmission

  Advantages:
  - Continuous signal, easily transferable
  - No compression necessary
  - If the signal degrades its noticeable

  Disadvantages:
  - Higher error rate
  - Very difficult to use image recognition software with interference
  - Requires signal amplification

Analog vs. Digital

- Using Digital Communications Link
  - Capture 24 bit color images (9 bits per pixel)
  - FCB resolution: 380,000 pixels
  - RF Modem: SRM6100 Data-Linc Tech (166 k baud)

  - Maximum file size of 3.3 Mb
  - Average Cruise : $(Effective\ Resolution) * (24 - bit\ color\ image) = Max\ File\ Size$

$$\frac{File\ Size\ (Mb)}{Baud\ Rate\ (bps)} = Transfer\ time\ (s)$$

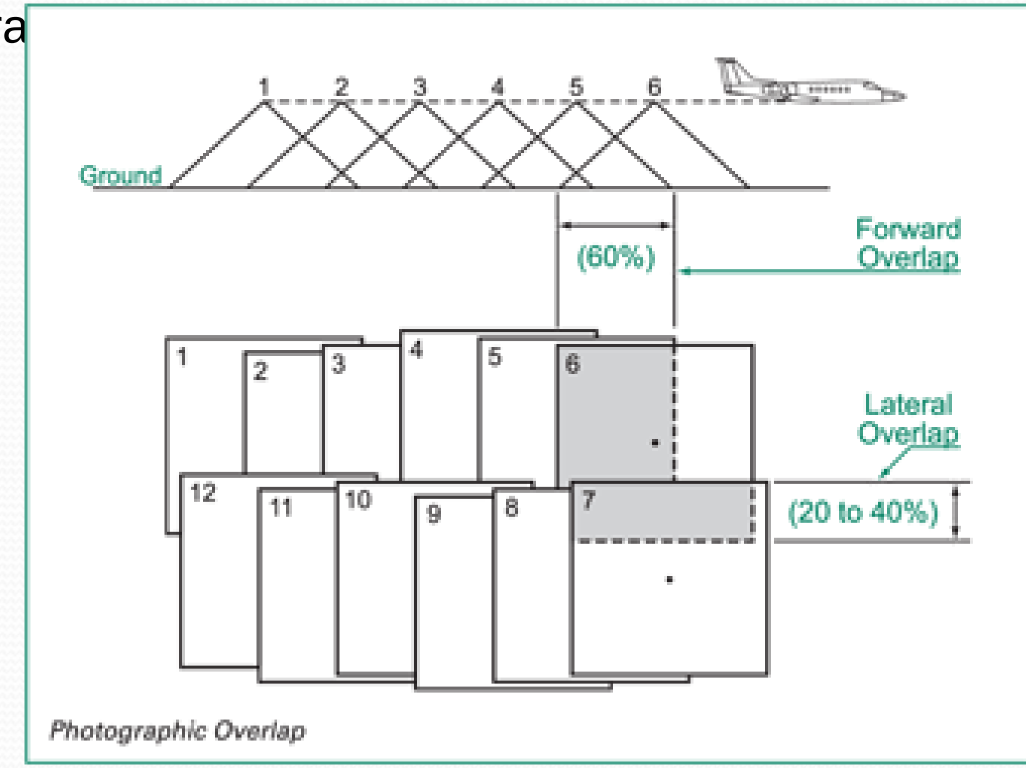
Approximate transfer time = **2.5 MINUTES**!

Equivalent to an image ever **1.875 MILES**!

Transmitters are also limited to 1 watt of power according to the Radio Communications Class License 2000, Item 26.

Analog Video Tx

- Time varying continuous signal are directly sent over the channel. This allows images to arrive in “real-time”.
- Target Identification
  - Image fra d.



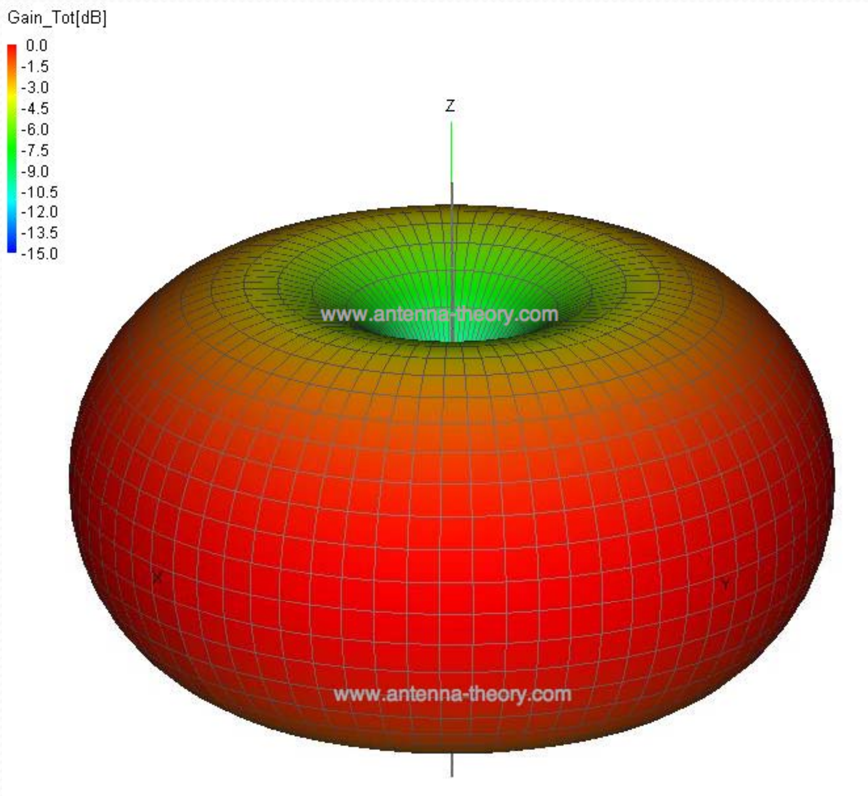
Antenna Selection

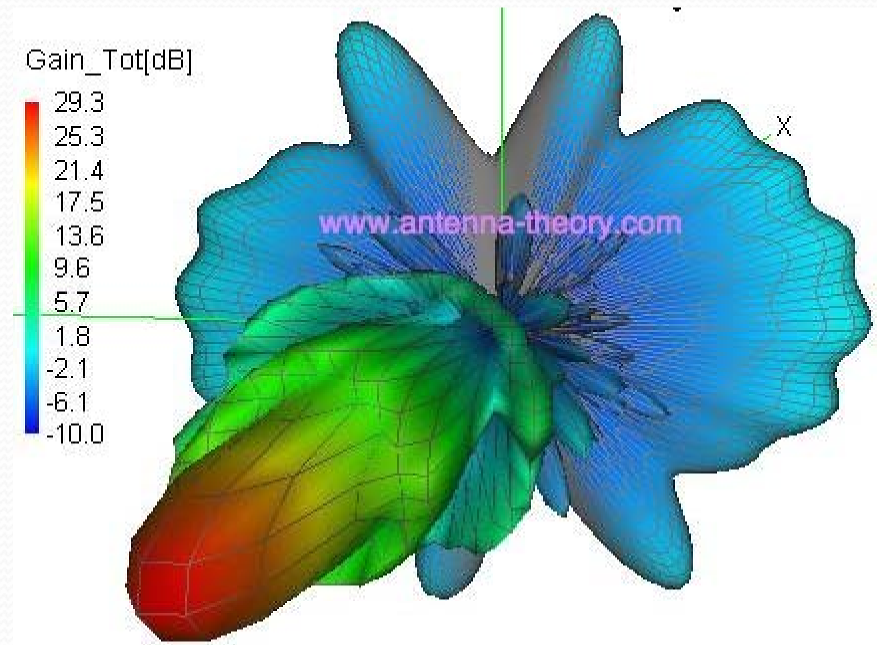
- Flight coverage area = 2 miles.
- Antennas form elliptical polarization converge into two types:
  - Linear
    - Vertical (Omni-directional antenna)
    - Horizontal (Directional or Yagi antenna)
  - Circular
    - Curvilinear
- Free Space Path Loss: geometric spreading of wave drops signal power.
- Signal power decreases as the wave propagates through solid objects.

Antenna Selection

Gain α Directivity

- Omni-directional aircraft antennas provide unilateral signal broadcast to the ground.
- Ground station directional antenna (9-24 dB) for strong signal reception.



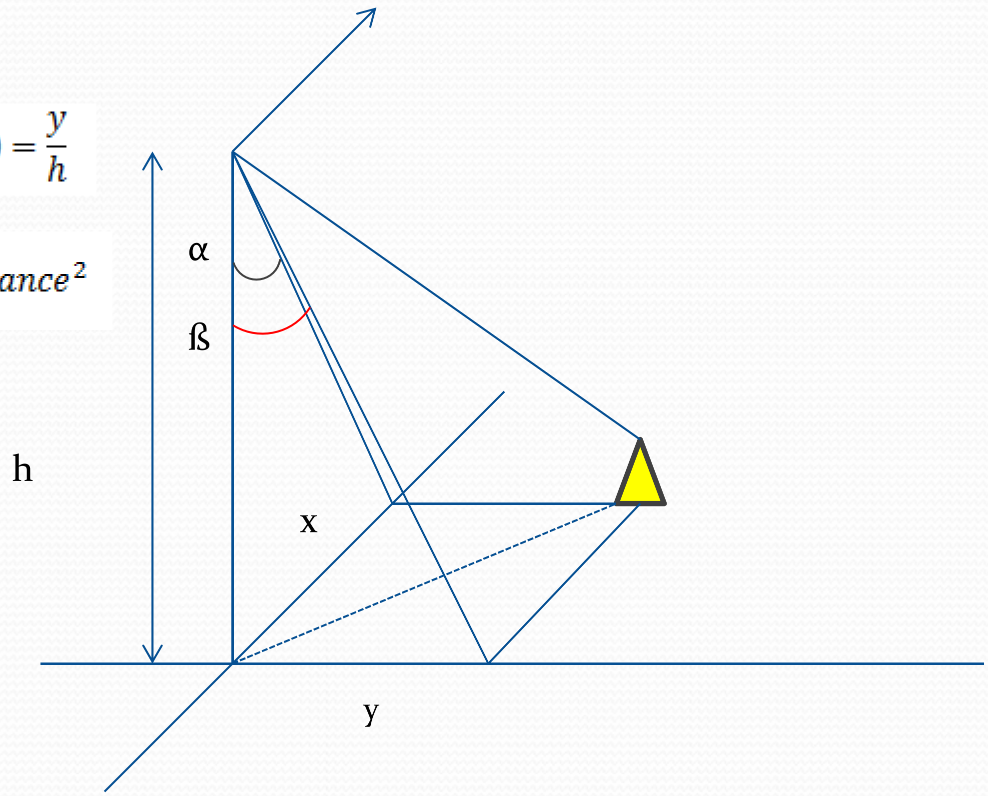


Where's the Target?

- Calculating GPS coordinates from the aircraft.
- Longitude and Latitude from UAV, α is tilt and ß is pan.
- Reading altitude and heading from Autopilot GPS, x and y can easily be computed.

$$\tan(\alpha) = \frac{x}{h} \quad \tan(ß) = \frac{y}{h}$$

$$x^2 + y^2 = ground\ distance^2$$



- Assuming no changes in target altitude.

End of Presentation