AUVSI DESIGN COMPETITION

Team 8

Sponsor: Dr. Shih, FIPSE

Advisor: Dr. Frank, Dr. Alvi

Instructor: Dr. Gupta

Students: David Hegg, Christopher Bergljung, Jermaine Dickey, William Di Scipio, Gavarni Leonce, John Murnane, Tavarius Slaughter

Agenda

- **Introduction**
- **Background**
- **Competition Overview**
- **Goals and Objectives**
- **Design**
  - Mechanical
  - Electrical
- **Environmental, Safety, and Health Concerns**
- **Flight Testing**
  - Quadrotor
  - Quad + Plane Body
  - Hybrid
- **Budget**
- **Schedule**
- **Conclusion**

Introduction

Team 8 Senior Design Project:

The goal of this project is work effectively as an international team to create a Vertical Takeoff and Landing (VTOL) aircraft for future success at the 2016 AUVSI SUAS Competition.

Multi-disciplinary team

- 5 Mechanical Engineering & 2 Electrical Engineering Students
- Two semester project (continuation of last year's project)
- Utilize group cooperation, time management, & classroom teachings

Fund for the Improvement of Postsecondary Education (FIPSE)

- Two members of Team 8 were studying in Itajuba, Brazil during the 2014 Fall Semester
- International experience
- Communication and Teamwork skills

Background

Unmanned Aerial Vehicle (UAV): An aerial vehicle without a human pilot aboard

Military Uses:

- Reconnaissance
- Combat
- Logistics

Civilian Uses:

- Land Surveying
- Film Making
- Supply Delivery

Benefits:

- Rescue missions
- High precision of navigation
- Low cost

Strong desire to improve UAV technology for commercial and military applications

AUVSI Design Competition

Competition Overview:

- Association for Unmanned Vehicle Systems International (AUVSI)
- Student Unmanned Aerial System (SUAS) Competition
- Promotes innovation in UAV technology
- 2015 AUVSI rules used as reference for design

Primary objectives:

- Autonomous Takeoff and Landing
- Autonomous waypoint navigation
- Image recognition capabilities

Secondary objectives:

- Off-axis imaging
- Object detection/avoidance
- IR imaging
- And more…

Goals & Objectives

"The goal of this project is work effectively as an international team to create a Vertical Takeoff and Landing (VTOL) aircraft for future success at the 2016 AUVSI SUAS Competition."

Objectives:

- Design a hybrid VTOL aircraft using existing Senior Telemaster plane
- Build to meet all AUVSI design specifications
- Achieve autonomous vertical takeoff and landing
- Show transitional flight possiblity

Design Requirements

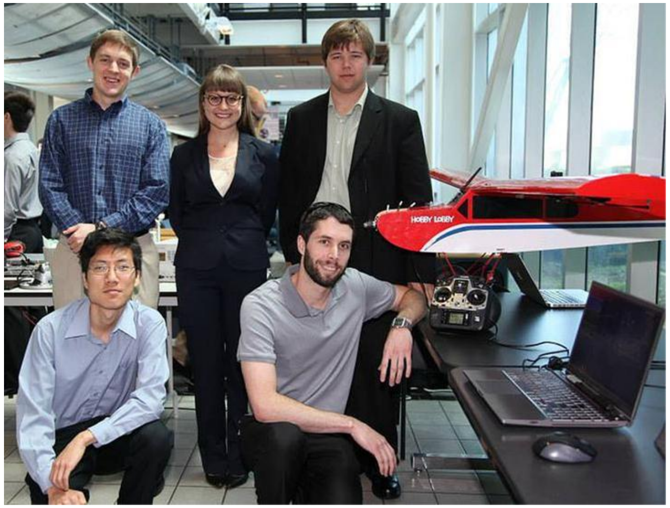
AUVSI Specifications:

- Aircraft shall comply with Official Academy of Model Aeronautics (AMA) National Model Aircraft Safety Codes
- Capable of autonomous flight
- Transmit on Wifi (2.4/5.8GHz) and on multiple Radio Frequencies (RF)
- Flight Time = 40 minutes maximum
- Stay in controlled flight within the no fly zone
- Display their aircraft location and altitude in real time
- Sustain flight between 100 and 750 feet MSL entire flight
- Maximum airspeed of 100 KIAS (Knots Indicated Airspeed)
- The aircraft shall be capable of manual override
- Aircraft shall be less than 55 lbs

2013-2014 Aircraft

- **The 2013-2014 Team provided:**
  - Senior Telemaster Plane
  - Proved Autonomous Flight Capabilities
  - Proved Video Capture Capabilities

- **<u>Did not</u> provide or broken:**
  - GoPro video camera
  - Adrupilot APM 2.5 flight controller
  - 3DR Telemetry Kit



Design Options

- **Key Components:**
  - Technical Development for Team 8
  - Cost and Build Time
  - Automation
  - Performance Characteristics

	Importance	Plane	Multirotor	Hybrid
Cost	10	9	5	5
Build Time	10	9	3	4
Weight	4	6	5	4
Durability	4	4	7	6
Troubleshooting	7	3	6	4
Tech. Development	10	4	8	10
Future	5	3	7	10
Stability	3	5	8	8
Payload	5	8	5	8
Flight Time	8	7	5	8
Horz. Velocity	6	7	5	7
Automation	8	8	7	5
Airdrop	4	5	8	7
Agility	4	5	8	6
	Total	**553**	**524**	**570**

Fixed Wing Plane

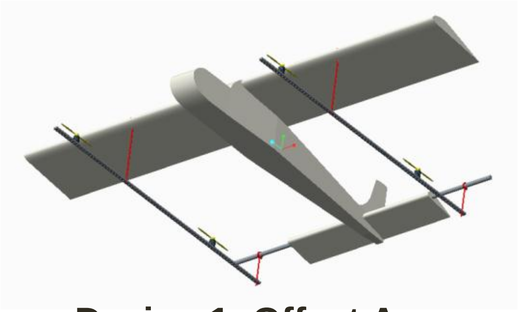
Multirotor

Hybrid VTOL Aircraft

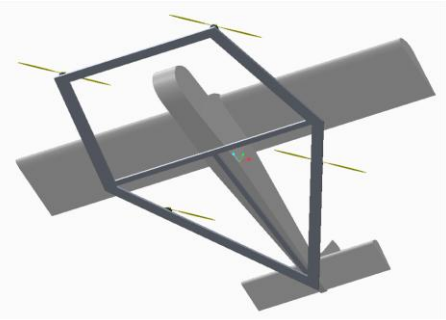
Design Concepts

- **Key Components:**
  - Cost
  - Build Time
  - Weight
  - Strength

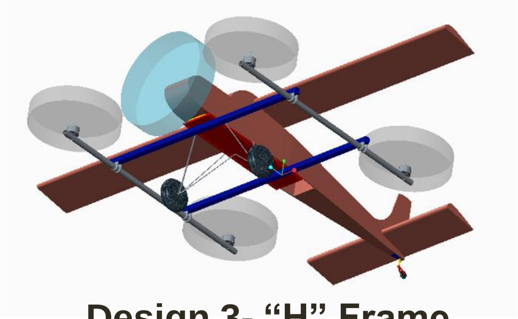
	Importance	Design 1	Design 2	Design 3
Cost	10	4	4	7
Build Time	8	4	4	6
Weight	8	7	6	5
Difficulty	5	4	4	6
Strength	5	4	7	7
Aerodynamics	5	6	4	4
Vibration	5	4	4	6
Variability	3	4	4	8
	Total	230	227	297



Design 1- Offset Arms



Design 2- Diamond Frame



Design 3- "H" Frame

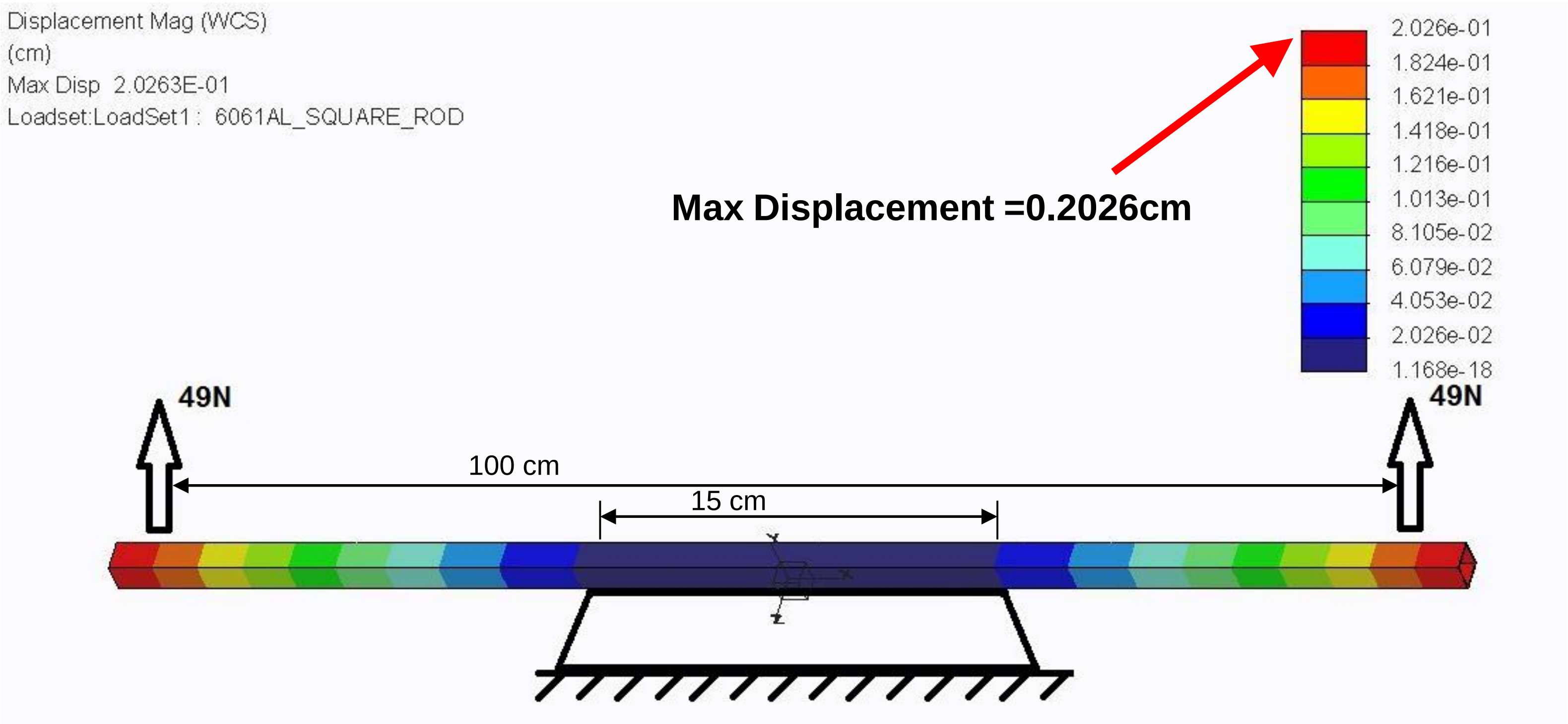
Material Selection

- **Material Weight and Cost Estimate:**

Frame Design: Weight and Cost Analysis							
Component	Description	Weight/Part (lb)	Price	Qty.	Weight (lb)	Subtotal	Extras
Plywood	Base	1.171	$0.00	1	1.171	$0.00	
G10	Motor Mount Adapter Excellent Tensile and Impact Strength	0.055	$0.00	8	0.443	$0.00	
Carbon Fiber Tubes	Parallel Arms for holding the motors Excellent Tensile Strength	0.716	$35.87	2	1.432	$71.74	$35.87
6061 Al	Square Tubes Cross Bar Good/good : Tensile/Impact	1.015	$23.38	2	2.030	$46.76	$23.38
Foam Spacer	Padding to Protect Plane and Decrease Vibration	0.406	$34.03	1	0.406	$34.03	
D.B. Orange	Double/Bubbe Orange Epoxy, 10 Pack High Peel Stgth.	0.000	$16.00	1	0.000	$16.00	
Velcro	Industrial Strength Double Sided Velcro to Attach the Frame to the Plane	0.250	$20.00	1	0.250	$20.00	
Zip Ties	Zip ties to Secure the Carbon Fiber Tubes to the Cross Bars	0.000	$10.00	1	0.000	$10.00	
Hardware	Screws, Bolts, Etc.	0.000	$70.00	1	0.000	$70.00	
				Subtotal	5.733	$268.53	$58.87
				Total	2.600	kg	$327.40

Material Selection

- **Aluminum 6061 Tube Displacement:**
  - Maximum thrust of each motor during flight ≈ 5kg = **49N**
  - Thrust forces applied 100 cm apart
  - Fixed about 15 cm width of plane



Component Selection

Mass Plane	Mass Quad	Mass Total	Desired Thrust
5488.6 g	2750 g	8238.6 g	4119.3 g

$$M_{total} = M_{plane} + M_{quadrotor}$$

$$T_{desired} = \frac{M_{total}}{4} \times 2\ (FoS)$$

- **Using Desired Thrust Calculation:**
  - (4) Cobra 4510 DC Multirotor Motors
  - (4) 18" long x 5.5" pitch APC Propellers

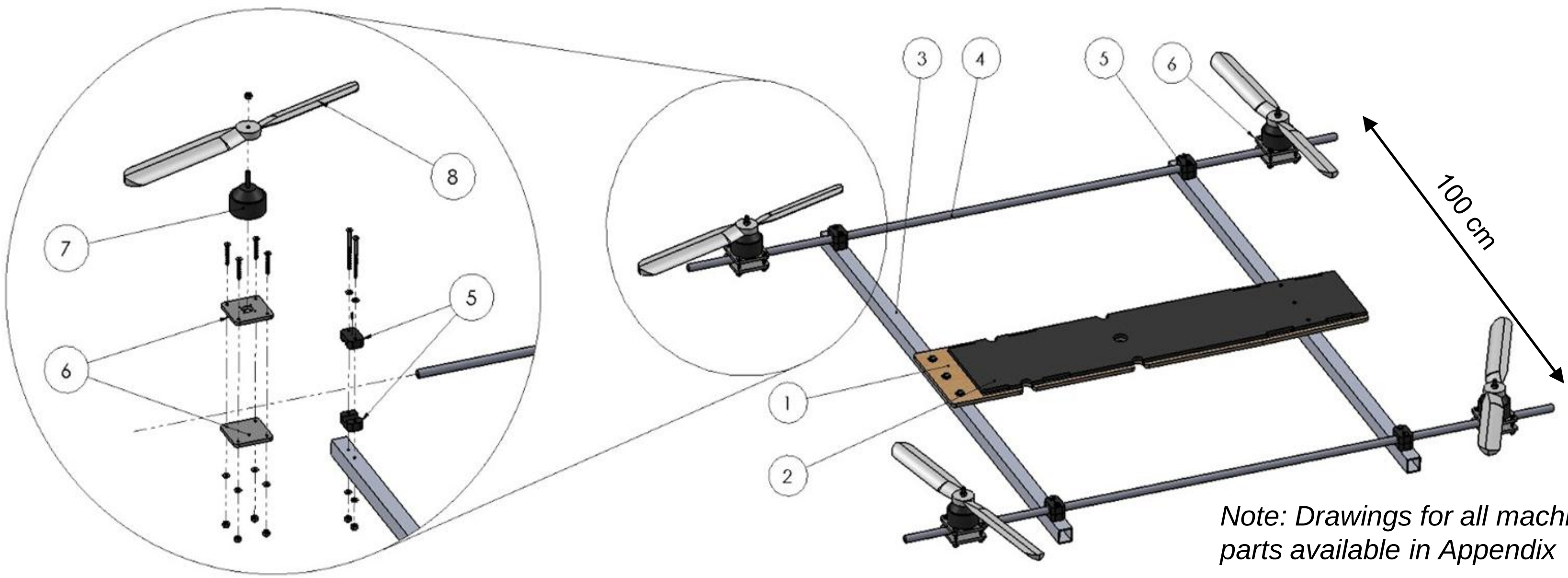
- **Manufacturer's Specifications of 4468g**
- **Verified using eCalc and Static Thrust Calculators**

Thrust Calculators	Thrust
Manufacturer's Specs.	4468 g
eCalc Calculator	4144 g
Static Thrust Calculator	5560 g

Note: All calcs. done using 22.2V 6 cell battery

Quadrotor Design

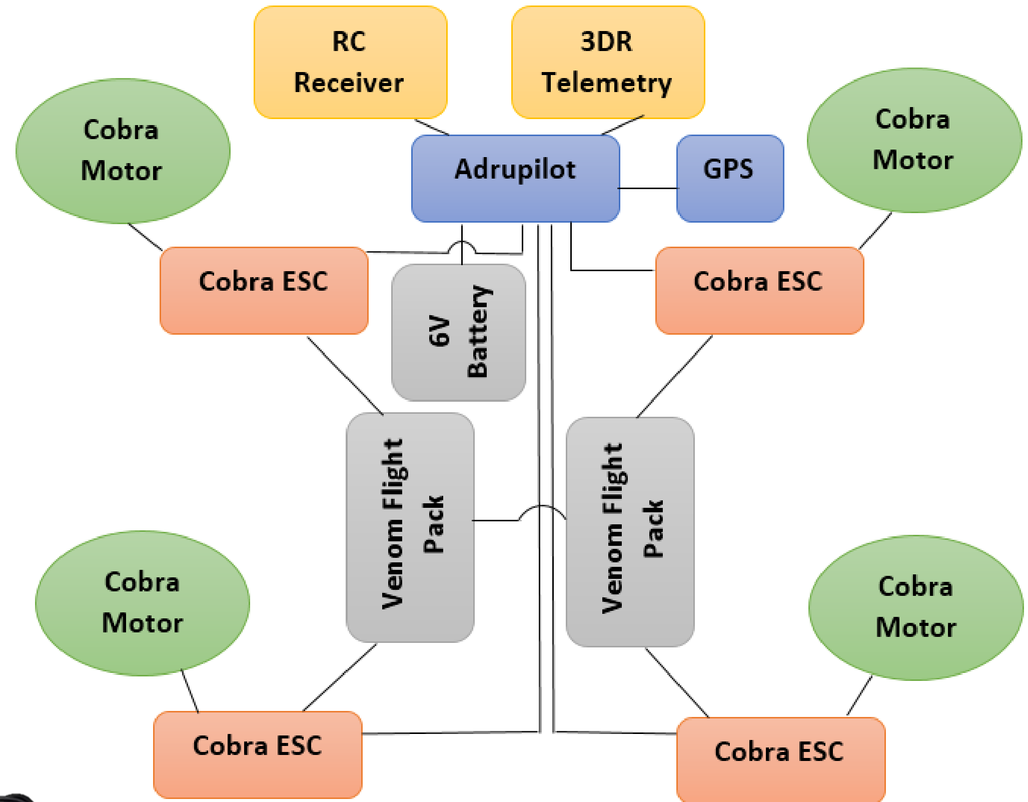
- **Design Components:**
  1. Plywood Base
  2. Quick-Recovery Foam Pad
  3. (2) Aluminum Cross Bars
  4. (2) Carbon Fiber Arms
  5. (4) ABS Arm Clamps
  6. (4) G-10 Motor Mounts
  7. (4) Cobra 4510 DC Motors
  8. (4) APC 18x5.5” Props



Note: Drawings for all machined parts available in Appendix

Electrical Design

- **Component Selection:**
  - Futaba 2006GS receiver
  - Futaba 6J transmitter
  - (2) 5000mAh Venom Flight Packs
  - (4) Cobra 60A ESC
  - Ardupilot APM 2.6
  - NiMH 6V battery
  - 3DR Telemetry Kit
  - 3DR Ublox GPS
  - 3DR PPM sum



Flight Time Calculation

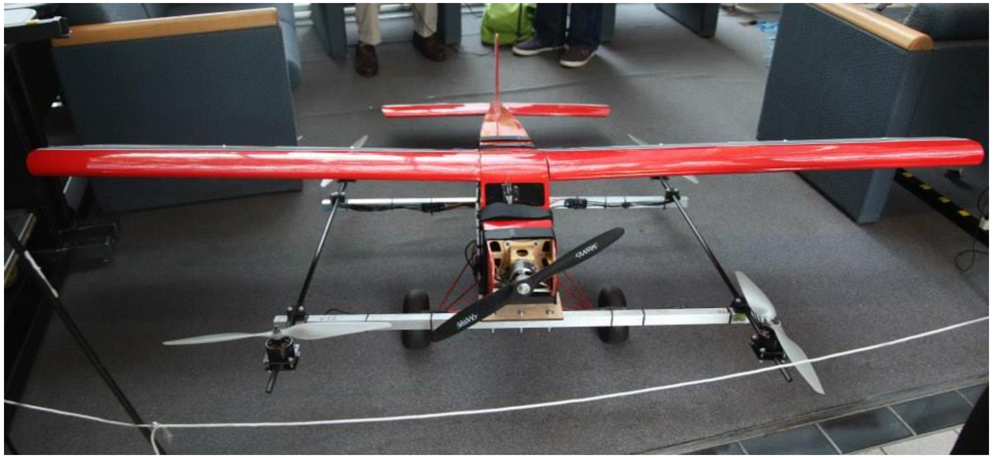
- **Flight Time for Quadrotor**
  - (2) 5000 mAh batteries for a total of **10 Ah**
  - Ideal takeoff speed = 0.5 m/s at 75 % throttle
  - Each motor draws an average of 30 amps for a total of **120 amps**
  - Maximum Depth of Discharge (DoD) of batteries = **80%**

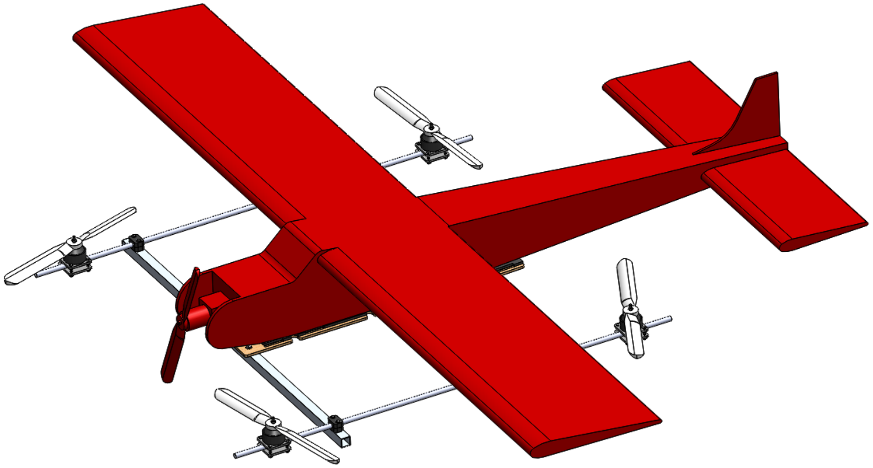
$$Flight\ time = \frac{(.8 * battery\ capacity\ )}{(total\ current\ drawn)} \frac{(60\ \text{min})}{(hours)} = \frac{(.8 * 10Ah\ )}{(120A)} \frac{(60\ \text{min})}{(h)} = 4\ min$$

- **Operation Time for APM 2.6**
  - Maximum current = 2.25 A and Operating voltage = 5.37V
  - Power output = **12.08 Wh**
  - NIMH battery output power = **12 Wh**
  - The maximum depth of discharge (DoD) for the batteries is **80%**

$$Operation\ time = \frac{(.8 * battery\ output\ power\ )}{(APM\ power\ output)} \frac{(60\ \text{min})}{(h)} = \frac{(.8 * 12\ Wh\ )}{(12Wh)} \frac{(60\ \text{min})}{(h)} = 47.67\ min$$

Final Design





Results:	
Vertical Thrust	17.87 kg
Total Weight	8.23 kg
Quadrotor Flight Time	4.00 mins

Environment, Safety, & Health

- **Environment**
  - Portable workspace cleared of excess material to ease maneuverability in emergency
  - Batteries should not leak, be brightly colored so they can be found if crash occurs
  - Verify all components adequately secured to vehicle

- **Safety**
  - Safety inspections shall include a physical inspection, fail safe check, flight termination check, and a maximum weight check.
  - All testing was done a safe distance away from buildings and people
  - Aircraft tied down with a tether during test flights
  - Aircraft is always flown within the operator line of sight
  - Batteries are unplugged before handling craft
  - Obey all FAA laws: https://www.faa.gov/uas/regulations_policies/

- **Health**
  - Chemicals arranged to be stored in designated sections
  - Gloves are used when handling Epoxy
  - Other Personal Protective Equipment (PPE) used when machining or handling chemicals

Flight Testing

- **Importance:**
  - Is prototype fully functional as it was designed?
- **Goal:**
  - Achieve stable autonomous Takeoff and Landing
- **Safety:**
  - Hazards to people and the model
  - Obey all local and federal Laws
- **Assumptions:**
  - APM will compensate for minor changes
  - Minor adjustments to PID would fix any problem
- **Uncertainty:**
  - What needs to be changed to fix any remaining issues?
- **Validation:**
  - Results of 3 phase testing

Phase 1: Quadrotor

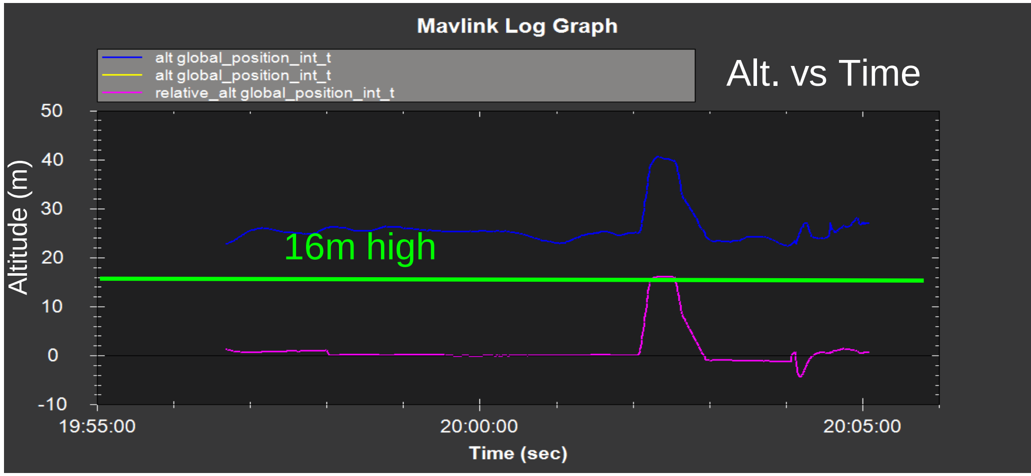
- **Manual test**:
  - Test roll, pitch, and yaw movements
  - Record data

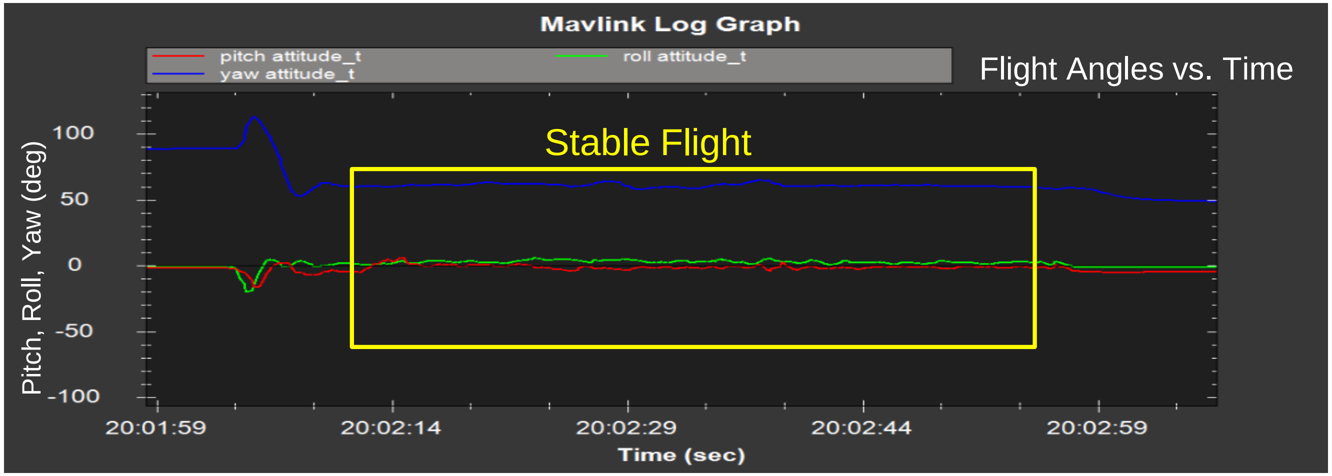
- **Autonomous test:**
  - Setup mission planner
  - Record data

Quadrotor Video

Quadrotor Results

- **Video Results**
  - Stable flight obtained both manually and autonomously
  - Flew to 16m height
- **Mission Planner Results**
  - Pitch, Roll, Yaw, Altitude



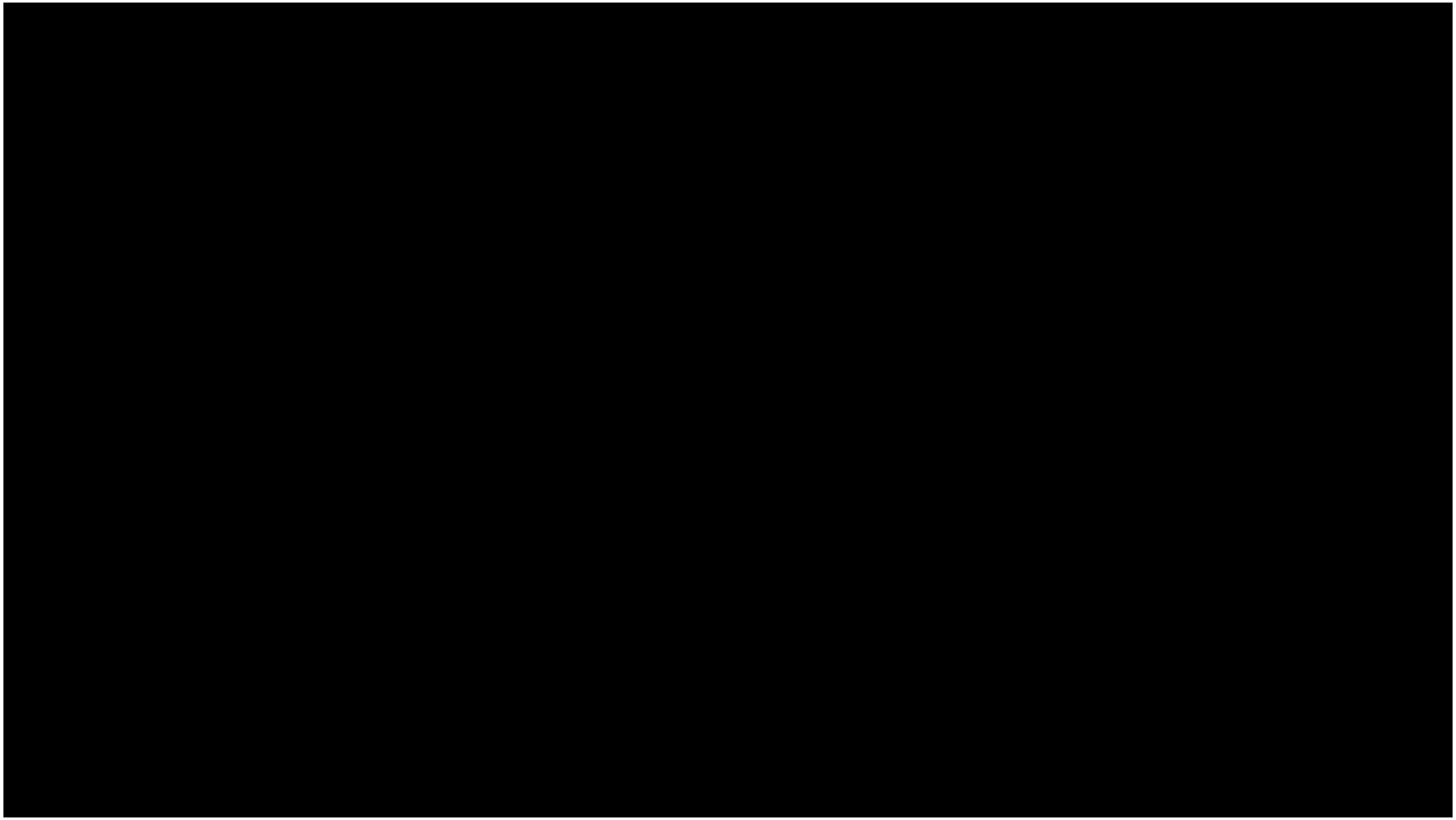


Phase 2: Quad + Plane Body

- **Manual test:**
  - Test Roll, Pitch, and Yaw movements
  - Record data

- **Autonomous test:**
  - Setup Mission Planner
  - Record Data

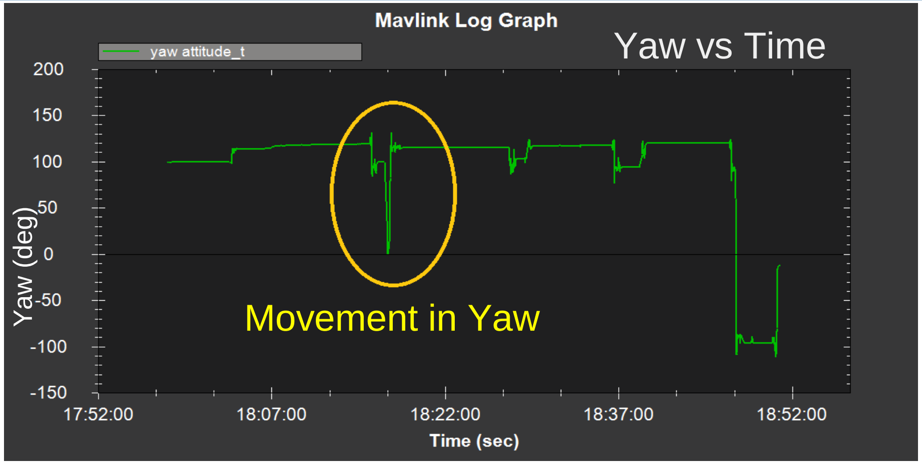
Quad + Plane Body Video

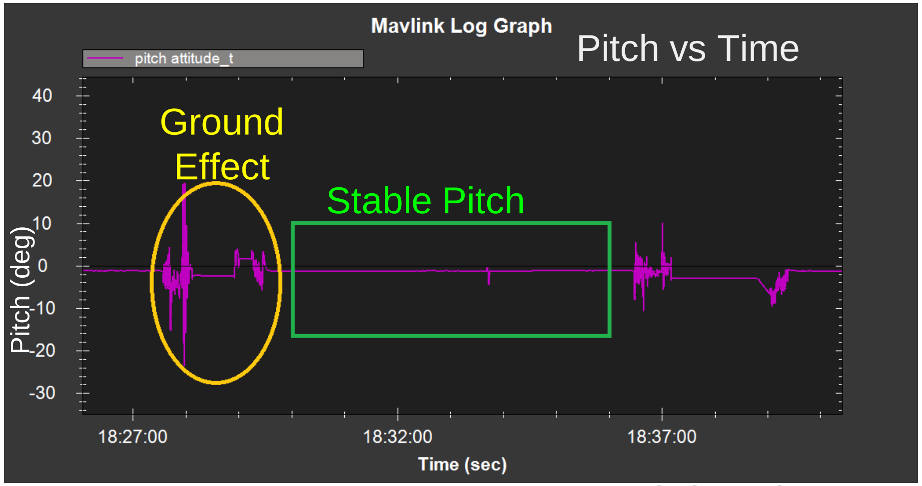


Quad + Plane Body Results

- **Video Results:**
  - Pilot noticed yaw movement during manual flight
  - Autonomous flight also showed yaw sway

- **Mission Planner Results:**
  - Pitch, Roll, Yaw



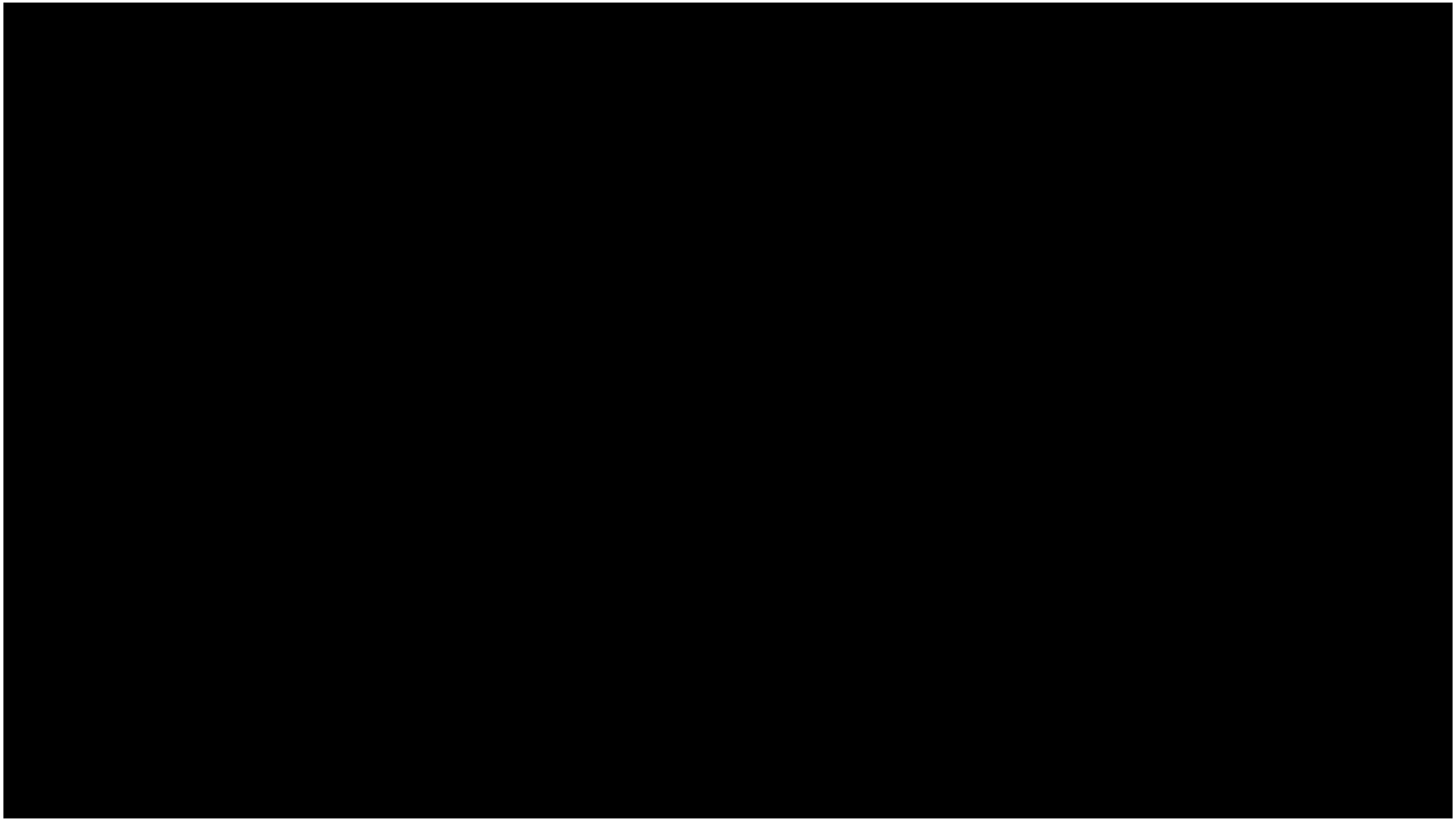


Phase 3: Hybrid

- **Manual test:**
  - Test roll, pitch, and yaw movements
  - Record data

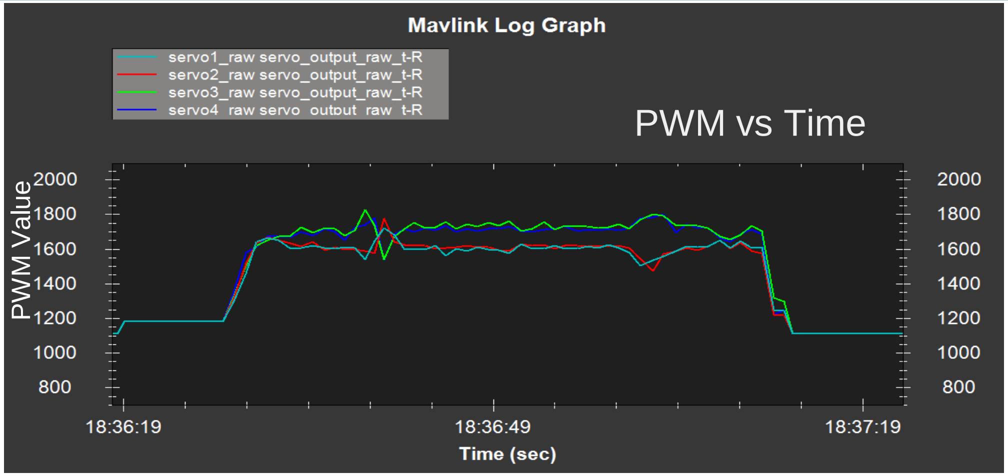
- **Autonomous test:**
  - Setup mission planner
  - Record data

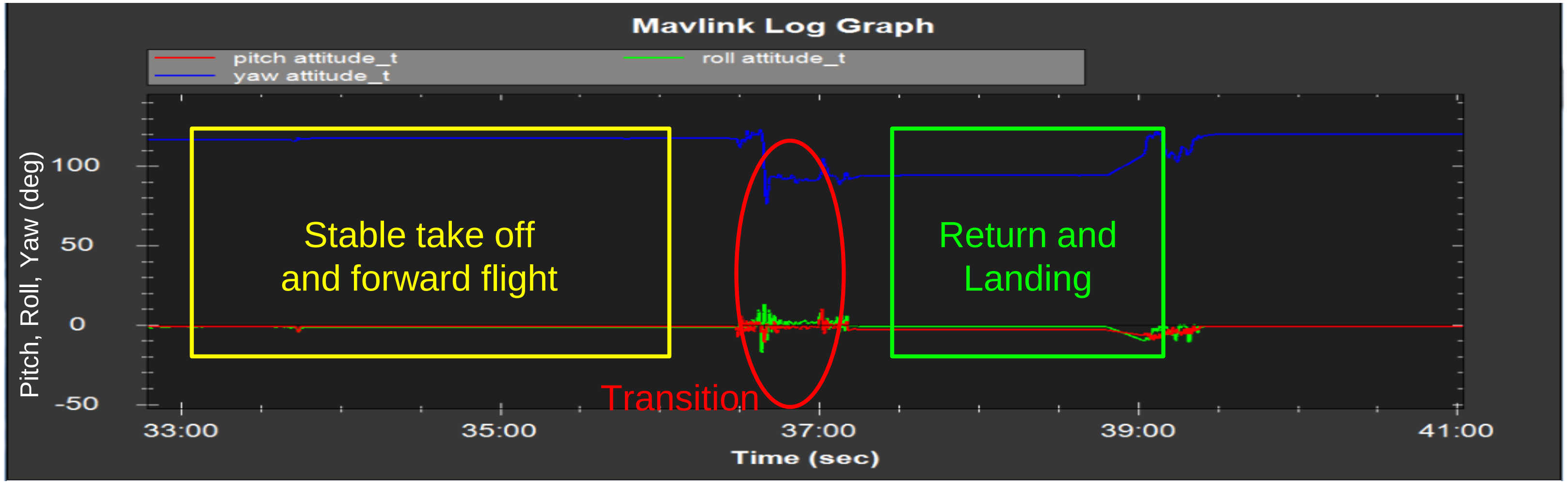
Hybrid Video



Hybrid Results

- **Video Results**
  - Stable flight obtained
  - Adjustments needed in Yaw
- **Mission Planner Results**
  - Stable flight





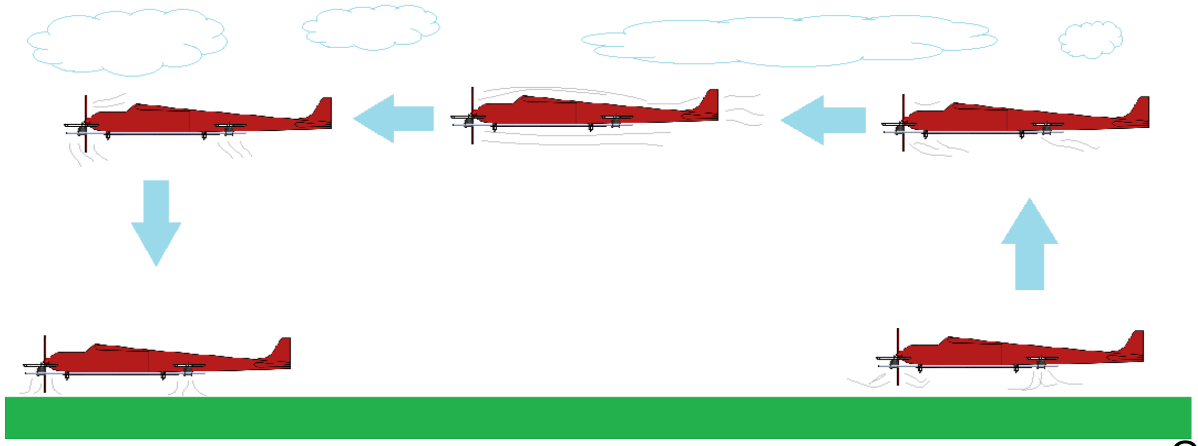
Transition Flight

To achieve transition flight a custom firmware needs to be developed
Firmware needs to be coded for hover to horizontal flight:

1. Begin slow forward flight with quadrotor
2. Gradually increase front propeller RPM's, until desired thrust is achieved
3. Once desired forward velocity is achieved, quadrotor motors can be cut off

Firmware also needs to be coded for horizontal flight to hover:

1. Plane will maintain current altitude at slowest flight speed at which it can still maintain lift
2. Quadrotor frame will turn on to generate lift while also slowing the vehicles motion
3. Aircraft will fly under the control of the quadrotor

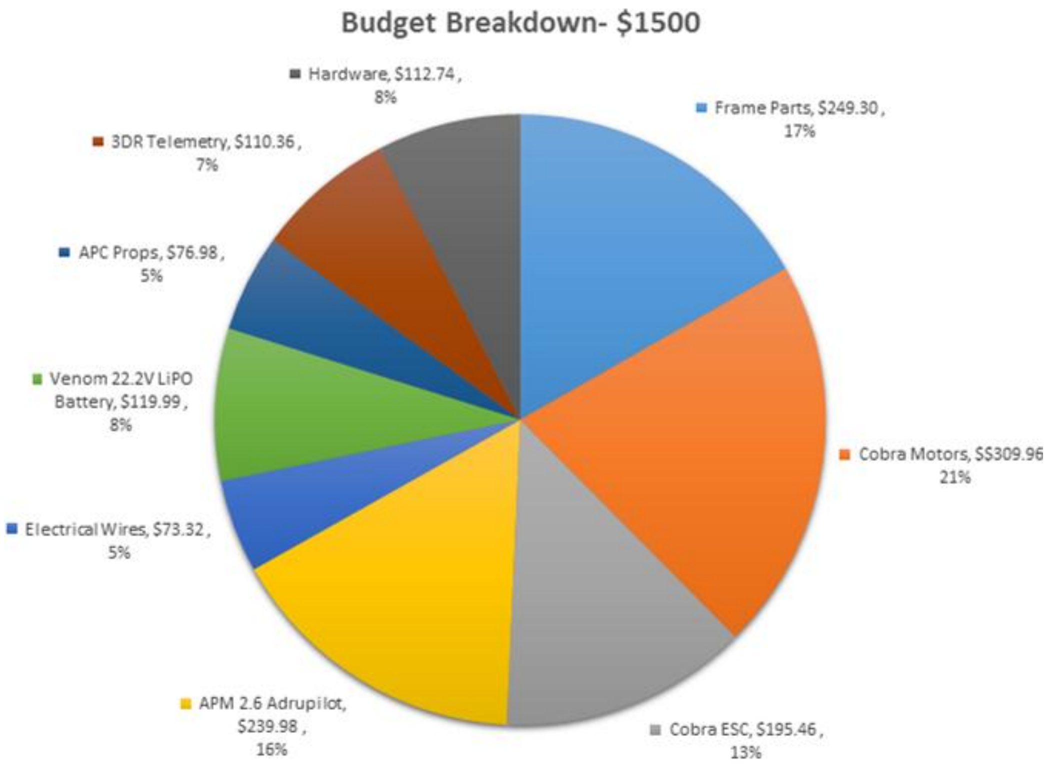


Bill of Materials

Mechanical BOM		
Part	**Quantity**	**Cost**
Carbon Fiber 0.5" Tubes	3	$41.05
Industrial Strength Velcro	6	$30.39
Double Bubble Orange Epoxy	6	$11.99
APC 18"x5.5" Props	6	$76.98
Resilient Foam Base	1	$40.44
Aluminum 1"x1" Tubes	3	$85.71
Fasteners	1	$70.36
Total		**$356.92**

Electrical BOM		
Part	**Quantity**	**Cost**
Adrupilot APM 2.6	1	$239.98
12 AWG Wire and Connectors	16	$64.40
Cobra 4510 DC motors	4	$299.96
Cobra 60A ESC	4	$195.44
Venom LiPo Battery	1	$119.99
3DR Telemetry Kit	1	$110.36
Shipping	1	$101.04
Total		**$1,131.17**

Budget



- **Accomplishment:**

Team 8 was able to stay within $1500 project budget over the course of the project

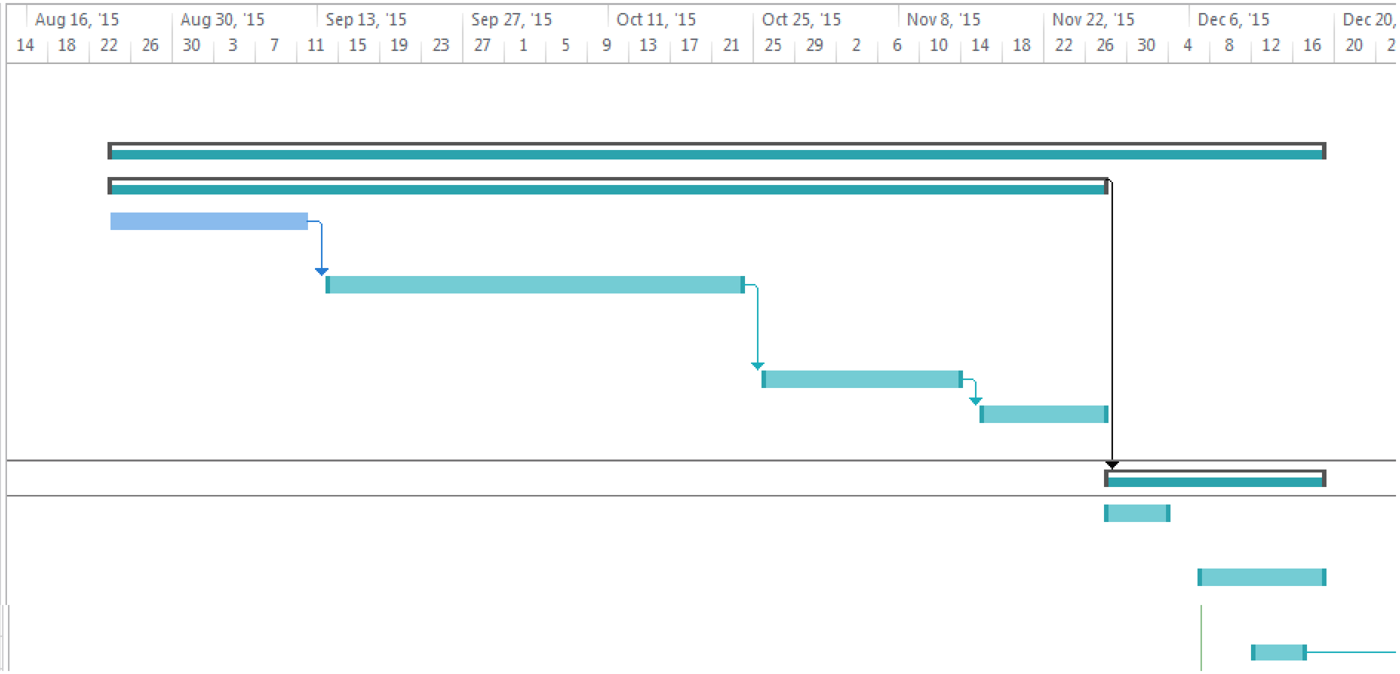
- **Breakdown:**

1. Utilized $1488.09 (99.2%) of the budget
2. Replacing Broken Parts- $350.34 (23%)
3. Purchased Surplus Parts

Schedule

TT CHART

Task Name	Duration
Fall Semester 2014	**16 wks**
Spring Semester 2015	**16 wks**
Fall Semester 2015	**17 wks**
Transitional Flight	**14 wks**
Research Transitional Flight Options	3 wks
Implement the best option for transitional flight	6 wks
Test Transitional Flight	3 wks
Troubleshoot and supplemental test	2 wks
Competition Secondary Task	**3 wks**
Research and select secondary task	1 wk
Designs for secondary Task	2 wks
VTOL/Stability	
Assessment and Future Plans	1 wk



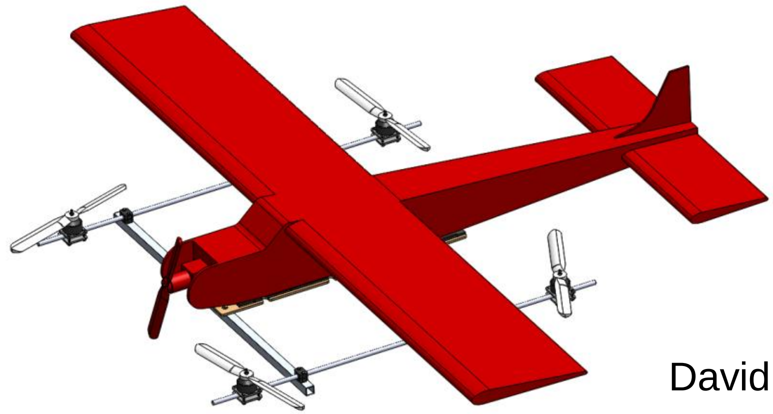
Lessons Learned

What was learned:

- International communications skills
- Working with multidisciplinary teams
- Time management and planning
- Work experience in an innovative field
- Control systems
- Autonomous flight

What could have been done differently:

- Ensure passed down parts function properly
- Use resources better (professors and facilities)
- Better communication with sponsor and advisors



Conclusion

Conclusion:

It was possible to achieve autonomous VTOL with a Senior Telemaster plane by adding a quadrotor attachment

How it was achieved:

- Designed an operating quadrotor attachment which included:
  - Motor Selection
  - Power design
  - Center of Gravity
  - Aerodynamics
- Selecting and configuring APM 2.6
- Extensive testing of autonomous and manual flight

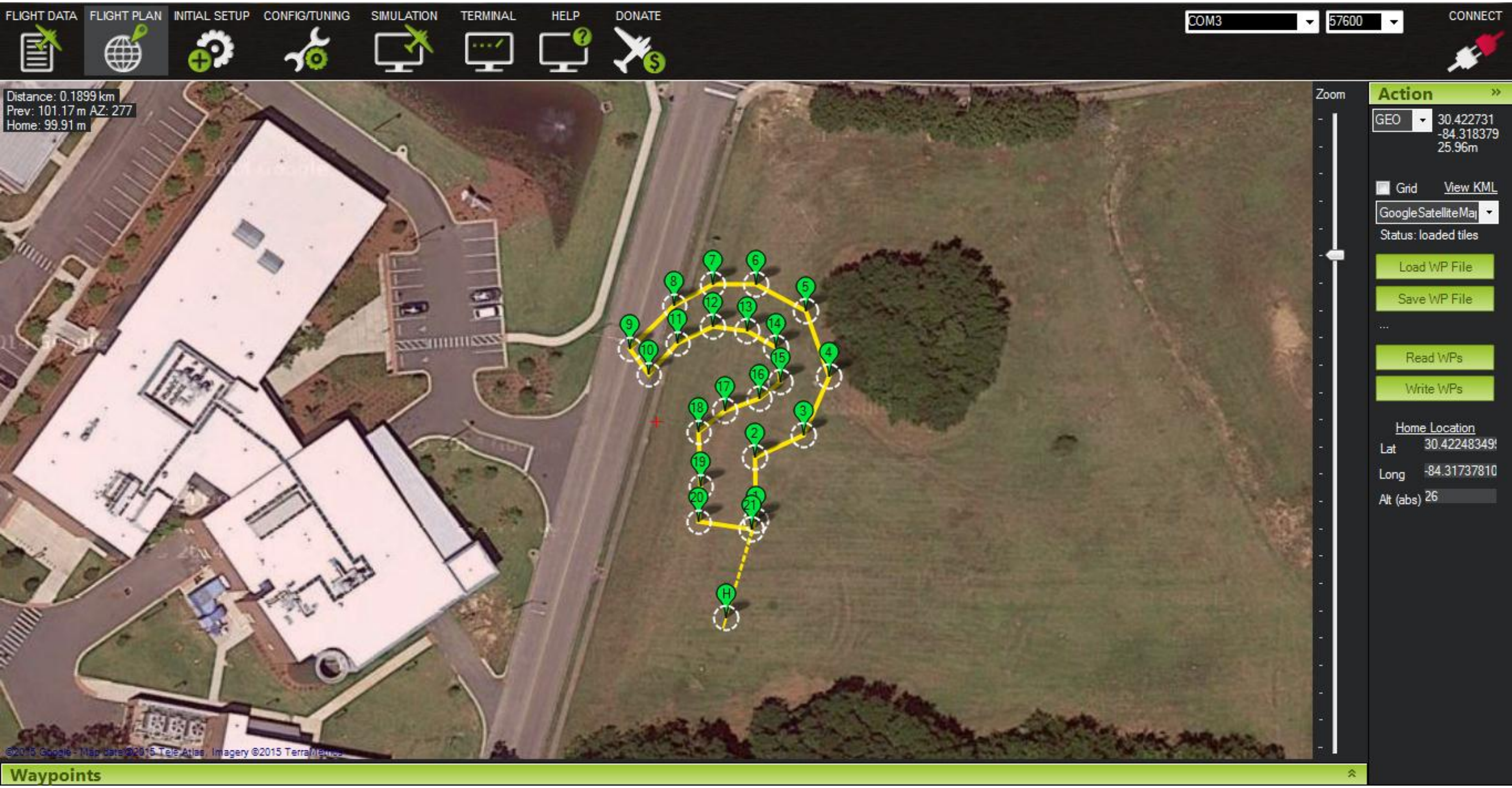
Impact for 2015-2016 Team:

- Ability to focus on transitional flight and secondary objectives
- Critical parts are in working condition
- AUVSI competition is within reach

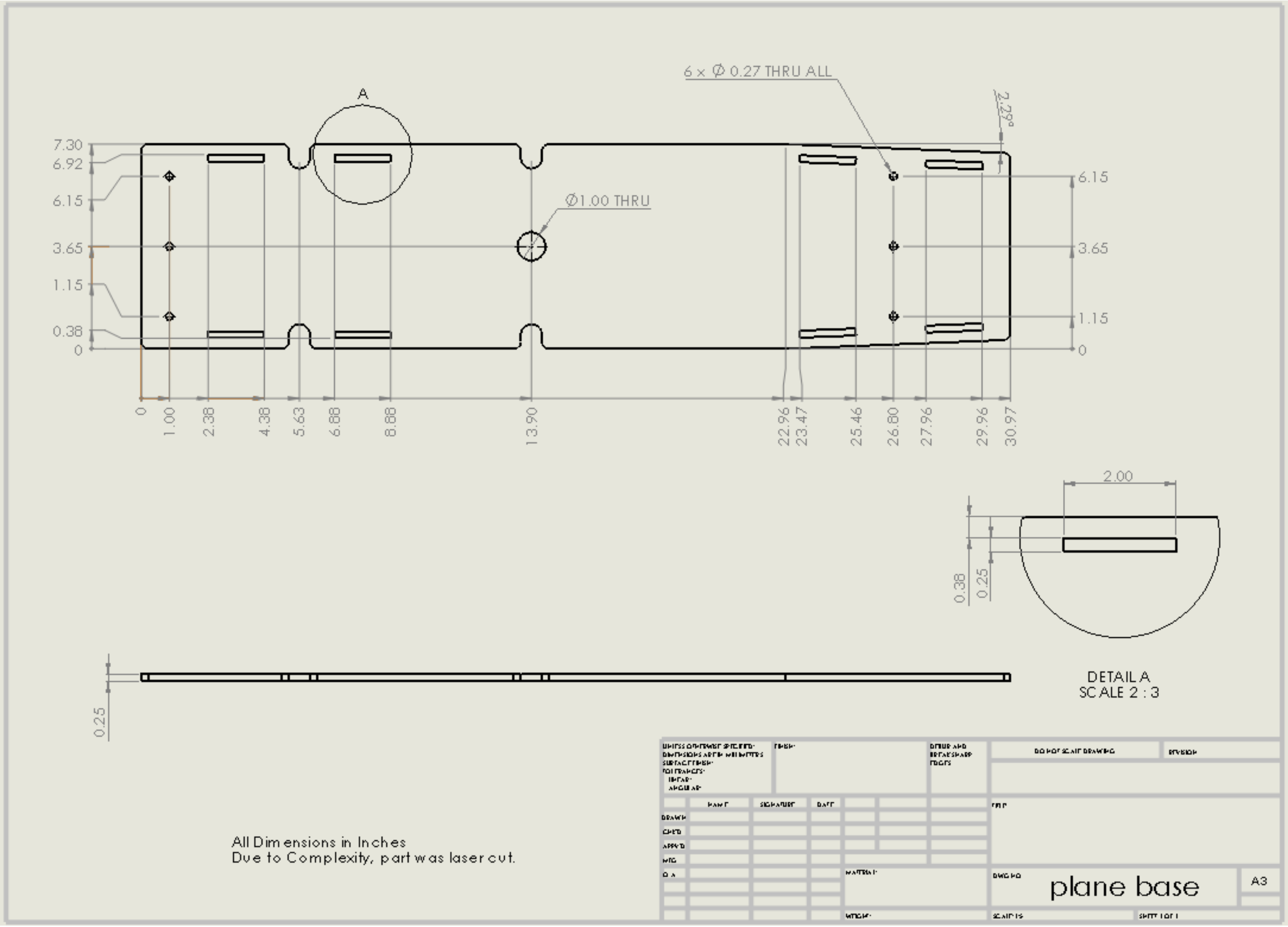
References

1. http://www.marksanborn.com/blog/5-questions-agenda-today/
2. http://usatoday30.usatoday.com/tech/news/surveillance/2006-08-06-drones_x.htm
3. https://www.uavs.org/commercia
4. https://www.uavs.org/advantages
5. https://higherlogicdownload.s3.amazonaws.com/AUVSI/fb9a8da0-2ac8-42d1-a11e-d58c1e158347/UploadedFiles/2015%20SUAS%20Rules.pdf
6. http://www.modelaircraft.org/files/105.pdf
7. http://jer10d.wix.com/auav
8. http://www.hobbyexpress.com/senior_telemaster_plus_oversize_1034837_prd1.htm
9. http://store.3drobotics.com/products/iris
10. http://www.arcturus-uav.com/aircraft_jump.html
11. http://www.cobramotorsusa.com/
12. https://www.apcprop.com/
13. http://www.ecalc.ch/
14. http://personal.osi.hu/fuzesisz/strc_eng/
15. http://www.zazzle.com.au/drone+stickers
16. http://pixgood.com/brazilian-american-flag.html

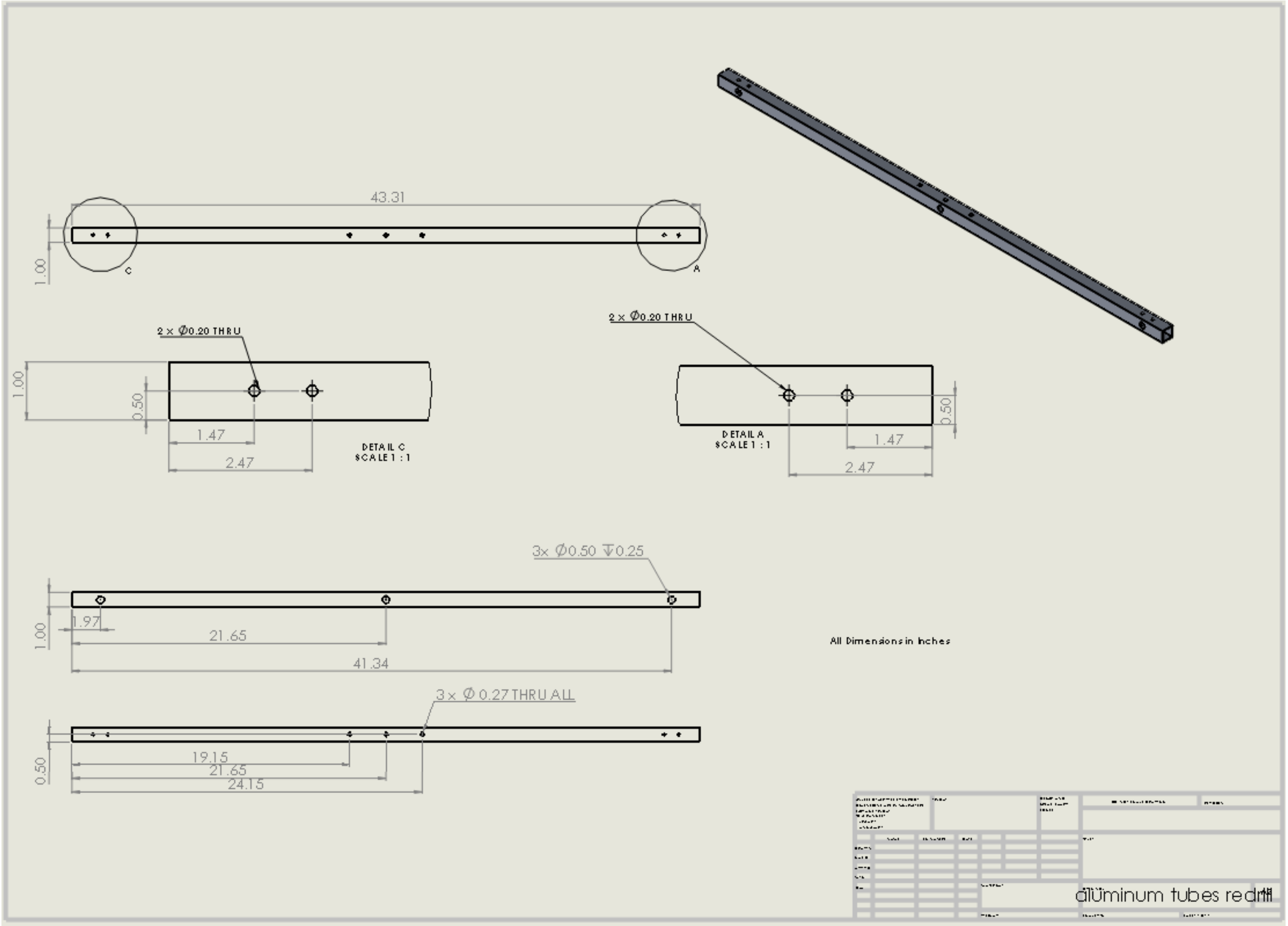
Questions?


FLIGHT DATA
FLIGHT PLAN
INITIAL SETUP
CONFIG/TUNING
SIMULATION
TERMINAL
HELP
DONATE
COM3
57600
CONNECT
Distance: 0.1899 km
Prev: 101.17 m AZ: 277
Home: 99.91 m
Zoom
Action
GEO
30.422731
-84.318379
25.96m
Grid
View KML
Status: loaded tiles
Load WP File
Save WP File
Read WPs
Write WPs
Home Location
Lat
Long
Alt (abs)
26
Waypoints

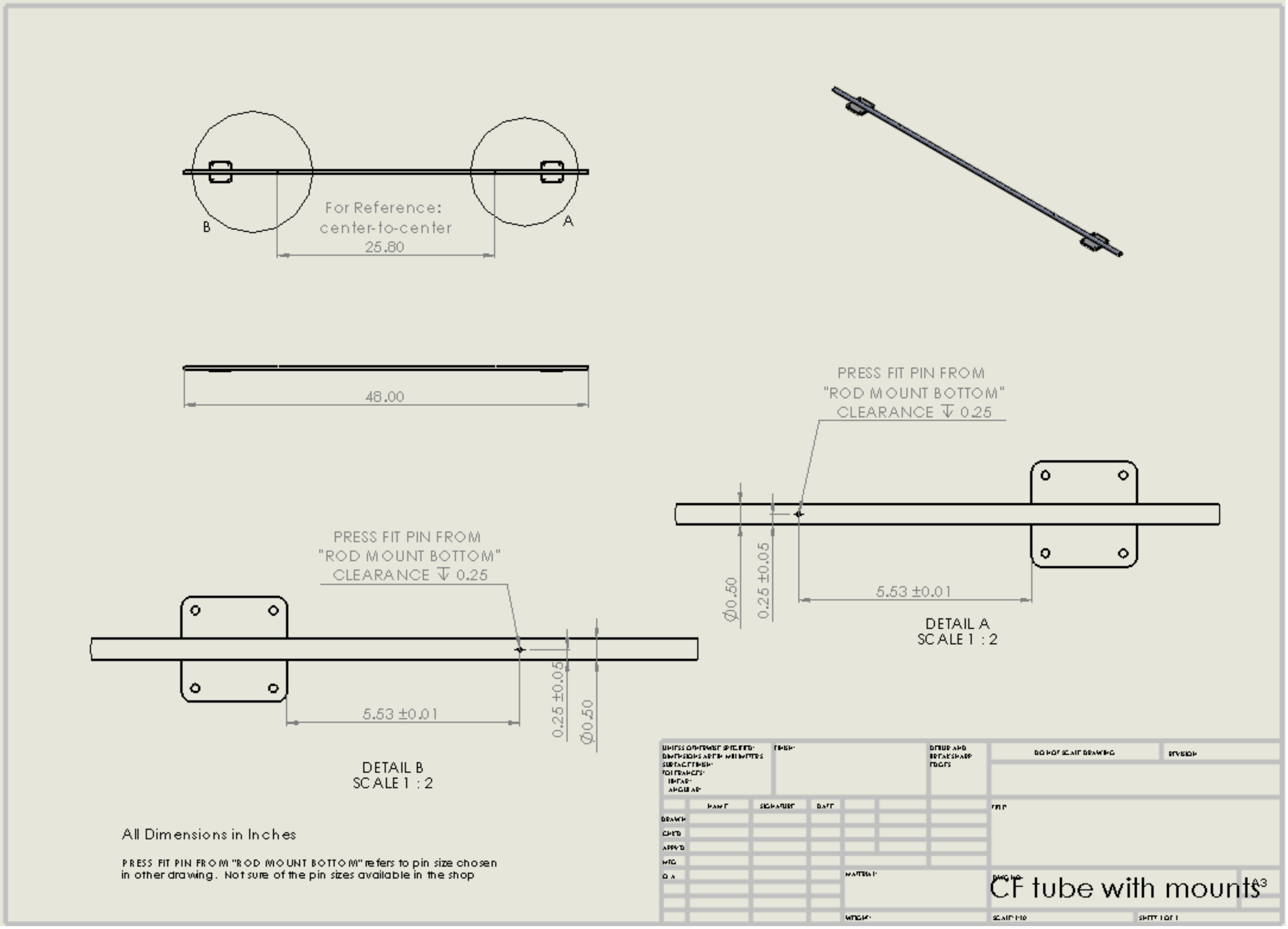
Appendix: Plywood Base



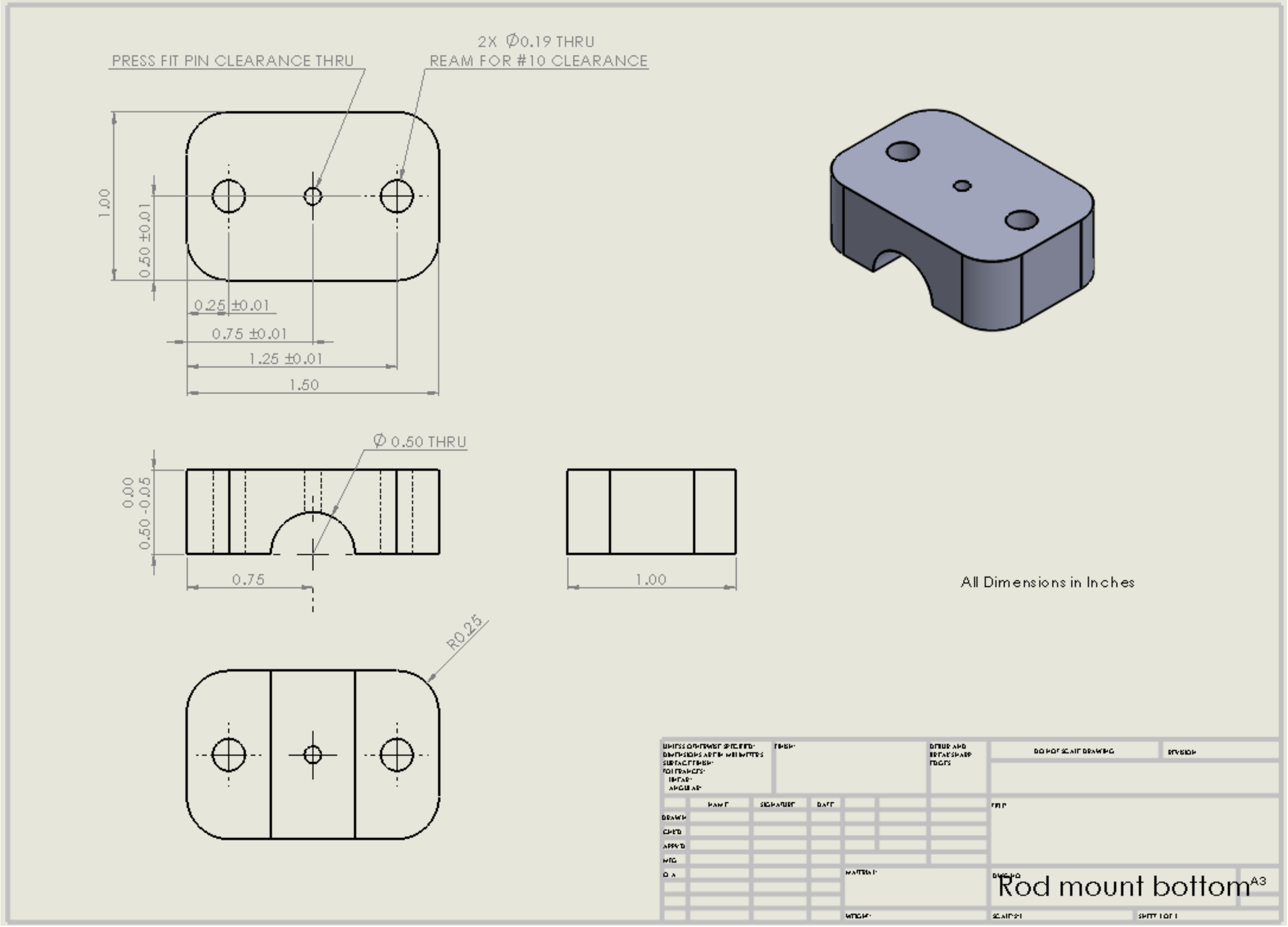
Appendix: Aluminum Tubes



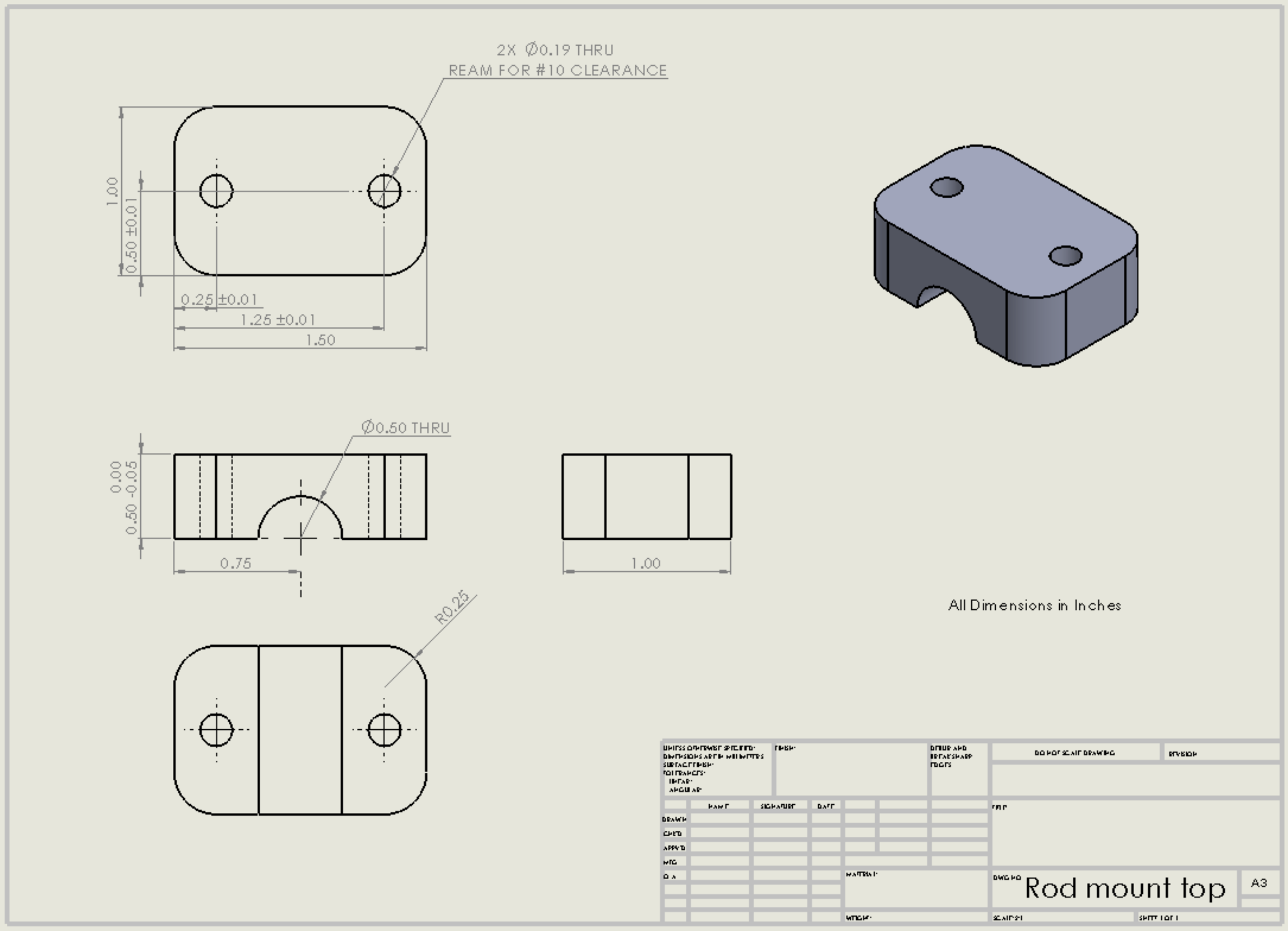
Appendix: Carbon Fiber Tubes



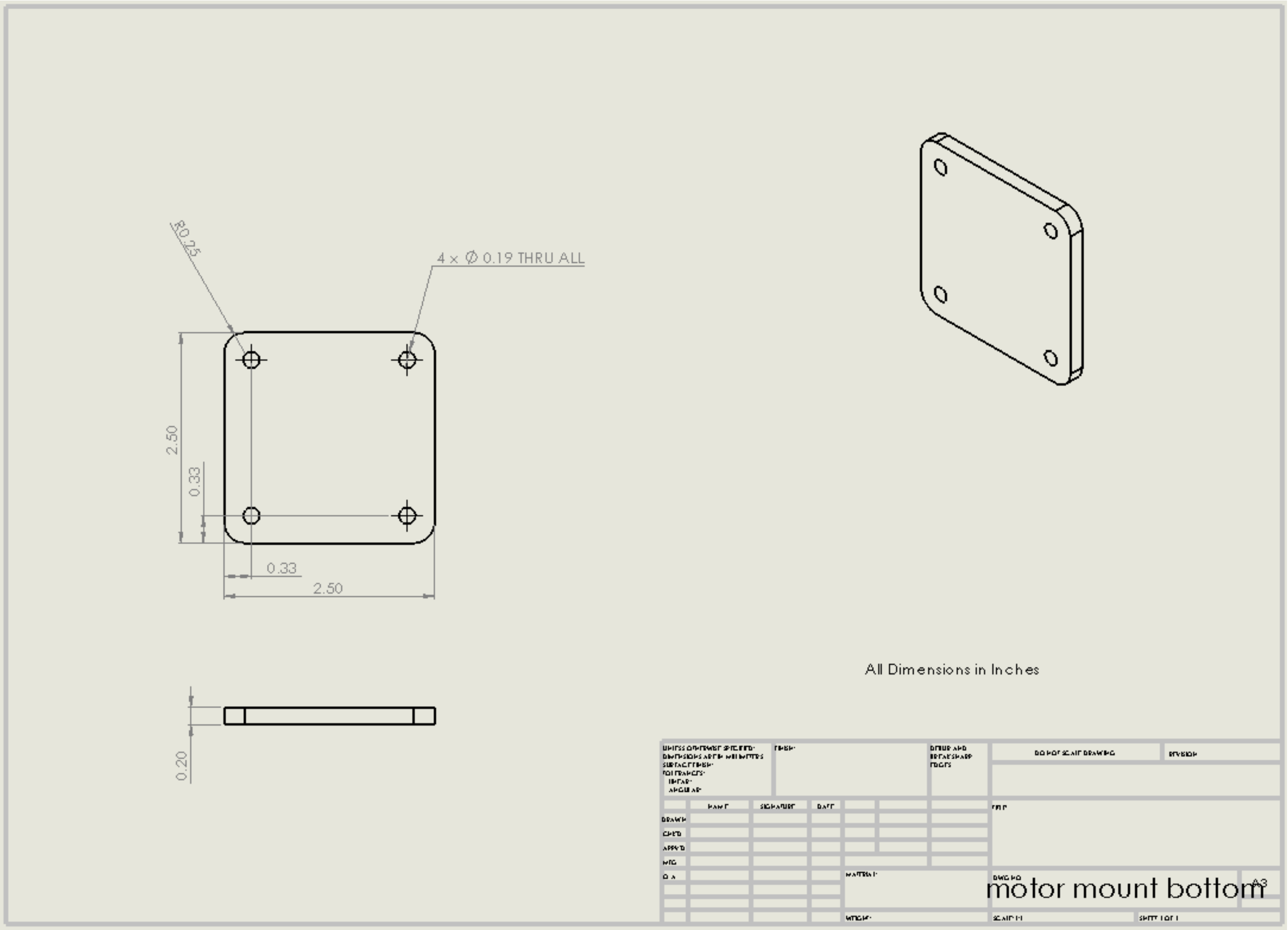
Appendix: Clamp Bottom



Appendix: Clamp Top



Appendix: Motor Mount Bottom



Appendix: Motor Mount Top