Critical Design Review 2020

SpeedfestX

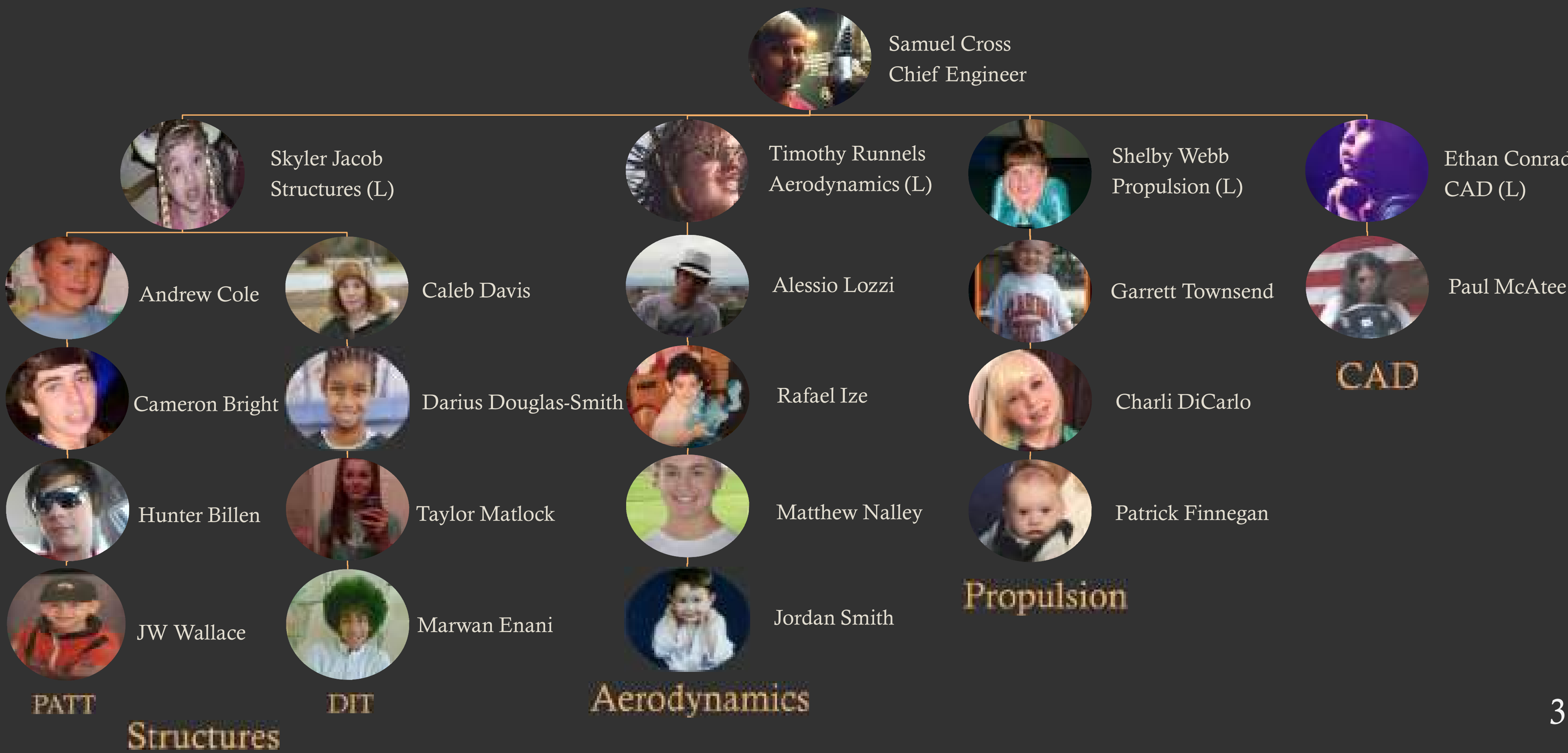
OSU BLACK TEAM

BDT

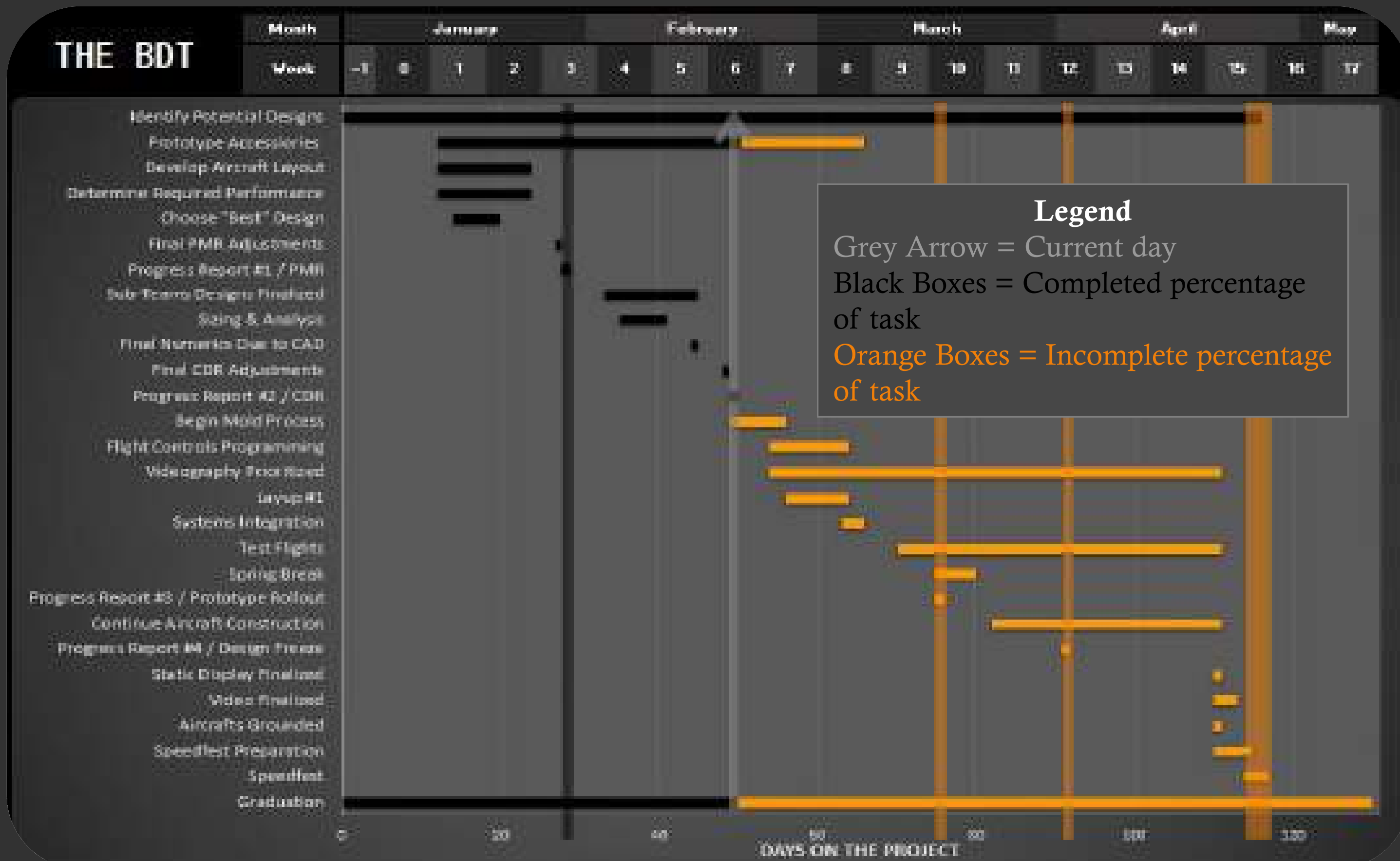
Outline

- PMR Recap
- Aerodynamics
- Propulsion
- Structures
  - Design Implementation
  - Accessories
- Test and Evaluation Plan
- Program Management
  - Scheduling
  - Budget
  - Performance

Black Team Roster



Gantt Chart


THE BDT
Month
January
February
March
April
May
Week
Identify Potential Designs
Prototype Accessories
Develop Aircraft Layout
Determine Required Performance
Choose "Best" Design
Final PMR Adjustments
Progress Report #1 / PMR
Sizing & Analysis
Final CDR Adjustments
Progress Report #2 / CDR
Begin Mold Process
Flight Controls Programming
Layup #1
Systems Integration
Test Flights
Spring Break
Progress Report #3 / Prototype Rollout
Continue Aircraft Construction
Progress Report #4 / Design Freeze
Static Display Finalized
Video Finalized
Aircrafts Grounded
SpeedFest Preparation
SpeedFest
Graduation
DAYS ON THE PROJECT
Legend
Grey Arrow = Current day
Black Boxes = Completed percentage of task
Orange Boxes = Incomplete percentage of task

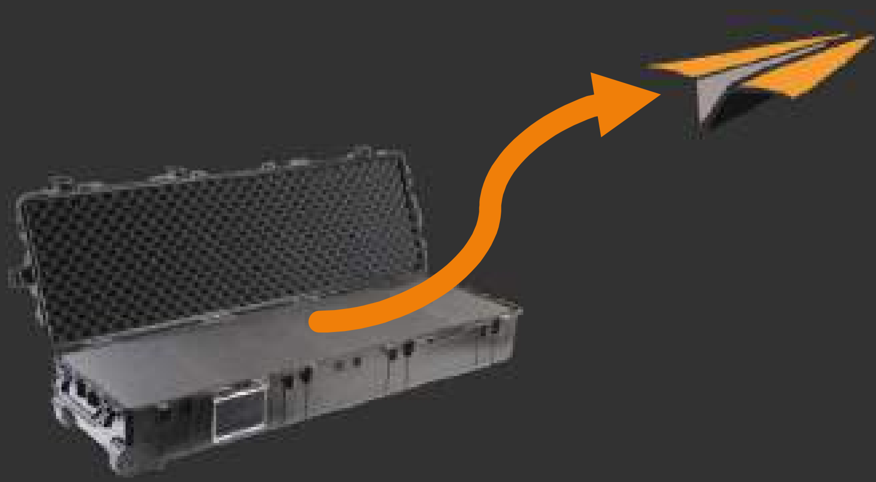
Speedfest Mission

Contractors are requested to demonstrate their ability to quickly design, develop and test, **a high-speed and efficient aircraft** powered by a very small turbojet. The aircraft must not only demonstrate specific speed and efficiency characteristics, but it also **must be easy and fast to assemble, and reliable**.

Contractors will develop and demonstrated prototype aircraft subject to the objectives set by the Statement of Work (SOW). The winning design will be chosen by a qualified team of judges selected from the aerospace industry, government, and academia.

CONOPS

Mission 1: Assembly/Launch



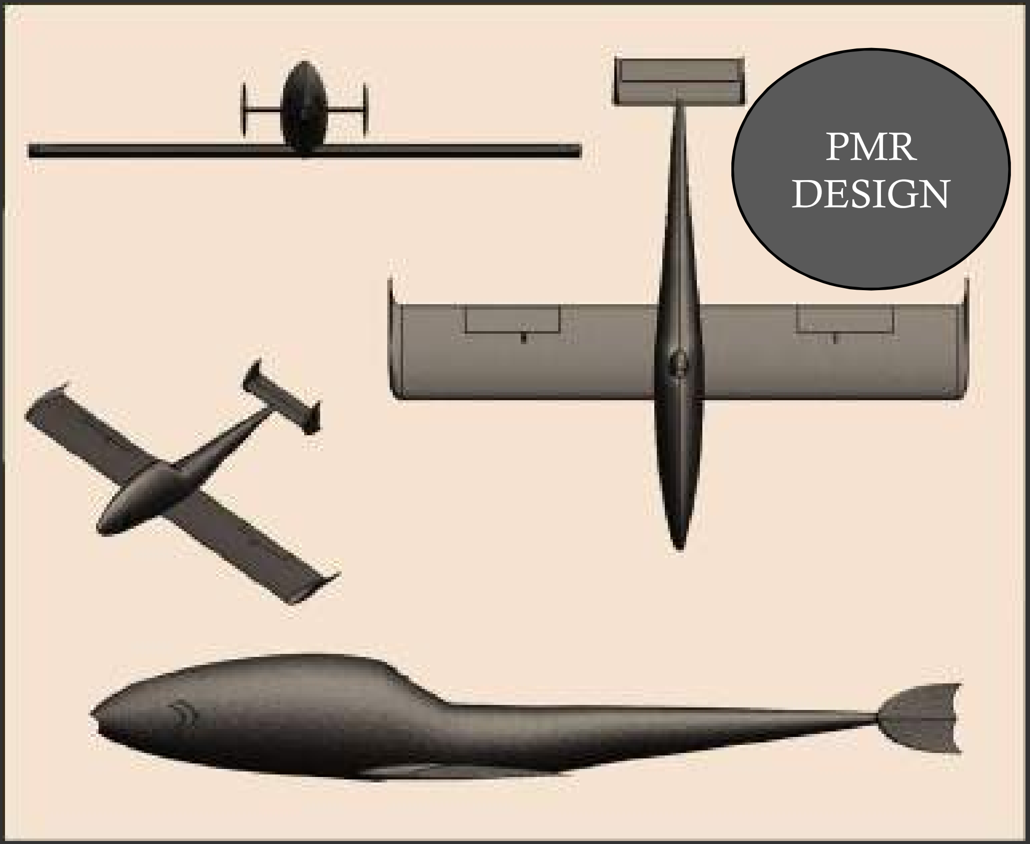
Mission 2: Speed and Efficiency

- Open case, assemble craft while simultaneously starting engine, then launch vehicle as quickly and safely as possible.
- Perform a simple and safe maneuver showing control of the craft then land.

- Phase #1: Takeoff and speed run 25 flags in figure 8 pattern.
- Phase #2: Cut engine and climb to optimal altitude.
- Phase #3: Endurance glide with landing and recovery.

PMR Recap

- Internal, High-Mount Engine
- Rigid, Custom Fuel Tank
- Low, Attachable Wing
- H-Tail Empennage
- Tall, Thin Fuselage



Any Questions Before We Get Started?

Aerodynamics

Timothy Runnels

Airfoil

SA 7035

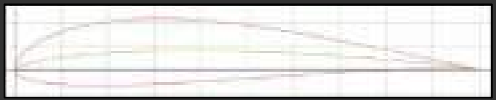
NACA 2412

NACA 4412

NACA 2410

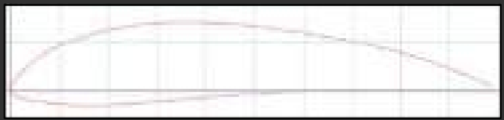
NACA 2212

NACA 2313



SD7062

NACA 6412

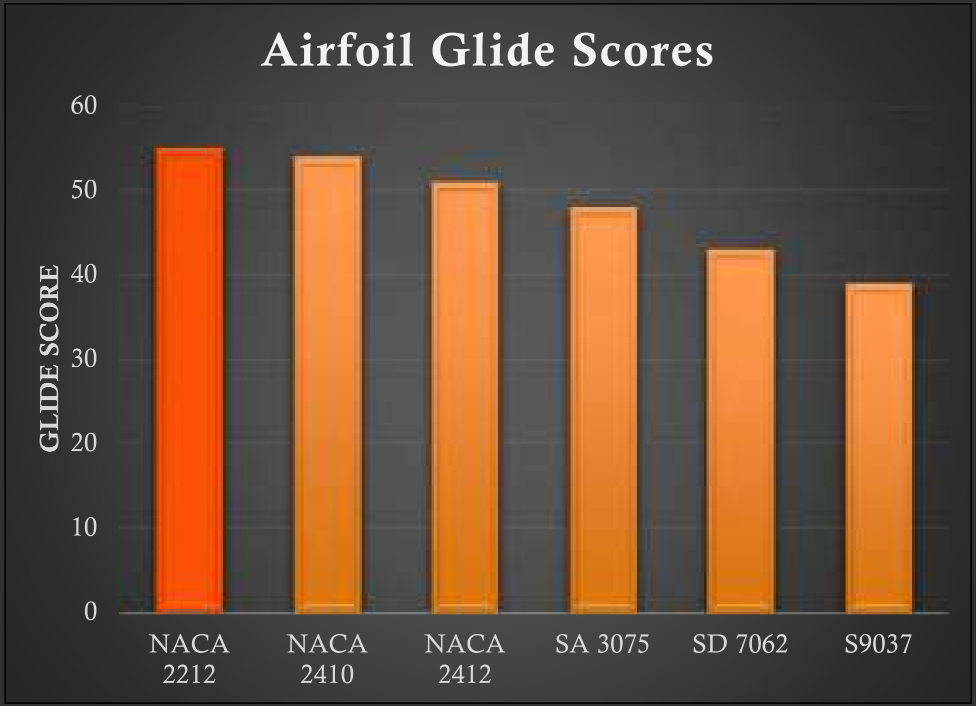


Rize 01

S9037

Airfoil Downselect

- Candidate airfoils were run through mission plan analysis
- Glide times for each airfoil were estimated
- Glide times were used to estimate score of each airfoil

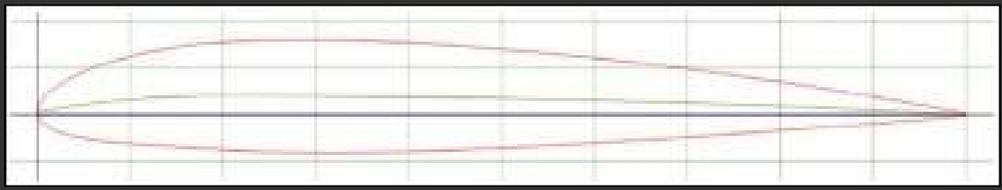


*not all airfoils shown

Selected Airfoil

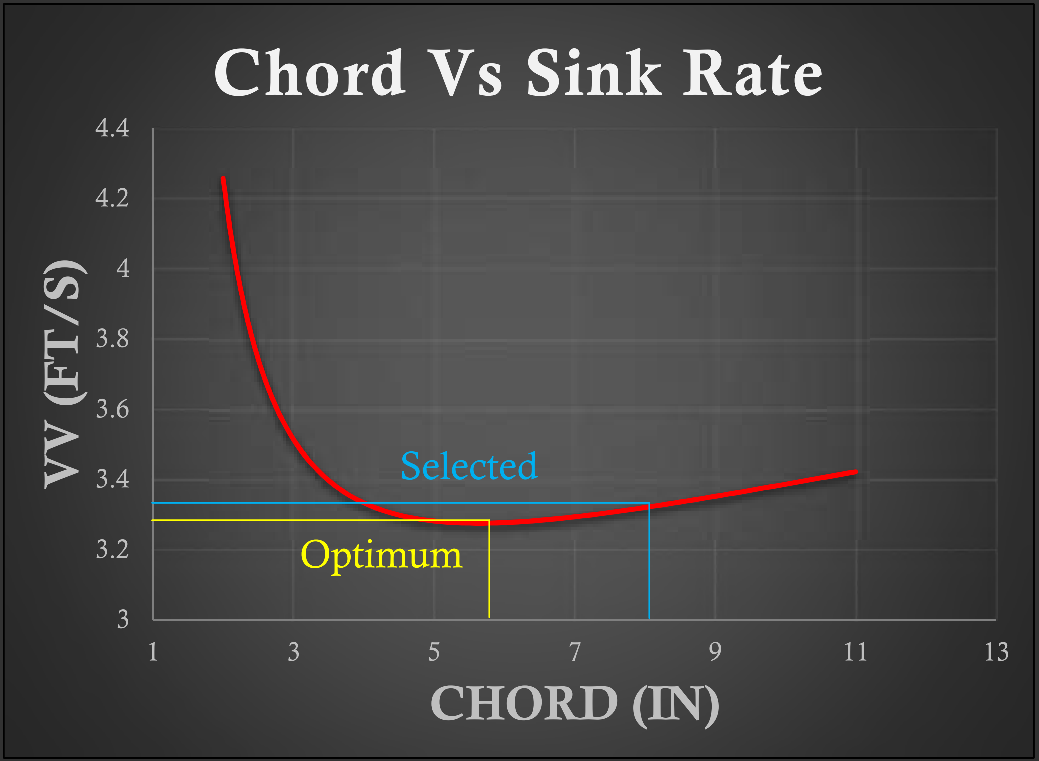
NACA 2212

- Best predicted score compared to other candidate airfoils
- Compromise between high speed performance and low speed (higher and lower Reynolds number)
- Best glide time and easy manufacturability



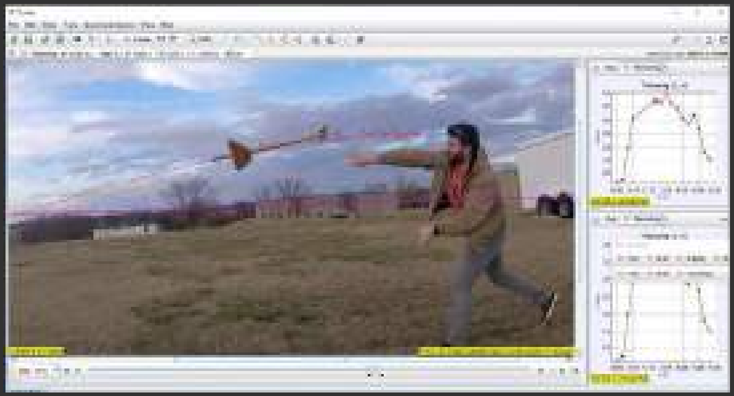
Wing Sizing

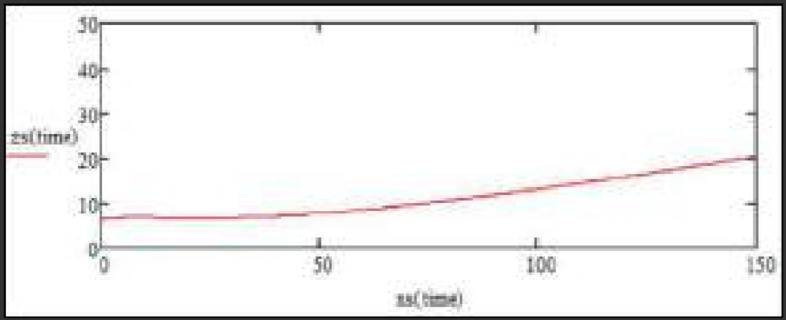
- Off optimum chord for minimum sink rate
- Increasing chord has a small impact
- Increasing wing area allows for larger margin of safety for hand launch

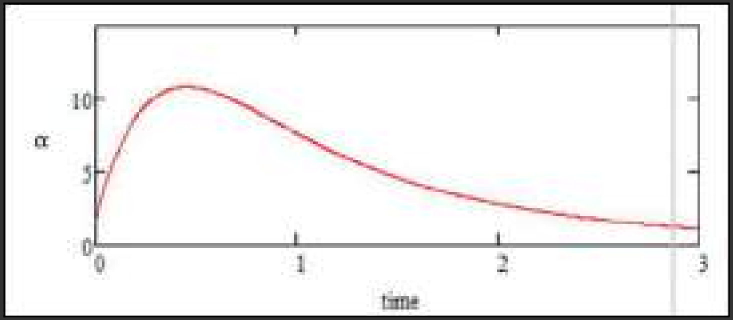


Hand Launch

- Aircraft will have the capability to be hand launched
- Hand launch was analyzed at worst case scenario
  - 25 ft/s throw (35ft/s nominal)
  - No wind
  - Aircraft over MTOW

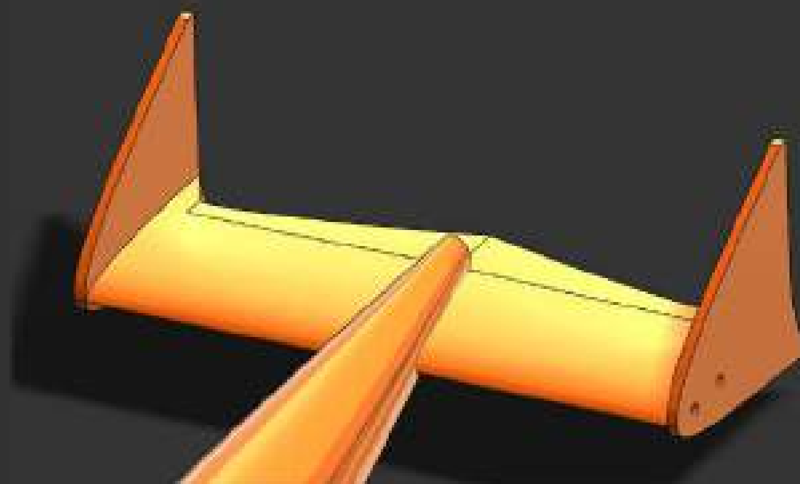






Stabilizer Sizing

- Sized using Raymer method and validated in CFD
- NP_H = 16 in from nose
- NP_V = 20 in from nose
  - Slightly over stable in yaw, helps to compensate for no yaw control

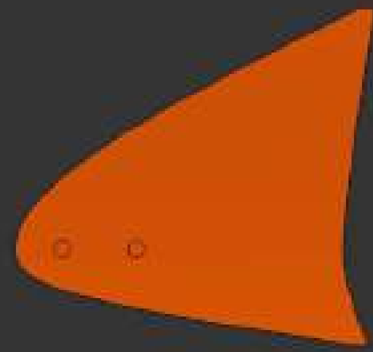


Horizontal Stabilizer

- Horizontal static margin: 13.8%
- Decent agreement between theoretical approach and
  - Theoretical AC_H = 15.8 in
  - CFD AC_H = 16 in
- Tail Volume: 0.4

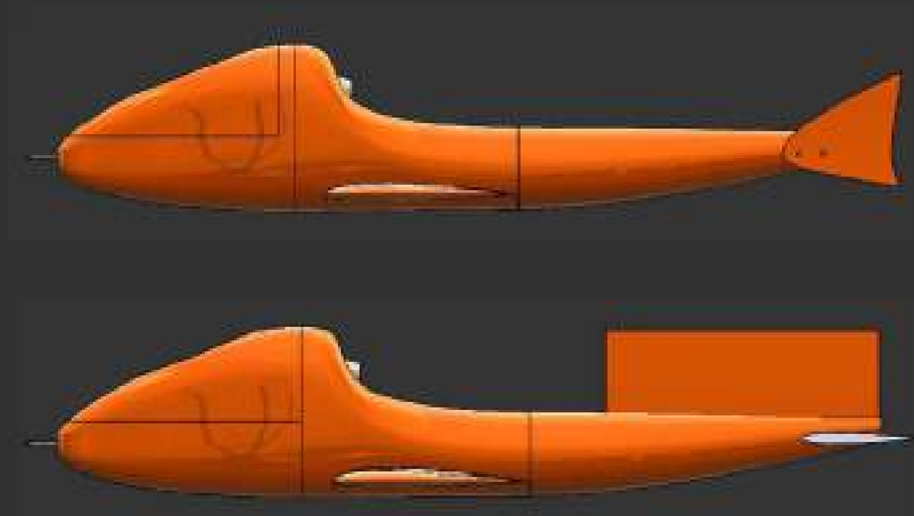
Vertical Stabilizers

- Vertical Static Margin: 66%
- Initial sizing via theoretical approach gave oversized stabilizers
  - Size was reduced from this estimate
  - Difference likely due to odd fuselage shape
- Tail Volume: 0.03



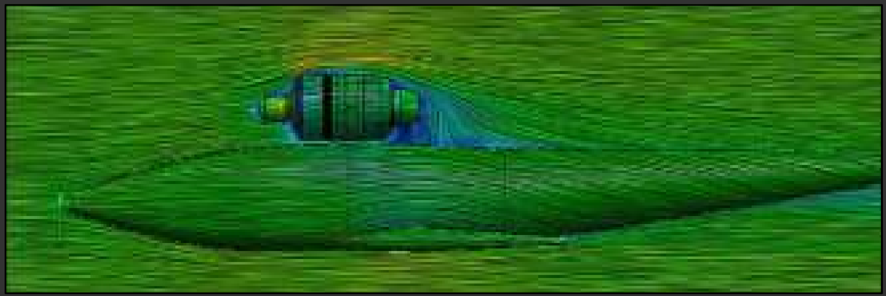
H-Tail

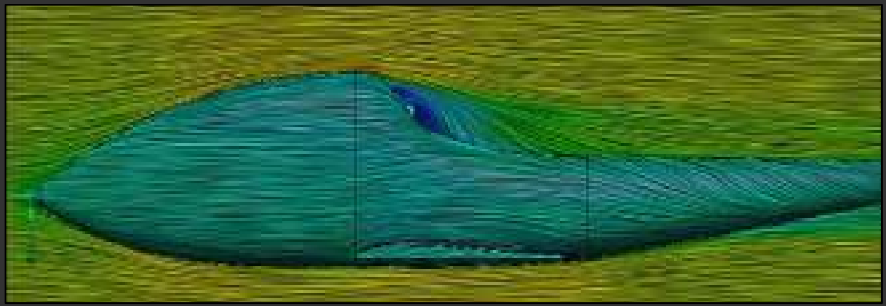
- Allows vertical stabilizers to fit in box
- No assembly required
- Increase effective aspect ratio of horizontal stabilizer



Internal Vs. External Engine

- Initial comparisons using drag buildups from Raymer, then with CFD
- Internal is predicted to have lower parasite drag
  - 15% less in cruise
  - 40% less in glide
- Internal is expected to increase score by 20 points compared to external

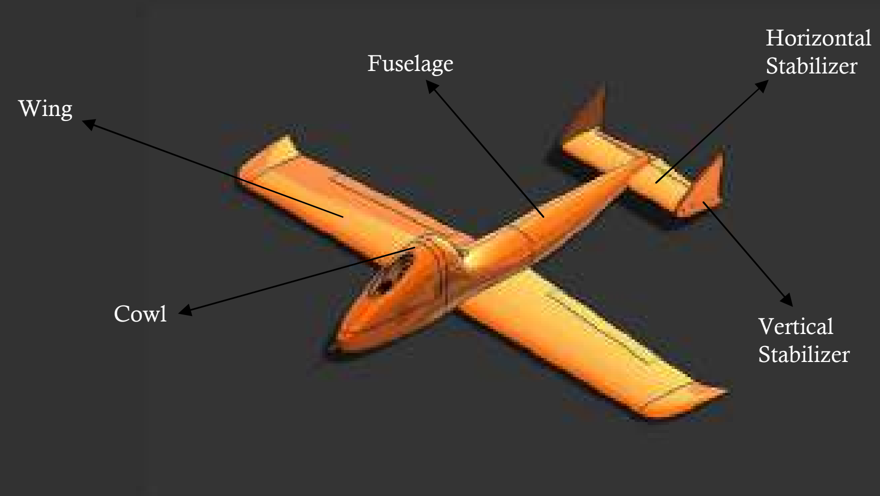




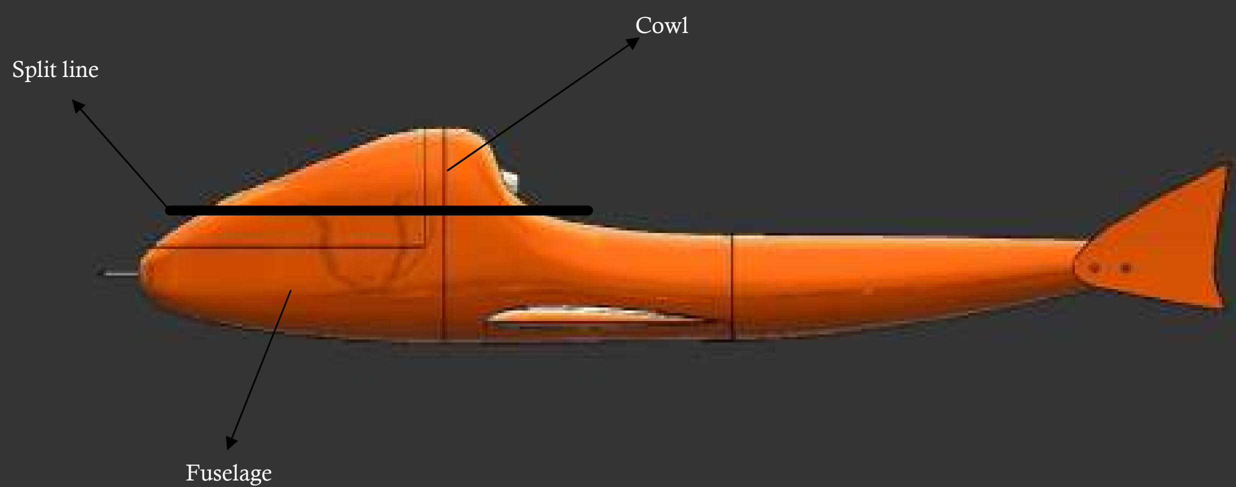
C_{D0} Refinement

- First iteration modeled Fuselage, Wing, and Empennage and estimated a C_{D0} of 0.02

- Second iteration split aircraft into Fuselage, Cowl, Wing, Horizontal Stabilizer, and Vertical Stabilizer and yielded a C_{D0} of 0.018

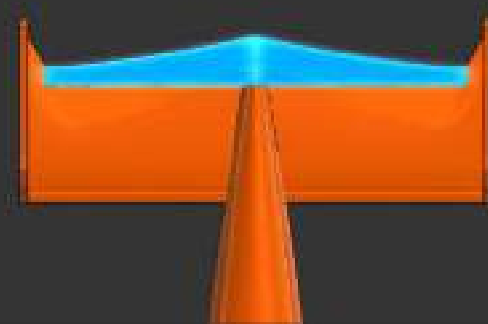


C_{D0} Refinement Cont.



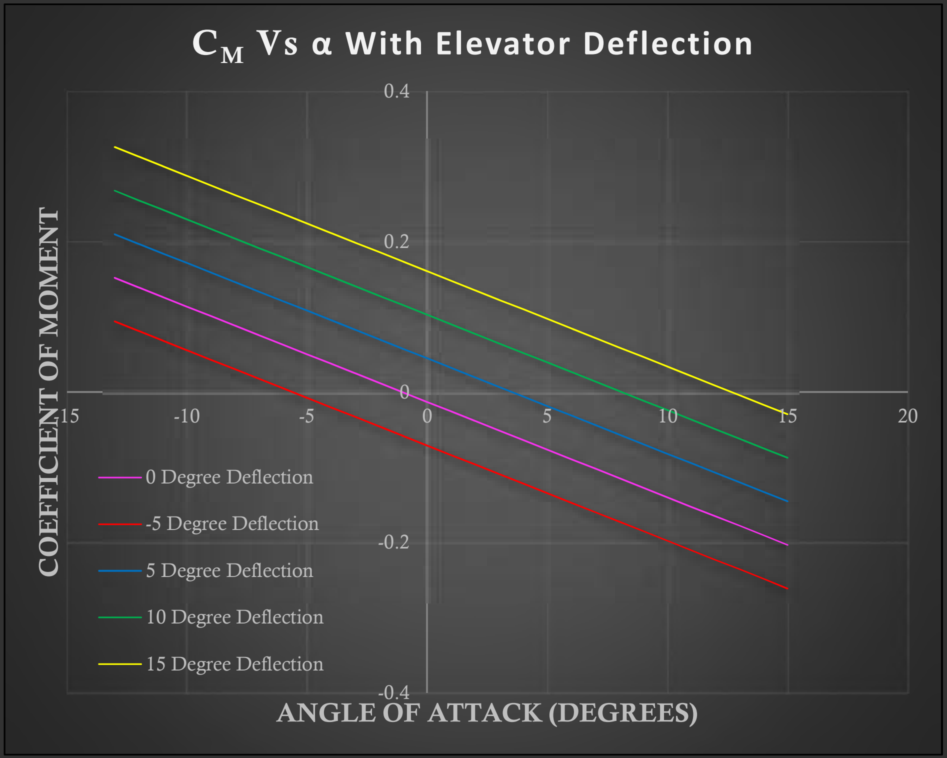
Control Surface Sizing

- Elevator was sized so that stall α can be reached at maximum aileron deflection
- Aileron sizing driven by handling qualities



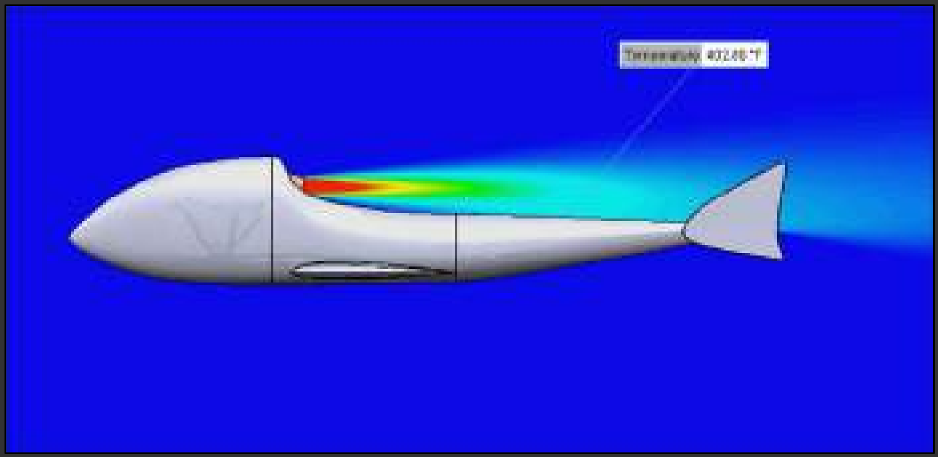
Trimmability

- C_{M0} value determined through CFD
- Value higher than expected through theoretical means, but still within trimmable range
- Likely due to odd fuselage shape



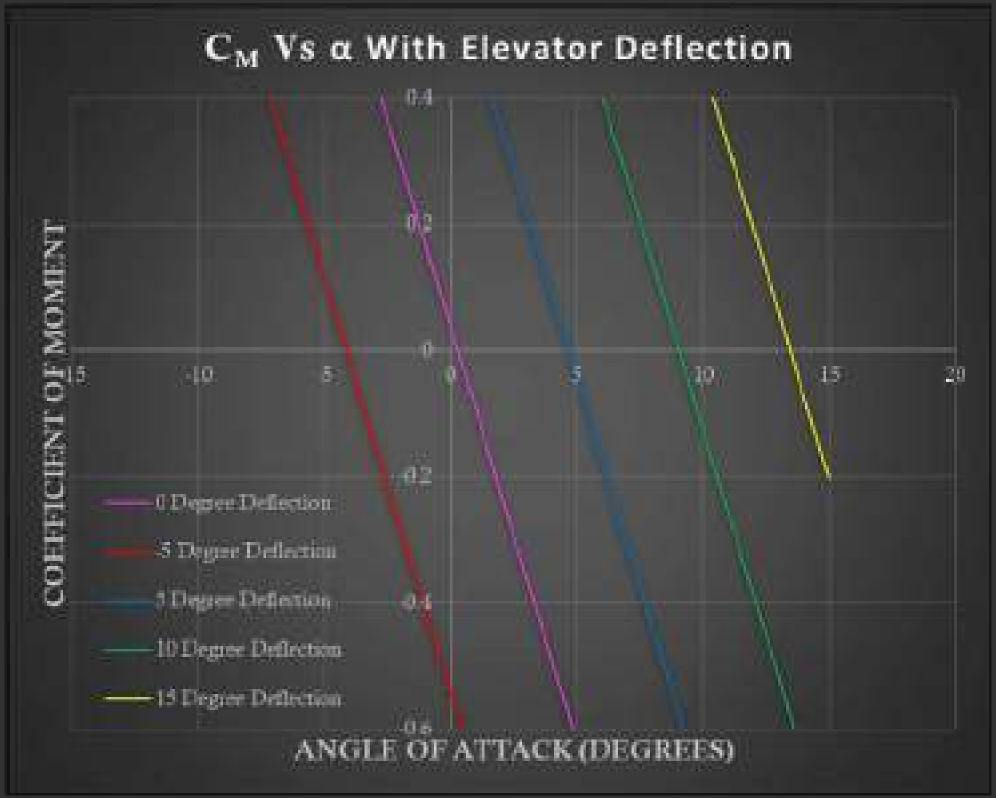
Exhaust Impingement

- CFD models used to investigate exhaust
- Simulations show exhaust near fuselage
- Temperatures are approximately 450°F



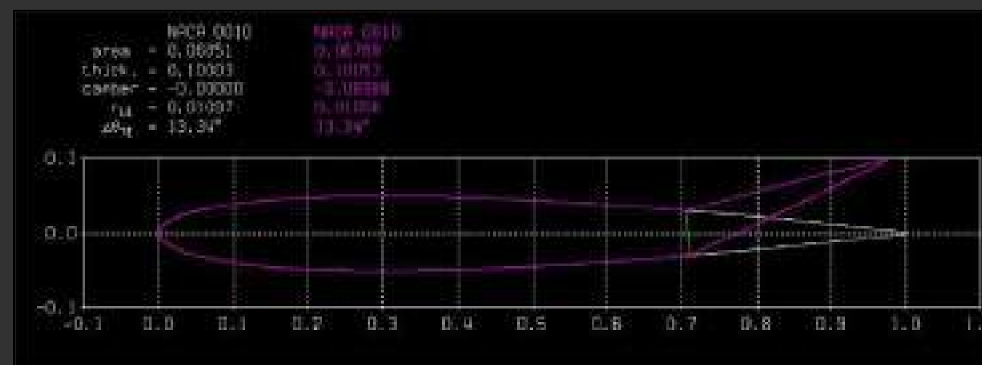
Engine Effect on Stability and Control

- Engine causes pitch down moment
- Engine exhaust over tail increases tail effectiveness
- Tail incidence set at 0° to avoid large change in trim point with engine shut off



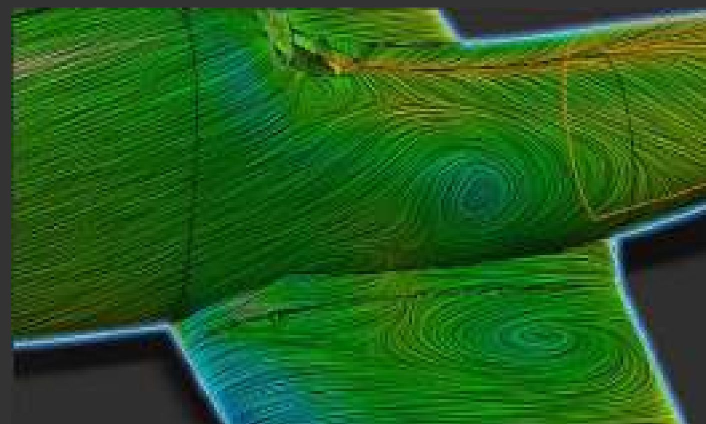
Hinge Moment Estimate

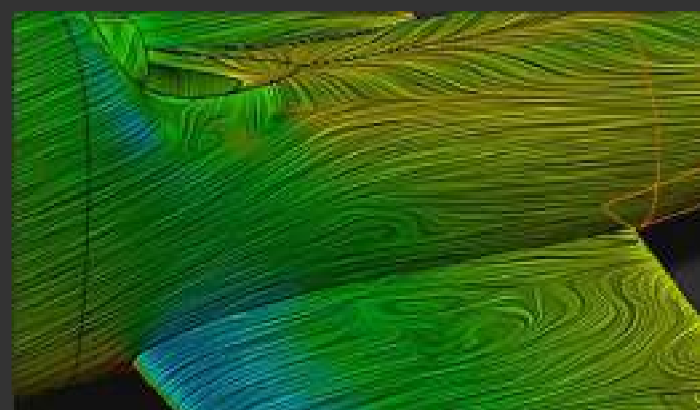
- Sizes taken from earlier analysis
- Coefficient of hinge moment determined in Xfoil
- Scaled to span of control surfaces



Wing Placement

- Rounded fuselage causes issues with low wing
- Move wing up to avoid this rounding
- Helps prevent pre-mature stall

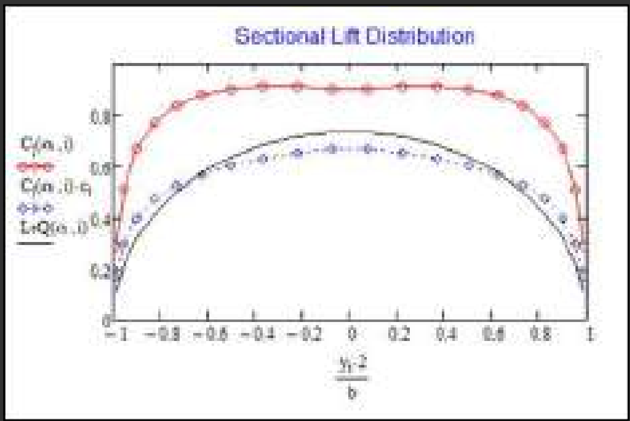




Taper

- Taper was selected for aesthetic purposes

- Study on effect of taper has shown no detriment to overall design

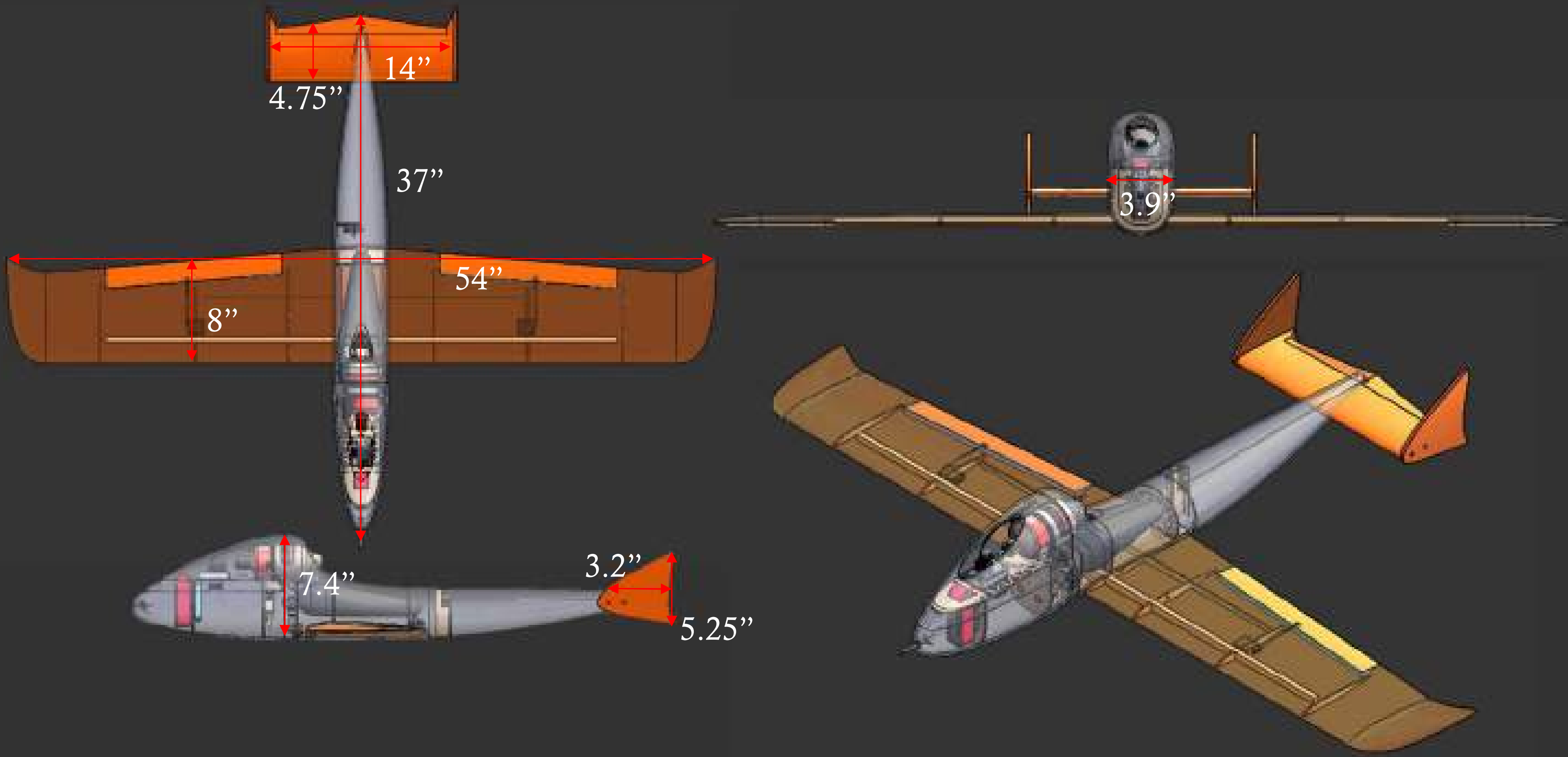


C.G. Travel

- Fuel is placed slightly off of C.G.
- Full fuel static margin: 14.9%
- Empty fuel static margin: 16.5%
- 1.6% total change in static margin

A.C.
C.G.

- A.C.
- C.G.



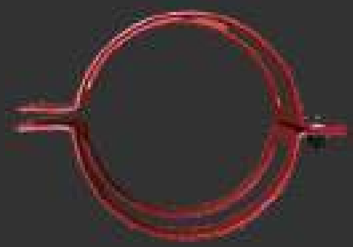
Aero Related Questions?

Propulsion

Shelby Webb

Engine Mount

- **Stock**
  - Horizontal Two Point Attachment
  - More Width Required
- **Custom**
  - Vertical Single Point Attachment
  - Extended Base
    - Reduce Possible Moment
- **Purpose**
  - Reduce
    - Fuselage Width
    - Parasitic Drag

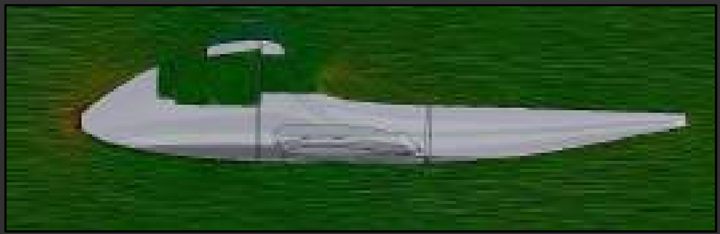


Stock Mount

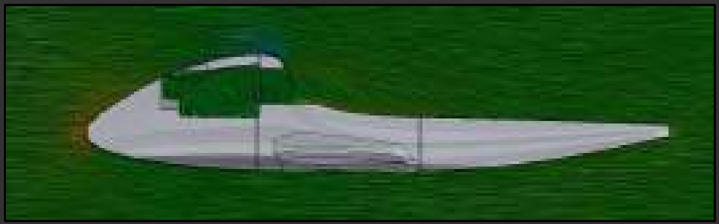
Custom Mount

Inlet

- Inlet Selection
  - Total Area
    - 3.0 in^2 - Benchmarked
  - Shape
    - Blow Hole
  - Location
    - Upper-Half of Fuselage
  - Inlet Built Into Hatch
    - Easy to Modify



Top: "Blowhole"



Side: “Gilled”

Inlet in Flight Simulation

- **Purpose**
  - Start Up Time
  - Take – Off Characteristics
  - In-Flight Characteristics
- **Further Testing Required**
  - Gilled
  - Blow Hole

Fuel Tank

- **Custom**
  - Commercial Tanks Not Compatible
  - Utilize Fuselage Internal Volume

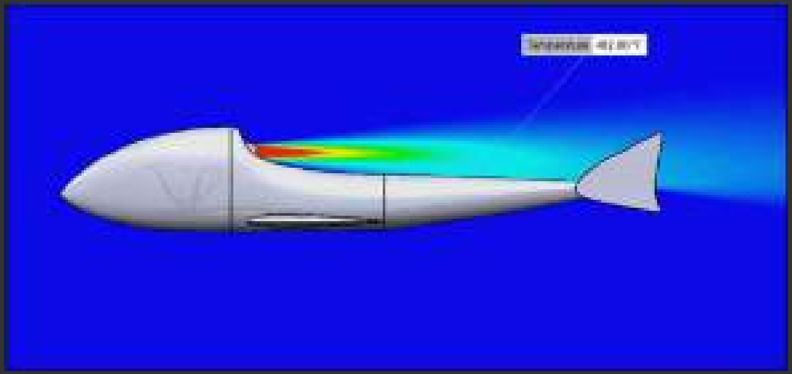
- **Materials**
  - Tool Glass
  - 3 oz. Fiber Glass
  - 30 Minute Epoxy

- **Estimated Fuel Required**
  - 1.23lbs

Exhaust Profiling

- **Exhaust Tests**
  - Temperature Distribution
    - Temperature Probe
  - CFD Analysis
    - Exhaust Flow

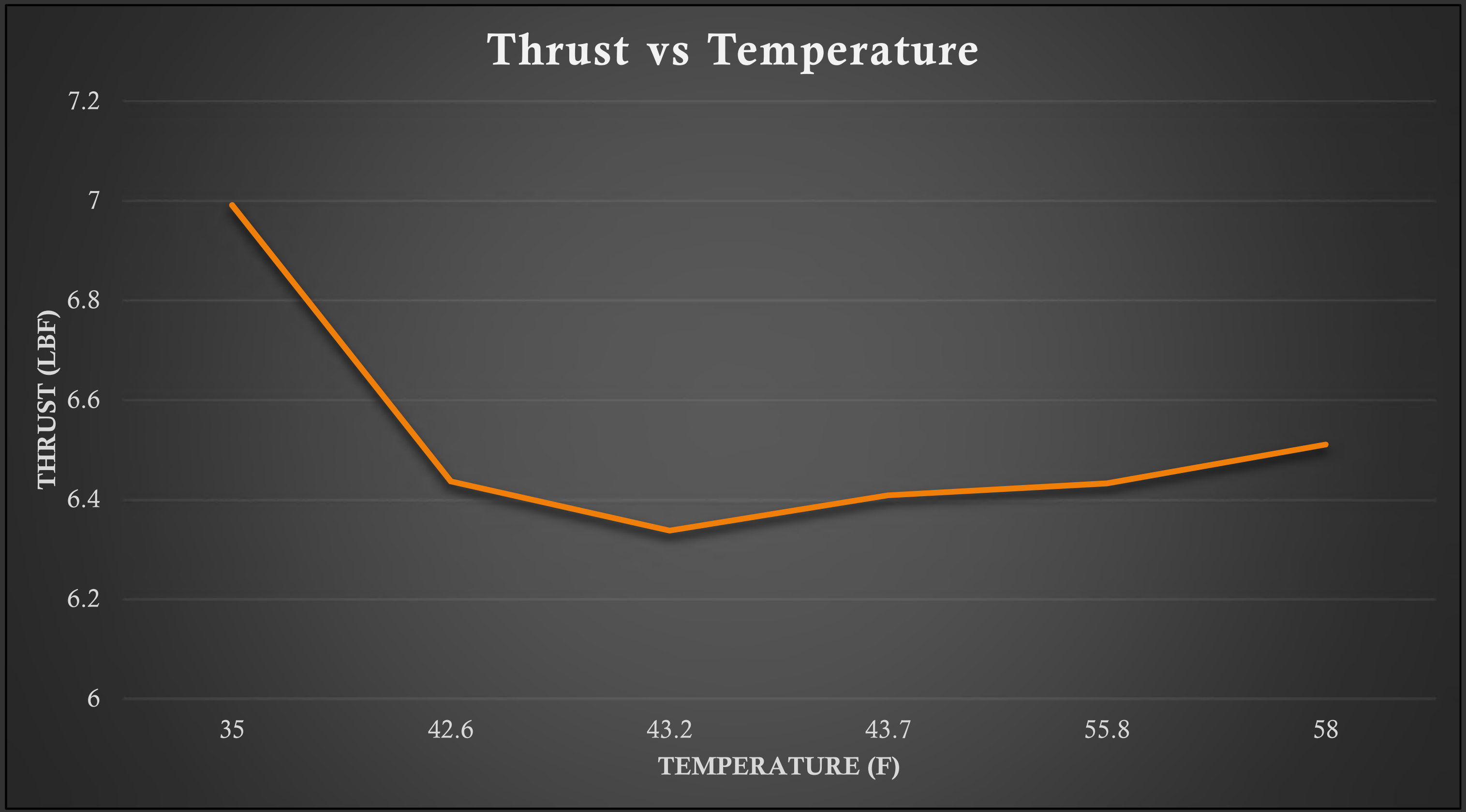
- **Purpose**
  - Characterize Flow Over Fuselage
  - Reduce Material Damage
    - Fuselage
    - Empennage



Custom Nozzle

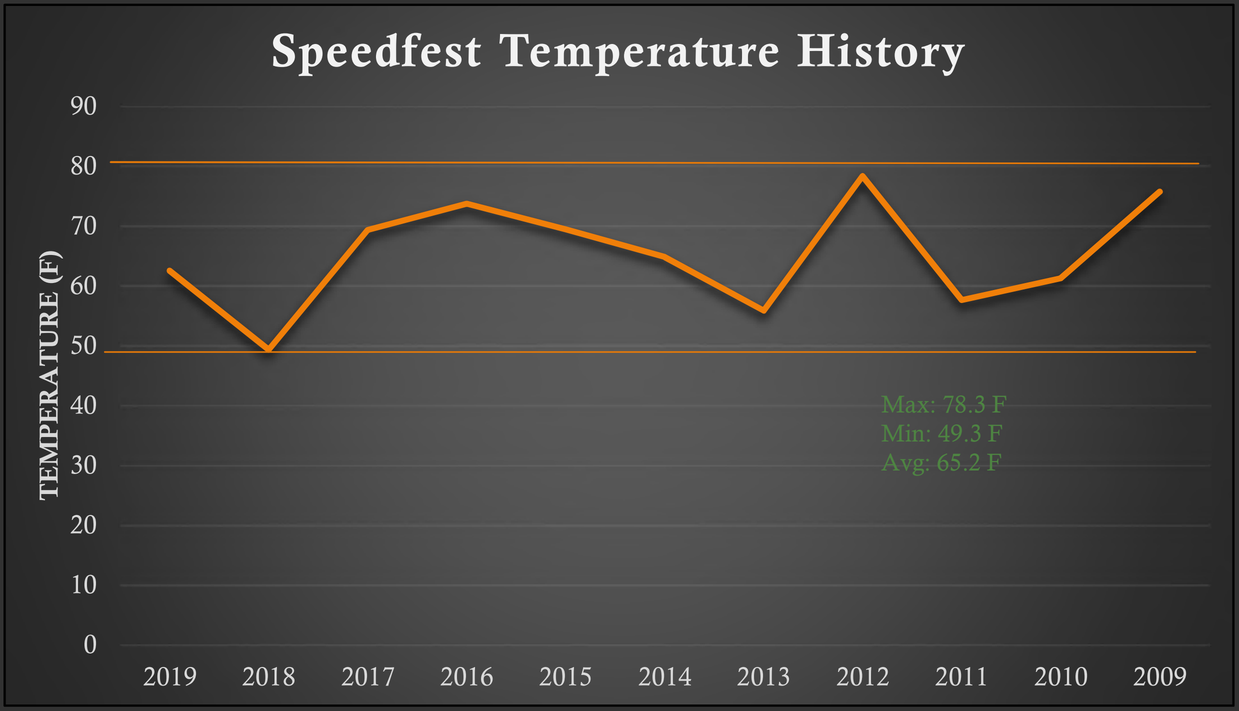
- **Nozzle Analysis**
  - Parametric Cycle Analysis (PCA) - Completed
  - Mass Flow Parameter (MFP) - Completed
  - CFD Analysis
    - Stock Nozzle
    - Custom Design Nozzle
- **Purpose**
  - Point Increase with 15% Thrust Increase
    - Glide
      - 5pt+ Increase

Thrust Results



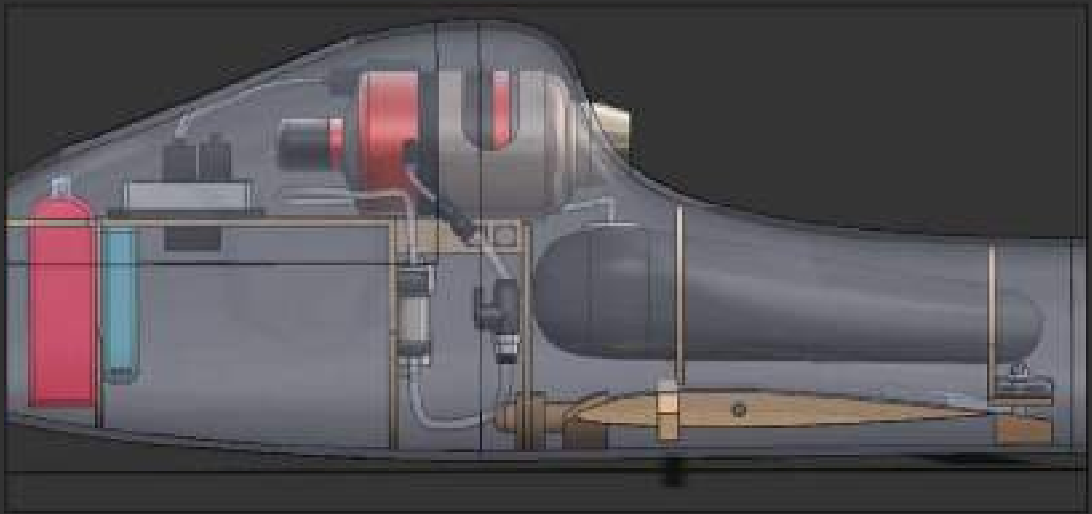
Weather Predictions

- **Speedfest Day Historically**
  - Temperature Range
    - 49.3F – 78.3F
- **Speedfest 2020**
  - Cool Day
    - Thrust: 6.8lbf
  - Warm Day
    - Thrust: 6.5lb



Propulsion Moving Forward

- Solidify Inlet
- Test Meshes over Inlets
- Slosh Tests
- Temperature Profile of Exhaust Flow
- Finish Nozzle Modifications
- Modify ECU Settings
  - Reduce Start Up Time
  - Change Stage(s) RPM Settings



Propulsion Related Questions?

Structures

Skyler Jacob and Andrew Cole

Structural Decisions and Concerns

- Design Implementation Team (DIT)
  - Material Selection
  - Avionics
  - Wing mounting and internals
  - Tail mounting and internals
  - Fuselage structural supports
- Prototype Accessory Testing Team (PATT)
  - Thermal Soaring
  - Inflatable Structure
  - Launch Dolly

DIT

Caleb Davis, Darius Douglas-Smith, Marwan Enani, and Taylor Matlock

Material Selection: Core

- Pre-cut Divinycell
  - Sheets – 32x48 (10.6 ft^2)
  - 0.07 lbs/ ft^2
  - $31.95/sheet or $3.02/ ft^2
  - 1/8" thick

- Balsa
  - Sheets – 12x24 (2 ft^2)
  - 0.03 lbs/ ft^2
  - $10.52/sheet or $5.26/ ft^2
  - 1/16" thick

Material Selection: Weave

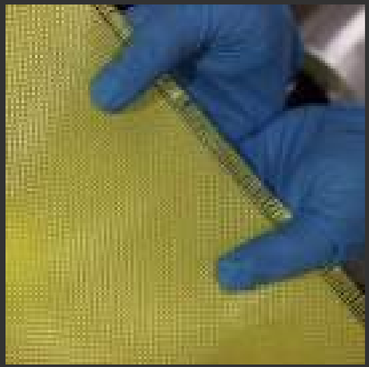
Costs Less and Weighs Less

- Fiberglass – 3 oz
  - 0.03 lbs/ ft^2
  - 0.01" thick
  - Equal weight epoxy

Costs More and Weighs More

- Carbon Fiber
  - Strong in tensile
  - Use
    - Key structure support

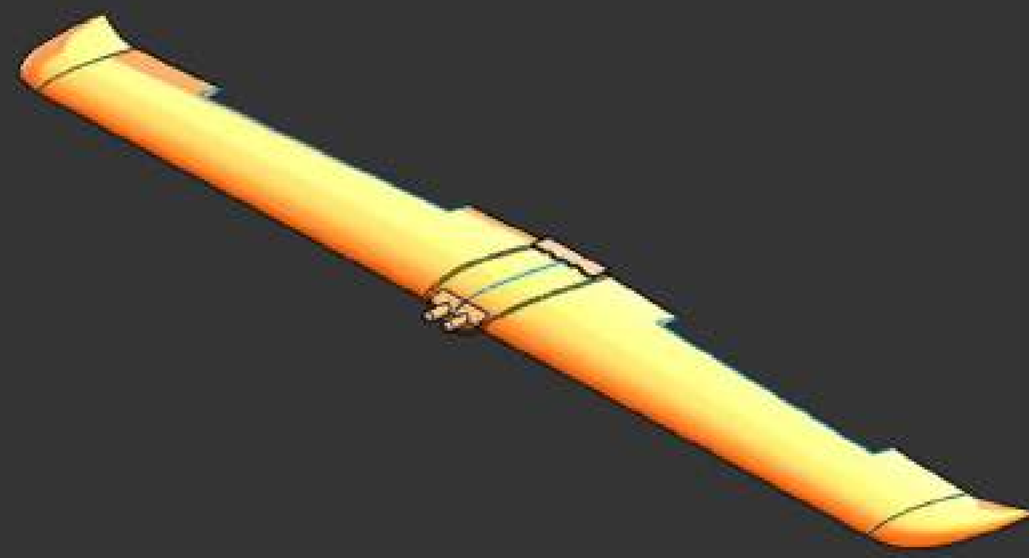
- Kevlar
  - Tear Resistant
  - Use
    - Hinges



Wing

Wing Skin

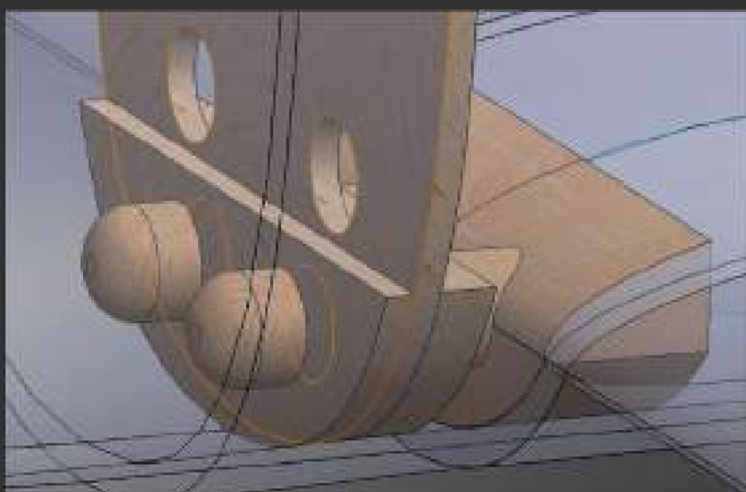
- Top/Bottom Mold
- Materials
  - Layup 1
    - 90-45-DIV-45-90
  - Layup 2+ (Tentative)
    - 45-DIV-45
- Estimated Weight: 1.4 lbs
- Dropping layer weight = Points



Wing Connection: ~8 Seconds

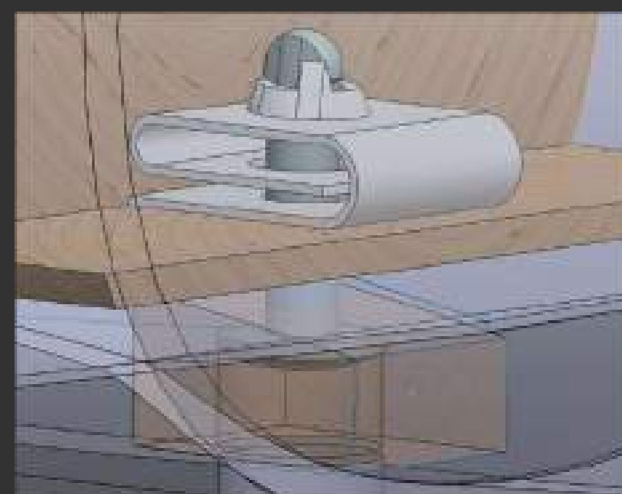
Forward

- Dowel rod connection
  - Tried and True

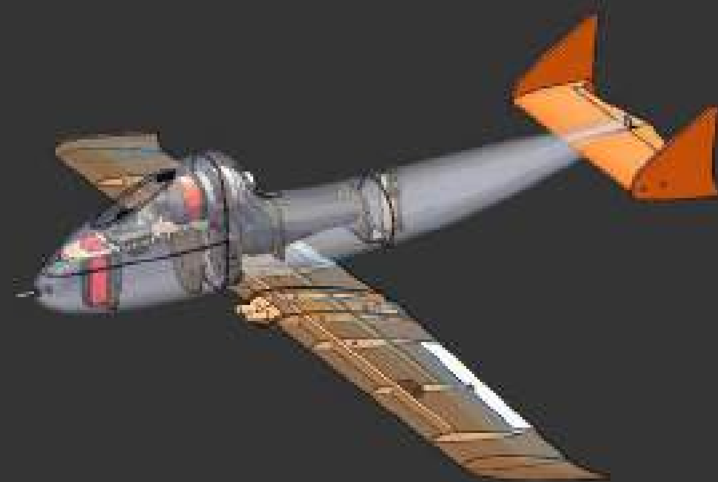


Aft

- Quarter Turn
  - Quick and Simple
- Length ~1 inch
  - Difficult to find
    - Sink



The Wing Connection (Video)

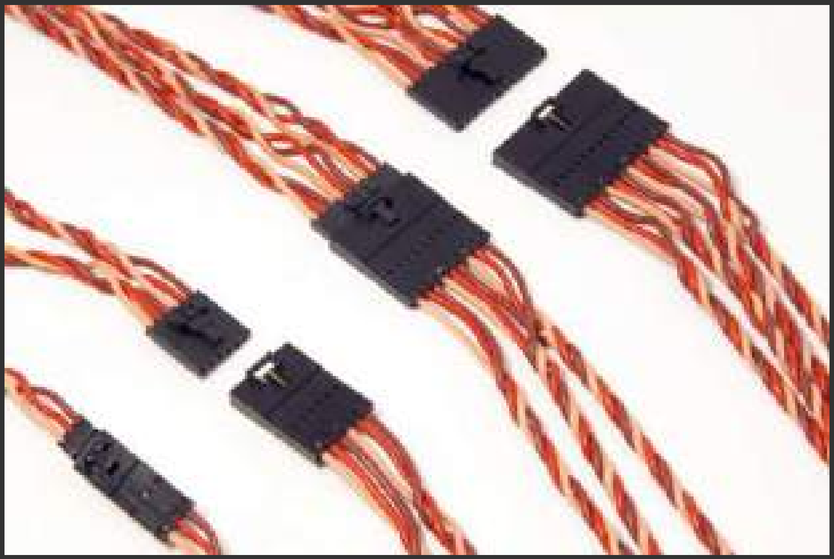


Servo Wing Connection: ~3 Seconds

Wire Harness

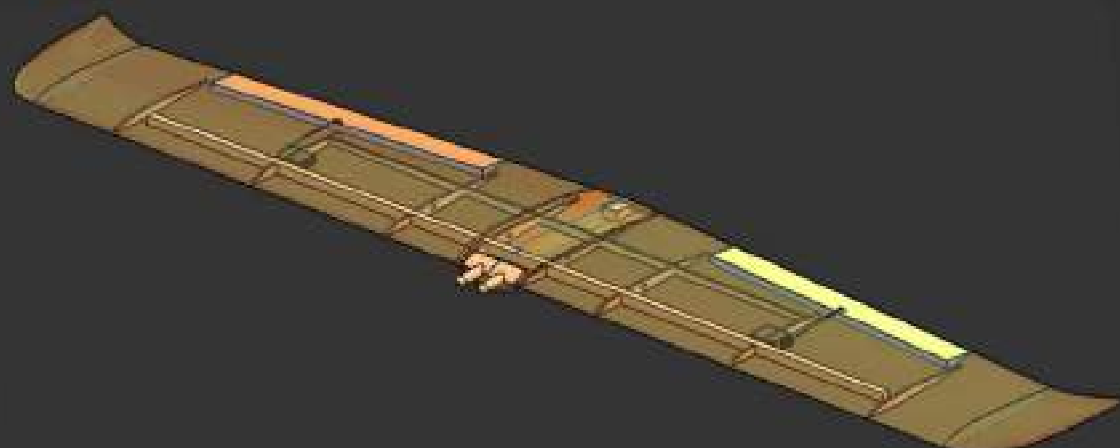
- $2.20/Connection
- Self manufacturable
- Quick and Simple

Placement in the box



Wing Spar and Ribs

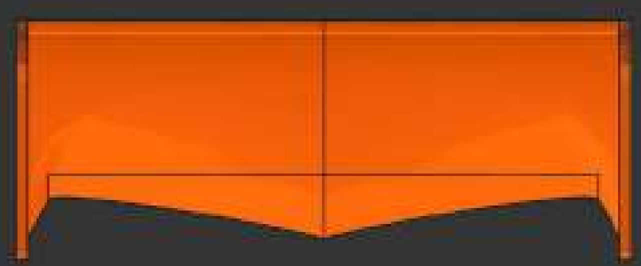
- Spar
  - 74% wingspan
  - Lay-up
    - Carbon Toed in
    - 2x 1/8th aeroply
    - 1x 45 fiberglass
- Ribs
  - 2 for fuselage support
  - 4 for ailerons support
  - 2 for servo support
  - 8x 1/8th aeroply

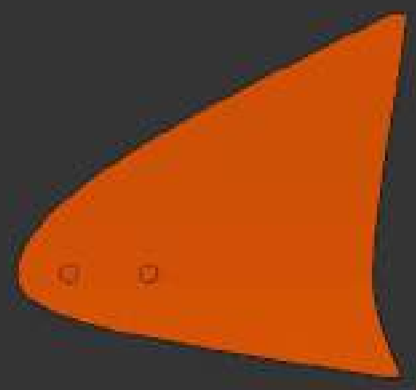


Tail

Tail Skins

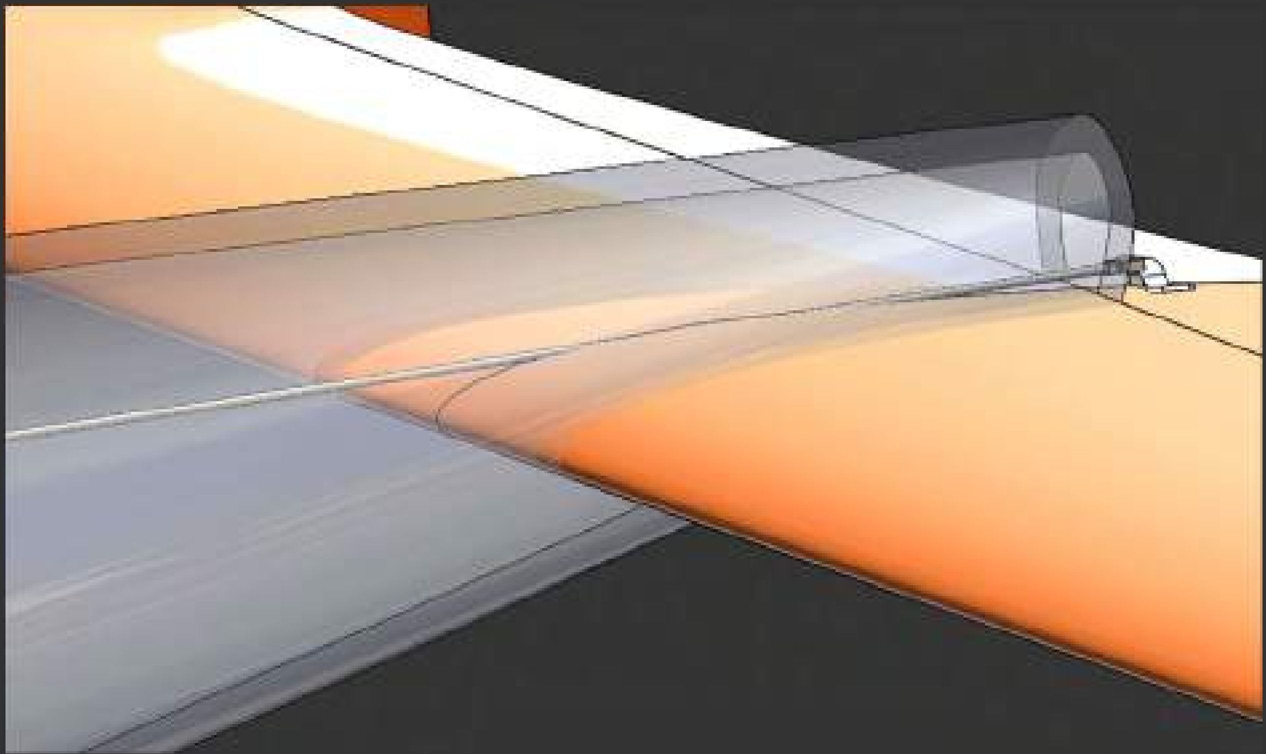
- Horizontal Stab
  - Top/Bottom Mold
  - 45-balsa-45
  - 0.15 lbs
- Vertical Stab
  - Flat Layups
  - 45-div-45
  - 0.1 lbs





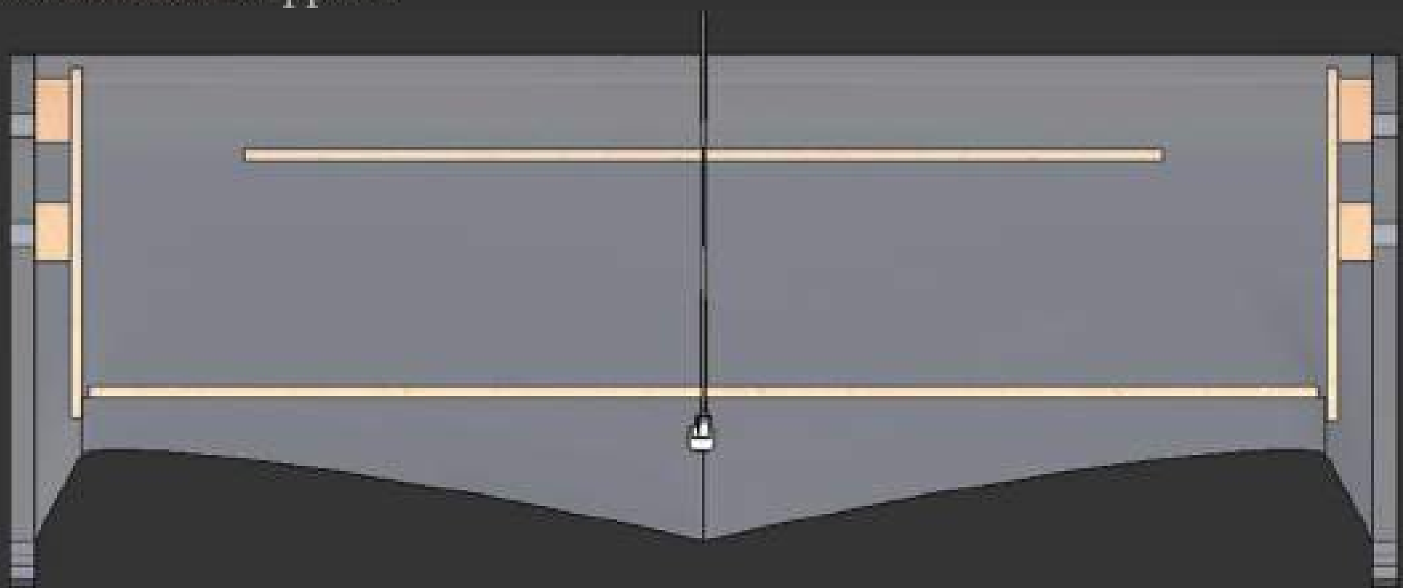
Horizontal Stabilizer Connection

- Cut in Fuselage
- Epoxy into place
- Hole for servo rod



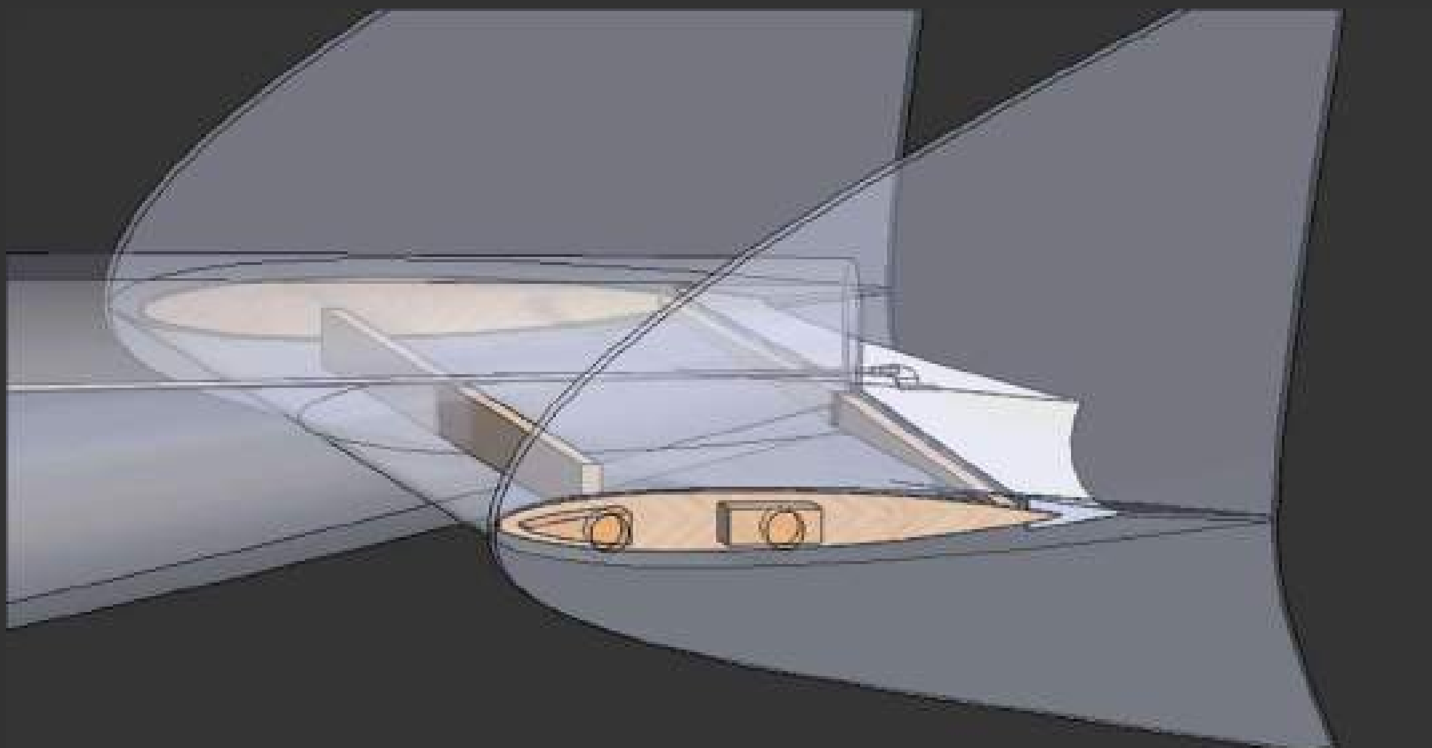
Horizontal Stabilizer Internals

- Spar – ¾ span
- Elevator Ribs and Support
- Vertical Stabilizer Supports



Vertical Stabilizer Connection

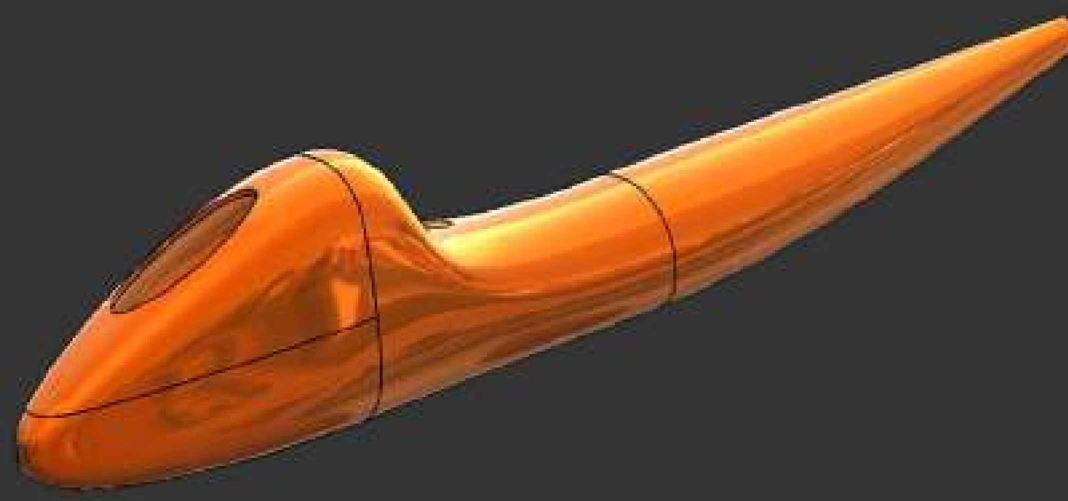
- Epoxy and screw into place



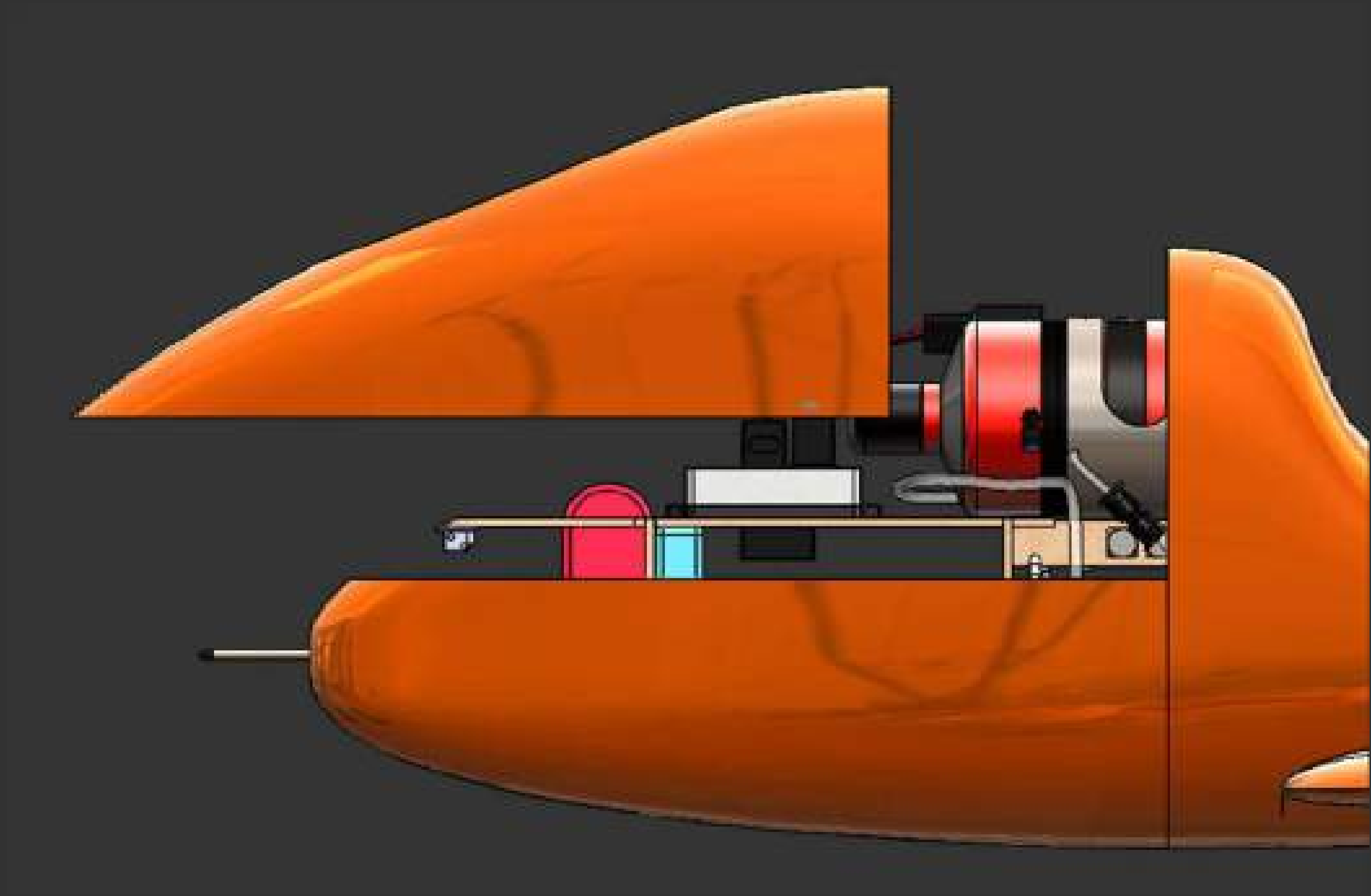
Fuselage

Fuselage Skin

- Left/Right Mold
- Materials
  - Layup 1
    - 90-45-Div-45-90
  - Layup 2+ (Tentative)
    - 45-Div-45
- Estimated Weight: 0.62 lbs



Fuselage Hatch

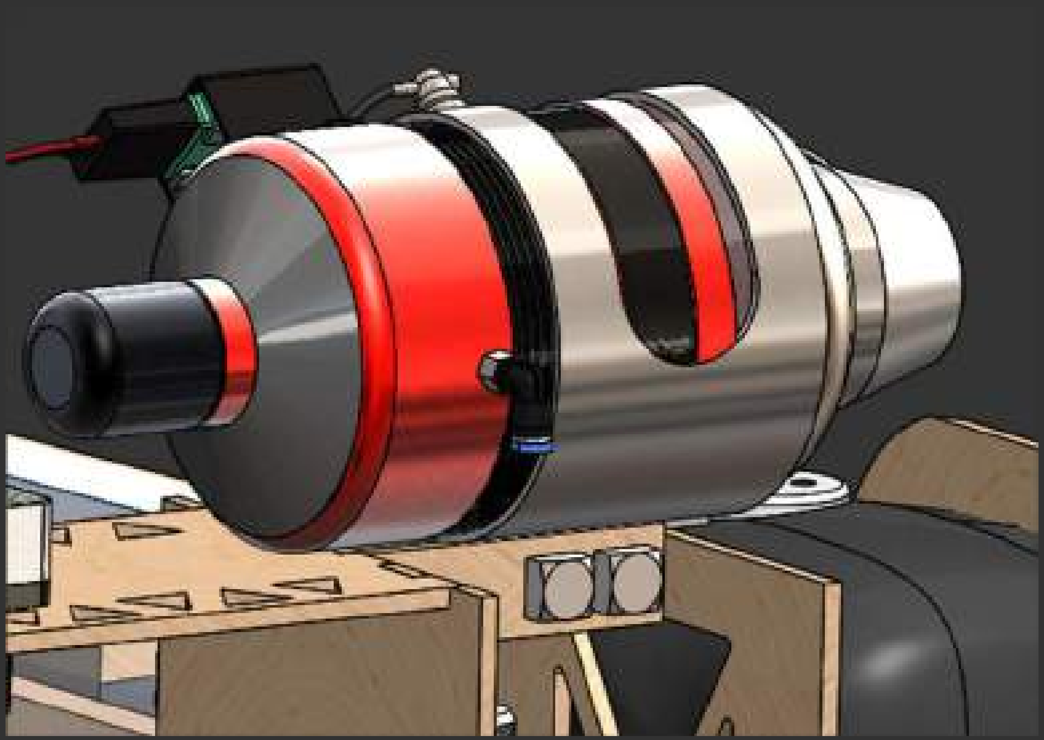


Engine Bulkheads

Forward

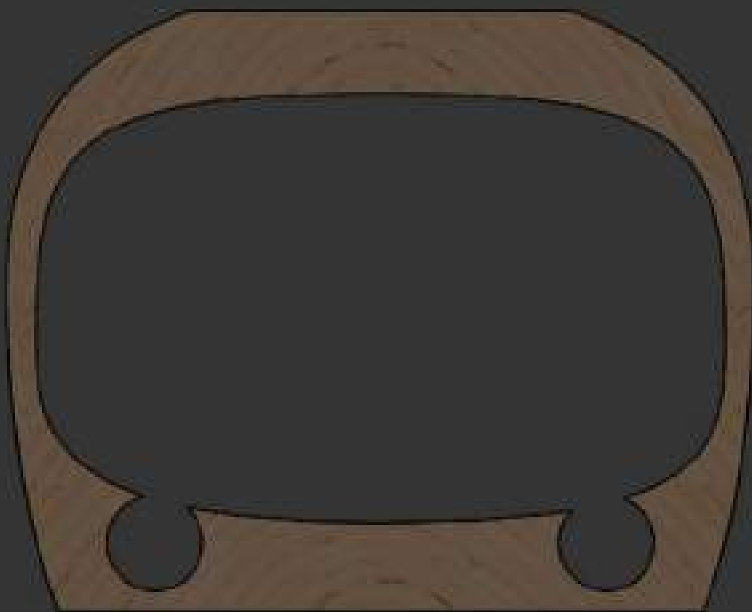
Aft

Engine Support



Wing Bulkheads

¼ Chord

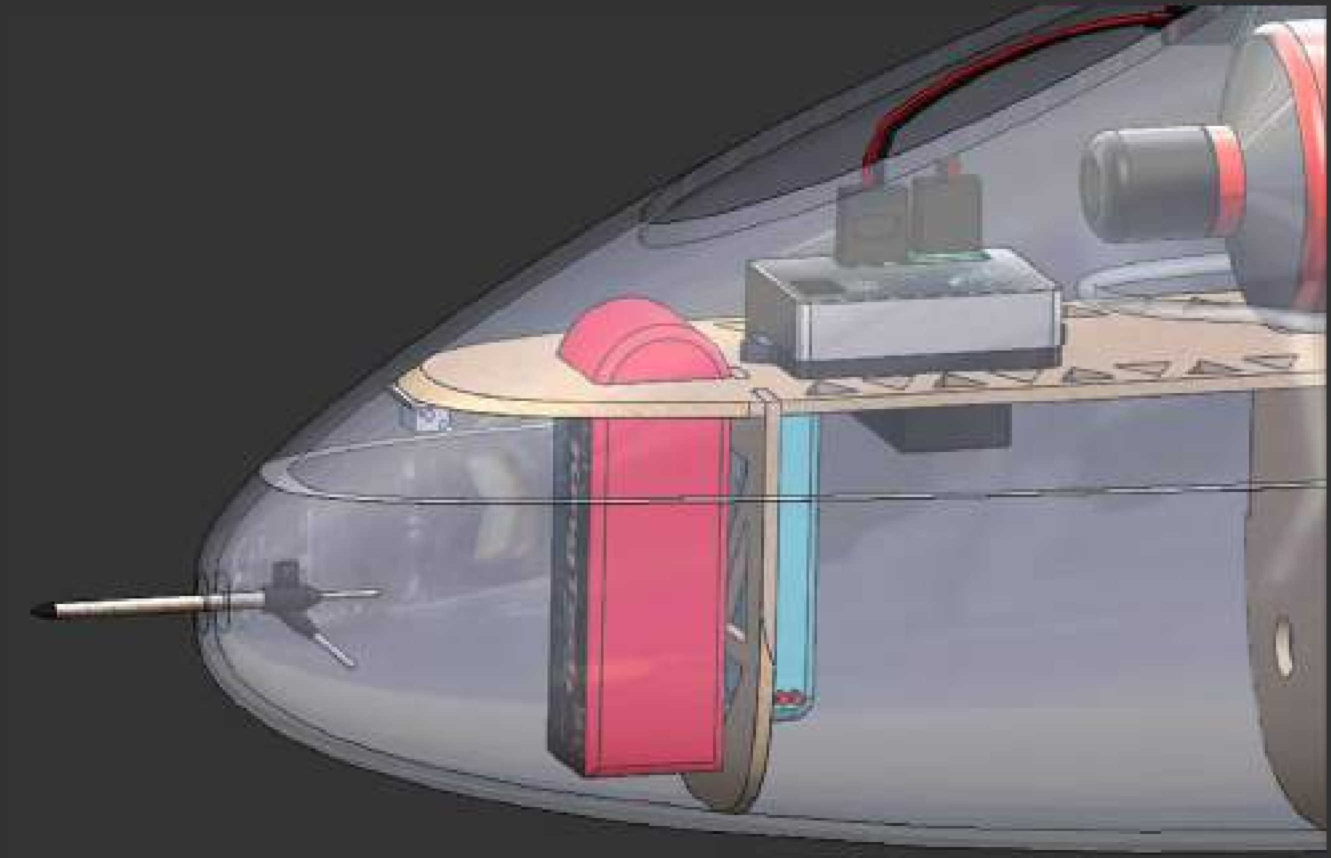


Trailing Edge

Avionics

Avionics List

- Batteries
- Servos
- ECU
- JETI receiver
- Airspeed Indicator
- Variometer



Batteries

Engine

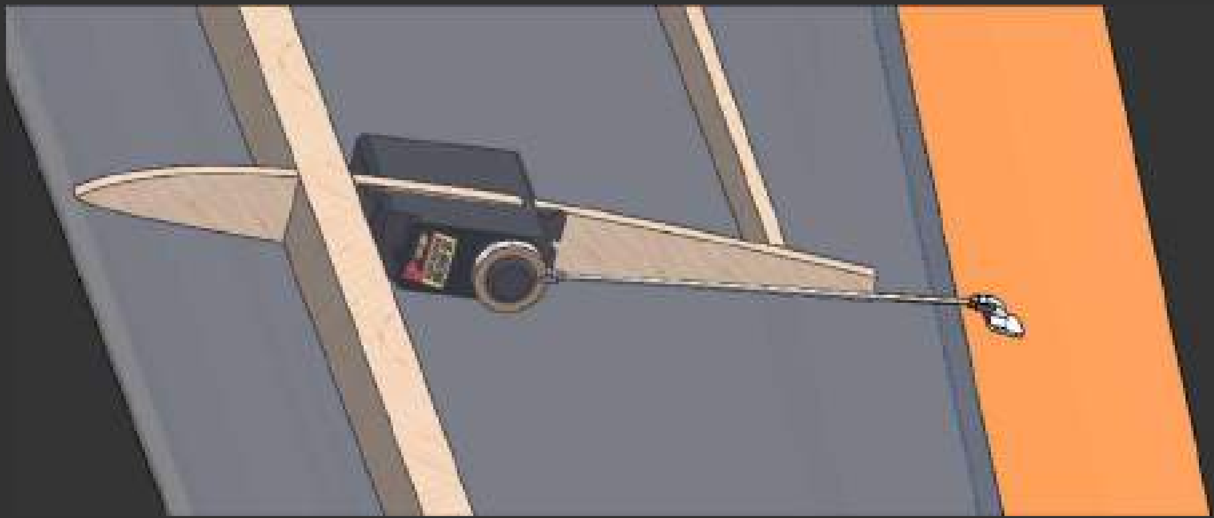
- Runs the ECU
- 3S 9.9V 2100 mAh
- 0.353 lbs

Avionics

- Runs JETI, Servos, and Airspeed
- At least 2S-6.6V 1100 mAh
- 0.180 lbs

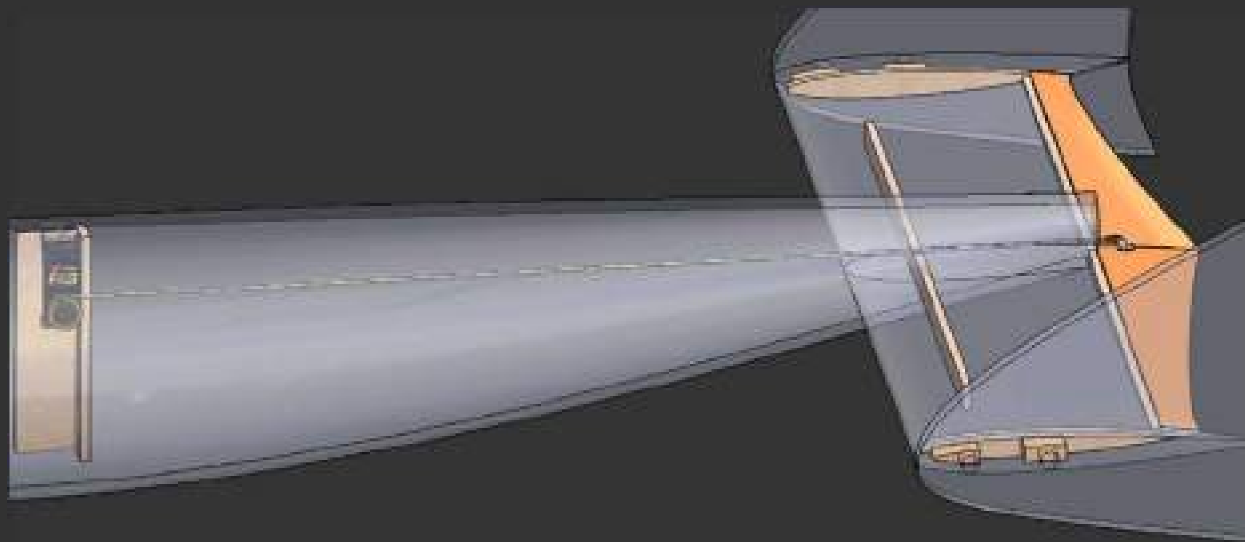
Aileron Servos

- Internal Wing Mount
- HS 5087 MH or comparable
  - Up to 7.4 Volts
  - 60 oz*in
  - Sized from Aerodynamics
- Incorporating (CAD Image)
- Thinner core
- Magnetic Hatch



Elevator Servo

- Internal Fuselage Mount
- HS 5087 MH or comparable
  - Up to 7.4 Volts
  - 60 oz*in
  - Sized from Aerodynamics
- Incorporating (CAD Image)
- Magnetic Hatch
- Straw Tube



Weights and CG

- Large Table on slide 111
- Estimated structural weight is 4.4 lbs
- Estimated total weight is 7.0 lbs
- Using final item locations the cg is at 14.6 inches from the nose

Aircraft Structural Order List &Cost

- Shell cost
  - ~$500
- Material cost per flightworthy aircraft
  - ~$2000

Material	Amount	Unit	Unit Cost	Cost
Fiberglass	3.8	yd^2	7.65	29
Kevlar	0.025	yd^2	43	0.95
Carbon Fiber	0.085	yd^2	45	3.3
1/16" Balsa	0.89	ft^2	5.85	5.5
Divinycell	8.9	ft^2	31.95	27.3
Aeroply	1.8	ft^2	0.8	1.5
Dowel Rods	6	in	1.21	0.15
Magnets	44		0.12	5.28
Tool Glass	0.15	yd^2	16.85	2.53
Wood Blocks	3	in^3	1	1
Epoxy	0.8	lbs	51.85	7.5
Hardener	0.3	lbs	20	5.1
Servos	3		40	120
Servo Materials	3		5	15
A. Battery	1		72	72
E. Battery	1		12	12
Airspeed Ind.	1		50	50
Variometer	1		50	50
JETI	1		80	80
Engine	1		1500	1500
Quarter Turn	1		4	4
QT Receptacle	1		3	3
Engine Screws	2		0.5	1
			Total Cost	1996.11
		Cost(No Engine)		496.11

Build Related Questions?

PATT

Andrew Cole, Cameron Bright, Hunter Billen, and JW Wallace

Overview

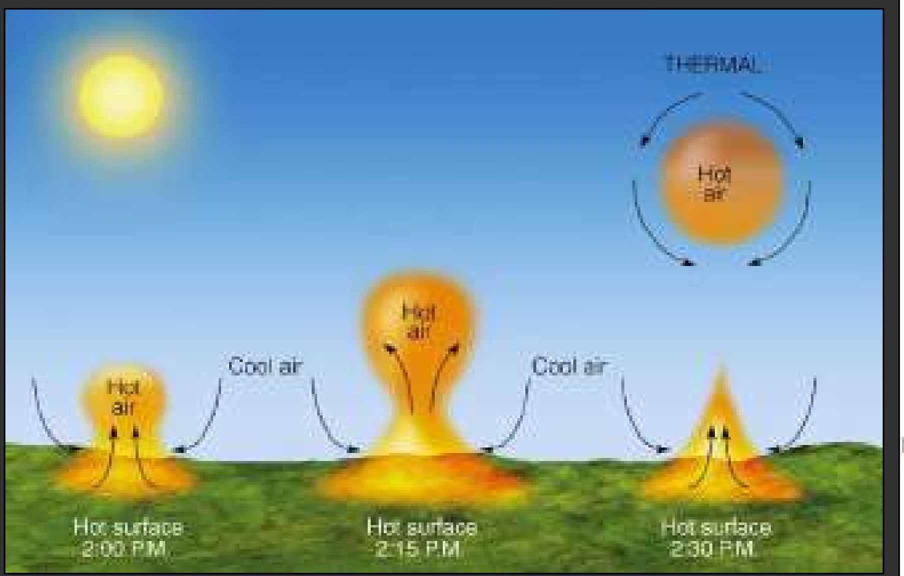
Concepts Moving Forward

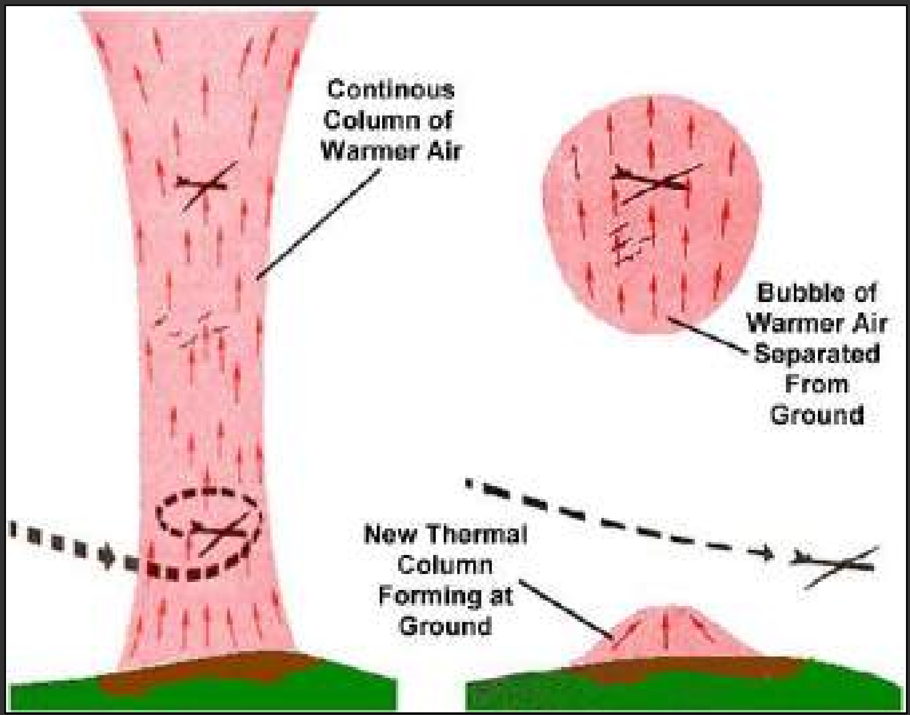
- Thermal Soaring
- Inflatable Structure
- Launch Dolly

Concepts Moving Past

- Augmented Flight Modes
- Squirrel Suit Gliding
- Deployable Wing Extensions

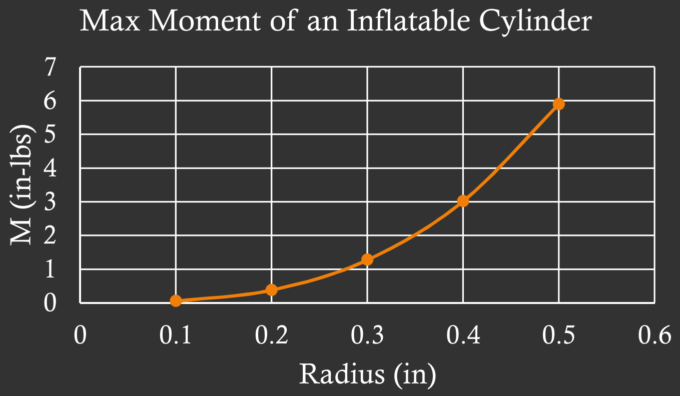
Thermal Soaring

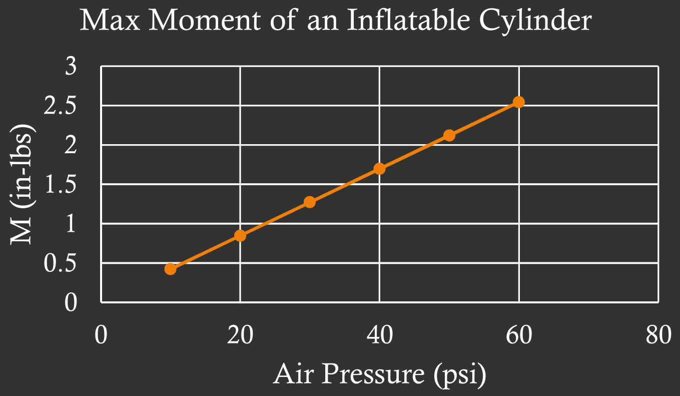




Inflatable Structure

$$M_{Brown} = \frac{\pi p r^3}{2}$$





Launch Dolly

RATO Cart

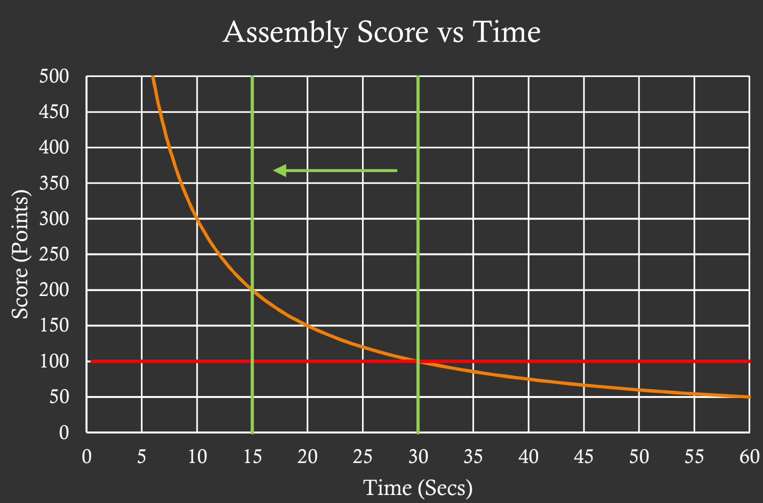
- Rocket mounted on launch dolly instead of directly onboard plane

Electric Cart

- Fully electric cart designed for high acceleration

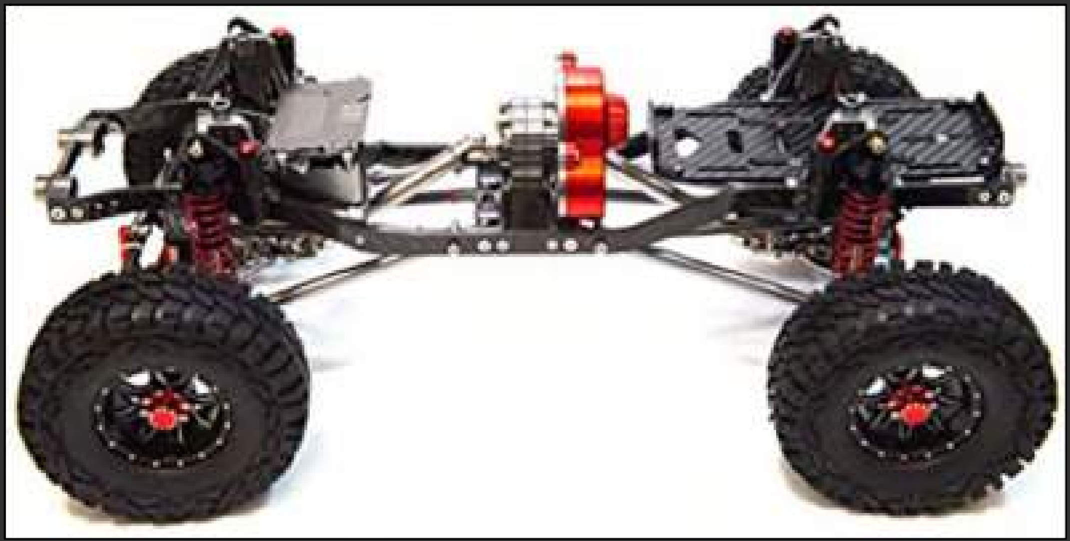
RATO

- Enables launch during and before engine spool up
- Low design impact
- RATO is cheap
- Promising initial tests



Electric Dragster

- Similar performance as RATO
- Cheaper long term than RATO
- Safer storage and handling
- Higher impact on cost bid

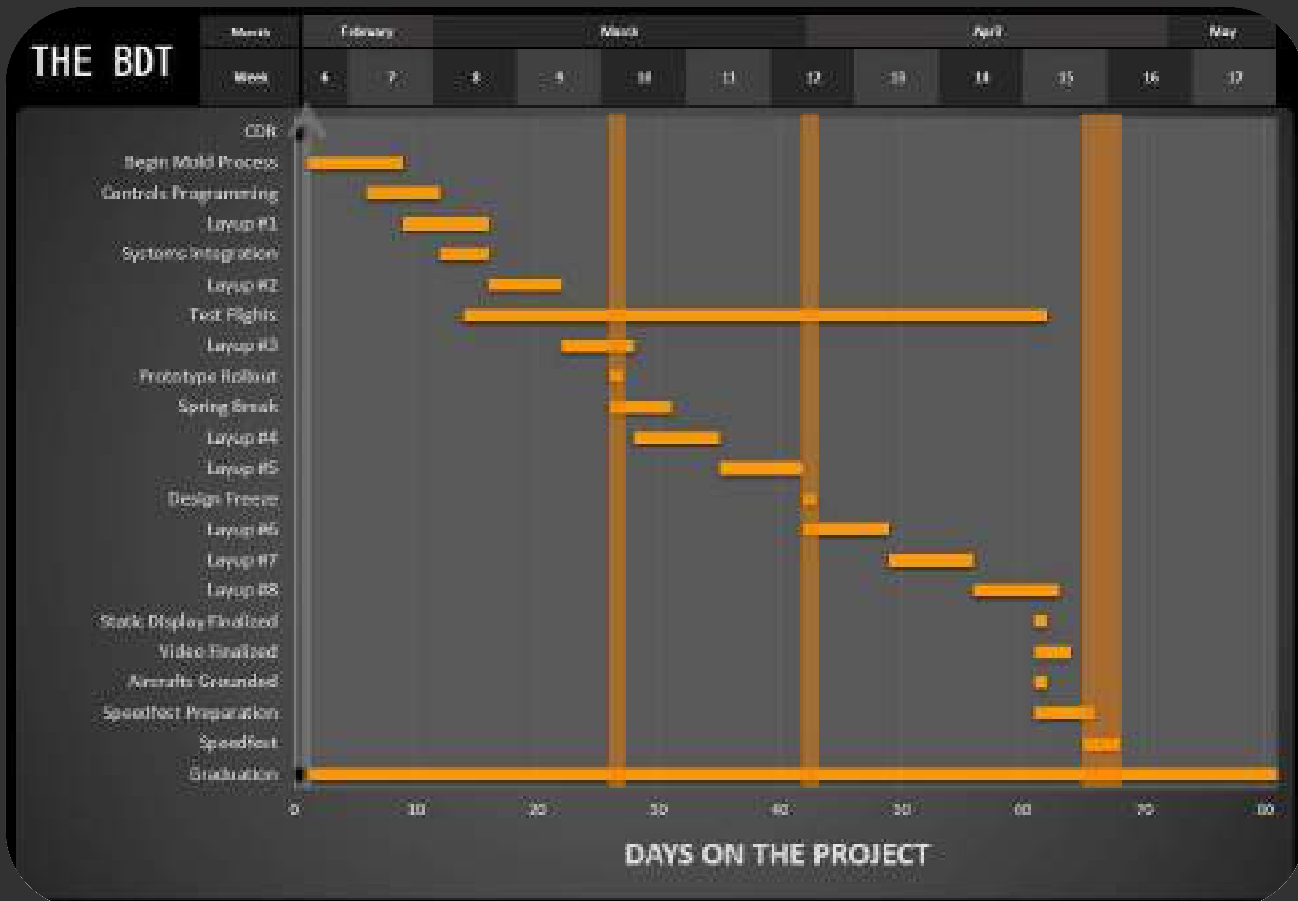


Test and Evaluation Plan

- Accessory Evaluations
- Structures Evaluations
- Propulsion Engine Tests
- Aero Flight Tests

PATT Related Questions?

Manufacturing Schedule



Legend

- 8 days for mold process
- 7 days per layup
- First orange box is prototype rollout
- Second orange box is design freeze
- Third orange box is Speedfest

Budget

- **Material Costs**: Everything except avionics
- **Launcher Costs**: Potential powered speed sled divided per 4 planes
- **Machining Hours**: CNC mold and laser cut divided per plane
- **Labor Hours**: Mold, layups, and builds

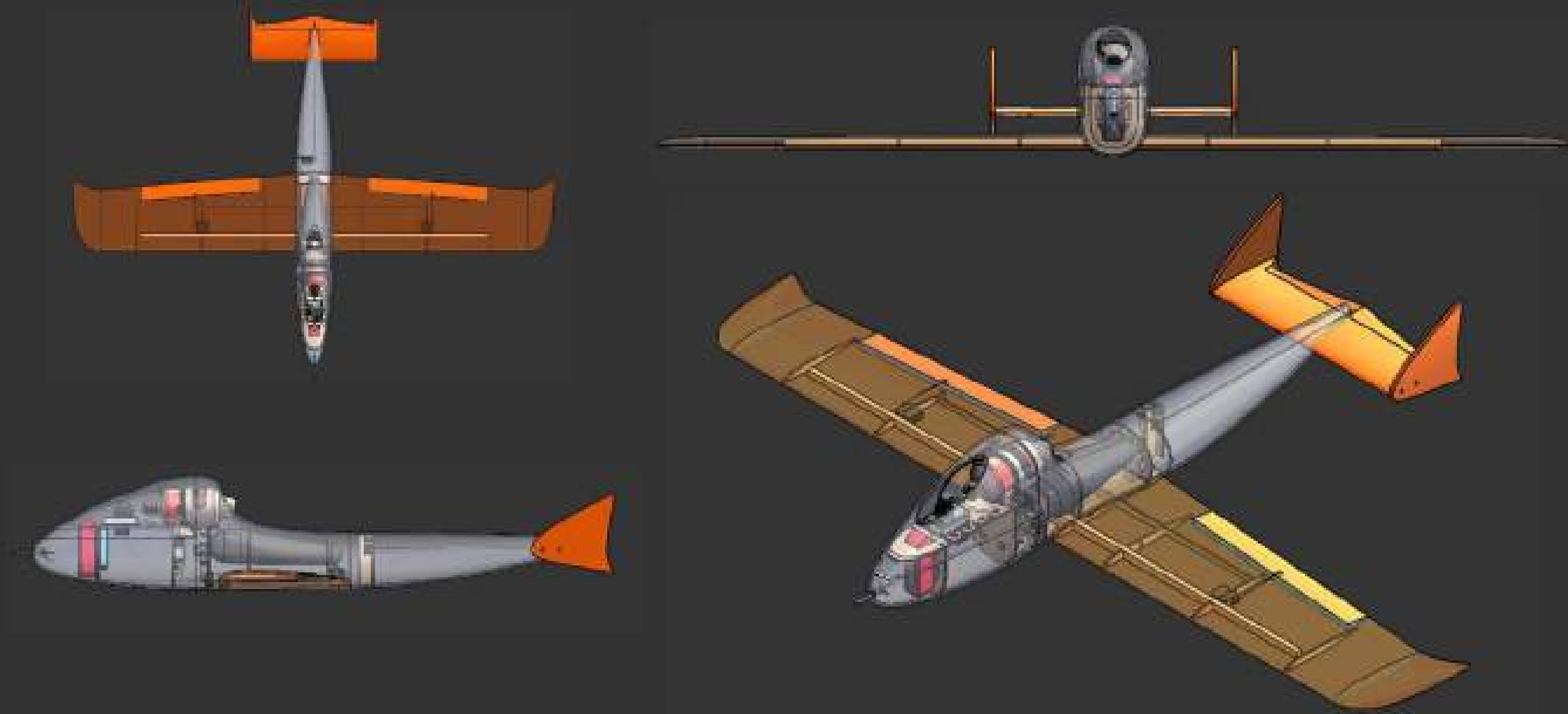
Total Expected Cost		
Avionics	$ -	$ -
Propulsion	$ 1,650.00	$ 1,650.00
Structures	$ 500.00	$ 500.00
Launcher	$ 100.00	$ 100.00
Machining	$ 50.00	$ 50.00
Labor	$ 700.00	$ 2,700.00
Total	$ 3,000.00	$ 5,000.00
Labor Hours	18	68

Performance

- Assembly Mission: 30 seconds
- Efficiency Mission: 180 seconds
  - Takeoff: 60 seconds
  - Flags: 210 seconds
  - Glide: 180 seconds
  - Recovery: 60 seconds
  - Total: 8.5 out of 10 minutes
- Total Weight: 7.00 pounds
- Estimated Speed: 175+ knots
- Static Margin: 14.9%
- Expected Points: 200 pts

Objective Scoring:		KPP			
Objective #	Objective	Threshold	Objective	Goal	
5.1	Assembly/Launch	10	10*(300sec/Ta)	**100**	30 sec A/L
5.2	Speed and Efficiency	20	20*(Tg/60sec)	**60**	3 min Glide
5.3	Best of Show	-	3	**3**	
5.4	Unit Cost Bid	2	7	**7**	
Design		-	**20**	**20**	
Marketing		-	**10**	**10**	
			TOTAL	**200**	

Final Configuration



Questions?