CRITICAL DESIGN REVIEW

SPEEDFEST ORANGE TEAM
OKLAHOMA STATE UNIVERSITY
WEDNESDAY, FEBRUARY 24, 2021

TEAM ROSTER

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Propulsion Lead
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- Nathan Rodenberg
- Ryan Tom
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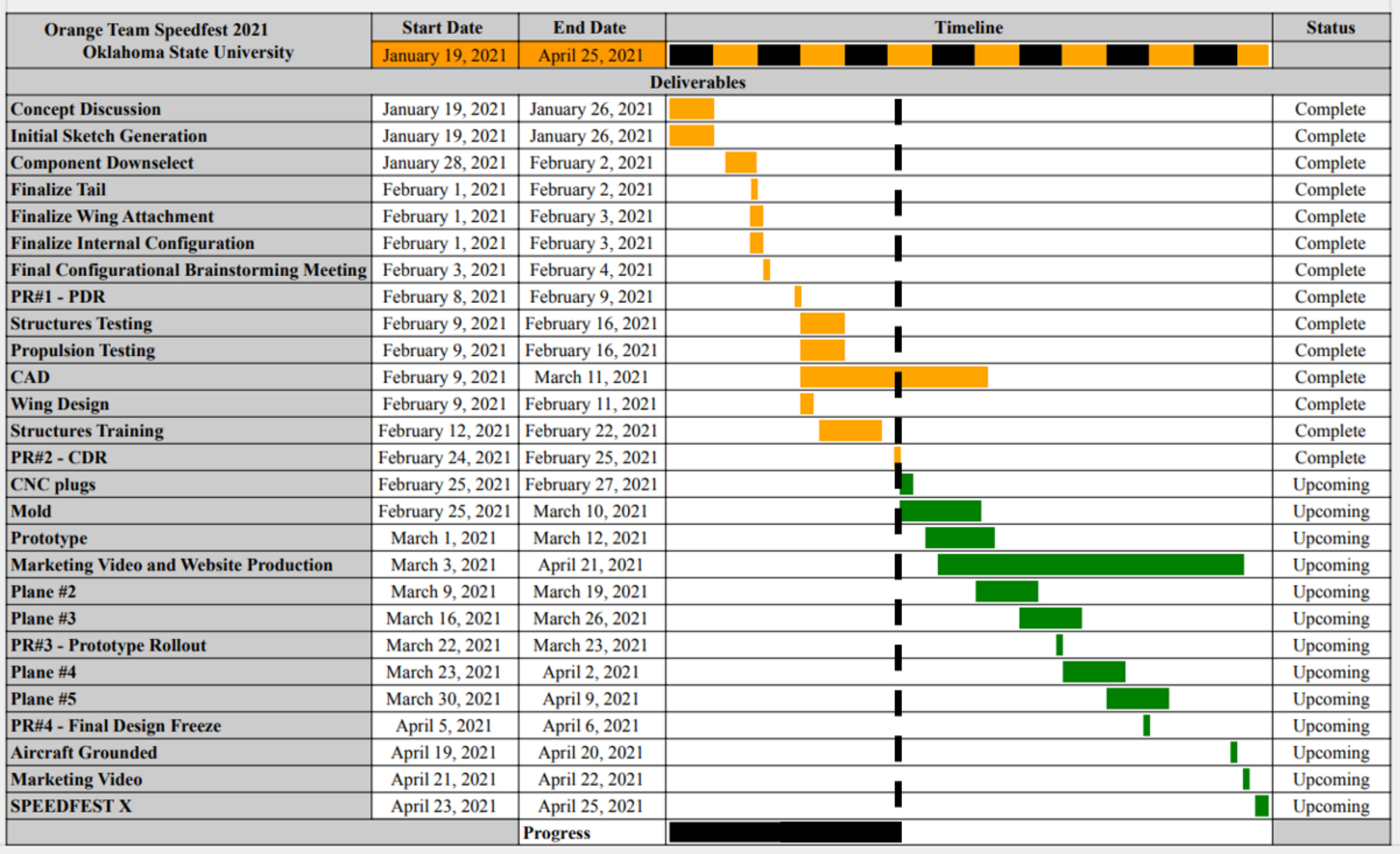
- Rhett Scroggs
- Sean Steinhilber
- Will Kresl
- Zach Hampton

CONTEST MISSION OBJECTIVE

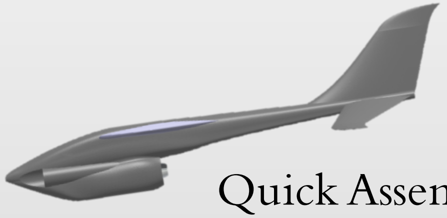
Speedfest 2021 has asked the contractors to demonstrate their ability to quickly design, develop and test, a new high-speed jet hotliner to compete in the 30N class. The aircraft must not only demonstrate specific speed and efficiency characteristics, but it also must be easy and fast to assemble, reliable and desirable for purchase.

MASTER SCHEDULE



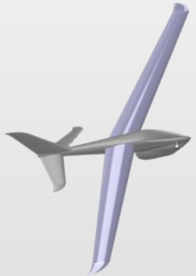
Orange Team Speedfest 2021 Oklahoma State University	Start Date	End Date	Timeline	Status
	January 19, 2021	April 25, 2021		
		Deliverables		
Concept Discussion	January 19, 2021	January 26, 2021	🟧	Complete
Initial Sketch Generation	January 19, 2021	January 26, 2021	🟧	Complete
Component Downselect	January 28, 2021	February 2, 2021	🟧	Complete
Finalize Tail	February 1, 2021	February 2, 2021	🟧	Complete
Finalize Wing Attachment	February 1, 2021	February 3, 2021	🟧	Complete
Finalize Internal Configuration	February 1, 2021	February 3, 2021	🟧	Complete
Final Configurational Brainstorming Meeting	February 3, 2021	February 4, 2021	🟧	Complete
PR#1 - PDR	February 8, 2021	February 9, 2021	🟧	Complete
Structures Testing	February 9, 2021	February 16, 2021	🟧	Complete
Propulsion Testing	February 9, 2021	February 16, 2021	🟧	Complete
CAD	February 9, 2021	March 11, 2021	🟧	Complete
Wing Design	February 9, 2021	February 11, 2021	🟧	Complete
Structures Training	February 12, 2021	February 22, 2021	🟧	Complete
PR#2 - CDR	February 24, 2021	February 25, 2021	🟧	Complete
CNC plugs	February 25, 2021	February 27, 2021	🟩	Upcoming
Mold	February 25, 2021	March 10, 2021	🟩	Upcoming
Prototype	March 1, 2021	March 12, 2021	🟩	Upcoming
Marketing Video and Website Production	March 3, 2021	April 21, 2021	🟩	Upcoming
Plane #2	March 9, 2021	March 19, 2021	🟩	Upcoming
Plane #3	March 16, 2021	March 26, 2021	🟩	Upcoming
PR#3 - Prototype Rollout	March 22, 2021	March 23, 2021	🟩	Upcoming
Plane #4	March 23, 2021	April 2, 2021	🟩	Upcoming
Plane #5	March 30, 2021	April 9, 2021	🟩	Upcoming
PR#4 - Final Design Freeze	April 5, 2021	April 6, 2021	🟩	Upcoming
Aircraft Grounded	April 19, 2021	April 20, 2021	🟩	Upcoming
Marketing Video	April 21, 2021	April 22, 2021	🟩	Upcoming
SPEEDFEST X	April 23, 2021	April 25, 2021	🟩	Upcoming
		Progress		

CONOPS



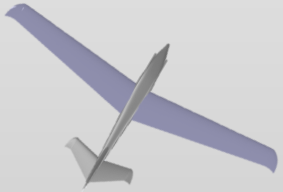
Quick Assembly

Less than 2 minutes



Fast Performance

3-minute figure-8 pylon race



Aerobatics

4-minute maneuvers demonstration

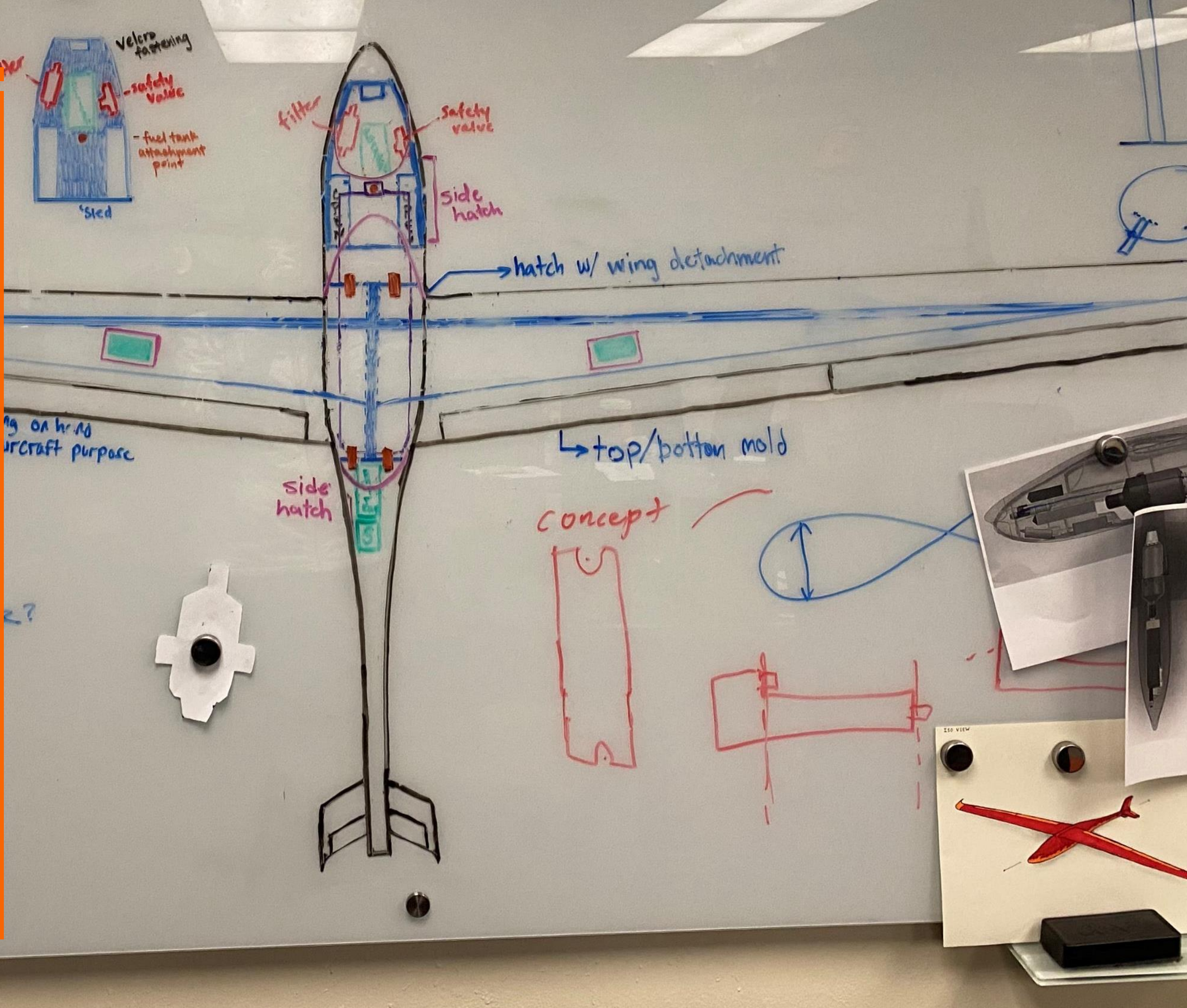
Objective #	Objective	Threshold	Objective
5.1	Assembly / Simplicity / Reliability		10*(1-TA/TTHA)
5.2	Performance		# of Flags
5.3	Aerobatics		4 minute flight
5.4	Hotliner Marketing		
5.5	Unit Cost Bid	$5,000/plane	$3,000/plane

Subteam	Part Name	Price/Pkg	Qty Needed	Price for order
Avionics	Servos - D145SW (1.659"x1.457"x.4")	$ 59.99	5	$ 299.95
Avionics	Servos - HS-7245MH (1.734"x1.612"x.655")	$ 69.99	2	$ 139.98
Avionics	Jeti Duplex EX R12 REX Assist EPC 2.4GHz Receiver w/Telemetry, Stabilization, Variometer, G-Force	$ 195.00	1	$ 195.00
Avionics	Jeti Receiver Battery Pack 1300mAh 6.6V LiFe	$ 15.00	1	$ 15.00
Avionics	Intellect VOLT 9.9v LiFe 20C 1400 mAh Mini Type AEG Airsoft Battery	$ 27.95	1	$ 27.95
Avionics	Jeti Telemetry Sensor Airspeed MSpeed 450 EX	$ 95.00	1	$ 95.00
Avionics	Jeti Telemetry Sensor Airspeed MSpeed Replacement Pitot Tube	$ 23.00	1	$ 23.00
Propulsion	K-30G3 and Assembly	$ 1,500.00	1	$ 1,500.00
Structures	Neodymium Magnet Magnetized Through Thickness, 1/16" Thick, 1/4" OD	$ 0.48	12	$ 5.76
Structures	1/16 x 4 x 48 Aero Light Balsa	$ 13.09	5.33	$ 69.81
Structures	Divinycell DIVINYMAT 1/8"	$ 31.95	0.30	$ 9.52
Structures	1/8 x 12 x 48 birch ply 3ply Aeroply	$ 13.15	0.04	$ 0.55
Structures	1/2 x 12 x 24 birch ply 3ply Aeroply	$ 12.82	0.04	$ 0.53
Structures	Carbon Fiber Tape	$ 109.95	0.36	$ 39.58
Structures	Kevlar	$ 52.95	0.05	$ 2.65
Structures	3.0 oz. Fiberglass Cloth, 50" Wide, Style 2116, Plain Weave, Rolled on tube	$ 4.73	3.29	$ 15.55
Structures	Labor Hours	$ 40.00	20	$ 800.00
Propulsion	PETG 3D Printer Filament (1kg)	$ 32.99	0.08925	$ 2.94
			Total Cost	**$ 3,242.78**

COST BID ESTIMATE

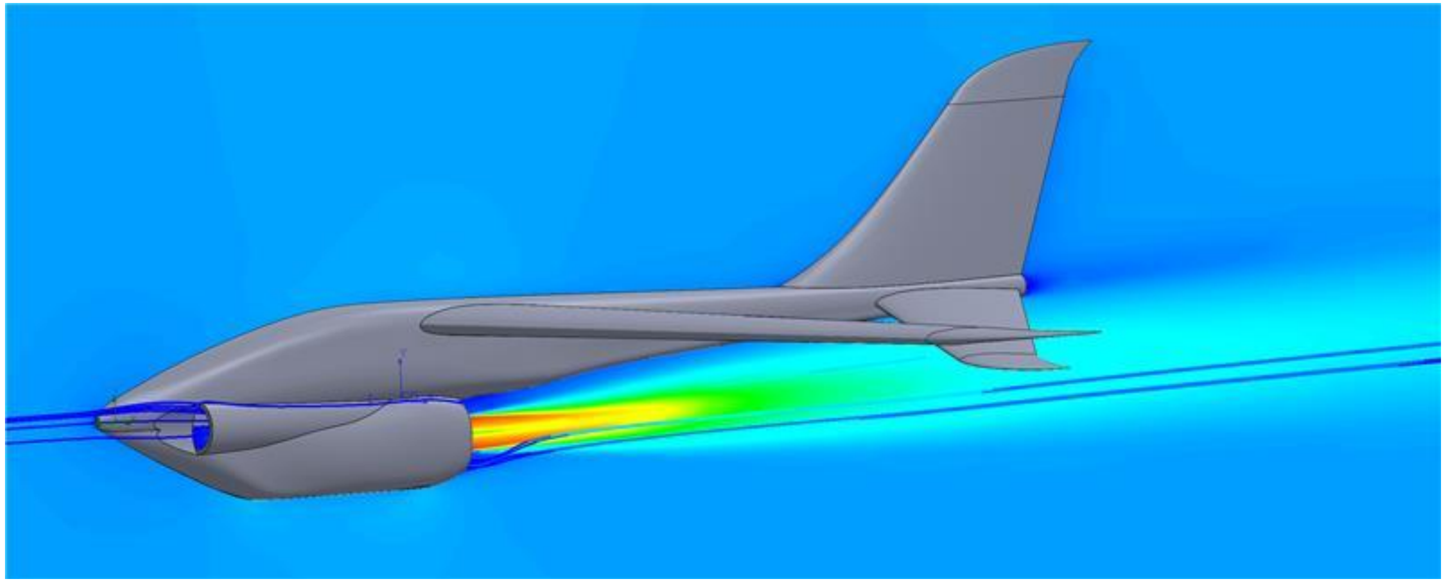
PDR RECAP

- Single Wing Mold
- Low Mounted Internal Engine
- Inverted-Y Tail
- Custom 3D Printed Fuel Tank



MARKETING STRATEGY

- Product
  - Jet propelled hotliner
- People
  - Ensure the product is desirable to the consumers
- Price
  - Keep it low, but with enhancements
- Presentation
  - Eye-catching design, cool name, and transportable size
- Promotion
  - Video, visually appealing and sell it with the soundtrack
- Place
  - Website which details everything a consumer needs to know on the product



AERODYNAMICS

TASKS ACCOMPLISHED SINCE PDR

- Airfoil selection process
- Wing sizing
- Fuselage sizing analysis
- Tail sizing and configuration justification
- Control surface selection
- CFD simulations
- CG and moment verification

AIRFOIL ANALYSIS/SELECTION

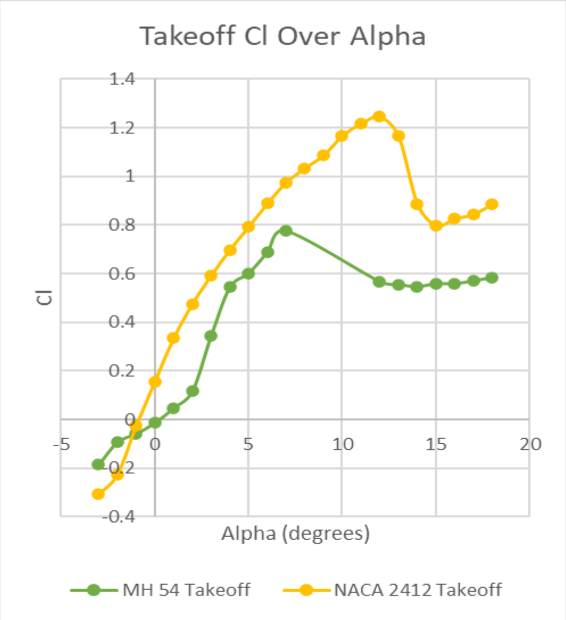
Design Objectives

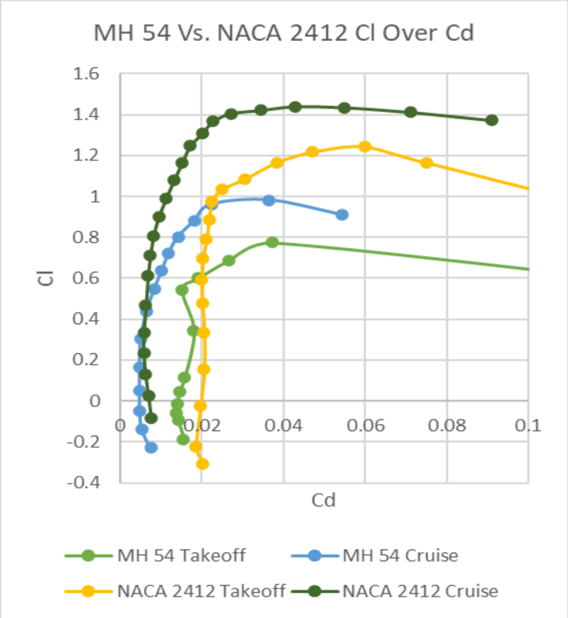
- Low Drag
- Accommodates Structural Components
- Low Cruise AoA
- High Stall AoA for Takeoff

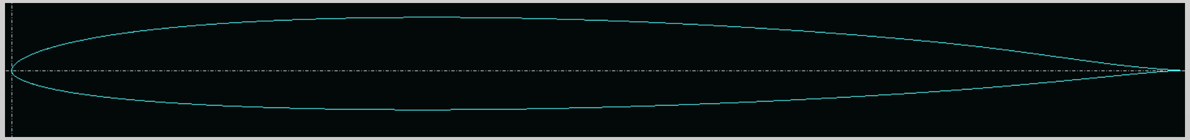
AIRFOIL ANALYSIS FINDINGS

Finding Middle Ground

- MH 54
  - Symmetry improves performance
  - TE tapers to difficult to manufacture thickness
  - Stalls at low AoA at takeoff
- NACA 2412
  - Improves hand launch speeds
  - High structural accessibility
  - Poor drag characteristics in cruise





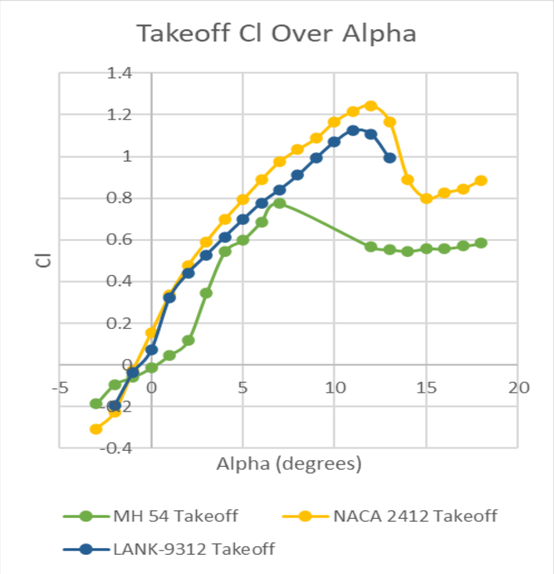


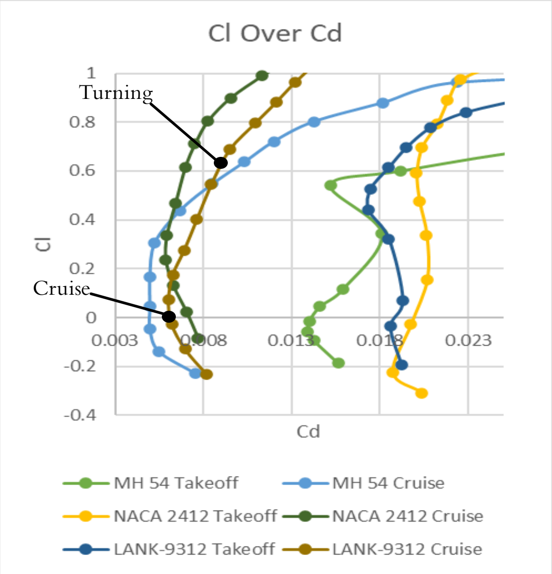
MH 54 Airfoil

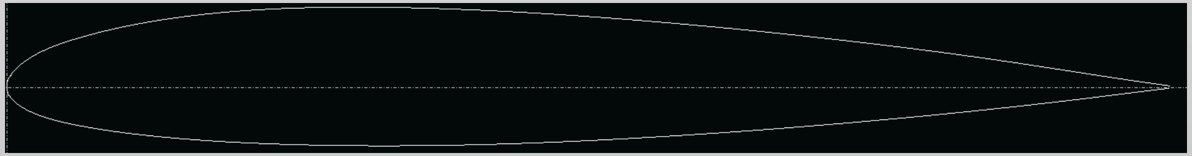
AIRFOIL ANALYSIS FINDINGS

The Solution

- Interpolation of the two airfoils (LANK-9312)
  - .9% Camber at 30% Distance from LE, 12% Thick
- Provides a middle ground for:
  - Drag at cruise and turn
  - Stall alpha
  - Internal structure accessibility







LANK-9312 Airfoil

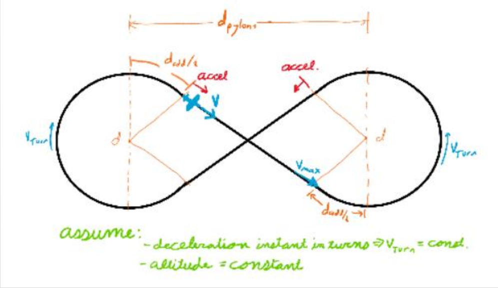
LAUNCH SPEED TESTING

- Since an appropriate throw speed was unknown, throw tests were done with a PVC and 2x4 representation
- 9 one handed throws were done by 3 different students
  - Vmin: 22.03 ft/s
  - Vavg: 30.10 ft/s
  - Vmax: 37.16 ft/s
- Throw speed aimed to be around 20-25 ft/s

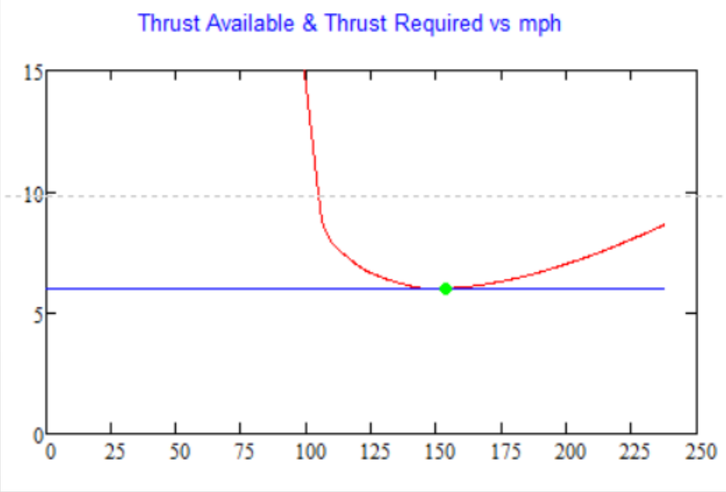
t (s)	x (ft)	y (ft)	v (ft/s)	a (ft/s²)
0.150	4.086	-5.152	28.68	164.1
0.167	4.533	-4.926	31.45	164.3
0.183	5.026	-4.688	34.09	118.0
0.200	5.560	-4.440	35.39	51.08
0.217	6.099	-4.198	35.27	34.99
0.233	6.637	-3.969	34.95	40.13
0.250	7.173	-3.749	34.68	47.97
0.267	7.710	-3.542	34.42	57.66
0.283	8.249	-3.353	33.98	51.41
0.300	8.782	-3.179	33.68	36.04
0.317	9.319	-3.014	33.59	20.16
0.333	9.854	-2.855	33.22	28.34
0.350	10.38	-2.696	32.77	27.18
0.367	10.90	-2.553	32.76	38.56
0.383	11.43	-2.412	32.65	44.73
0.400	11.96	-2.289	32.24	49.44
0.416	12.48	-2.181	32.03	37.57
0.433	13.00	-2.080	31.89	29.87
0.450	13.53	-1.989	31.91	27.79
0.466	14.05	-1.905	31.74	32.57
0.483	14.57	-1.828	31.51	35.19
0.500	15.09	-1.764	31.57	36.03
0.516	15.62	-1.707	31.54	28.96
0.533	16.14	-1.662	31.69	30.88
0.550	16.67	-1.620	31.70	36.45
0.566	17.19	-1.591	31.43	47.07
0.583	17.72	-1.574	31.36	37.08

WING AREA OPTIMIZATION

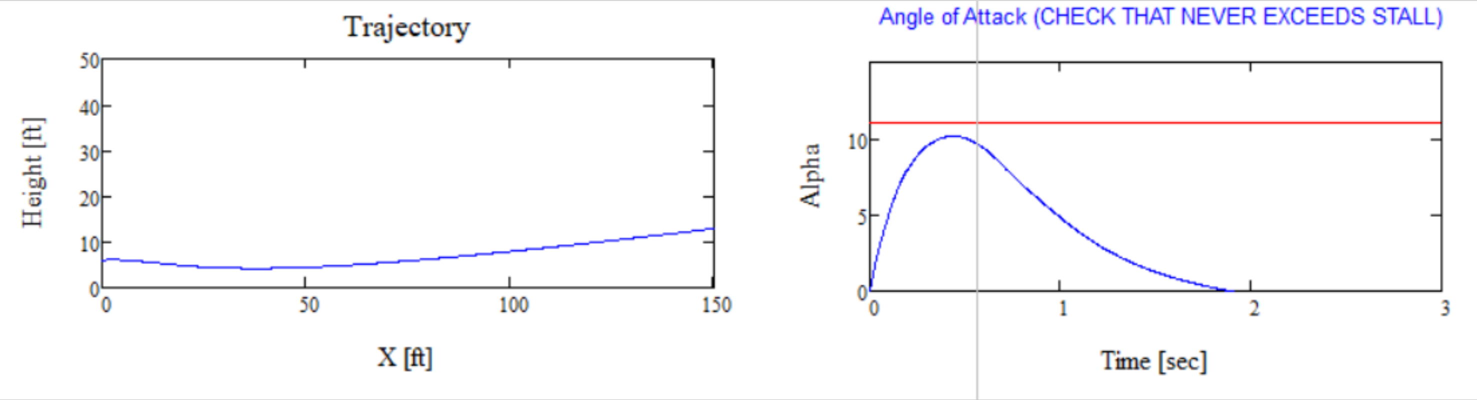
- The team was supplied with launch simulation and mission analysis Mathcad
- Iteration between the two using the selected airfoil allowed for wing area selection
- Iteration criteria:
    - Weight estimated to be 5.58 + 0.5(S) lbs
    - Launch angle of 0-10 degrees
    - Throw speed between 20-25 ft/s
    - 6 lbs of thrust
    - 6 ft wingspan



assume:
- deceleration instant in turns ⇒ V_{Turn} = const.
- altitude = constant

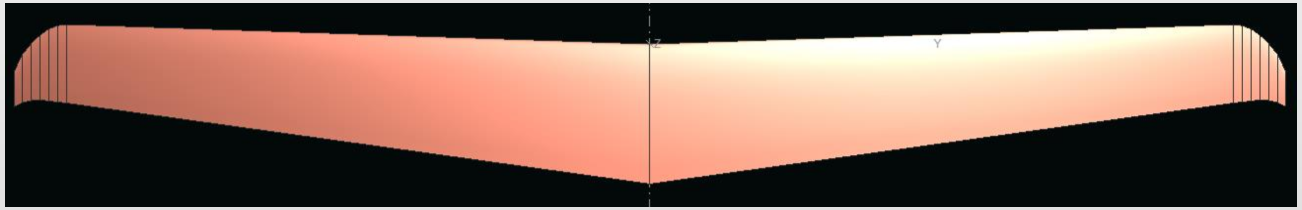


- Wing area found to be ideal at 3 ft^2
- Estimated 28 flags
- 15.5 G load turns

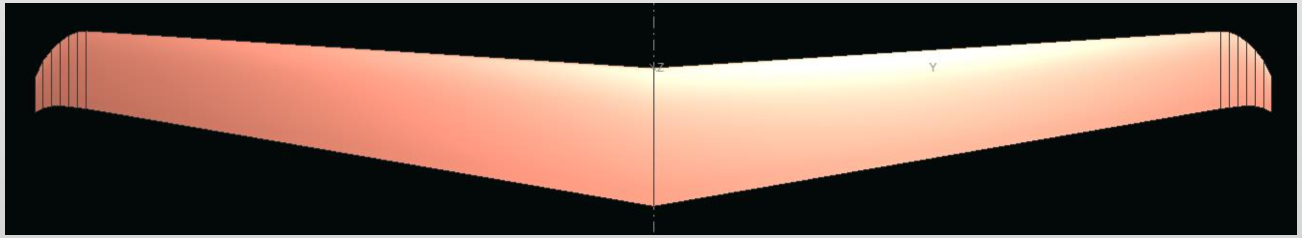


WING PLANFORM DESIGN

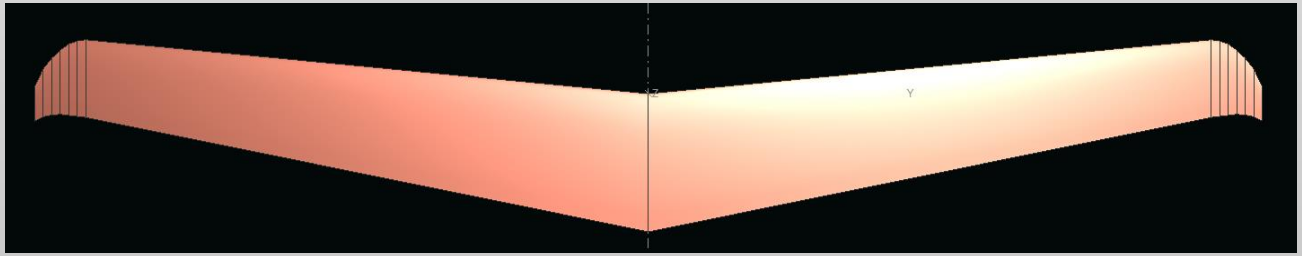
- In order to choose our sweep, multiple variations of the wing were generated with a range of root to tip sweep angles



- Wing #1 ≈ -2.0° Sweep



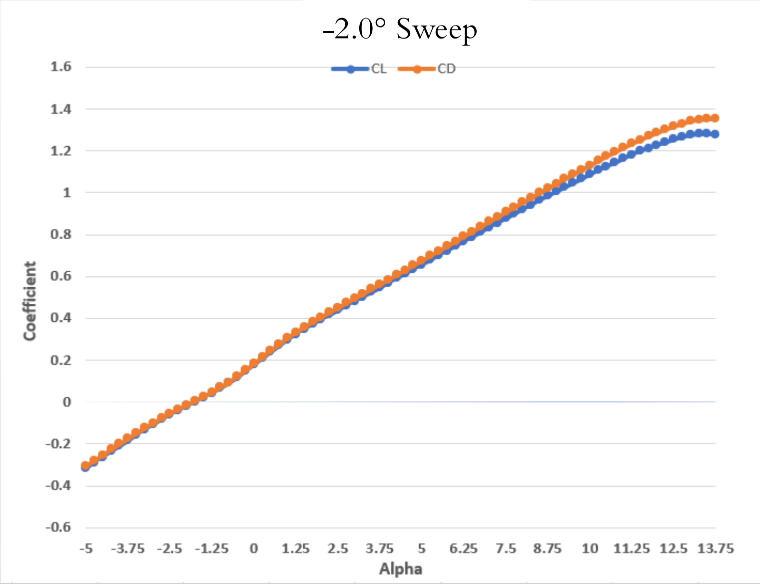
- Wing #2 ≈ -4.0° Sweep

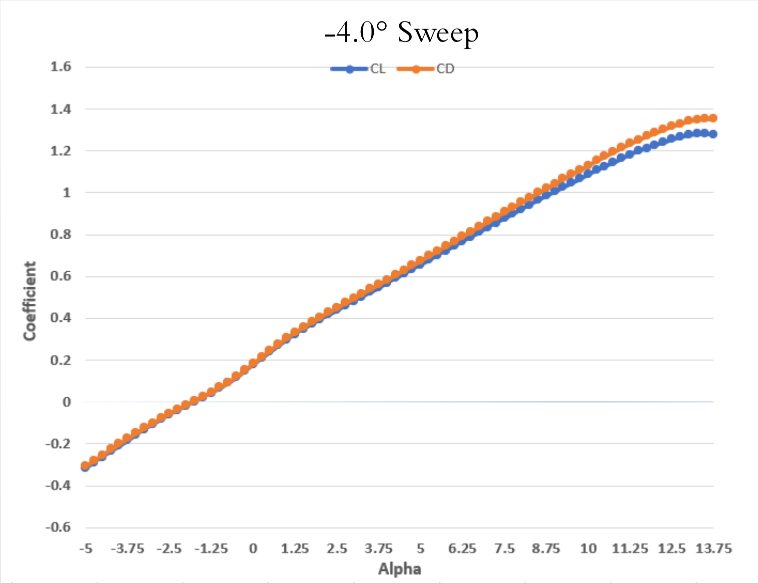


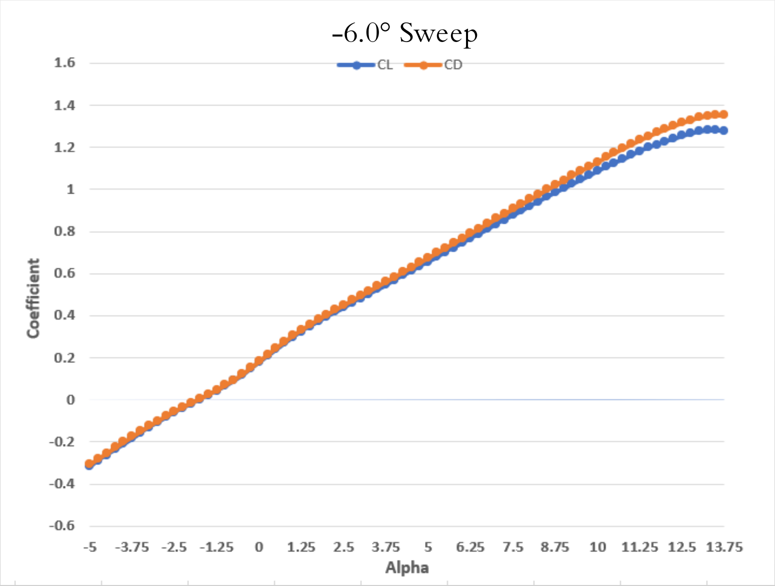
- Wing #3 ≈ -6.0° Sweep

WING PLANFORM DESIGN

- <u>Sweep Testing Data:</u> each of the wing sweep variations was tested in XFLR5 to ensure increasing the forward sweep would not create any Cl, or Cd issues


-2.0° Sweep

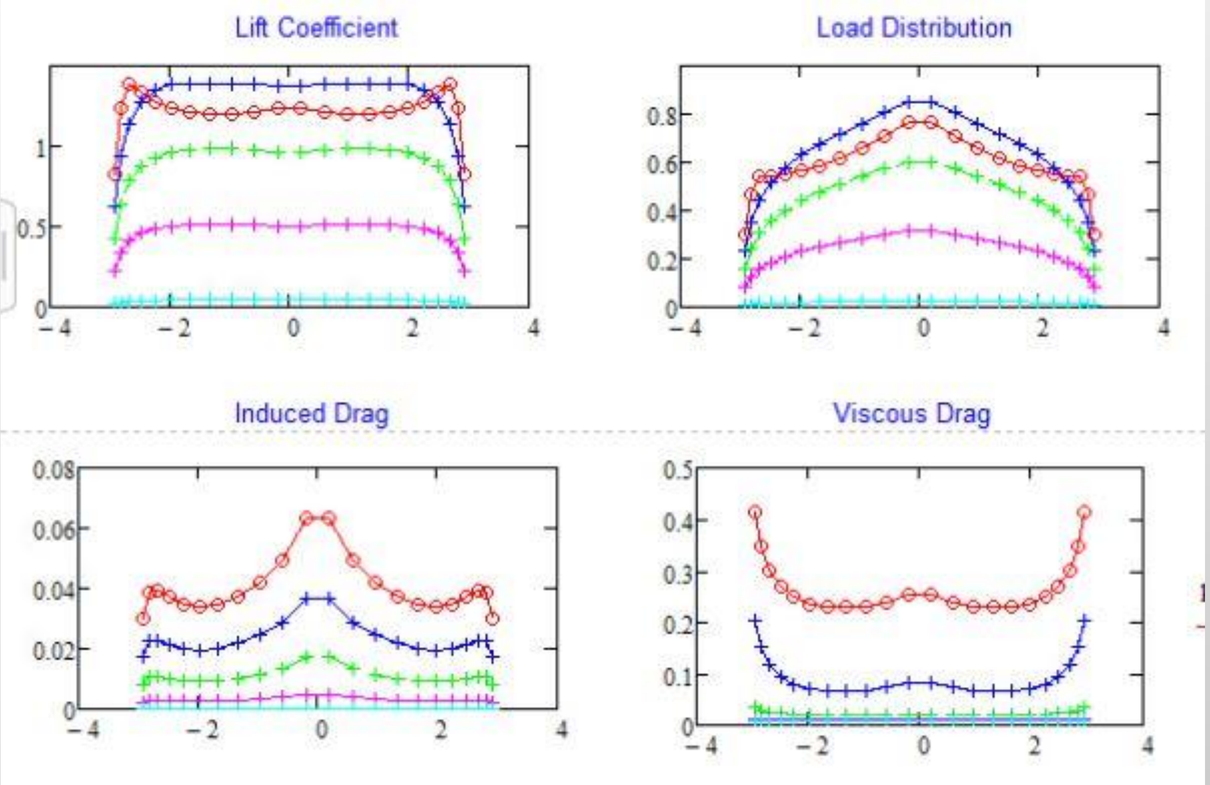

-4.0° Sweep


-6.0° Sweep

XFLR5 data shows that 3 different sweep variations of the wing had minimal changes to the CL and CD Characteristics
-6.0° gave us the aggressive look we wanted without any adverse aero affects

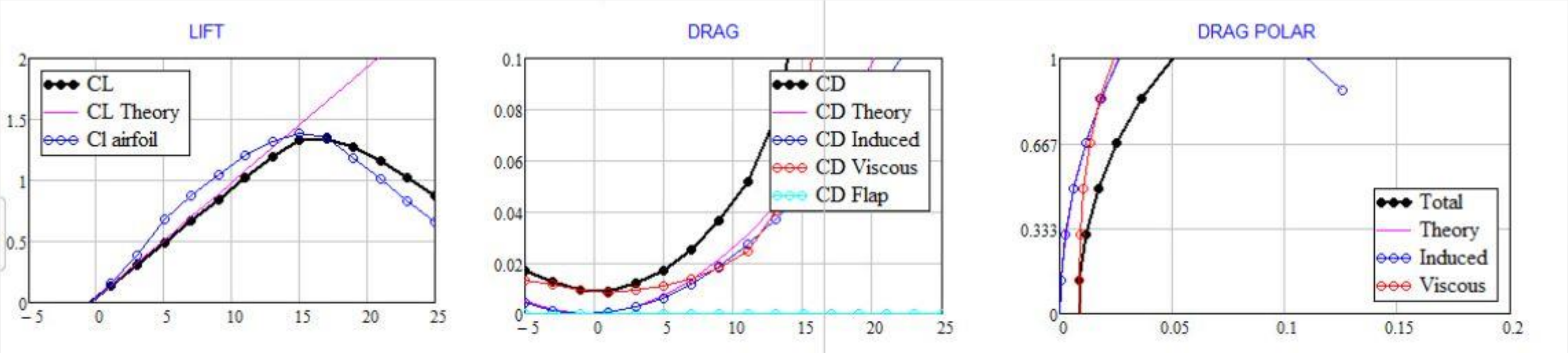
WING PERFORMANCE

- Analysis shown is for final wing design
- Iterated taper ratio from 1 to 0.4
- 0.562 ratio showed best compromise between performance and desired geometry



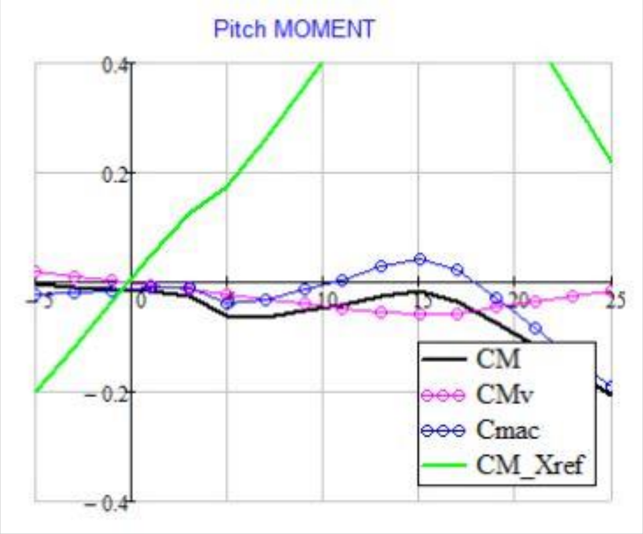
Analysis of –6 degree sweep with 0.562 taper ratio

WING PERFORMANCE



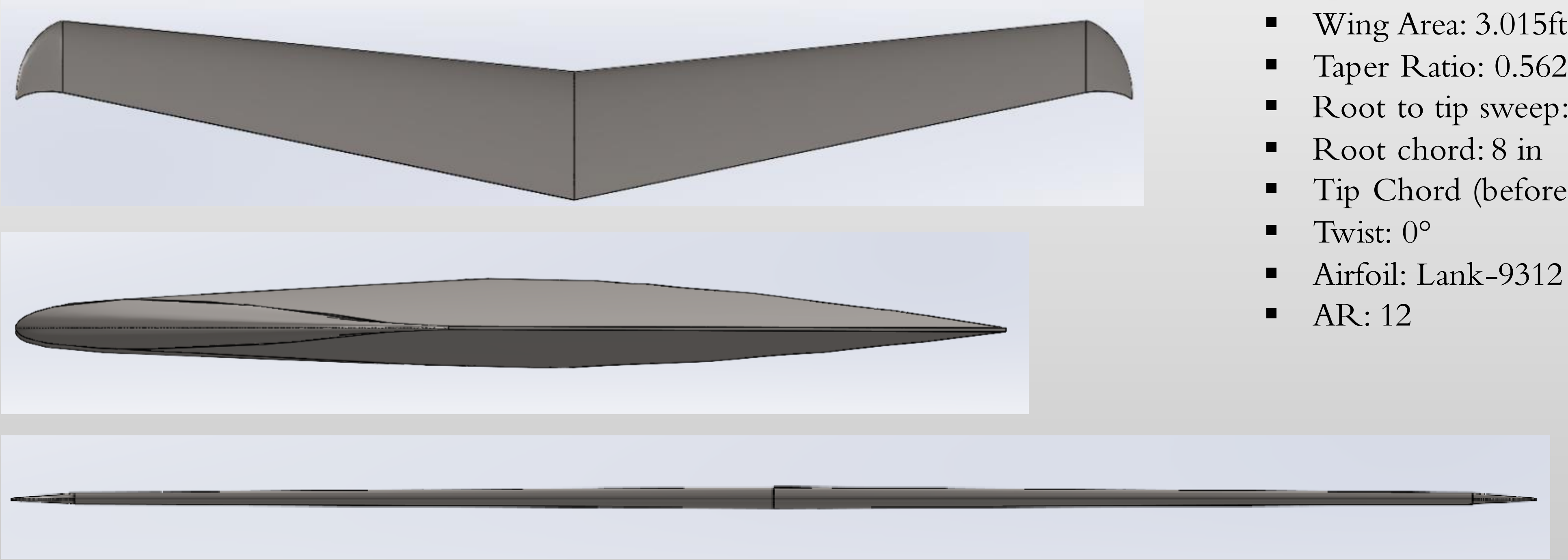
- Max CL of about 1.4 & 16 degrees AoA

- Acceptable pitch moment, keeping in mind that the tail is not yet factored in



WING PLANFORM DESIGN

- Result: Final Wing Design

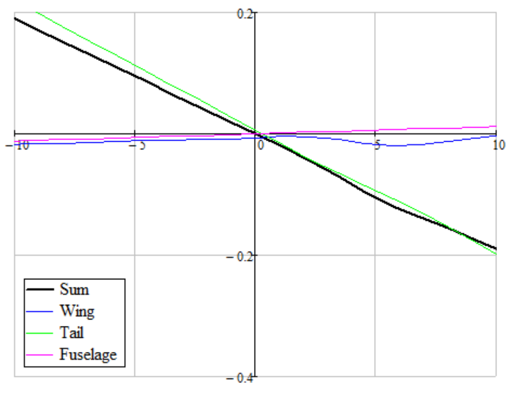


- Span: 6.0ft
- Wing Area: 3.015ft^2
- Taper Ratio: 0.562
- Root to tip sweep: -6.0°
- Root chord: 8 in
- Tip Chord (before tip): 4.5”
- Twist: 0°
- Airfoil: Lank-9312
- AR: 12

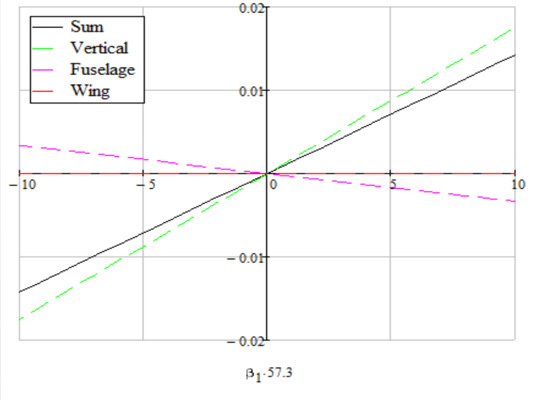
STABILITY ANALYSIS

- Initial Targets:
  - Pitch Static Margin: 20-25%
  - $C_n\beta$ = 0.08 - 0.1
- Final Values:
  - Pitch Static Margin: 24%
  - Cnβ = 0.091
- With propulsion:
  - Positive Pitching Moment
  - Most influential at low speeds

C_M vs. α

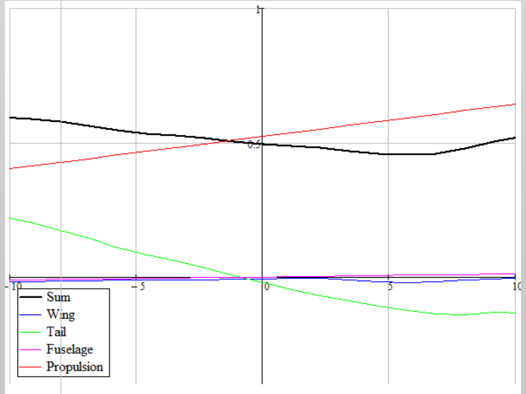


C_n vs. β

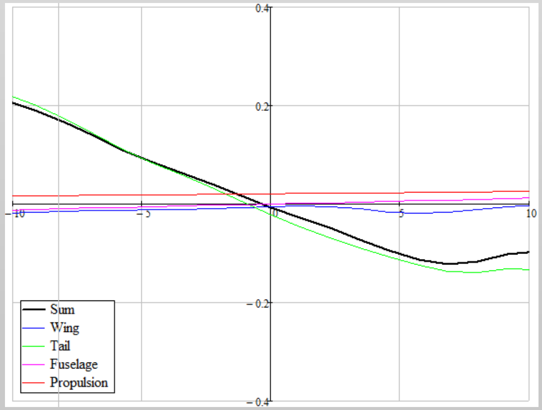


No propulsion

C_M vs. α (30 ft/s)



C_M vs. α (150 ft/s)



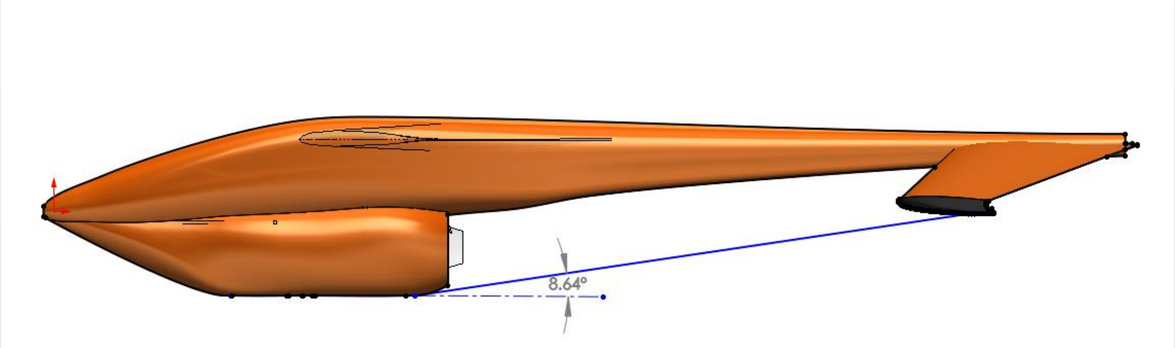
With propulsion

TAIL DESIGN AND SIZING

- Performance Targets:
  - SM_p = 20-25% and $Cn_\beta > 0.1$
  - Tail Length = 20 in
  - CG target = c/4 of MAC

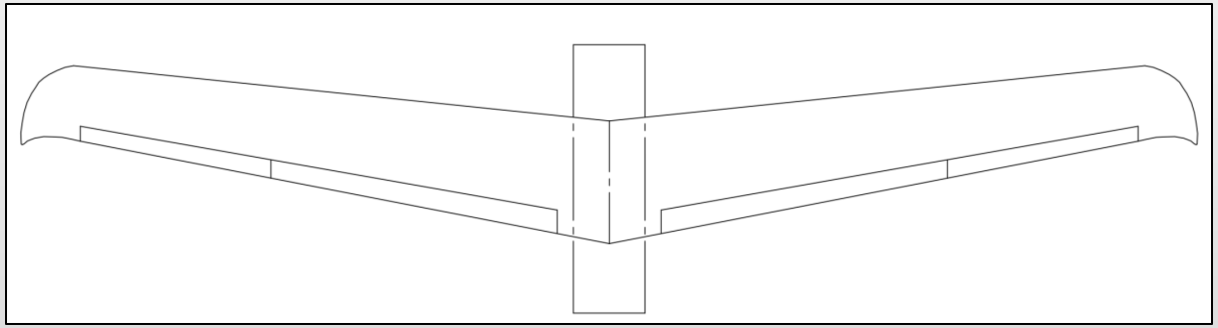
- Target Sizing:
  - $S_V = 75\ in^2$ $b_v = 13in$
  - $S_h = 75\ in^2$ $b_h = 18in$
  - Inverted-Y 15 degrees down from horizontal

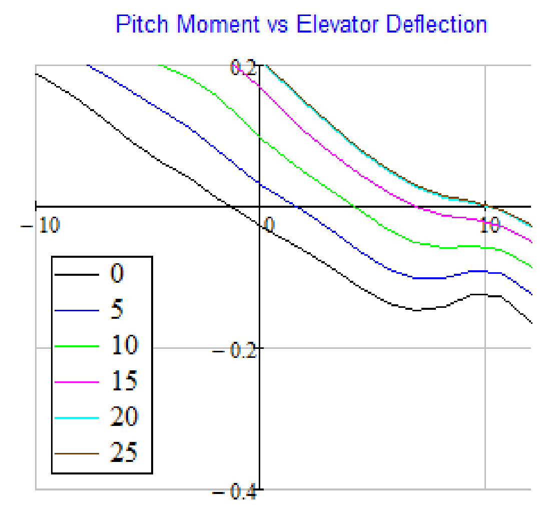
- Final Sizing:
  - $S_V = 72\ in^2$ $b_v = 12in$
  - $S_h = 73\ in^2$ $b_h = 16.8in$
  - Inverted-Y 15 degrees down from horizontal

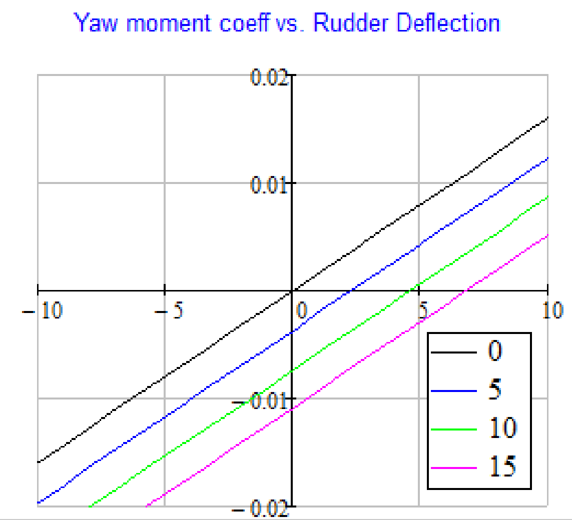


CONTROL SURFACE SIZING

- Flaps and Ailerons:
  - Decided primarily through benchmarking similar aircraft
  - Ailerons: 33% span; Flaps: 49% span; Both: 20% chord
  - Flaps can serve as ailerons if more control is needed
- Ruddervators
  - At full deflection trims to stall.
  - 0.5 in chord across full span
- Rudder
  - Allow for 15 mph crosswind during landing
  - 3 in cord across full span

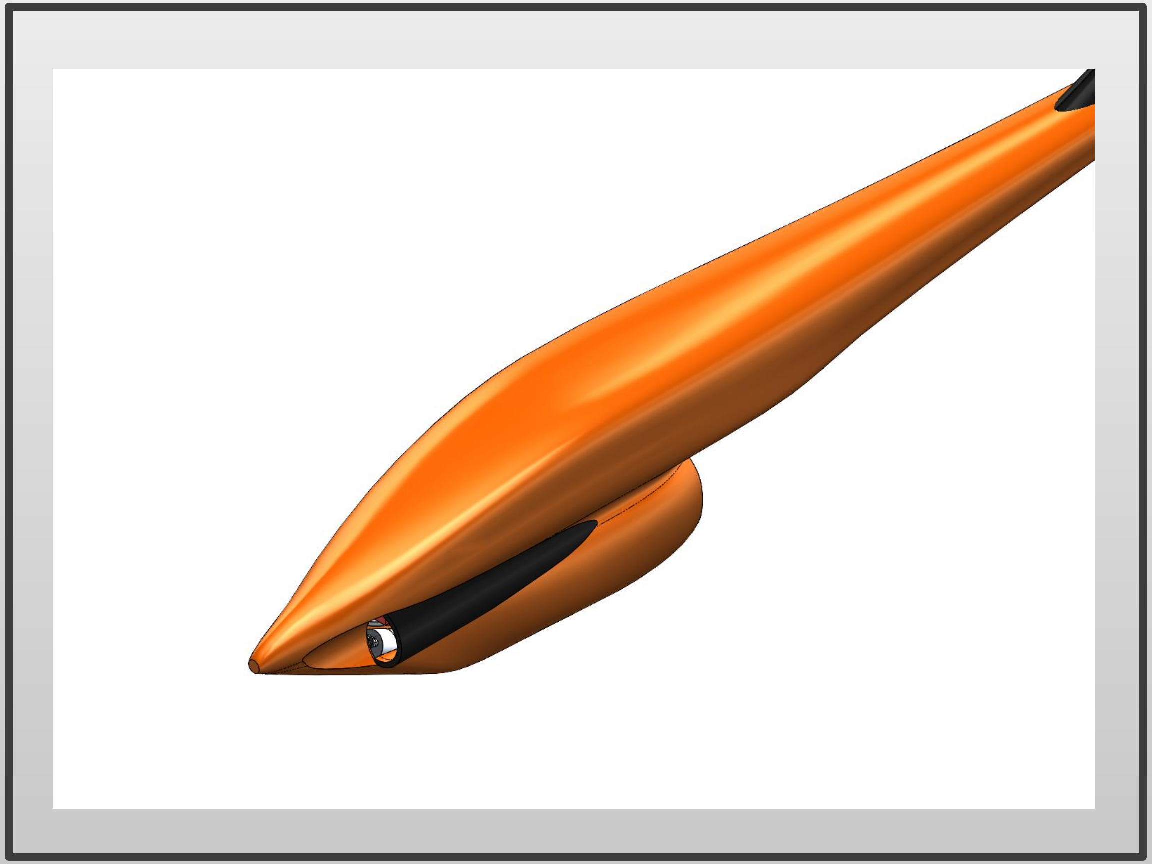



Pitch Moment vs Elevator Deflection


Yaw moment coeff vs. Rudder Deflection

*does not include ruddervator coltrol

FUSELAGE AERODYNAMICS

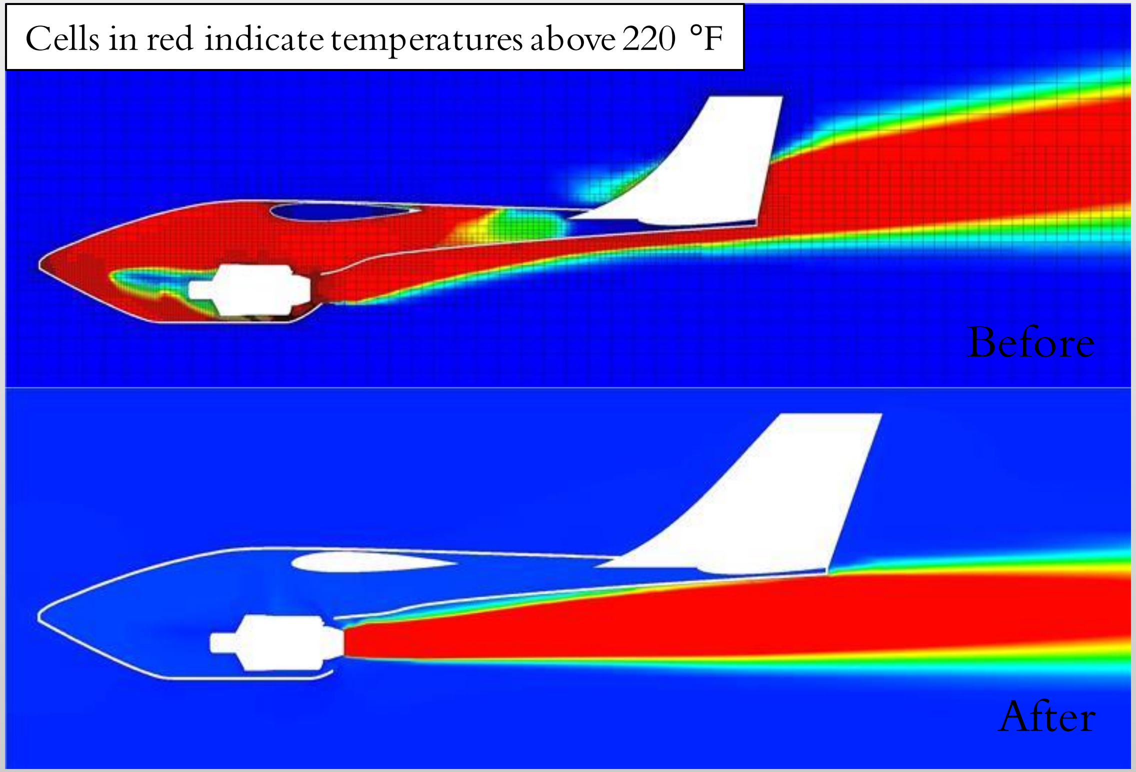


- Fuselage Length: ~37 in
- Empennage Length: 20 in from MAC

- As structures and propulsion builds the fuselage:
  - Ensuring the fuselage is aerodynamic, no spots to disrupt flow across the wing or tail
  - Using CFD to ensure that high temperature exhaust doesn’t burn the empennage
  - Making sure the CG is at target location

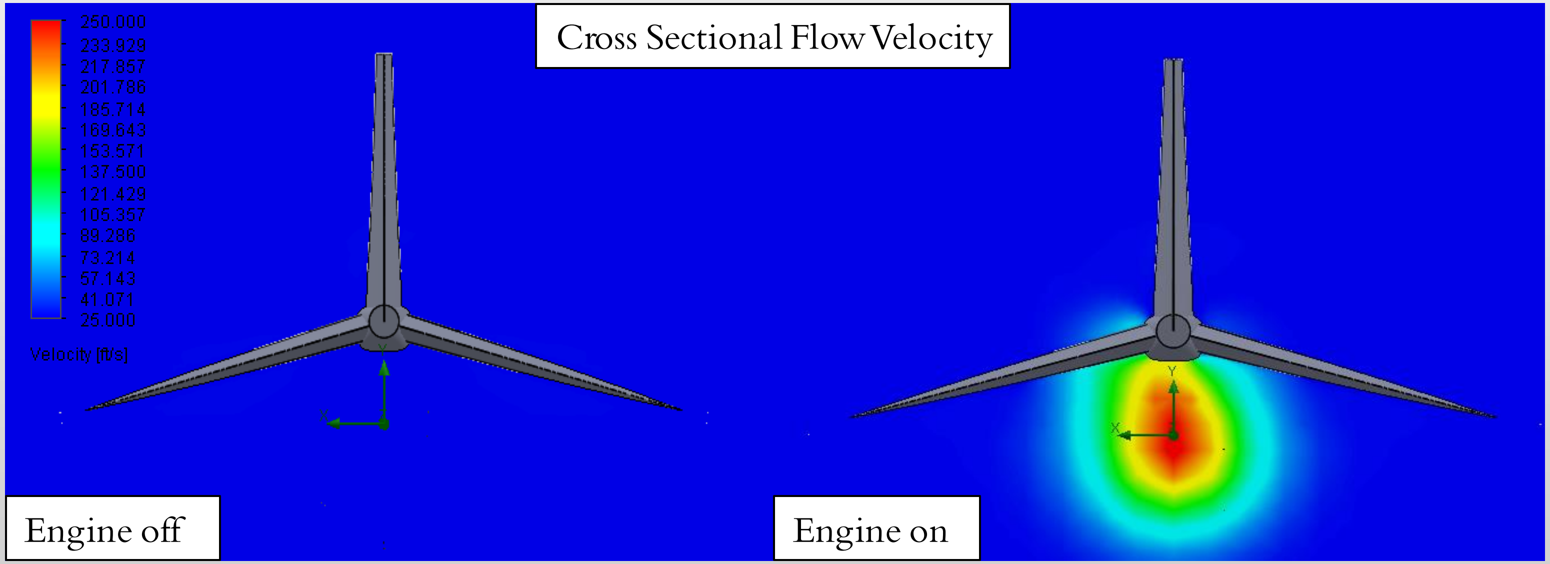
CFD RESULTS

- Findings
  - Engine too far back
    - Trapped exhaust
  - Jet wash flow attachment
  - Inlet too small
- Resulting corrections
  - Engine moved forward
  - Inlet size increased
  - Upper exhaust lip lifted


Cells in red indicate temperatures above 220 °F

CFD RESULTS

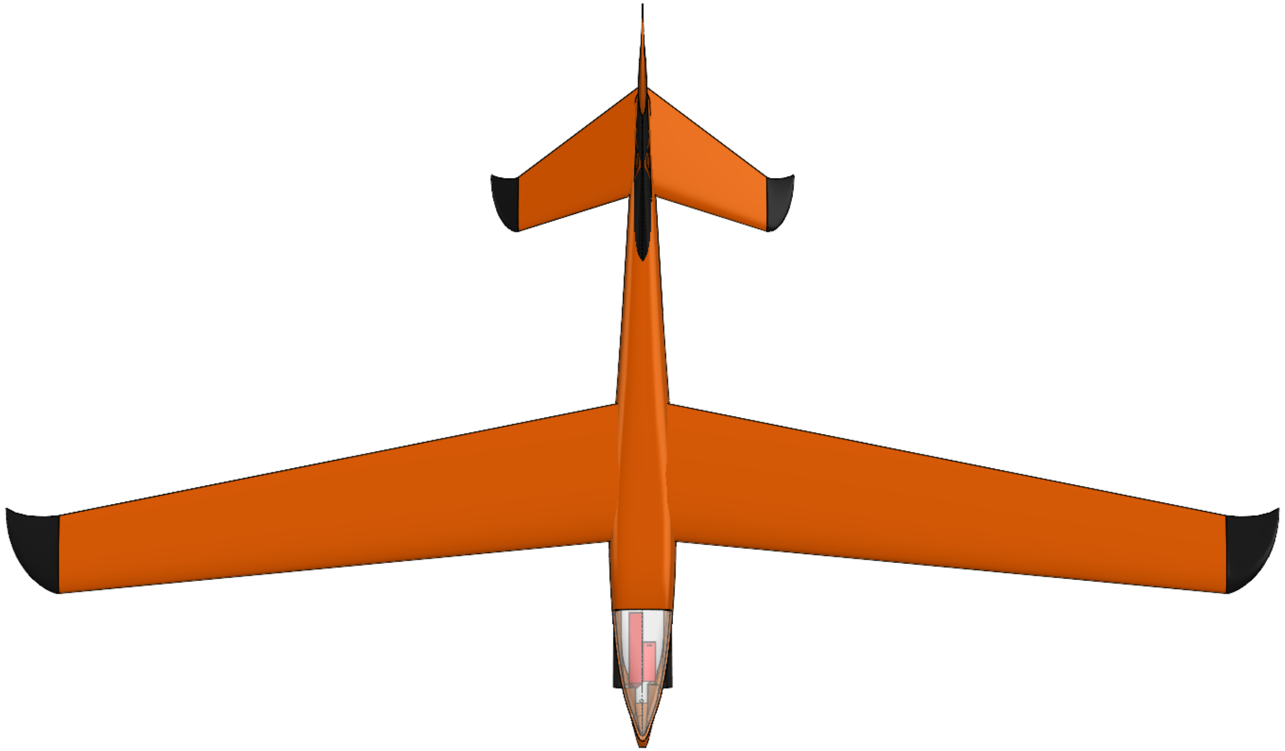
- Objective
  - Use jet wash to improve takeoff speed
- Findings
  - Flow hits the tail at takeoff speeds
  - Can achieve jet wash effect in necessary flight conditions



Cross Sectional Flow Velocity

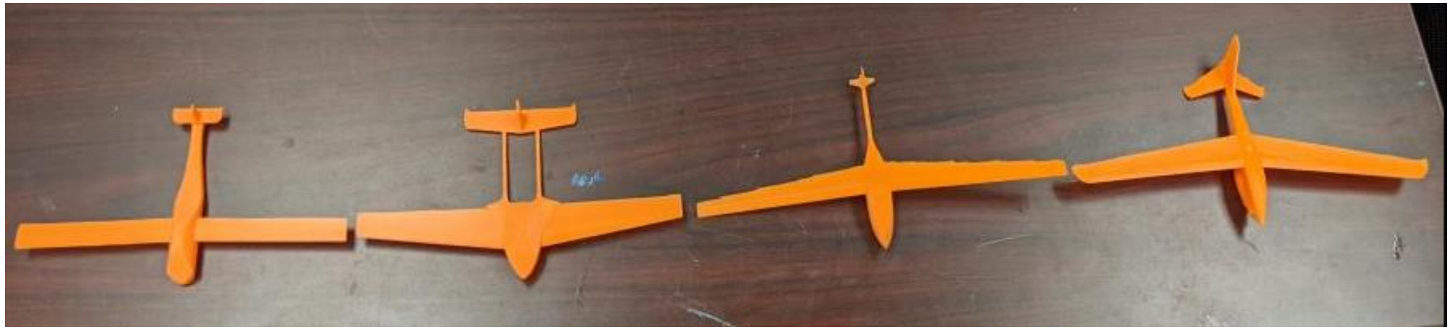
THE AERODYNAMICS TEAM MOVING FORWARD

- Ensuring CG is in a good location
- Performance tests, watching for possible changes and additional analysis
- Helping with marketing



STRUCTURES

- SKIN DESIGN
- INTERNAL COMPONENT LAYOUT
- WEIGHT AND CG ESTIMATION
- AVIONICS SYSTEMS LAYOUT
- HATCH LAYOUT
- INTERNAL FUSELAGE STRUCTURE
- WING/SPAR ANALYSIS
- FASTENER TESTING RESULTS
- HORIZONTAL AND VERTICAL TAIL STRUCTURE
- MANUFACTURING (MOLDING) STRATEGY
- STRUCTURES GOING FORWARD



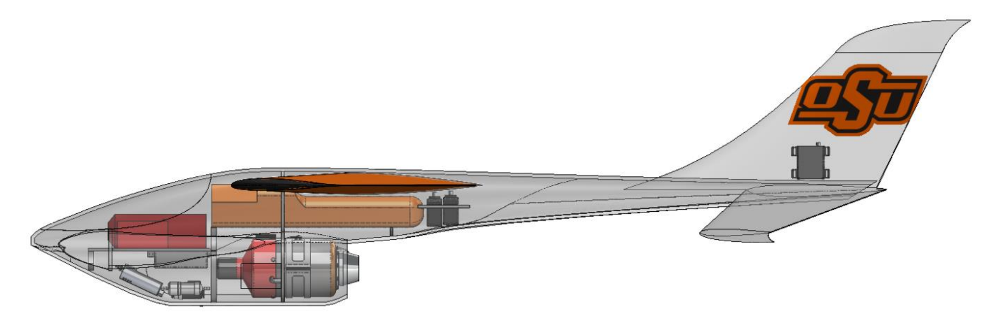
SKIN DESIGN

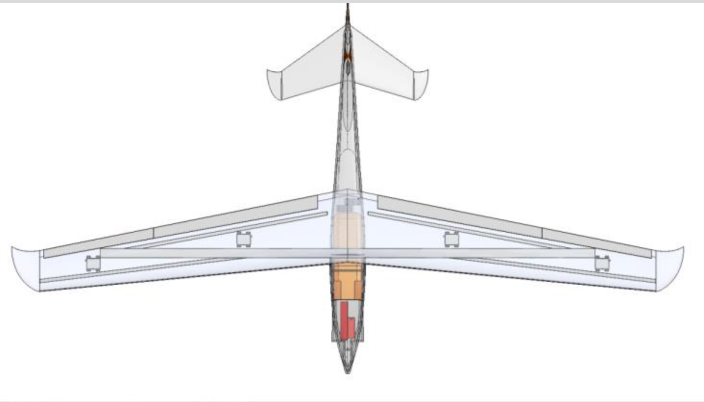
- Wing and Tail
  - 1/16-inch balsa
  - Strong and lightweight

- Fuselage Skin
  - 1/8th inch cross-scored Divinycell
  - Easily formable

INTERNAL COMPONENT LAYOUT

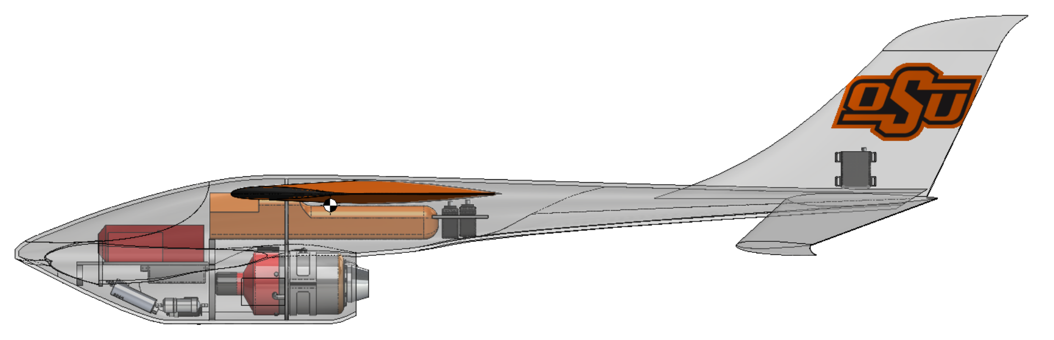
- Fuel tank located directly under wing and main hatch
- Engine mounted in lower, rear half of fuselage
- Internal sled at front of fuselage:
  - Batteries and servo mounted to top of sled
  - Fuel pump, filter, and safety valve mounted under
- Receiver and ECU mounted directly to fuselage below front sled.





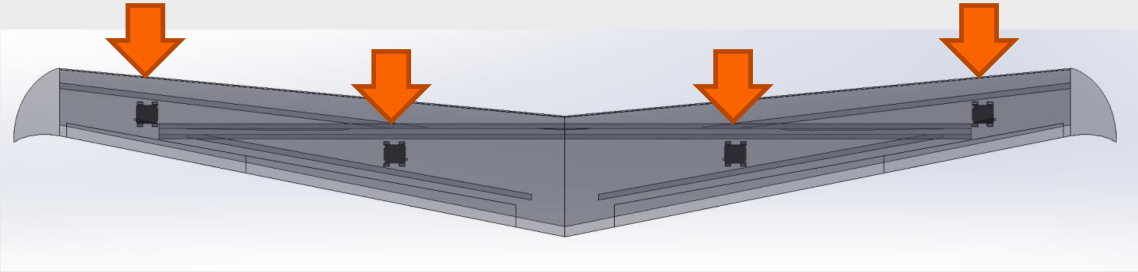
WEIGHT AND CG ESTIMATION

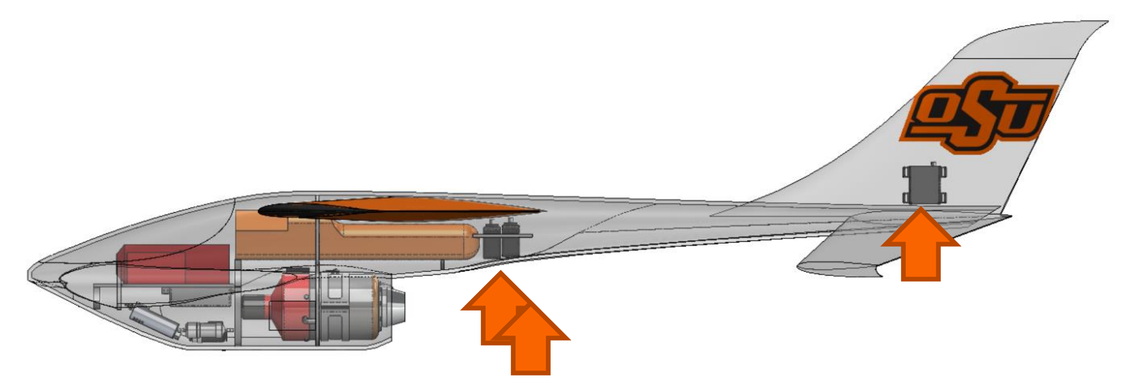
- CG estimates focused on staying in front of the mean aerodynamic chord quarter chord
- Forward sweeping wing problem:
  - MAC c/4 is farther forward than the root quarter cord
- Forward sweeping wing compliment:
  - CG for wing will also be moved forward
- Main focus moving forward:
  - Reducing tail weight

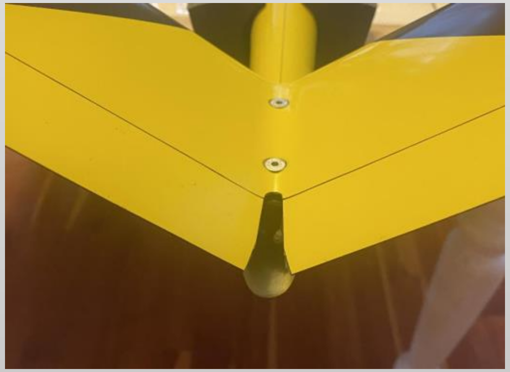


AVIONICS SYSTEMS LAYOUT

- Wing Servo
  - 4 Servos: Hatches made for access
- Tail Servos
  - Servo for vertical tail rudder: Hatch made for access
  - Ruddervator servos attached with composite push rod

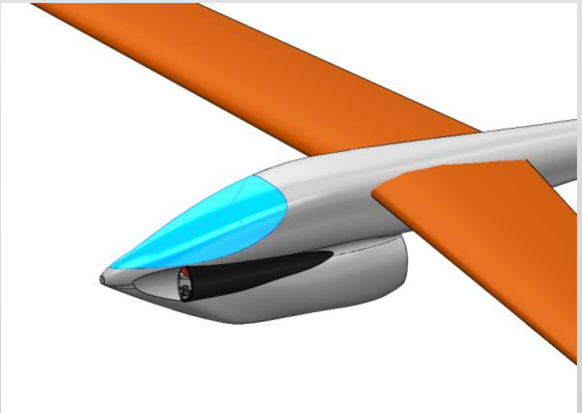




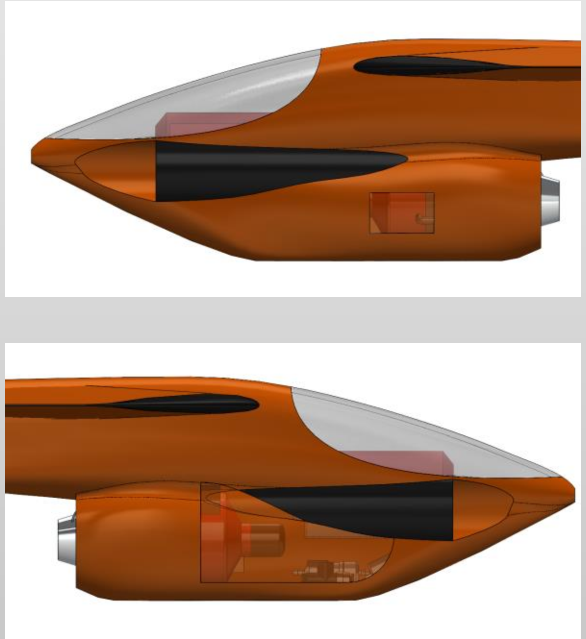


HATCH LAYOUT

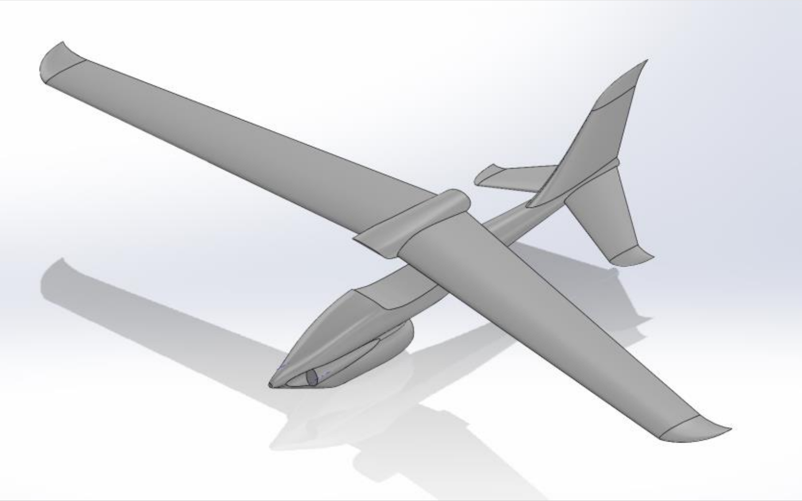
- Front Hatch
  - Attached by magnets



- 2 Side Hatch
  - Attached by magnets

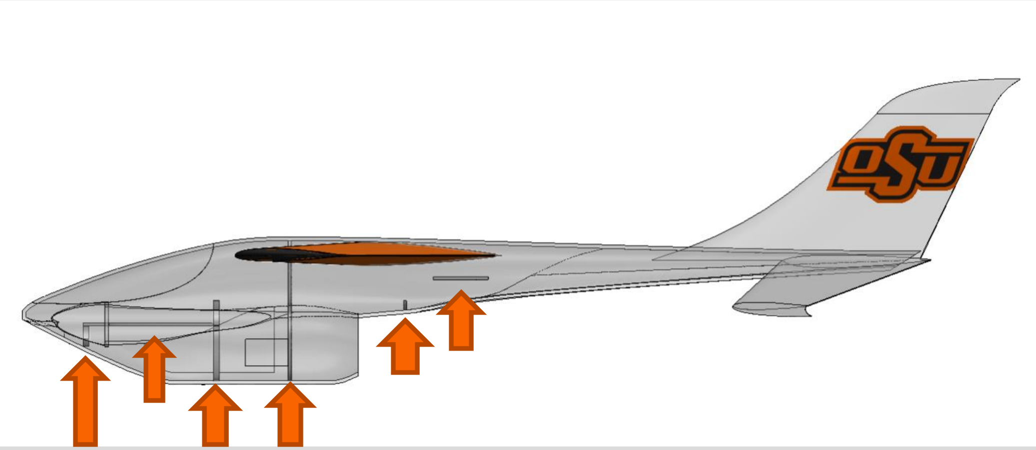


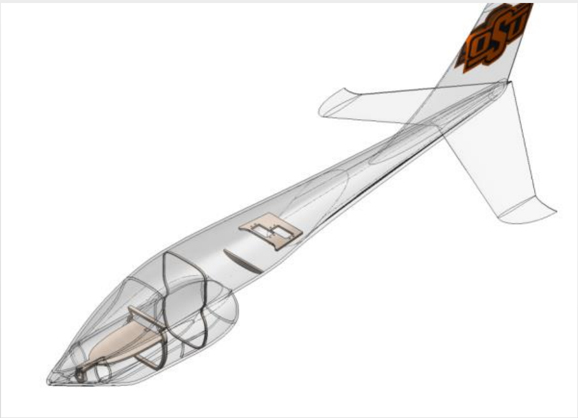
- Wing Hatch
  - Attached by ¼ turn fasteners
  - Apart of wing mold

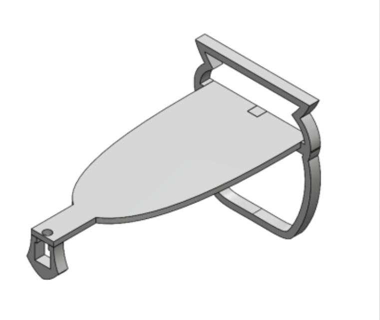


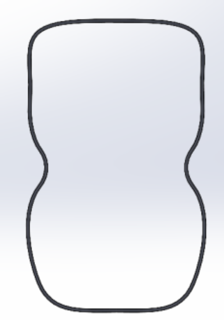
INTERNAL FUSELAGE STRUCTURE

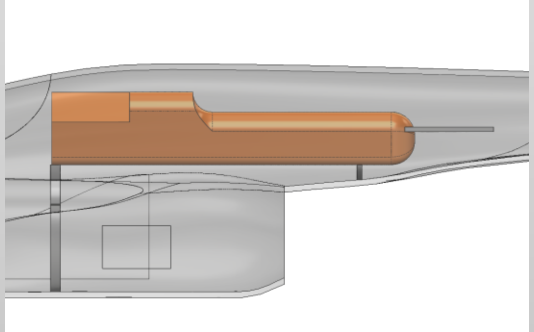
- 1st Picture
    - Sled and bulkhead mounts
- 2nd Picture
    - Cavitation Bulkhead
- 3rd Picture
    - Fuel tank mounts
- 4th Picture
    - Servo Mounts

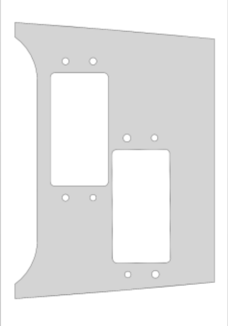






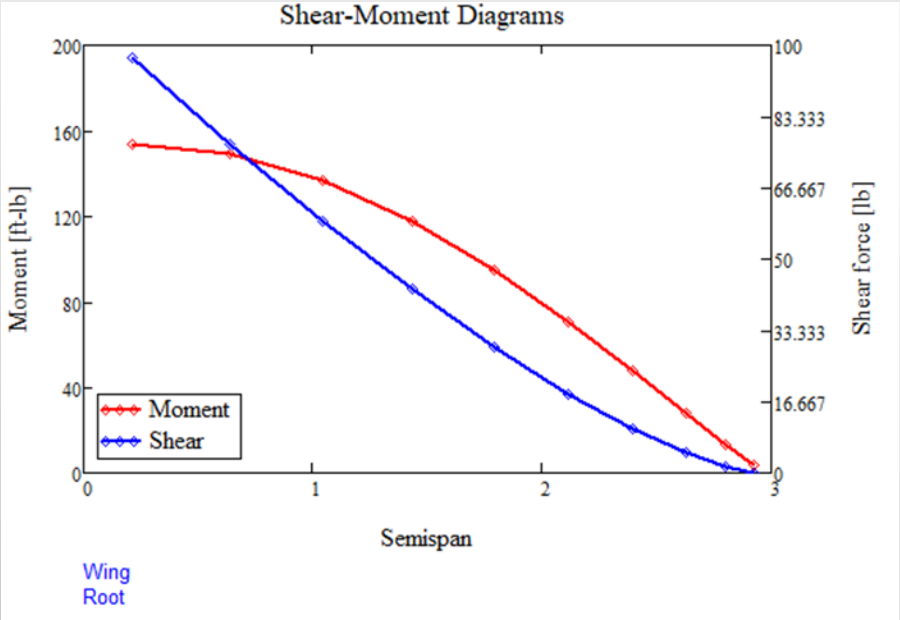






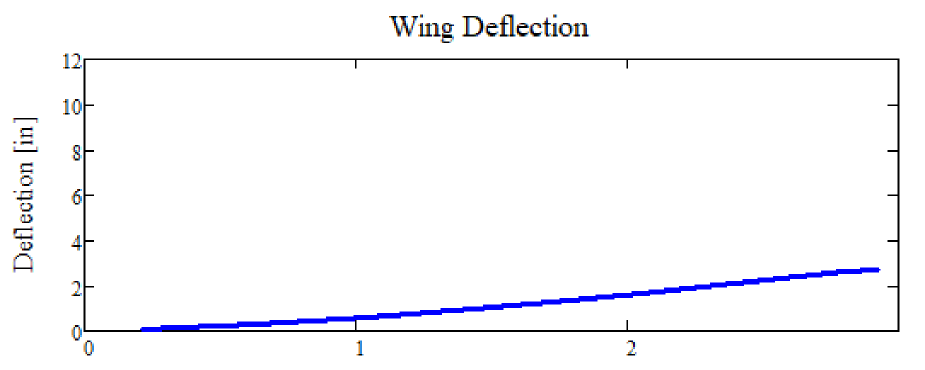
WING LOADING ANALYSIS

- Loading was estimated using airfoil polars, wing geometry, and flight speed.
  - Max g-load at max speed, highest alpha before stall
- As expected, bending moment and shear force decreased significantly towards wing tip.



WING/SPAR STRUCTURE

- Composite Spar
  - Layers of Carbon Tow built into skin to carry bending stress.
  - Cross grain balsa shear web to handle shear stress.
    - Taper is dictated by wing thickness/sweep
    - Possibility of adding fiber glass layers to increase strength without changing geometry.
- Balsa Shear Webs
  - Aft: Strengthen wing near control surfaces
  - Leading edge: Extra wing rigidity near tip
- Estimated max load of 33 Gs, with ~6% deflection
  - With additional shear webs and semi-monocoque skin, actual deflection will likely be much smaller



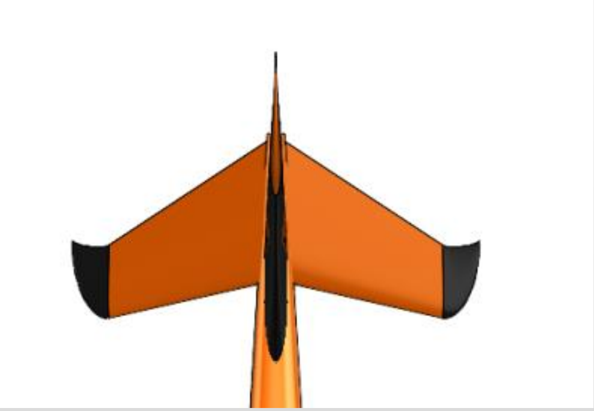
FASTENER TESTING RESULTS

- Aeroply will be sufficient
- Epoxy failed before design failed
  - Epoxy not part of real design
- Successful test
- Max Load: 46 lb

Assumptions		
Number of Bolts	4	-
Weight of Plane	7	lbs
G-load	25	-
Factor of Safety	1.5	-
Total Fastener Available Area	0.2495	in²
Calculations		
Load	175	lbs
Load Per Bolt	43.75	lbs
Total Force Per Area	175.37	lbs/in²
Factor of Safety Calculation		
Load	262.5	lbs
Load Per Bolt	65.625	lbs
Total Force Per Area FOS	263.05	lbs/in²
Material		
Birch	8,540	lbs/in²
Balsa	1,000	lbs/in²

HORIZONTAL AND VERTICAL TAIL STRUCTURE

- No shear web design for tail structure
  - Loads will be small
  - Reduces weight in tail
  - Testing required
- Horizontal tail molded in one piece
  - Cut in half
  - With jig, sand at inverted the Y angle
  - Epoxied back together in empennage with jig
- Vertical tail molded with fuselage

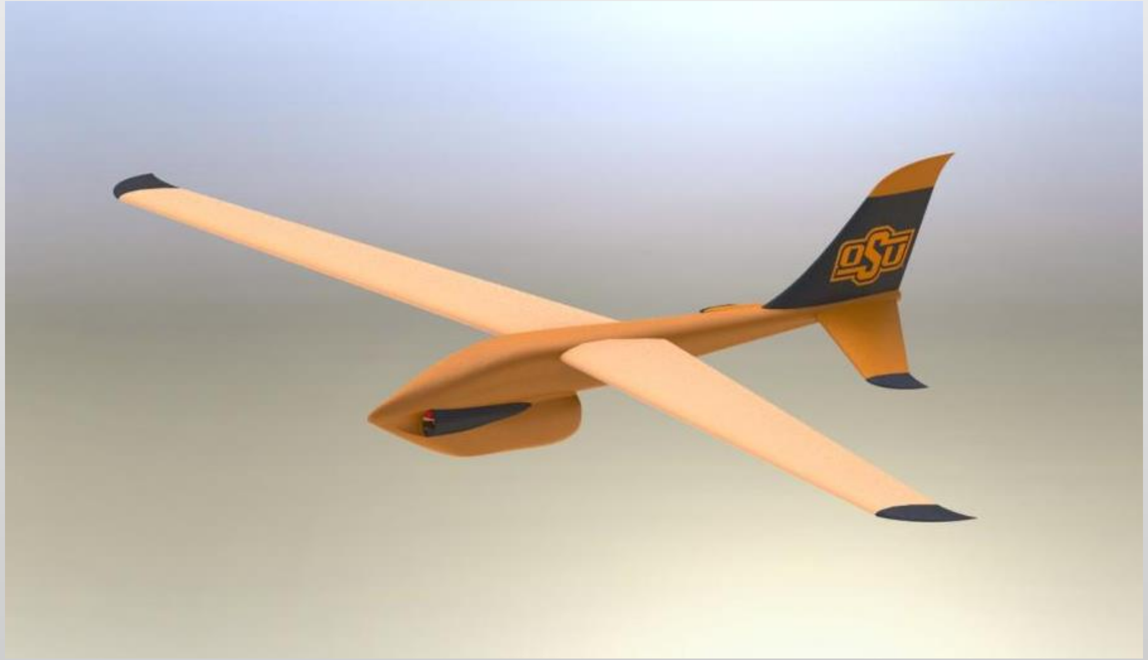


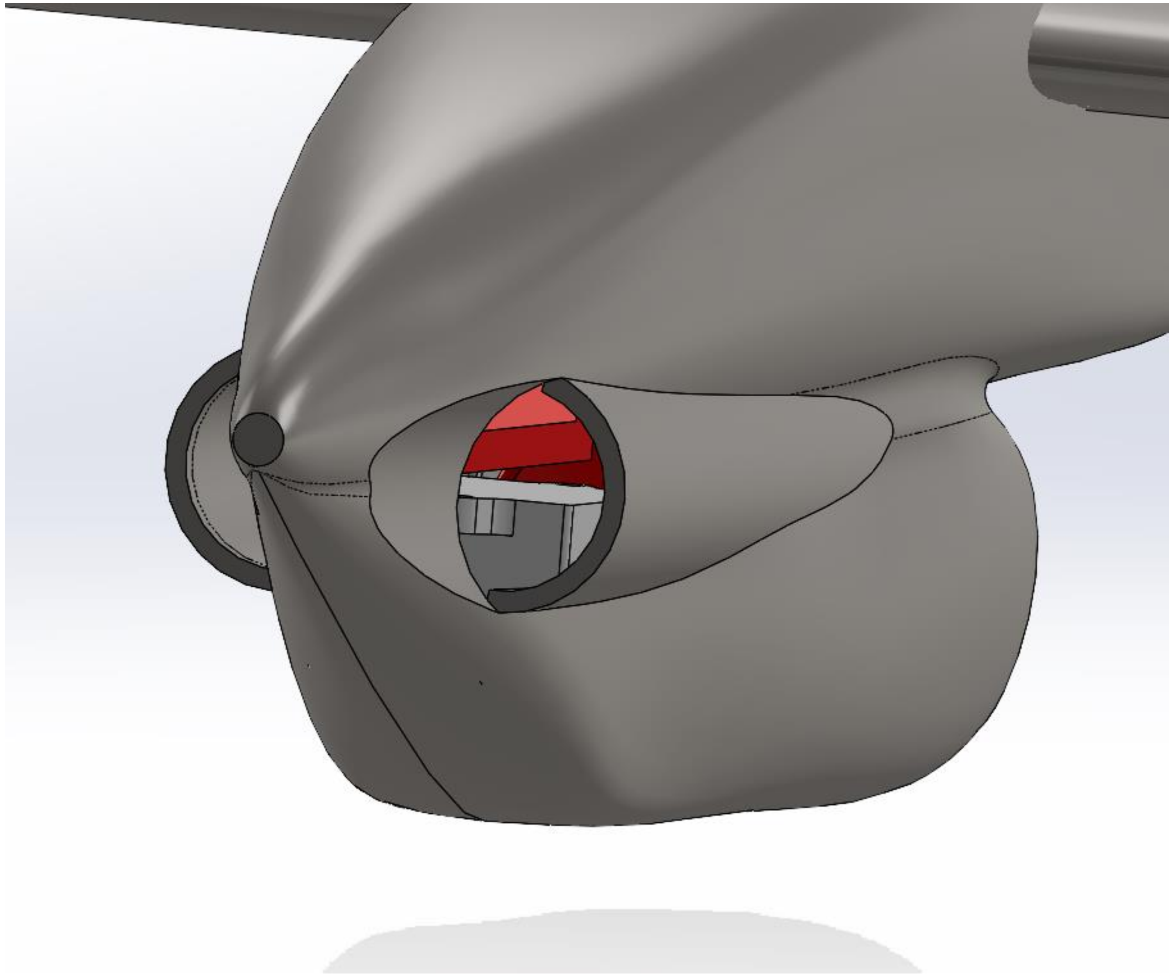
MANUFACTURING (MOLDING) STRATEGY

1. CAD design broken into parts
2. CNC plug and parting board
3. Sand down parting board so plug will fit flush with the board
4. Epoxy the 2 plug parts together
5. Prime both plug and parting board and sand smooth
6. Put plug back into parting board and paint release and wax both parts
7. Paint two layers of tool coat onto parting board and plug
8. Use 13 layers of fiberglass alternating between 90- and 45-degree layers
9. Let cure for 24 hours and then separate parting board and tool coat/fiberglass
10. Repeat step 6-9 of process for the other side
11. Layup our part and hatches, insert innards, epoxy two halves together

STRUCTURES GOING FORWARD

- Building starts immediately after CDR
- Tests:
  - Wing/Spar test
  - Horizontal Tail test
- Reaching a goal of 6 planes:
  - Detailed schedule
  - Incentive program
  - Driven by the want to win

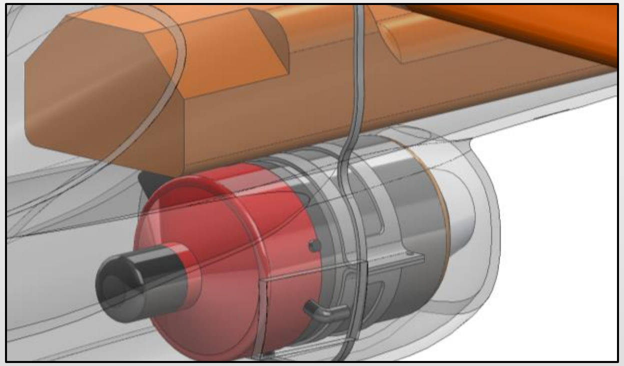




PROPULSION

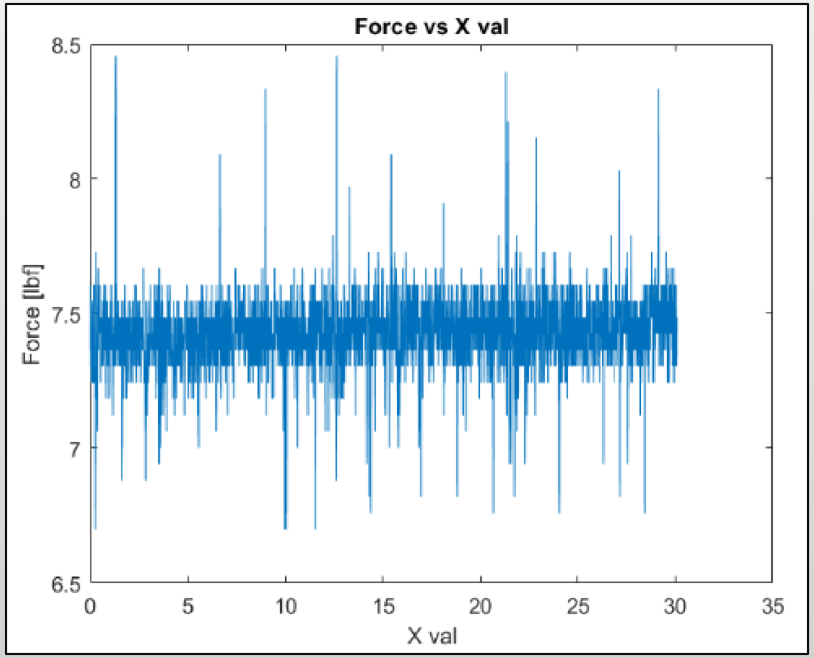
ENGINE INTEGRATION

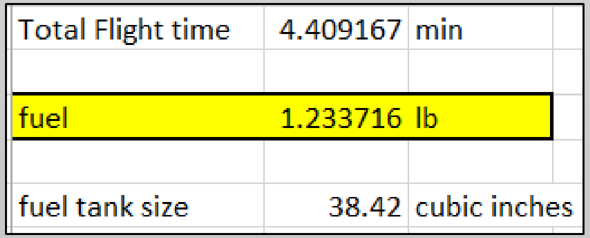
- Tapping Insert
- Like the "Pete" wing attachment
- Bonded flanges to the fuselage
- Current engine mount with cut and additional hole
- Installed with angled Allen Wrench



ENGINE PERFORMANCE

- Thrust data from Feb 5, 2020 Black Team
- Avg Thrust full throttle ~ 7.4 lbs
- Fuel burn data from Feb 10, 2020 Black Team
- Avg Fuel Burn full throttle ~ 8.7 in^3/min

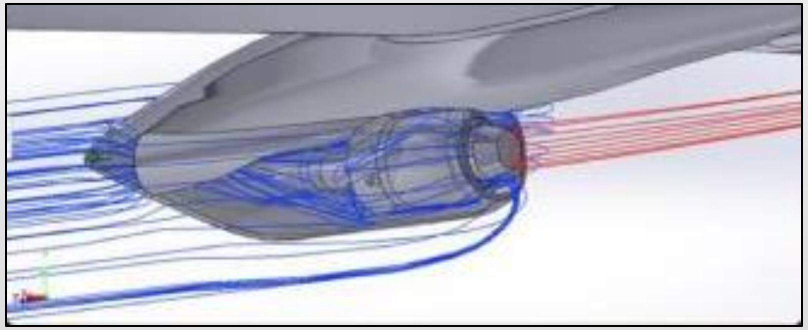


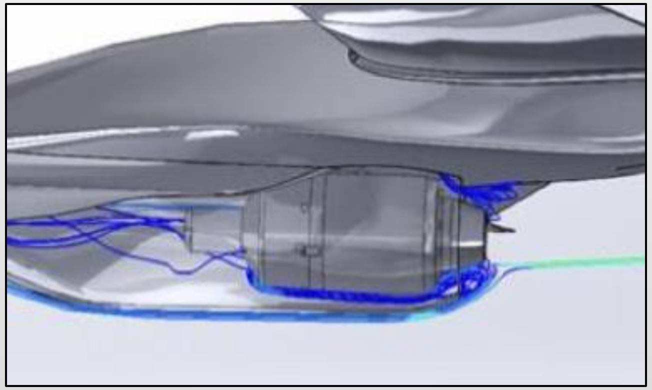


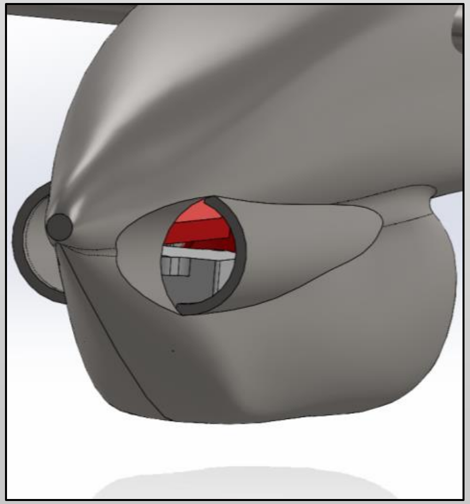
Total Flight time	4.409167	min
fuel	1.233716	lb
fuel tank size	38.42	cubic inches

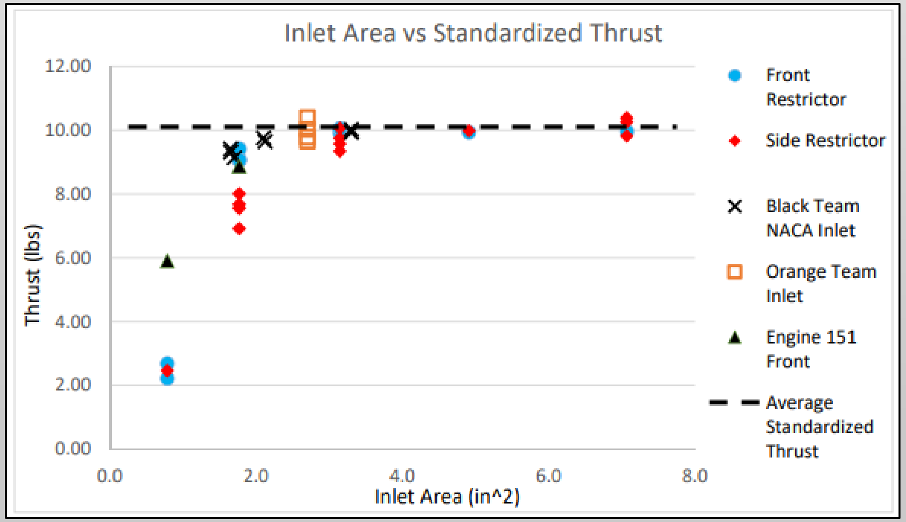
INLET DESIGN

- Original area of 1.2 in^2
    - Exhaust acted as inlet
- Goal to get 2.4 in^2
    - No flow entering exhaust
    - Produce more thrust
- CFD to confirm design







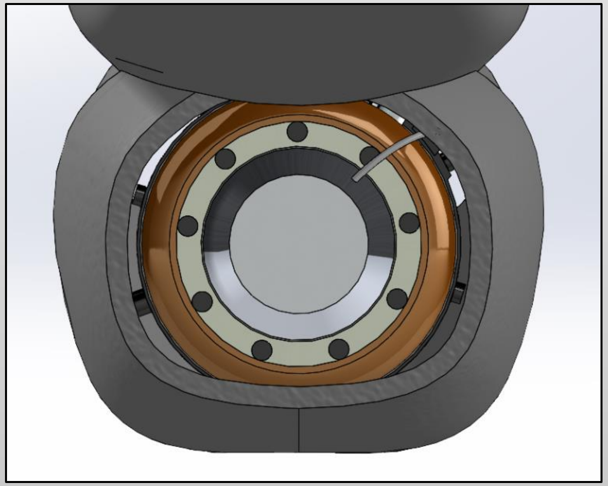


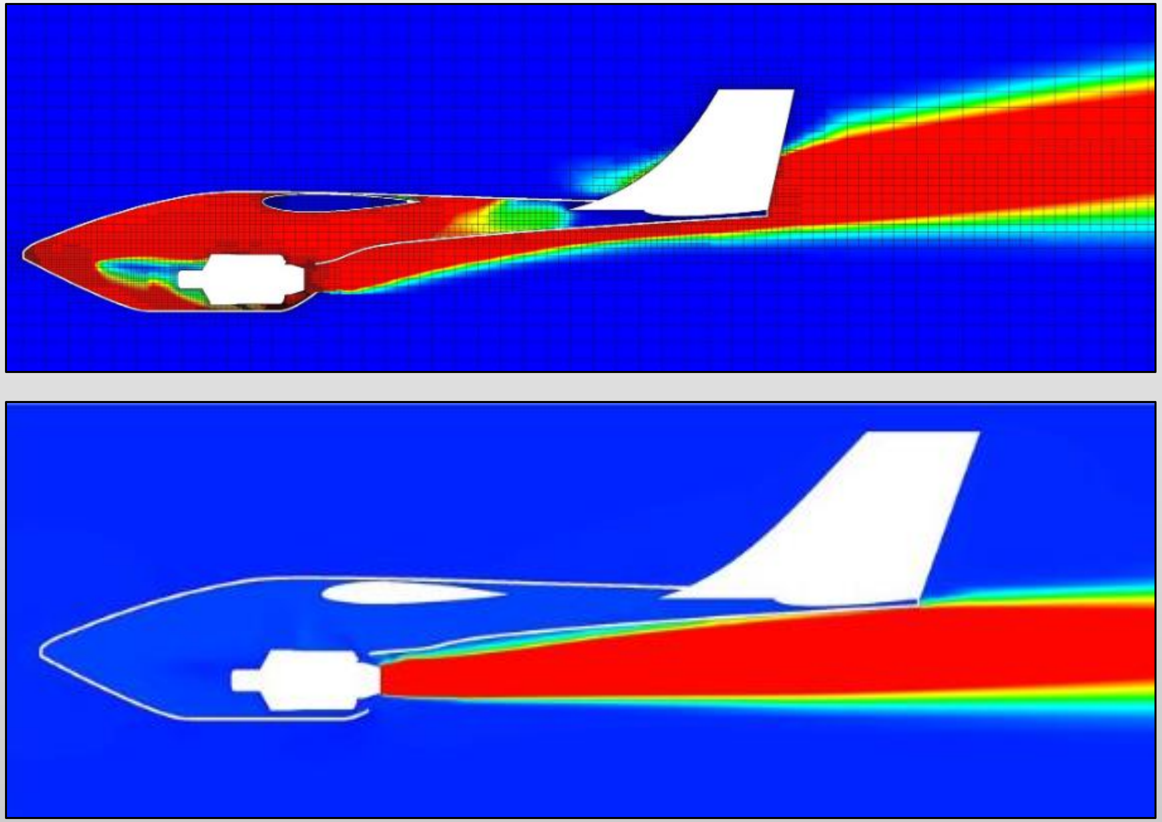
INLET TESTING

- Test Stand Changes
- PVC Pipe Continued Use for Testing
- Could not perform actual tests

EXHAUST DESIGN

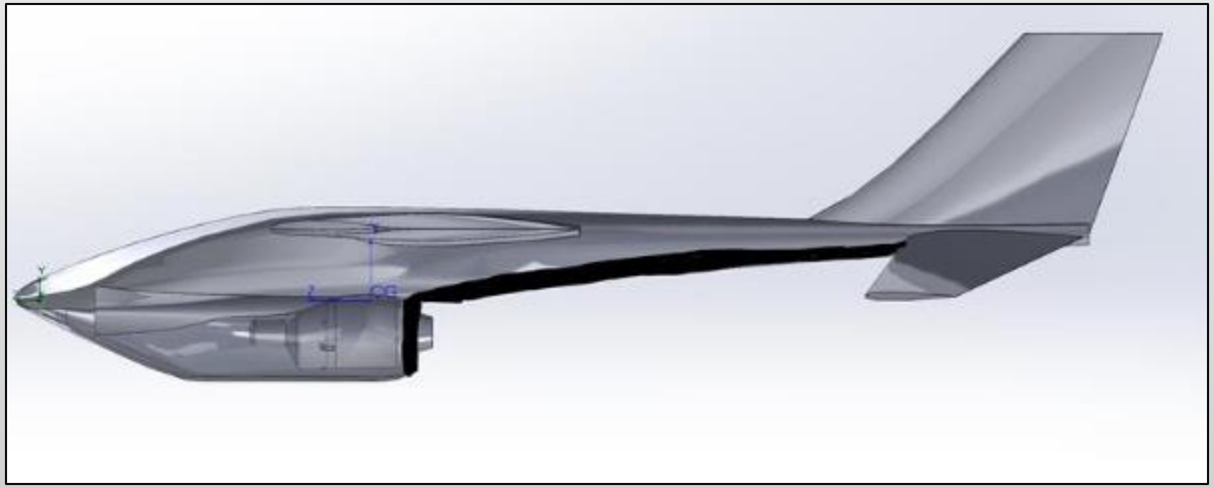
- Originally, exhaust trapped air inside fuselage
- Moved engine back to solve this
- Minimal CG change
- Nozzle sticks out .5in





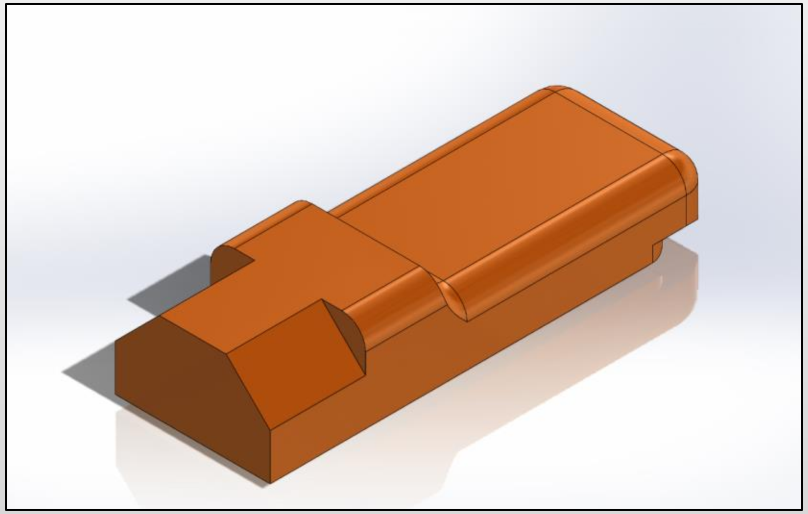
TAIL PAINT TESTING

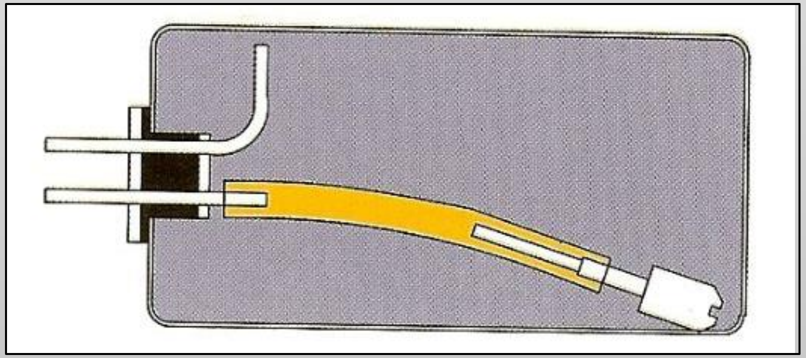
- Concerned about exhaust temps
- Rig up a mock empennage
- Put temp sensors next to tail
- Test temperature with paint applied



FUEL TANK DESIGN

- 3D Printed Tank
- Filament Choice PETG
- Sealed with epoxy
- Basic Plug
- Solder brass tube to clunk
- 40 in³
- About 4.6 minute flights





FUEL TANK TESTING

- Vacuum out air to fill gaps
- Submerged in water to test seal
- PETG and Epoxy are fuel resistant
- It works!

SUMMARY

- Mission
- Aerodynamics
- Structures
- Propulsion