SAE AERO MICRO

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INTRODUCTION

- SAE holds annual competitions across the country from which teams of college students would participate in with their best design product
- The SAE AERO competition involves competing teams in designing an original aircraft which is scored on aviation performance.
- Three different classes of the competition were offered for participation: Micro, Regular, and Advanced
- The Team spent its Capstone working on designing their aircraft while abiding by the rules and guidelines provided in the Micro Class portion of the competition

Figure 1: SAE Logo [1]

REQUIREMENTS

- The airplane must be able to complete the circuit shown in Figure 2.
  - Takeoff in a 200 ft runway
  - Immediately turn 180°
  - Fly straight for 400 feet
  - Turn 180° again
  - Land in a 200 ft strip of runway
- Wingspan of under 48”
- Must be able to carry a payload with dimensions of 6x6x4”

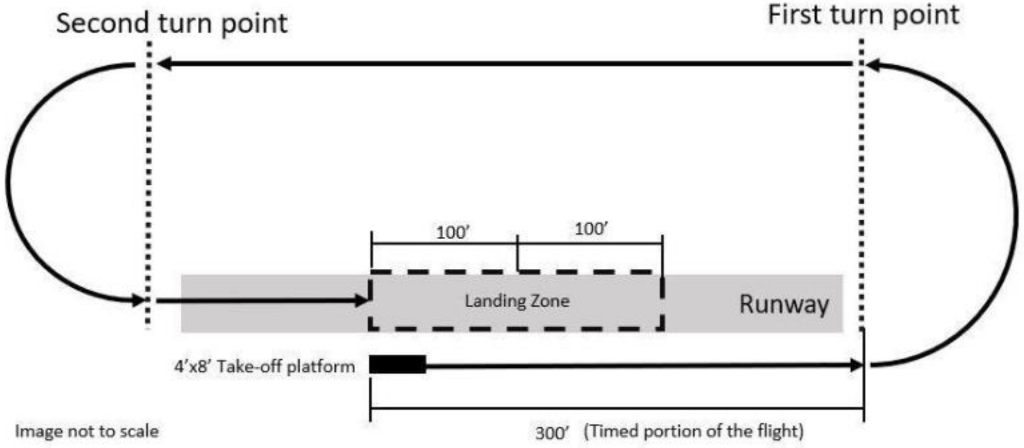

Figure 2: Competition Loop [2]

REQUIREMENTS

Customer Needs	Customer Weights	Wingspan	Cost	Battery	Thrust/Motor	Cargo Bay	Lift	Drag	Thrust	Weight	T/O velo	RC Signal Range	CG Marking	Ground Control	Flight Control	Durability	1 Poor	2	3 Acceptable	4	5 Excellent
Flight Time	9	9	3	1	9	3	9	9	9	3	9	3		3	9			AB	C		AB
Payload	9	3		3	9	9	9	1	3	9			9		3	9	AB			C	
Turning Radius/Maneuverability	3	3			3	1	1	1	9	1	9	3			3				C		AB
RC Signal Strength (2.4 GHz)	3		1	3								9								ABC	
Spare Parts	1	1	3	1												9					
Launch T/O	3	9	1		3	1	9	9	9	9	9			9	3			C	AB		
Landing	3	9	1		1	1	3	3	3	3	3			9	3			C			AB
Unloading Time	9	1												3			AB			C	
Technical Requirement Units		in	$	time	lbF/watts	in^3	N	N	N	kg	m/s	ft	in								
Technical Requirement Targets		48	2000	240	450	144	75	5	20	1.5	22	800	26								
Absolute Technical Importance		181	39	46	183	117	201	129	171	147	144	63	81	108	135	82					
Relative Technical Importance		3	12	11	2	9	1	8	4	5	6	4	6	10	7	7					

Figure 3: Quality Function Deployment (QFD)

REQUIREMENTS

The engineering requirements were driven by abiding with the rules and guidelines provided in the SAE AERO Handbook from which the aircraft was designed to meet the determined customer requirements.

Engineering Requirements:

- Wingspan
- Cost
- Battery Life
- Thrust
- Cargo Bay
- Lift
- Drag
- Weight
- RC Signal Range
- Center of Gravity
- Ground Control
- Flight Control

Customer Requirements:

- Ample time to catch flight
- Ability to carry a payload
- Achieve a turn radius midflight
- Contain an RC signal range
- Ample time for take off
- Ability to land
- Load and unload payload

DECISION MAKING - AIRFOIL

Airfoil Selection Criterion:

- Max lift at minimal angle of attack
- Minimal drag
- Best lift to drag ratio

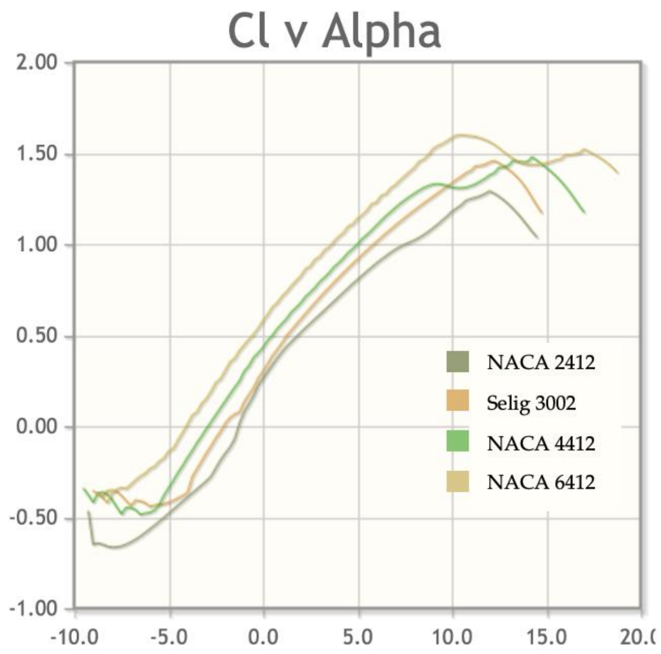

Figure 4: Lift Coefficients vs Angle of Attack for Various Airfoils [3]

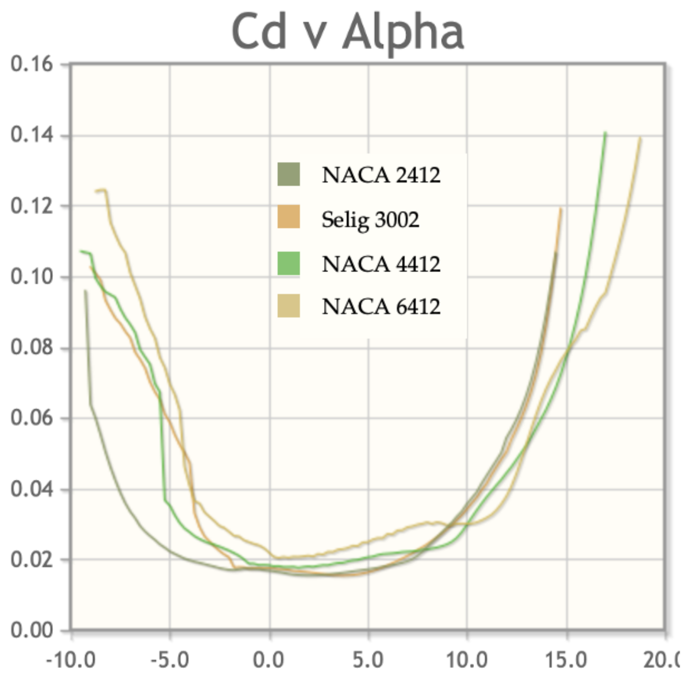

Figure 5: Drag Coefficients vs Angle of Attack for Various Airfoils [3]

DECISION MAKING - AIRFOIL

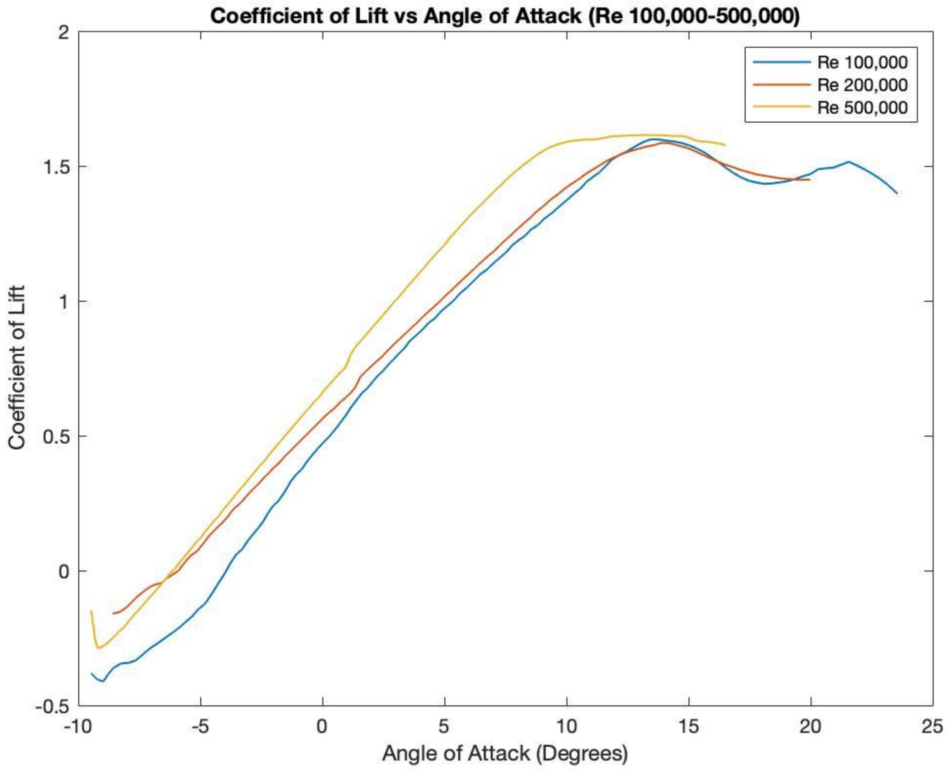

Figure 6: NACA 6412 Lift Coefficient vs Angle of Attack

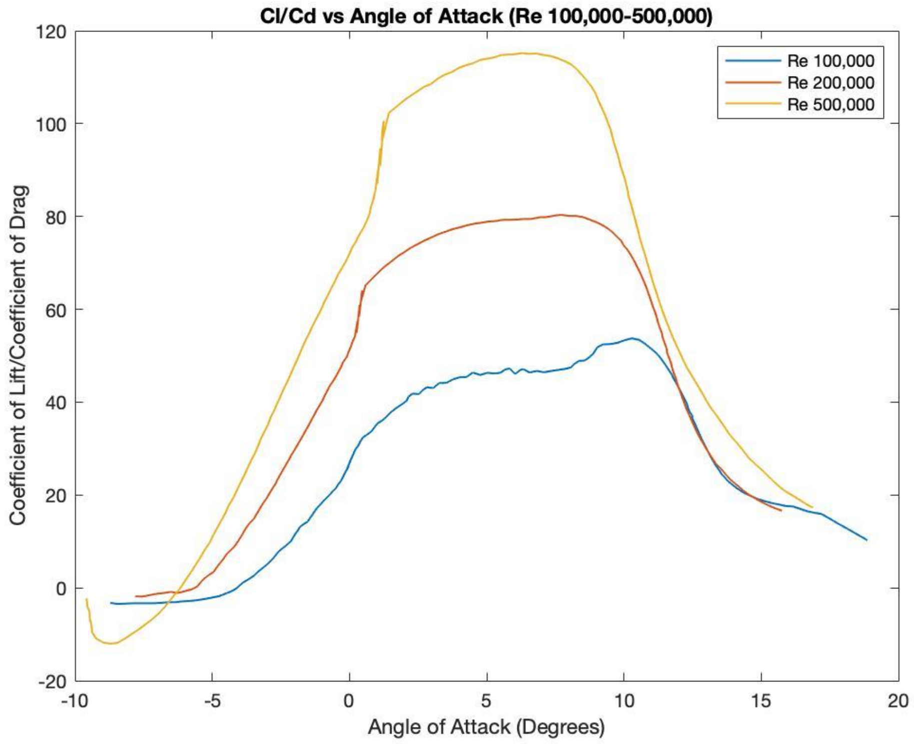

Figure 7: NACA 6412 Drag Coefficient vs Angle of Attack

Figure 8: Scorpion SII-3014-1040KV (v2)

DECISION MAKING – ELECTRONICS (THRUST)

- Selection of electronic components was centered around maximizing thrust
  - A motor manufacturer who posts thrust data was found
  - Final motor selection was Scorpion SII-3014-1040KV (v2)

DECISION MAKING – ELECTRONICS (POWER CONSUMPTION)

Component	Current Draw (mA)
Servos (x5)	3000
Receiver	30
Motor	30400
Total	**33430**

- Building in a slight factor of safety, total current draw is assumed to be 35000 mA
- A 1500 mAh battery will provide ~2.5 min of power

Figure 9: Turnigy Nano-Tech 1500 mAh Li-Po Battery [4]

DECISION MAKING – ELECTRONICS (OTHER)

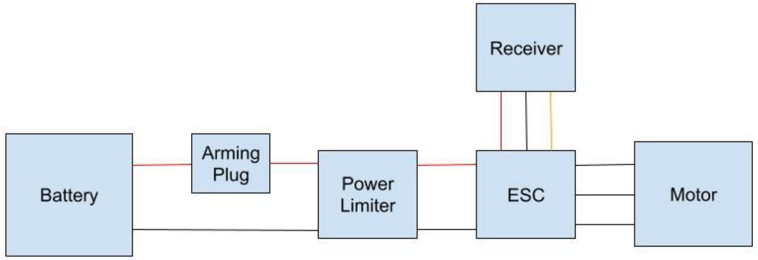

Figure 10: Electronics Schematic

Figure 11: HXT900 Servo Motor [5]

Figure 12: Neumotors SAE Power Limiter [6]

Figure 13: Turnigy 40A ESC [7]

Figure 14: Spektrum AR610 Receiver [8]

DESIGN PROCESS - AIRFOIL

- NACA 6412 Airfoil geometry selected
- 45-inch span with a 6-inch chord
- Aspect ratio: 7.5
- Carbon fiber shell reinforced with balsa wood rib and spar frame
- Servos mounted to balsa wood ribs
- Ailerons are adjusted by linked control horns and the interior servos

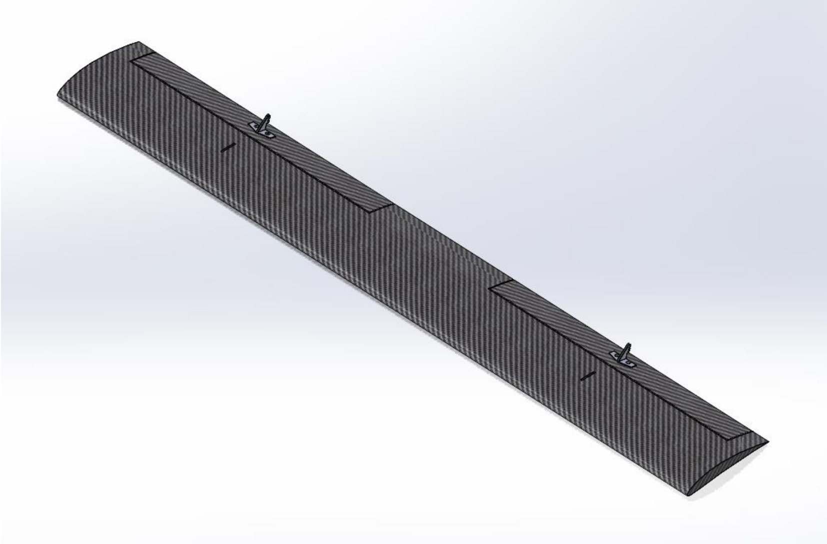

Figure 15: Wing CAD

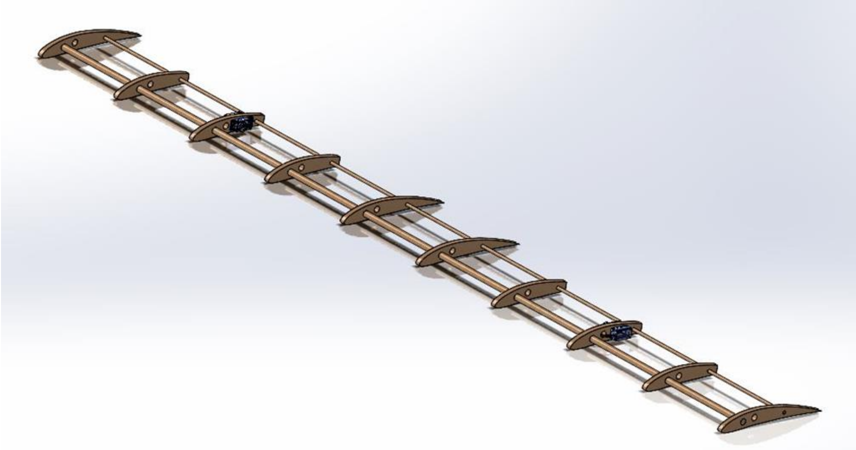

Figure 16: Internal Wing Structure CAD

DESIGN PROCESS - FUSELAGE

- Interior cargo bay large enough for carrying 6"x6"x4" payload
- Carbon fiber selected to increase durability and save weight
- Stabilizers integrated into fuselage as one piece
- Sufficient space in nose and tail sections for variable electronic configurations

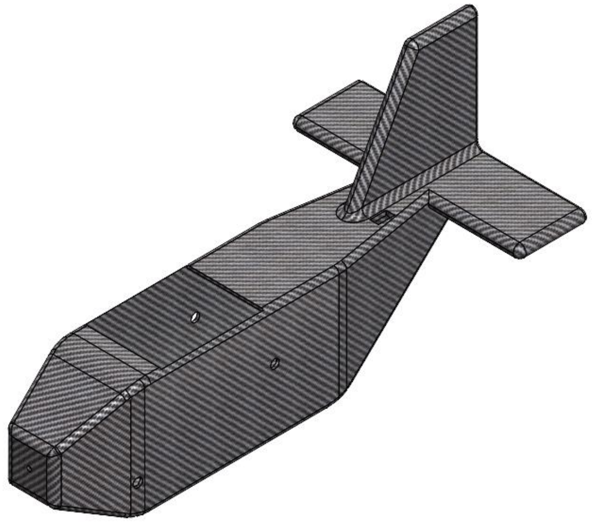

Figure 17: Fuselage CAD Isometric View

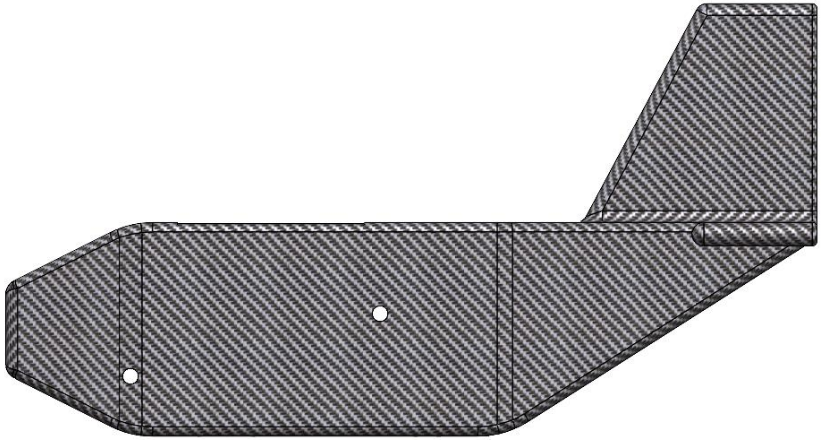

Figure 18: Fuselage CAD Side View

DESIGN PROCESS - TAIL

- Horizontal and vertical stabilizers are integrated into the fuselage
- Flat plate design for the rudder and elevator for ease in manufacturing
- Mounted to fuselage via hinges
- Control horns can be seen mounted to the rudder and elevator
- 16-gauge wire used as linkage between servos and control horns

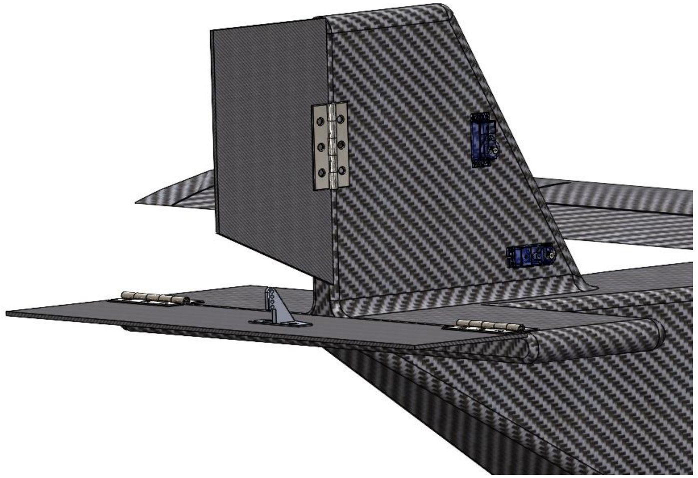

Figure 19: Horizontal and Vertical Stabilizers CAD

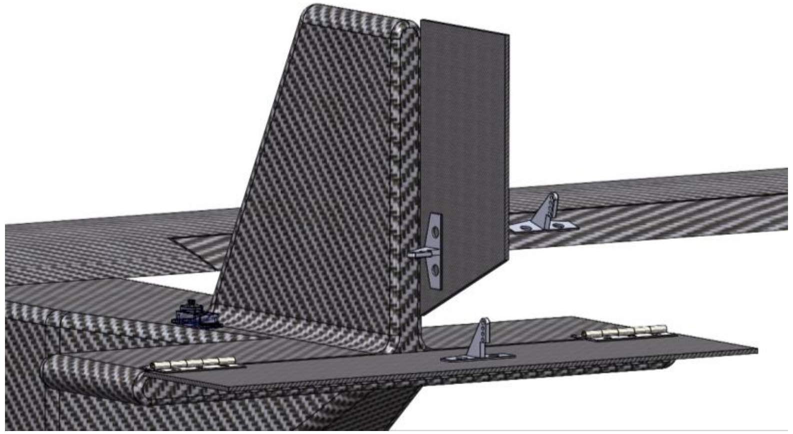

Figure 20: Horizontal and Vertical Stabilizers CAD

MANUFACTURING - AIRFOIL

- Began by 3D printing the airfoil, designed in SolidWorks with a 6" chord and 46" span
- Sanded (220Grit) until smooth, filled with bondo, and re-sanded (40Grit and up to 320Grit) until all imperfections gone
- Carbon layers were cut to size, while resin and hardener were mixed in preparation for the wet-layup
- Resin was applied to the top of the 3D print mold, and a layer of carbon was placed on top. Resin was pushed into the carbon with paintbrushes and plastic bondo spreaders. This process was repeated until all three layers were saturated in resin, and the excess carbon was trimmed with scissors
- Next step was to place the wet-layup in the open vacuum bag and cover it in peel-ply paper. This soaks up the resin as pressure is applied from the vacuum
- The bag is pulled over the mold, and 2-sided tape seals the bag off. The pressure gauge has a piece that stays inside, and the vacuum hose is hooked up. We used about 10" of Mercury to avoid the 3D print from crushing on the inside
- The mold was left at the partial vacuum overnight to harden

Figure 21: 3D Printed Wing Mold

Figure 22: Wet Layup Process

Figure 23: Wet Layup Vacuum Bag

Figure 24: Peel Ply

Figure 25: Removing Part from Vacuum Bag

Figure 26: Trimming with Dremel

Figure 27: Wing Before Being Trimmed

Figure 28: Wing After Being Trimmed

MANUFACTURING - AIRFOIL

- After an overnight vacuum pull, the bag was removed along with the peel-ply.
- All the excess fiber and material was hardened, so it was trimmed away with a Dremel and a low grit sandpaper.
- This was ½ of the wing, and the process was repeated for the bottom half of the wing. An overlap was left on the lower half of the wing, so that the 2 pieces would be able to snap together.
- The result was a 2-piece wing following the NACA 6412 airfoil, that maintained the ability to be opened quickly to access the internal spar, ribs, and control surface servos.
- After later testing, a layer of redundancy to ensure the wing would never open in flight was added by means of an 18-gauge wire running through the trailing edge. This doubled as a mounting point for the ailerons to hinge on.

MANUFACTURING - FUSELAGE

- Fuselage began as individual pieces of foam that were glued together with a plastic epoxy. The original mold was roughly 3 feet long, and it was sanded down and shaped with 40 Grit sandpaper.

- All rough edges were sanded away, while tapering the fuselage to the predetermined dimensions. All imperfections were corrected and measurements to keep the fuselage at 6"x6"x4" were taken

- The vertical and horizontal stabilizers were shaped separately and were epoxied to the fuselage. The stabilizers themselves are static, so it made sense to make them part of the overall mold to increase strength and rigidity.

- Wet-layup consisted of a top and bottom portion of the layup. The top was done first by the same process as the wing. Multiple layers of carbon fiber were layed and resin was pushed into each layer.

- The resin slowly began hardening, so the team continued to shape the layup while it was drying.

- Since the foam and the odd shapes couldn't survive the vacuum, the layup was left out overnight. Gravity was the only thing keeping the layup on the mold

Figure 29: Wet layup of Fuselage

Figure 30: Fuselage Foam Model

Figure 31: Wet layup of Fuselage

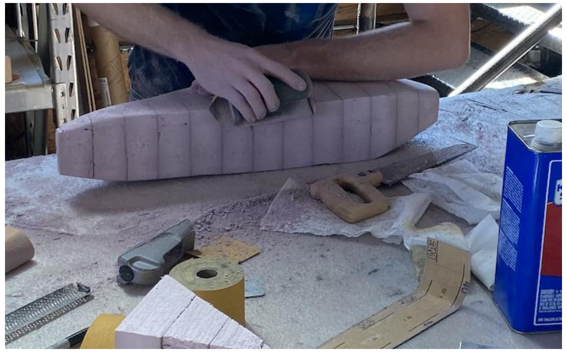

Figure 32: Shaping Foam Fuselage

MANUFACTURING - FUSELAGE

- After the top layer was hardened, the bottom layer was placed directly over top of the original. This allowed the bottom and sides of the fuselage to be extremely strong as they had upwards of 6 layers of carbon on it.
- After the bottom layer dried, a small hole was cut in the fuselage to remove all the foam mold. This was originally done with a screwdriver, then we switched to power tools. A drill with a cutting bit was used and was quite effective.
- The most effective foam removal process was acetone. The team poured acetone onto the foam, and it instantly vaporized it. The foam turned into a liquid, and was poured out as a pink, watery substance.
- The fuselage needed multiple patches on the tail portion. This was done by adding a layer of carbon onto the fuselage and infusing resin. After it set overnight, the team went back and sanded away all the imperfections.
- There were multiple "drips" of resin and carbon imperfections that were leftover. Power tools and sandpaper were used to correct all of these and leave a streamlined profile.

Figure 33: Removing Foam with Acetone

Figure 34: Fuselage Wet Layup

Figure 35: Fuselage Wet Layup

MANUFACTURING – CONTROL SURFACES

- All control surfaces were linked to servo motors via 16-gauge wire
- These servo motors move a control arm approximately 180°
- Control surfaces include ailerons, rudder, and elevator
- Rudder and elevator are mounted via piano hinges

Figure 36: Flat Plate Rudder and Elevator

Figure 37: Tail Assembly

MANUFACTURING - ASSEMBLY

- Landing gear mounted on the underbelly of the airplane
- Wing is secured to the fuselage via rubber bands and wooden dowels
- Motor is mounted to the nose of the plane
- All electronics used are housed inside the airplane

Figure 38: Final Aircraft Assembly

TESTING

- Takeoff Test - Tests the airplane's ability to takeoff from a standstill on the ground.
- Flight Test - Tests the maneuverability of the airplane. Ensures that all control surfaces and the motor are functioning.
- Landing Test - Tests the ability to land the aircraft in a designated 100-foot strip.
- Maintenance Test - Tests the ability of the team to change batteries and load or unload the payload in under 60 seconds.
- Crash Test - Tests the durability of the aircraft in a controlled test.

Figure 39: Crash Test

BUDGET

- Total Budget: $3000
- Registration: $1500
- Product Cost: $738.93
- Emergency Fund: $200
- Excess Budget: $561.07

SAEaero Capstone Project

NOTE: Difference columns in table will show if actual went over estimated amounts. Red numbers show went over (negative) and black shows under numbers (positive).

			Itemized Cost ($)			Total Cost ($)		
Area	Items	Quantity	Estimated	Actual	Difference	Estimated	Actual	Difference
Amazon	Dowel Rods 1/8" x 12"	1	($9.19)	($9.19)	$0.00	($9.19)	($9.19)	$0.00
Amazon	Dowel Rods 1/4" x 12"	1	($8.19)	($8.19)	$0.00	($8.19)	($8.19)	$0.00
Amazon	Amazon Shipping/Tax 2	1	($1.59)	($1.59)	$0.00	($1.59)	($1.59)	$0.00
Electronics	Amazon Adaptors	1	($10.00)	($9.42)	$0.58	($10.00)	($9.42)	$0.58
Electronics	Amazon Wires	1	($10.00)	($9.89)	$0.11	($10.00)	($9.89)	$0.11
Electronics	Amazon Z Shipping/Tax 1	1	($1.00)	($1.77)	($0.77)	($1.00)	($1.77)	($0.77)
Electronics	Hobby King Battery 1000mAh	3	($18.00)	($17.01)	$0.99	($54.00)	($51.03)	$2.97
Electronics	Hobby King Connectors	1	($4.00)	($3.03)	$0.97	($4.00)	($3.03)	$0.97
Electronics	Hobby King Servos	7	($4.00)	($3.49)	$0.51	($28.00)	($24.43)	$3.57
Electronics	Hobby King Speed Controller	1	($22.00)	($21.99)	$0.01	($22.00)	($21.99)	$0.01
Electronics	Hobby King Z Shipping/Tax 1	1	($15.00)	($29.36)	($14.36)	($15.00)	($29.36)	($14.36)
Electronics	SAE Competition Power Limiter	1	($75.00)	($83.00)	($8.00)	($75.00)	($83.00)	($8.00)
Electronics	Hobby King Battery 1500mAh	6	($17.39)	($17.39)	$0.00	($104.34)	($104.34)	$0.00
Electronics	Hobby King Shipping/Tax 2	1	($15.00)	($16.20)	$1.20	($15.00)	($16.20)	($1.20)
Motor	Scorpion Motor 2	1	($110.00)	($109.99)	($0.01)	($110.00)	($109.99)	$0.01
Motor	Scorpion Motor Shipping/Tax 2	1	($50.00)	($49.24)	($0.76)	($50.00)	($49.24)	$0.76
Motor	Motor and Tax 1	1	($120.00)	($146.57)	($26.57)	($120.00)	($146.57)	($26.57)
Propeller	acp 9x4 Propeller	7	($3.00)	($2.84)	$0.16	($21.00)	($19.88)	$1.12
Propeller	acp 9x4 Propeller Z Shipping/Tax 1	1	($5.00)	($4.50)	($0.50)	($5.00)	($4.50)	$0.50
Propeller	acp 9x4 Propeller	4	($3.00)	($2.84)	($0.16)	($12.00)	($11.36)	$0.64
Propeller	acp 9x4 Propeller Z Shipping/Tax 2	1	($5.00)	($5.42)	$0.42	($5.00)	($5.42)	($0.42)
Registration Fee	Registration Fee	1	($1,500.00)	($1,500.00)	$0.00	($1,500.00)	($1,500.00)	$0.00
Total Budget	Total Budget	1	$3,000.00	$3,000.00	$0.00	$3,000.00	$3,000.00	$0.00
Wings	Horizon Hobby Material for Wings	1	($13.00)	($12.99)	$0.01	($13.00)	($12.99)	$0.01
Wings	Horizon Hobby Material for Wings Z Shipping/Tax 1	1	($5.00)	($5.55)	$0.55	($5.00)	($5.55)	($0.55)
Subtotal			$975.64	$928.54	($45.62)	$801.69	$761.07	($40.62)
Total spent (excluding registration)			($571.46)			($738.93)		
Unexpected Costs ($200)			($200.00)			($200.00)		
Total costs			$728.54			$561.07		

FUTURE WORK

Figure 40: Completed Aircraft Design

- Get a more reliable landing gear
- Focus on moving the center of gravity forward
- Decrease the amount of weight on the tail
- Enclose motor inside a housing
- Design better wing attachment to fuselage
- Establish better attachment for elevator

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