SAE Aero Design

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NORTHERN ARIZONA UNIVERSITY

SAE INTERNATIONAL

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Introduction

- Dr. John Tester, advisor for the NAU SAE club
- Build an airplane that adheres to SAE competition requirements
- Testing flight performance in preparation for SAE competition

Need Statement

- Northern Arizona University currently does not have an operational airplane to compete in the SAE Aero design competition

Project Goals

- Design and build an aircraft that adheres to the SAE Aero competition requirements
- Gain valuable knowledge in the mechanical engineering design and manufacturing processes, specifically in airplane design

Objectives

Objective	Measurement	Units of Measurement
Carry max payload	Weight	lbf
Carry a payload from point A to B	Distance	ft
Small turning radius	Distance	ft

Constraints

- Freestanding aircraft must not exceed a combined length, width and height of 175 in
- Aircraft must be powered by a commercially available lithium-polymer battery pack
- Must use a new 2015 version 1000 W power limiter provided by Neumotors.com
- Interior payload bay must be smooth and dimensions must be 10’’x4’’x4’’ (length, width, height) with a tolerance of +0.125”
- Payload must be secured to an airframe, with payload plates
- Airplane must land and take off within 200 ft
- Must complete all tasks within 180 s

Quality Function Deployment

Regular Class Design Requirements	Weights	Size	Safety	Material	Motor	Gear Box	Battery	Radio System	Interior Dimension
AIRCRAFT DIMENSION REQUIREMENT	5	9	1	0	0	1	0	0	9
MATERIAL AND EQUIPMENT RESTRICTIONS FOR REGULAR CLASS	5	3	9	9	9	1	3	3	1
AIRCRAFT SYSTEM REQUIREMENTS	5	3	9	3	9	1	9	9	0
PAYLOAD REQUIREMENTS	5	3	3	9	3	1	3	0	9
	Raw score	90	110	105	105	20	75	60	95
	Scaled	1	1	1	1	1	1	1	1
	Relative Weight	14%	17%	16%	16%	3%	11%	9%	14%
	Rank	5	1	2	2	8	6	7	4

Component Criteria

Airfoil

- Coefficient of Lift (max)
- Design Lift Coefficient
- Coefficient of Drag
- Lift-to-Drag Ratio
- Lift Curve Slope (max)
- Pitching Moment Coefficient
- Stall Quality

Vertical and Horizontal Stabilizers

- Stability Coefficient
- Pitching Control
- Yaw Control
- Weight

Wing Placement Configuration

- Weight
- Loading
- Coefficient of Lift (max)
- Coefficient of Drag (min)
- Lift-to-Drag Ratio

Landing Gear Configuration

- Weight
- Strength
- Coefficient of Drag
- Control

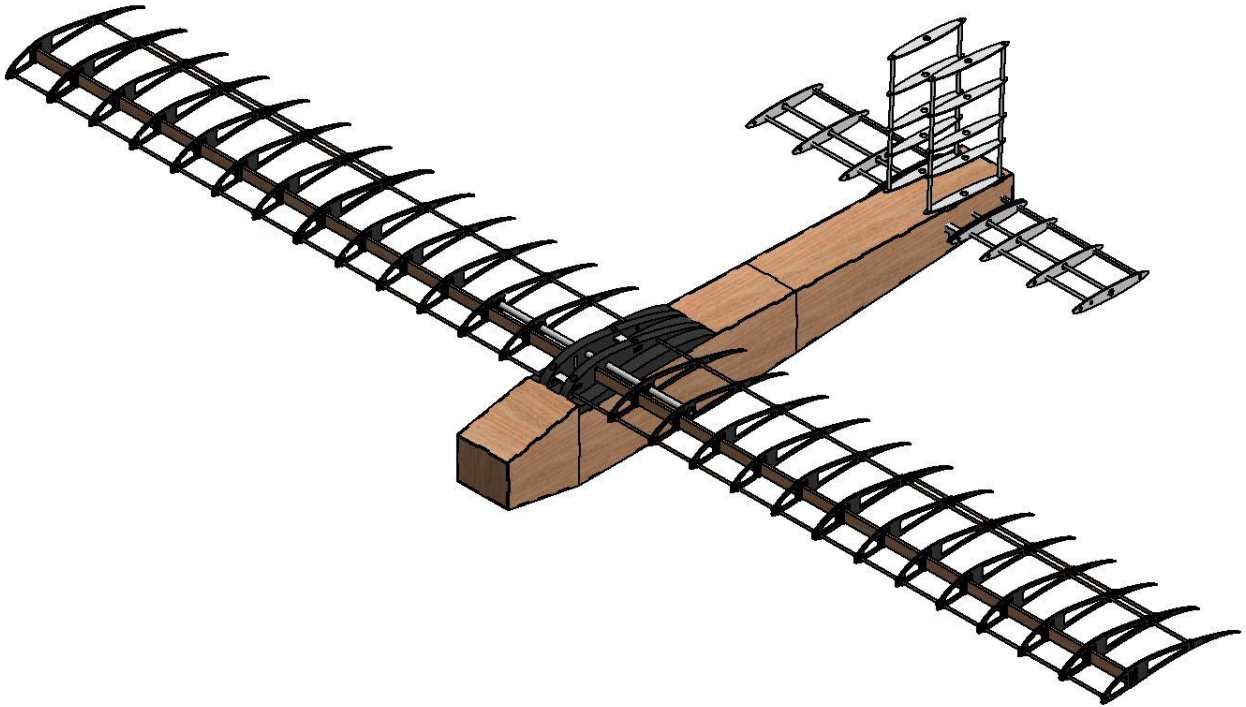
Fuselage Design

- Weight
- Strength
- Coefficient of Drag
- Length

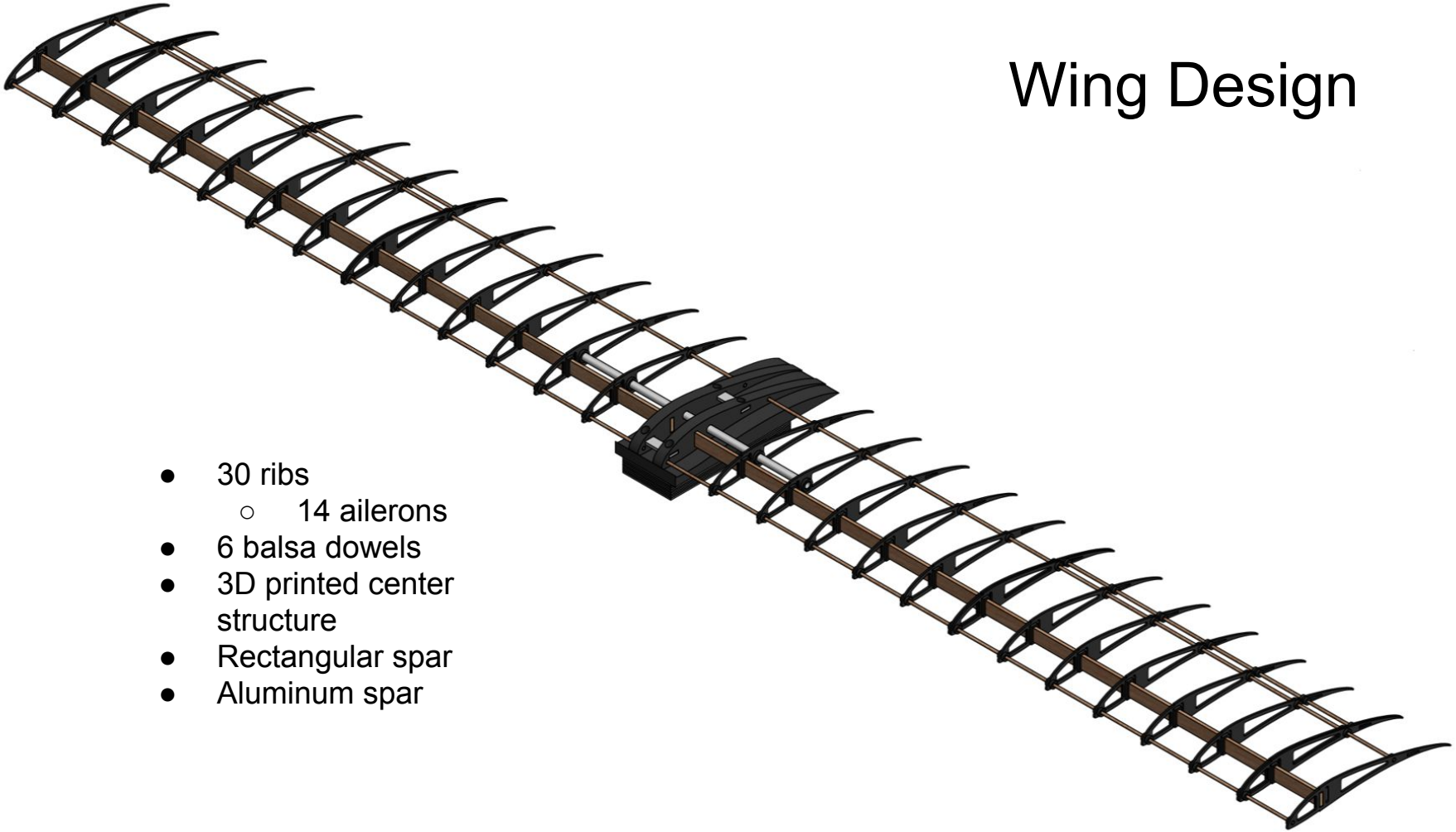
Payload Configuration

- Payload
- Weight
- Cost
- Ease of Construction

Final Design - CAD Drawing

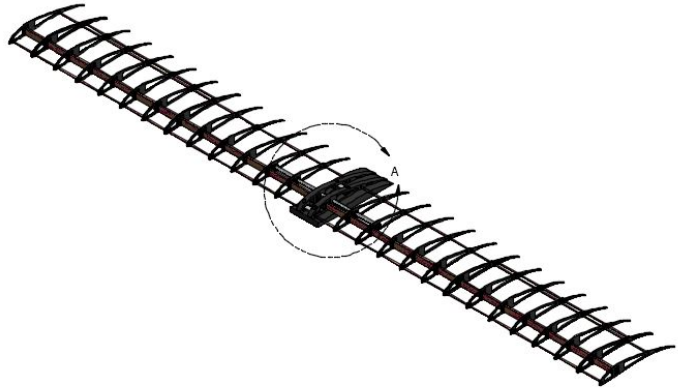


Wing Design

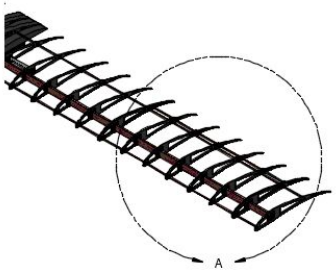


- 30 ribs
  - 14 ailerons
- 6 balsa dowels
- 3D printed center structure
- Rectangular spar
- Aluminum spar

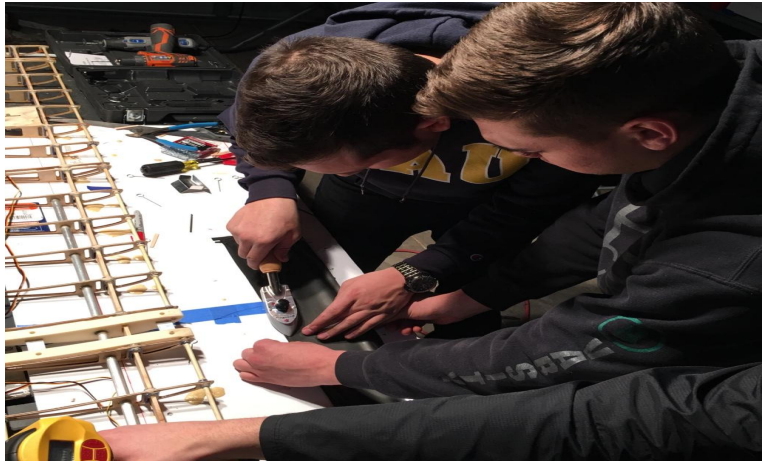
Wing Design - Details

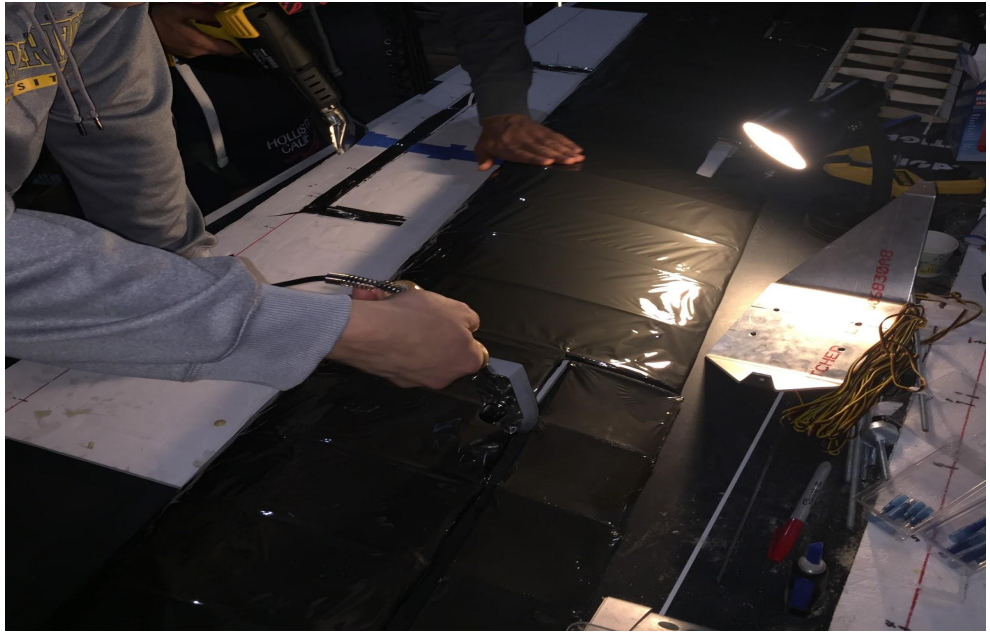


Wing Design - Details



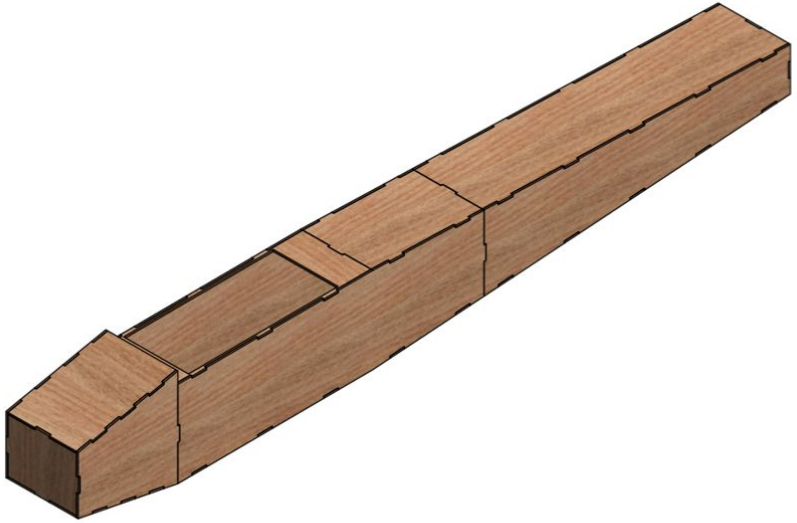
Wing Fabrications

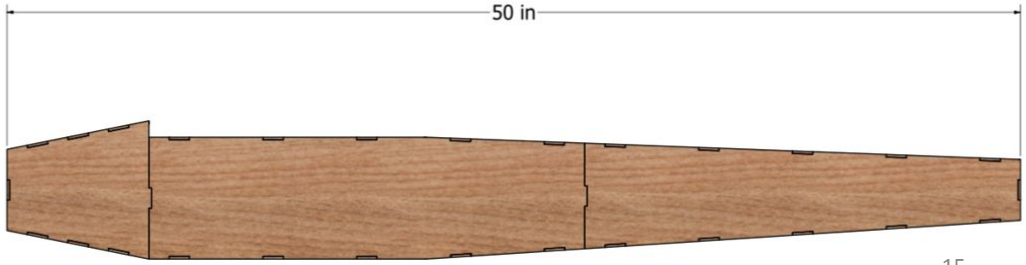




Completed Wing

Fuselage Design



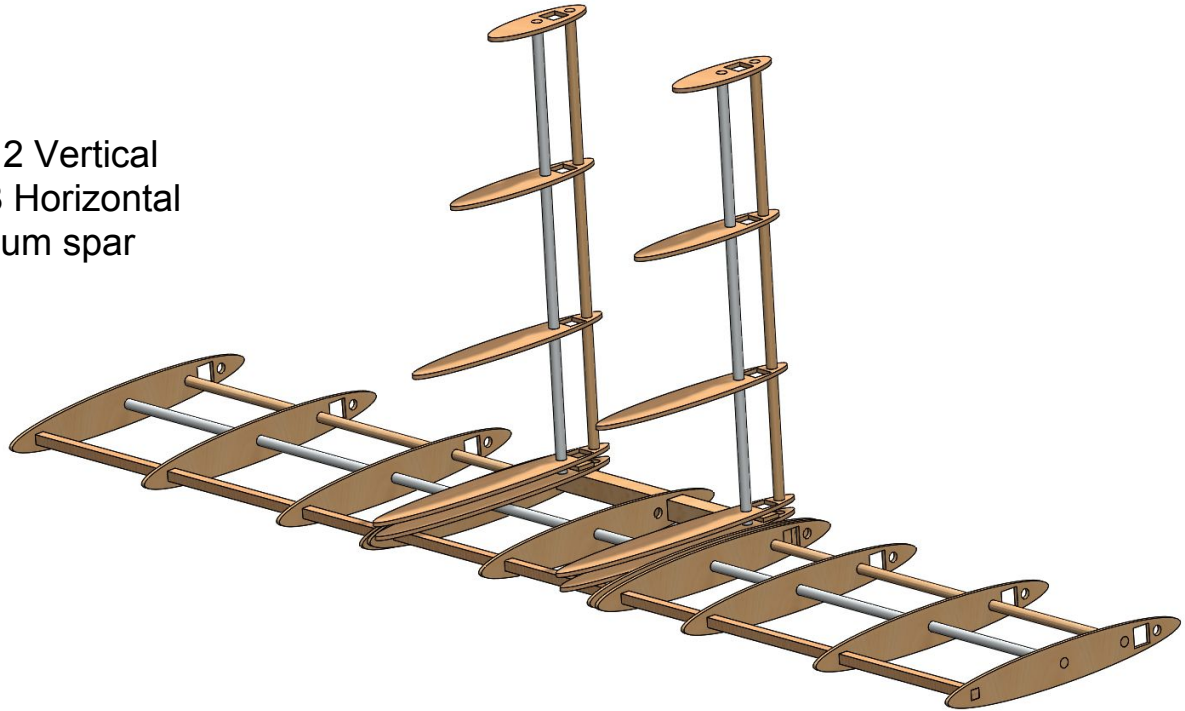


Fuselage Fabrications

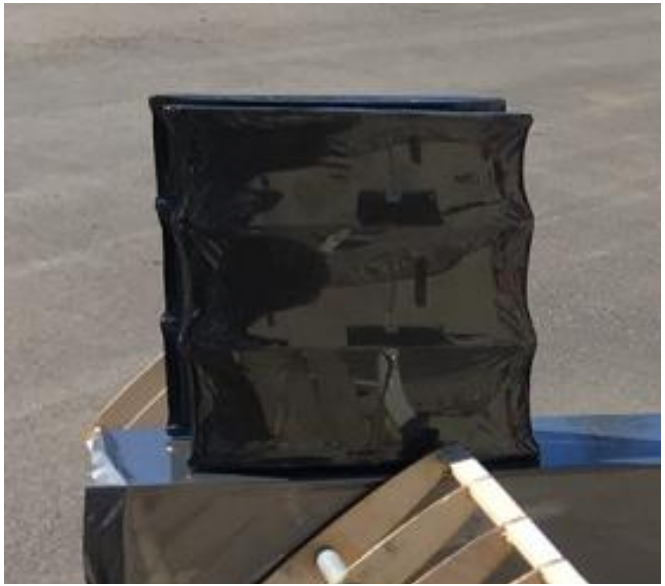
Completed Fuselage

Tail Design

- 20 ribs
  - 12 Vertical
  - 8 Horizontal
- Aluminum spar



Tail Fabrications



Completed Tail

Electronics

- Motor - AXI 5325/16 GOLD LINE

- Propeller - APC 18x12WE

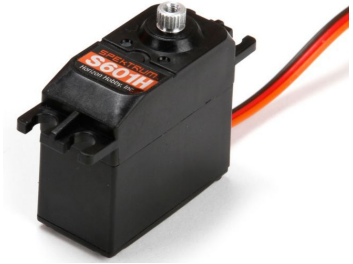
- ESC/BEC-CASTLE CREATIONS Phoenix Edge 75

Electronics

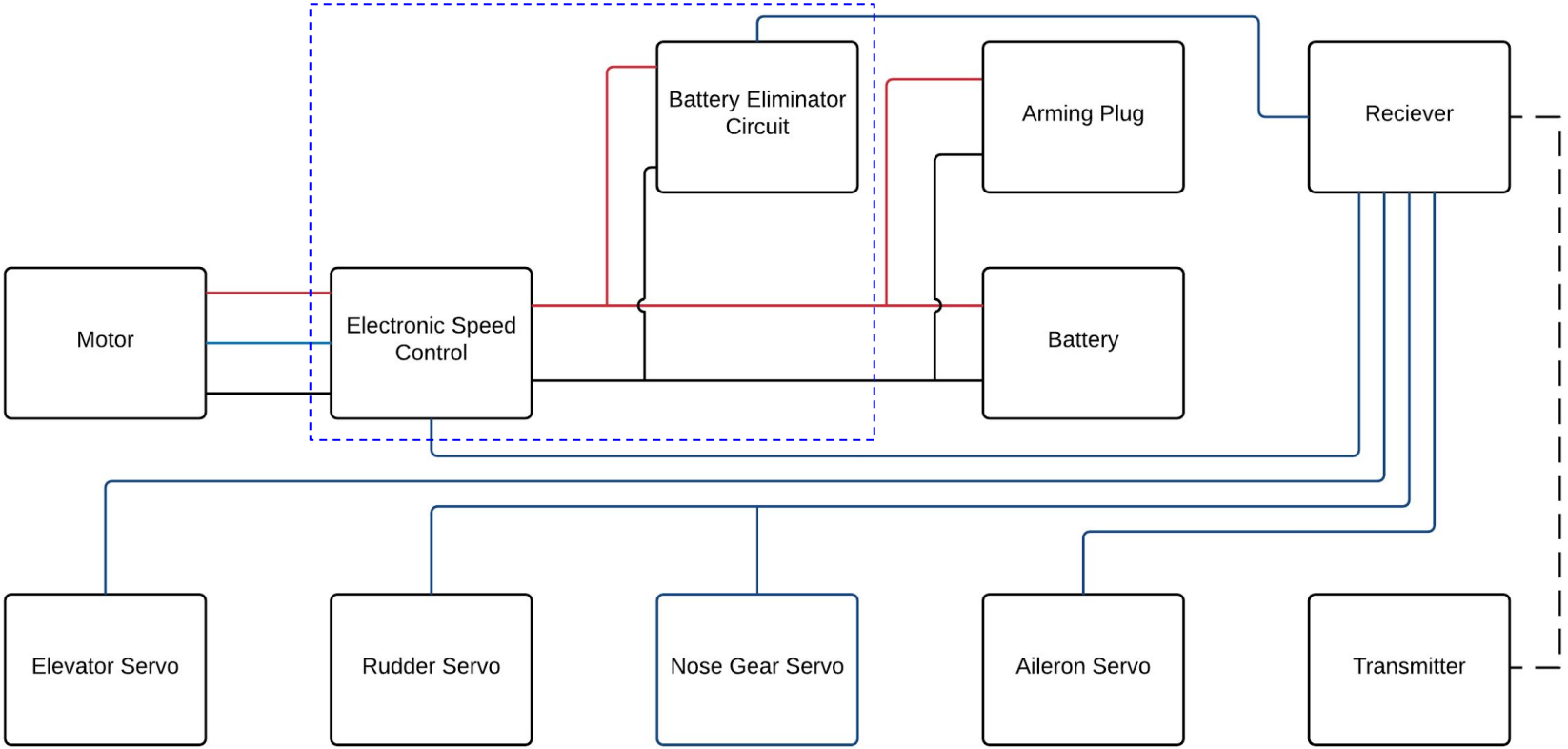
- Battery-Turnigy 5000mAh 6S 22.2V 20C LiPo, 12AWG EC3

- Receiver-AR610 6-Channel DSMX Aircraft Receiver (SPMAR610)

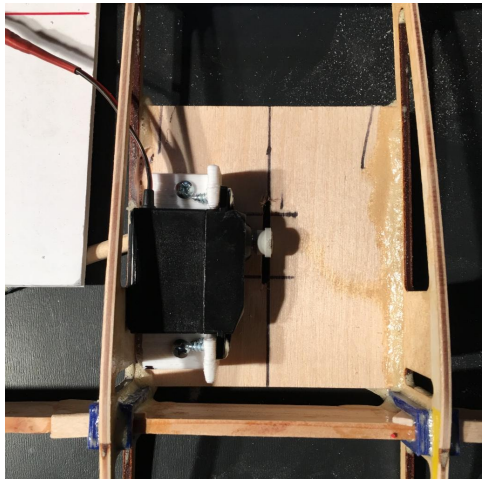
- Servos-Extra High Torque Servo (SPMS601H)

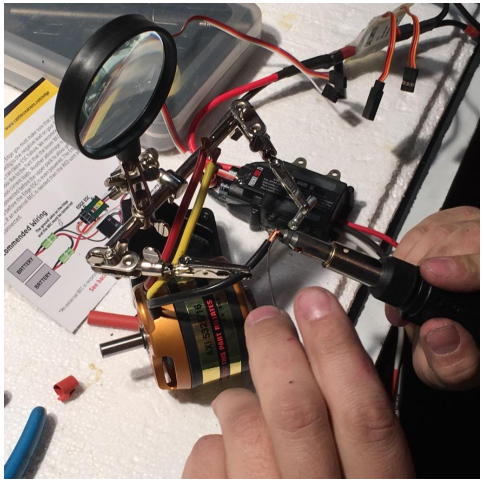


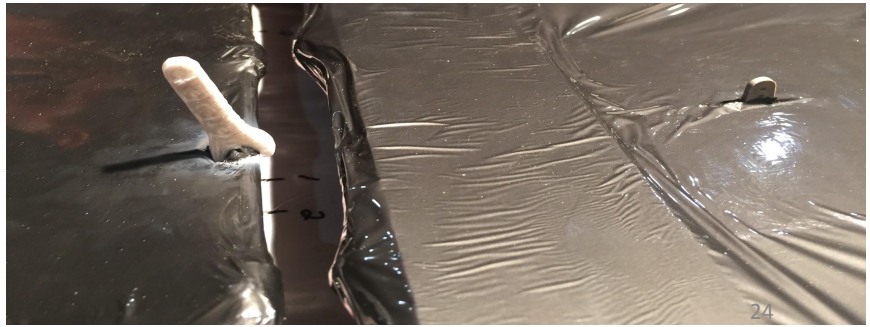
Circuit Diagram



Electronics







Flight Calculations

General	Motor Cooling: medium ▼	# of Motors: 1 (on same Battery)	Model Weight: 4536 g / 160 oz incl. Drive ▼		Wing Area: 96.8 dm² / 1500 in²	Field Elevation 500 m ASL / 1640 ft ASL	Air Temperature 25 °C / 77 °F	Pressure (QNH): 1013 hPa / 29.91 inHg	
Battery Cell	Type (Cont. / max. C) - charge state: LiPo 3300mAh - 30/45C ▼ - normal ▼	Configuration: 6 S 1 P	Cell Capacity: 3300 mAh	Total Capacity: 3300 mAh	Resistance: 0.0052 Ohm	Voltage: 3.7 V	C-Rate: 30 C cont. / 45 C max	Weight: 93 g / 3.3 oz	
Controller	Type: CC Phoenix Edge 75 ▼	cont. Curent: 75 A	max. Curent: 75 A		Resistance: 0.010 Ohm			Weight: 114 g / 4 oz	
Motor	Manufacturer - Type (Kv): AXI ▼ 5325/16 (350) ▼ search...	KV (w/o torque): 350 rpm/V	no-load Current: 2.1 A @ 30 V	Limit (up to 15s): 85 A ▼	Resistance: 0.026 Ohm	Case Length: 59 mm / 2.32 inch	# mag. Poles: 14	Weight: 575 g / 20.3 oz	
Propeller	Type - yoke twist: APC Electric E ▼ - 0° ▼	Diameter: 18 inch	Pitch: 12 inch	# Blades: 2	PConst / TConst: 1.08 / 1.0	Gear Ratio: 1 : 1	Flight Speed: 32.2 km/h / 20 mph	calculate	

Flight Calculations

Load:

Mixed Flight Time:

Current:

est. Temperature:

Thrust-Weight:

Pitch Speed:

Remarks:

Battery		
Load:	20.21	C
Voltage:	20.12	V
Rated Voltage:	22.20	V
Capacity:	3300	mAh
Energy:	73.26	Wh
Flight Time:	3.0	min
Mixed Flight Time:	5.2	min
Weight:	558	g
	19.7	oz

Motor @ Optimum Efficiency		
Current:	33.62	A
Voltage:	20.81	V
Revolutions*:	6725	rpm
electric Power:	699.8	W
mech. Power:	633.1	W
Efficiency:	90.5	%

Motor @ Maximum		
Current:	66.69	A
Voltage:	19.45	V
Revolutions*:	5927	rpm
electric Power:	1297.3	W
mech. Power:	1136.6	W
Efficiency:	87.6	%
est. Temperature:	75	°C
	167	°F

Propeller		
Static Thrust:	6615	g
	233.3	oz
Revolutions*:	5927	rpm
Stall Thrust:	3844	g
	135.6	oz
Thrust @ 32.2 km/h:	4650	g
Thrust @ 20 mph:	164	oz
Pitch Speed:	108	km/h
	67	mph
Tip Speed:	511	km/h
	317	mph
specific Thrust:	2.96	g/W
	0.1	oz/W

Total Drive		
Drive Weight:	1372	g
	48.4	oz
Power-Weight:	326	W/kg
	148	W/lb
Thrust-Weight:	1.46	: 1
P(in) @ max:	1480.5	W
P(out) @ max:	1136.6	W
Efficiency @ max:	76.8	%

Airplane		
All-up Weight:	4536	g
	160	oz
Wing Load:	47	g/dm²
	15.4	oz/ft²
Cubic Wing Load:	4.8	
est. Stall Speed:	33	km/h
	20	mph
est. Speed (level):	97	km/h
	60	mph
est. Speed (vertical):	33	km/h
	20	mph
est. rate of climb:	10.1	m/s
	1982	ft/min

Flight Calculations

Motor Partial Load												
Propeller rpm	Throttle %	Current (DC) A	Volage (DC) V	el. Power W	Efficiency %	Thrust g	Spec. Thrust g/W	Pitch Speed km/h	Thrust oz	Spec. Thrust oz/W	Pitch Speed mph	Flight Time (85%) min
800	11	0.3	22.2	6.2	45.3	121	19.6	15	4.3	0.69	9	599.9
1200	17	0.7	22.2	14.8	63.9	271	18.4	22	9.6	0.65	14	250.2
1600	22	1.4	22.2	30.0	74.5	482	16.1	29	17.0	0.57	18	122.9
2000	28	2.5	22.1	54.1	80.6	753	13.9	37	26.6	0.49	23	67.8
2400	34	4.1	22.1	89.6	84.1	1085	12.1	44	38.3	0.43	27	40.8
2800	40	6.4	22.0	138.9	86.2	1476	10.6	51	52.1	0.37	32	26.2
3200	47	9.5	21.9	204.5	87.4	1928	9.4	59	68.0	0.33	36	17.7
3600	53	13.6	21.8	288.9	88.1	2440	8.4	66	86.1	0.30	41	12.4
4000	60	18.7	21.6	394.9	88.4	3013	7.6	73	106.3	0.27	45	9.0
4400	**67**	**25.2**	**21.4**	**525.1**	**88.5**	**3646**	**6.9**	**81**	**128.6**	**0.24**	**50**	**6.7**
4800	75	33.2	21.2	682.3	88.4	4339	6.4	88	153.0	0.22	55	5.1
5200	83	42.9	20.9	869.2	88.2	5092	5.9	95	179.6	0.21	59	3.9
5600	92	54.9	20.5	1088.9	88.0	5905	5.4	102	208.3	0.19	64	3.1
5927	100	66.7	20.1	1297.3	87.6	6615	5.1	108	233.3	0.18	67	2.5

Final Design Specifications

- Final Dimensions-99” Width x 55” Length x 19” Height
- 173” Total Linear Dimension
- Heavy Duty Tricycle Landing Gear
- 4” Wheels
- Stabilator Vertical and Horizontal Control Surfaces
- 22.2V DC Motor
- 18x12 Propeller

Modifications

Final Prototype

Flight Test

Testing Result

What went wrong?

- Connection to control surface on left side of wing failed
- Without the control surface the pilot could not correct the movement of the plane
- Resulting in loss of control of the aircraft
- In the next iteration, the team will improve the control surface connections and establish extensive preflight inspections

Bill of Materials

Bill of Materials

Items	Quantity	Description	Cost
Motor	1	AXI 5325/16 GOLD LINE	$299.99
Motor mount	1	N/A	
Propeller	1	APC 18x12WE	$11.72
Nose gear	1	Nose Gear with Nose Gear Mount Block (HAN1306)	$4.99
Landing gear	1	Constructing at machine shop	
ESC/BEC	1	CASTLE CREATIONS Phoenix Edge 75	$101.96
Battery	1	Eflight 3200mAh 6S 22.2V 30C LiPo, 12AWG EC3	$99.99
Arming plug	1	SAE 2016 Arming Safety Harness	$30.00
Power limiter	1	SAE Limiter V2 2016	$50.00
Receiver	1	AR610 6-Channel DSMX Aircraft Receiver (SPMAR610)	$49.99
Servos	5	Extra High Torque Servo (SPMS601H)	$44.99
Y-harness	2	Y-Harness: Telemetry (SPM1516)	$5.99
Wheels (2 orders)	4	Big Wheels, 4" (DUB400RV)	$15.49
Balsa dowels	10	3/16" x 3' balsa dowels	$57.80
Balsa sheeting	6	Balsa Sheet 3/16 x 12 x 36	$112.59
Pine spar	2	2in.x4in.x10ft Kiln-Dried Heat Treated Spruce-Pine-Fir Lumber (161659)	$4.05
Aluminum tubing	1	36 in. x 1/2 in. x 1/16 in. Aluminum Round Tube	$10.67
Aluminum sheeting	n/a	3/16" Aluminum Scraps	Donated
1/32-in nylon-coated cable	1	Loos Galvanized Steel Wire Rope, Nylon Coated, 7x7 Strand Core	$12.16
ABS	29.58in^3	$250/52in^3	$142.22
TOTAL			**$1,054.60**

Conclusions

- Dr. John Tester tasked us to construct an airplane for the SAE competition
- Constructed an RC aircraft that fulfills specified constraints and objectives
- Majority of the aircraft was constructed out of birch wood and rapid prototyped components
- Testing revealed design flaws in the control surface connections that will be rectified in future iterations
- Gained valuable knowledge in the mechanical engineering design process

Acknowledgements

- Dr. Srinivas Kosaraju
- Dr. John Tester
- NAU Mechanical Engineering Department
- Mr. Craig Howdeshell, Coconino High School
- Mr. Seth Lawrence

References

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Questions ?