College of ENGINEERING & TECHNOLOGY
UTAH VALLEY UNIVERSITY

Spring 2022 ME 4820 Capstone II

UAV Capstone Team

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22 April 2022

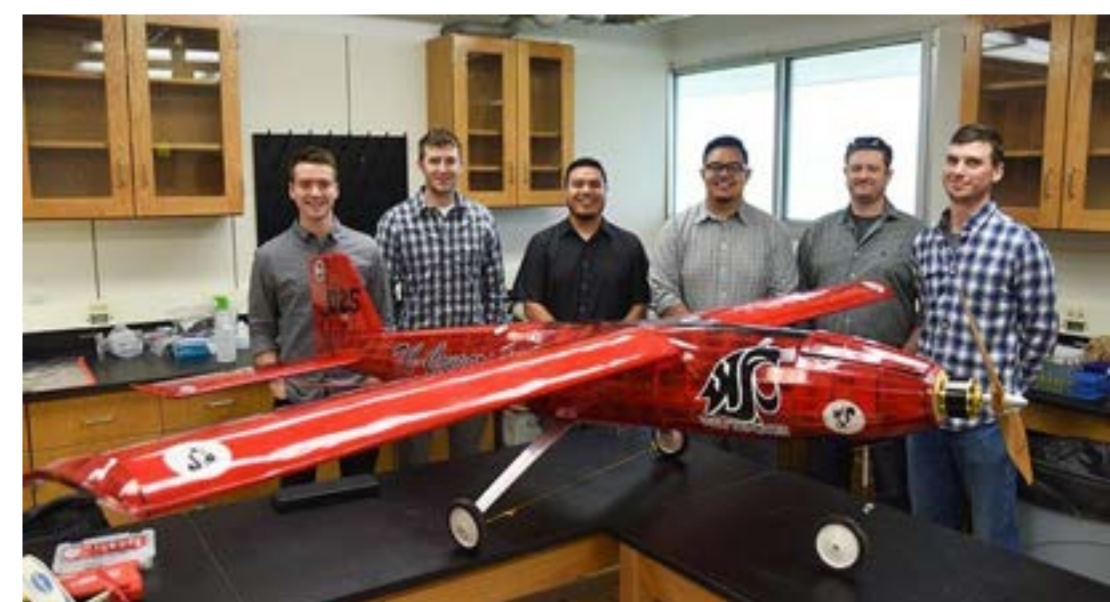
Presentation Overview

- Project Summary/Goals
- Problem Definition
- Concept Generation/Selection
- Modeling, Testing, and Analysis
- Final Design

Problem Definition

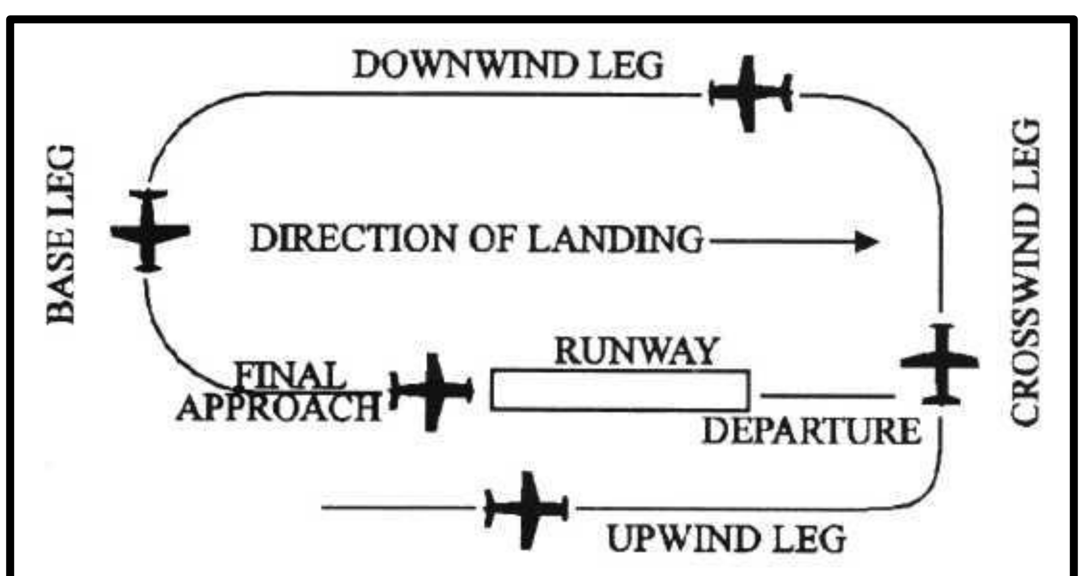
- **Society of Automotive Engineers Aero Design competition**
  - International fixed wing unmanned aerial vehicle competition

- **Customers**
  - UVU
  - R/C enthusiasts, search and rescue teams
  - SAE International
  - Other regulating bodies (FAA, IEEE, FCC)



Customer Needs SAE

- **Most needs were collected from SAE Aero Design competition Rules.**
- **Most relevant**
  - Take off in <100 ft
  - Wingspan <10 ft
  - Carry at least one soccer ball



1. All electric.
2. Completely original
3. Properly labeled (2.1)
4. Fixed wing only (2.2)
5. Center of gravity labeled(2.3)
6. Gross take-off weight less than 55lbs (2.4)
7. Controllable in the air and on ground (2.5)
8. 2.4 GHz radio control system (2.6)
9. System shutdown if signal is lost(2.6)
10. Spinner safety nut used(2.7)
11. No metal props (2.8)
12. No lead (2.9)
13. Payload cannot contribute to structure of UAV (2.10)
14. Payload plates secured to bay as one mass (2.11)
15. No excessive slop in control surfaces (2.13)
16. Servo sizing analysis required for design report(2.1)
17. Clevis must have mechanical keepers (2.15)
18. Motor must be only source of power (2.16)
19. No homemade batteries. Secured properly. (2.17)
20. Power limiter from Neumoteros.com only (2.18)
21. Red arming plug to disarm propulsion system, properly placed (2.19)
22. To receive full flight score the Aircraft must remain intact (3.5)
23. Takeoff in under 180 sec (3.7)
24. Takeoff in 100 ft, and turn in 400.(3.8)
25. Land in 400ft (3.9)
26. Payload needs to be able to be unloaded in less than 2 minutes. (6.0) (Conflicts with section 7.5)
27. Wingspan less than 10ft(7.1)
28. Cannot use FRP with exceptions(7.2)
29. Rubber bands cannot be used to secure wing or payload (7.2)
30. No gyroscopic stability assistance (7.2)
31. Only one electric motor for propulsion(7.3)
32. Prop RPM = Motor RPM (7.3)
33. Lithium polymer battery pack must be used. Minimum requirements given (7.3)
34. Must have a 2019 V@ or newer 1000 watt power limiter. (7.3)
35. Servo battery must be adequately sized, with an external switch (7.3)
36. Payload must be inside the craft (7.4)
37. There are two types of cargo: Spherical (Size 5 Soccer Balls) and Regular boxed cargo. (7.4)
38. Payload is easily accessible (7.4)
39. Payload can't be exposed to airstream (7.4)
40. Only one cargo bay (7.4)
41. No tape, Velcro, rubber bands, container systems and friction systems alone may not be used to support payload plates (7.4)
42. Soccer ball must be proper size and pressure (7.4)
43. One cargo bay(7.4)
44. Unload cargo in 1 minute or less (7.5)
45. Wingspan must be under 120".

Customer Needs Non-SAE

- **Needs collected from FAA regulations, or from speaking with RC hobbyists.**
- **Most Relevant**
  - High weight short wingspan
  - Fly below 400'
  - Withstand up to 10 mph

$$FS = 120 * \frac{3 * S + W_{Payload}}{b + L} \Rightarrow FS = 120 * \frac{3 * S + W_{Payload}}{b + (3 + S * D_s)}$$

$L = Length\,of\,CargoBay$

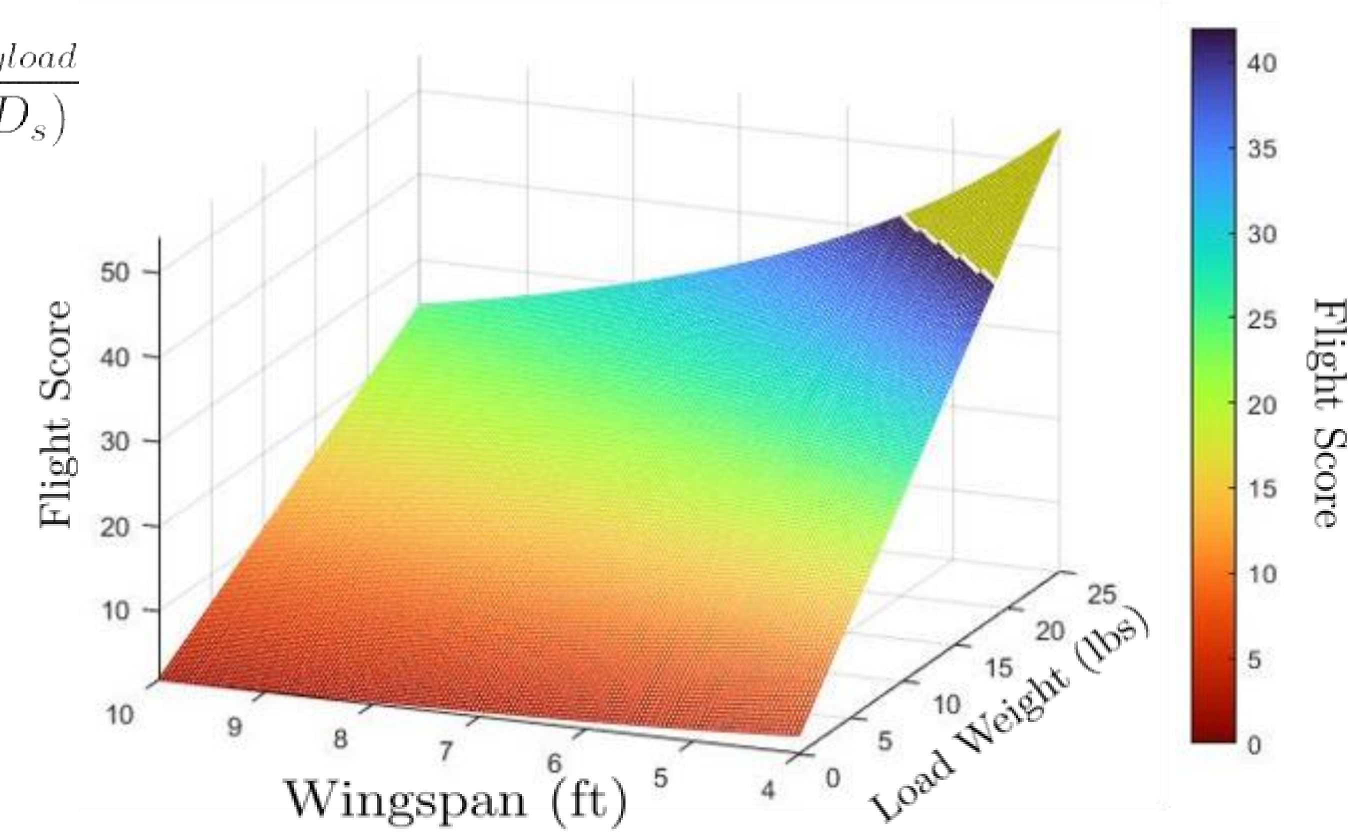
$D_s = Diameter\,of\,Soccer\,Ball$

$S = Number\,of\,SoccerBalls$

$b = Wingspan$

$W_{Payload} = Weight\,of\,Boxed\,Cargo$

46. Needs to be able to be transported in bed of truck or similar.
47. Needs to withstand up to 10 mph of wind from any direction.
48. Can be flown in a mild rain storm.
49. Must follow all FAA drone requirements to fly recreationally. (faaregisterdrone.com)
    a. Register and label drone
    b. Fly at or below 400'
    c. Pass the TRUST test
    d. Used only for Recreational Flight
50. Must be able to be manufactured in a timely manner.
51. Short wingspan
52. Heavy carry capacity
53. Short load bay
54. One soccer ball
55. Gust wind capability
56. Winning score



Specifications

❑ Conversion to specifications

- Many are binary

Metric #	Need(s)	Metric	Imp	Units	Value
1	1	All electric powered	1	binary	Yes
2	2	Original Design	1	binary	Yes
3	4	Fixed wing aircraft	1	binary	Yes
4	5	Center of Gravity labeled	1	binary	Yes

- Others are quantified

46	50	Time to manufacture	2	days	≤21
47	51	wingspan max length	1	ft	10
48	56,52	load weight minimum	1	lbs	20
49	56,53	load bay maximum length	1	in	15

- Level of importance determined (Imp)

Metric #	Need(s)	Metric	Imp	Units	Value
1	1	All electric powered	1	binary	Yes
2	2	Original Design	1	binary	Yes
3	4	Fixed wing aircraft	1	binary	Yes
4	5	Center of Gravity labeled	1	binary	Yes
5	6	Weight	1	lbs	≤55
6	7	Can stay in designated taxiways, runways, and airspace	1	binary	Yes
7	8	Uses radio control system	1	GHz	2.4
8	9	System shuts down when signal is lost	1	binary	Yes
9	10	Uses safety spinner nut	1	binary	Yes
10	11	Uses metal for propellor	1	binary	No
11	12	Uses lead	1	binary	No
12	13	Payload contributes to structer of UAV	1	binary	No
13	14	Payload plates must be secured to the cargo bay.	1	binary	Yes
14	15	Control surface slope	1	degrees	<10
16	17	Uses redundant clevis closure	1	closure methods	2
17	18	Motor is only source of power	1	binary	Yes
18	19	Battery is comercially available	1	binary	Yes
19	19	Battery is secured	1	binary	Yes
20	20	Power limiter is supplied from Neumoteros.com	1	binary	Yes
21	21	UAV has red arming plug to disarm propulsion system	1	binary	Yes
22	22	Aircraft is durable enough to stay intact	1	binary	Yes
23	23	Time to takeoff	1	s	≤180
24	24	Length to turn after start	1	ft	≤400
25	24	Takeoff length	1	ft	≤100
26	25	Landing length	1	ft	≤400
27	22,38,44	Time to unload payload	1	min	1
28	27	Wingspan length	1	ft	≤10
29	28	Uses Fiber Reinforced Polymer	1	binary	No
30	29	Uses Rubber bands	1	binary	No
31	30	Uses Gyroscopic stability	1	binary	No
32	31	Uses only one motor	1	binary	Yes
33	32	Uses 1:1 Gearing ratio	1	binary	Yes
34	33	Powered by a 6s 25c Defined capacity battery	1	mAh	≥3000
35	34	Uses a 2019 or newer 1000 Watt limiter	1	binary	Yes
36	35	External switch for servo power source	1	binary	Yes
37	36,39	Enclosed Payload	1	binary	Yes
38	37	Carries round and cubic cargo	1	binary	Yes
39	40,43	One cargo bay	1	binary	Yes
40	14,41	Payload is soley secured with tape, Velcro, rubber bands, container systems and friction systems	1	binary	no
43	45,46	Can be transported in a truck bed or smaller	2	Feet	≤10
44	47	Plane can withstand wind	2	mph	10
45	3,49	Meets FAA Regulations to fly recreationally in the US	1	binary	Yes
46	50	Time to manufacture	2	days	≤21
47	51	wingspan max length	1	ft	10
48	56,52	load weight minimum	1	lbs	20
49	56,53	load bay maximum length	1	in	15
50	56,54	one soccer ball	1	binary	yes
51	48	IP65 waterproof	2	binary	yes
52	55	Withstand wind gusts	3	mph	20

Concept Generation & Selection

Morph Chart

Number of Wings	Wing Shape	Chord Length	Wing Orientation	Wing Tips	Control System	Unconventional
1	Straight	Short	Forward Sweep	Up Swept	Traditional	Channel Wing
2	Tapered	Medium	Back Sweep	Down Swept	Thrust Vectoring	Conveyor Belt
3	Curved	Long	Straight	Wing Plate		Acoustic Attachment
4			Stacked	Dual Sweep		Flow Injection

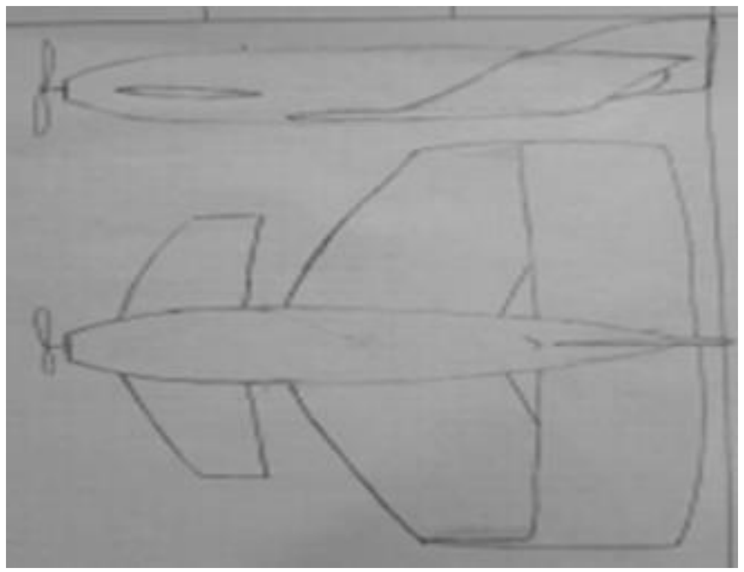
- "In most cases, an effective development team will generate hundreds of concepts, of which 5 to 20 will merit serious consideration…" (Ulrich and Eppinger, 2016)

Concept Generation & Selection

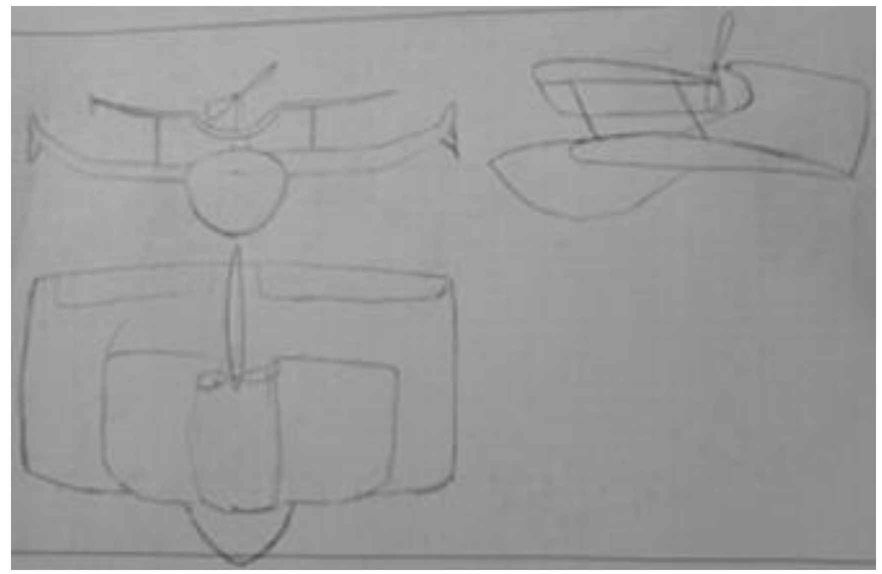
- ❑ Generated 70+ concepts using the Morph Chart.
- ❑ Wide range of designs.

Concept Generation & Selection

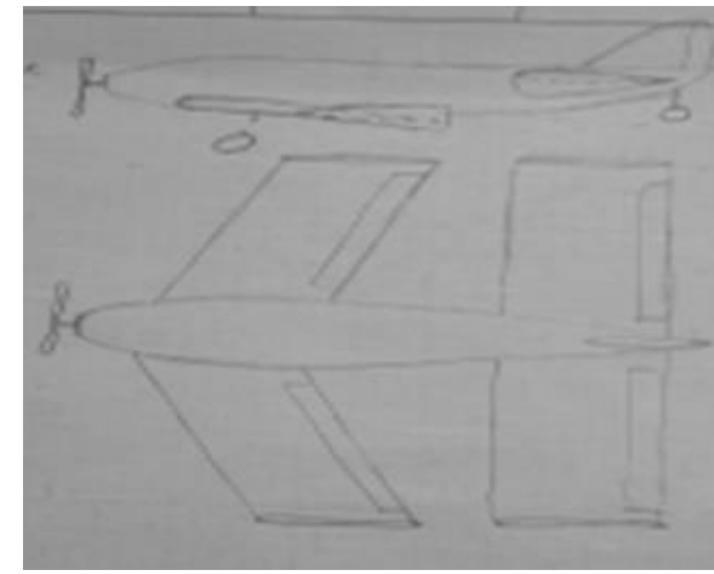
Top Concept Categories



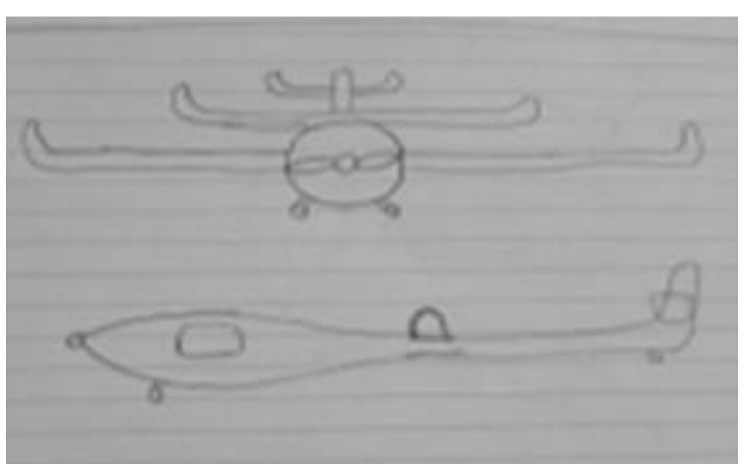
A. SkyCandy



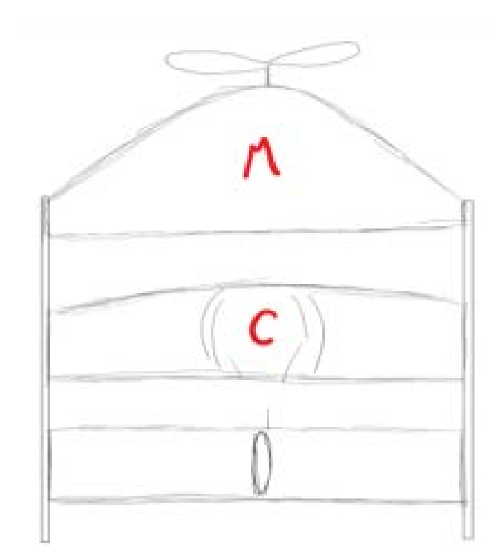
B. Penguin



C. Front & Back Wing

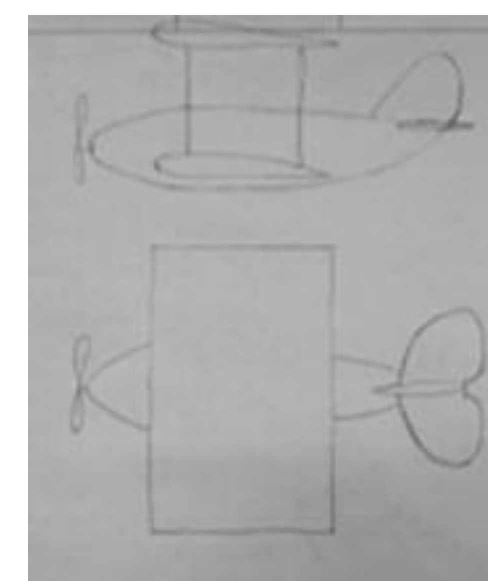


D. MidWing



E. Three Flying Wings

F. Ground Effect



G. Biplane

Concept Generation & Selection

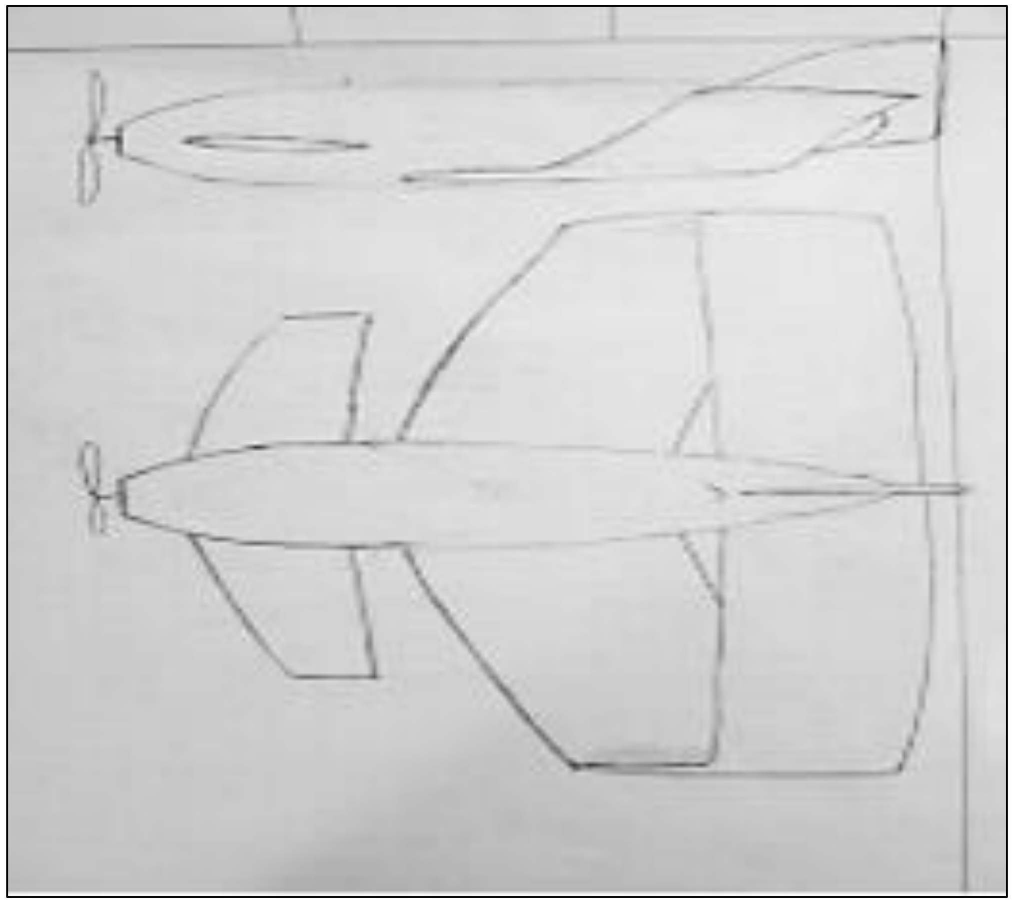
Scoring Matrix

	Concepts								
Selection Criteria	Weight	A	B	C	D	E	F	G	Control
Lift Area	10	3	2	2	1	3	1	2	0
Easy to Manufacture	4	0	-2	0	0	1	-1	0	0
Easy to control	7	0	-1	0	0	-1	-1	0	0
Cost Effective	3	0	-1	0	0	-1	0	0	0
Durability	6	3	2	-1	0	-1	3	2	0
Easy to repair	3	0	-1	0	0	-1	-1	0	0
Net Score		48	11	14	10	15	14	32	0
Rank		1	5	4	6	3	4	2	NA

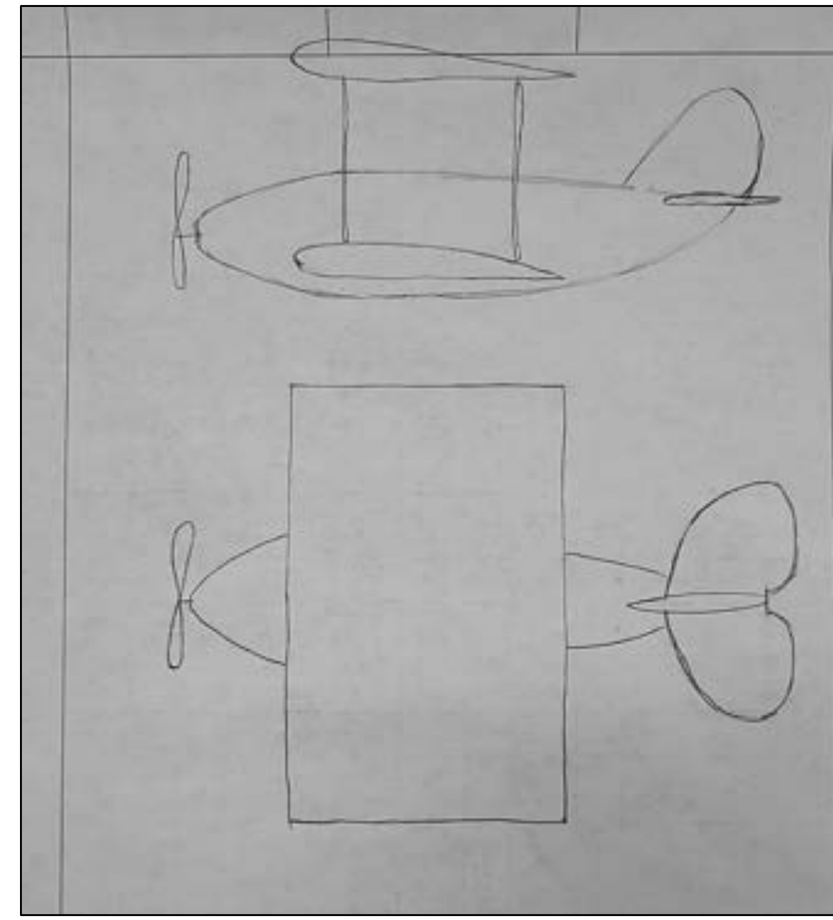
Legend	
Control	Bush Plane
A	SkyCandy
B	Penguin
C	F&B
D	MidWing
E	3FW
F	Ground Effect
G	Bi plane

- ❑ **Criteria from specs**
- ❑ **Weighted crucial criteria**
- ❑ **Values are based off inspection**

Concept Generation & Selection



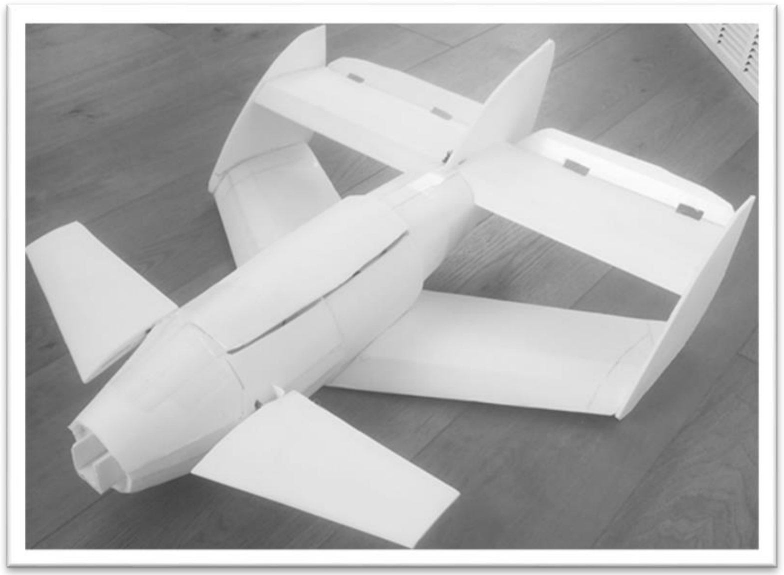
Sky Candy
- More Durable
- More Stable flight



Bi-Plane
- Traditionally successful design
- High Lifting Area

1/2 Scale Prototyping

SkyCandy



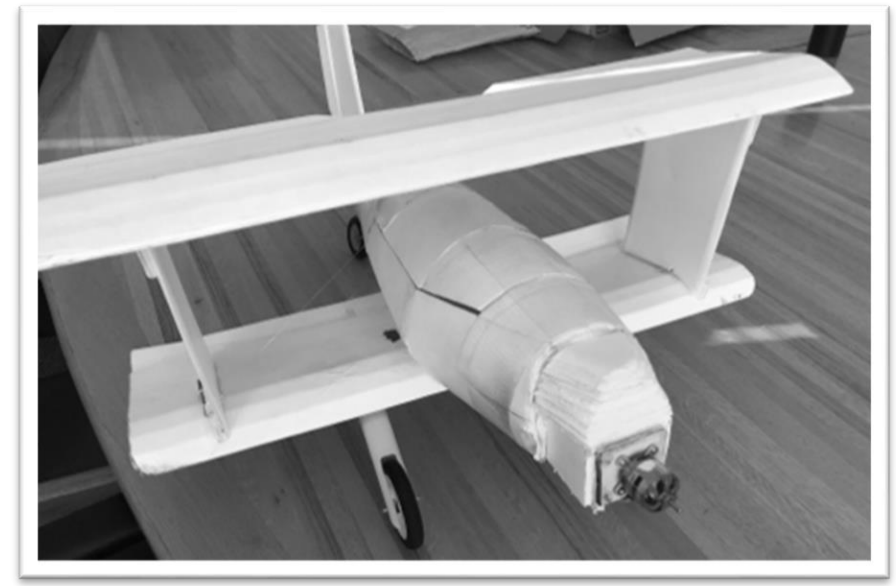
- ❑ Take off failures
- ❑ Stable flight

Max Cargo: **0.5 lbs.**

Theoretical Full Scale Cargo: 4 lbs.

VS.

Biplane



- ❑ Repeatable flights
- ❑ Less Stable in flight

Max Cargo: **1.5 lbs.**

Theoretical Full Scale Cargo: 12 lbs.

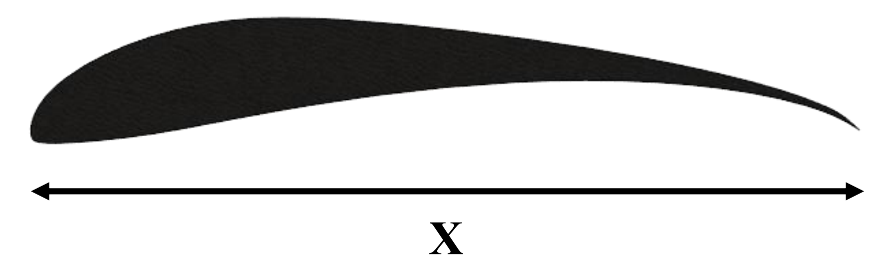
Prototyping and Analysis

❑ Selig S1223 Airfoil

- Designed for high lift, low Reynolds number

❑ Derivation of chord to lift/drag relationship

- Data collection using ANSYS



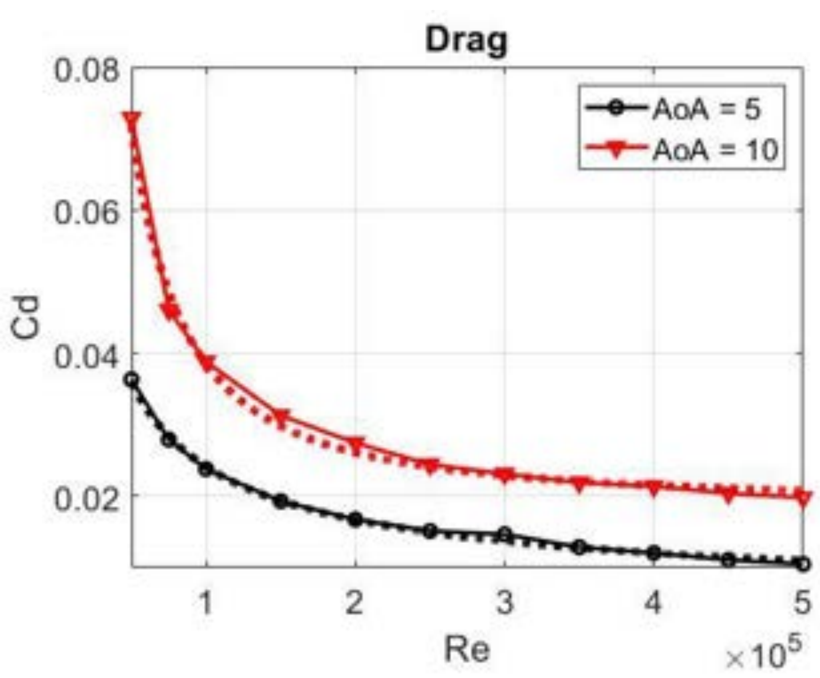
F = Drag or lift force

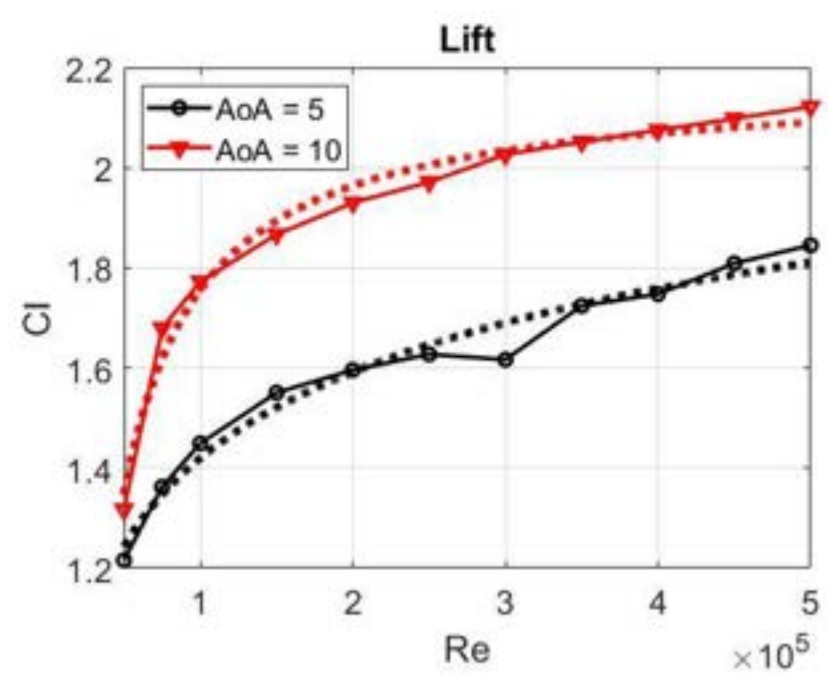
x = Chord length

μ = Dynamic viscosity

ρ = Air density

u = Velocity





$$C = \frac{F}{\rho\, u^2\, \frac{x}{2}} \qquad Re = \frac{\rho\, u\, x}{\mu}$$

$$C = f(Re)$$

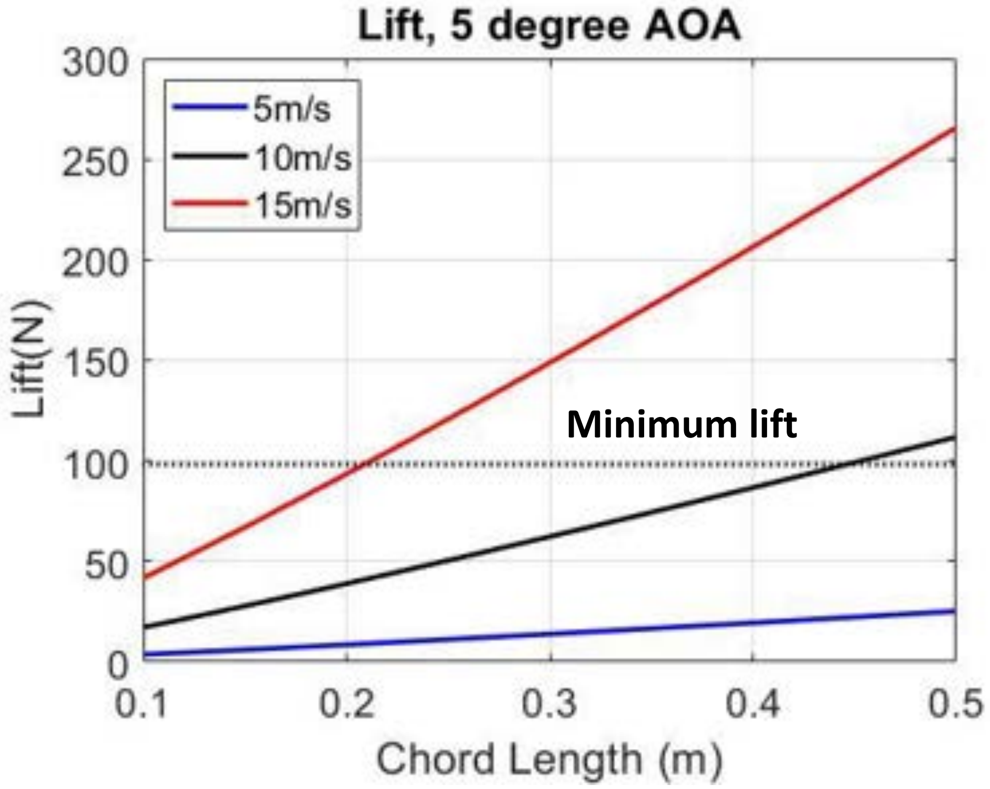
↓

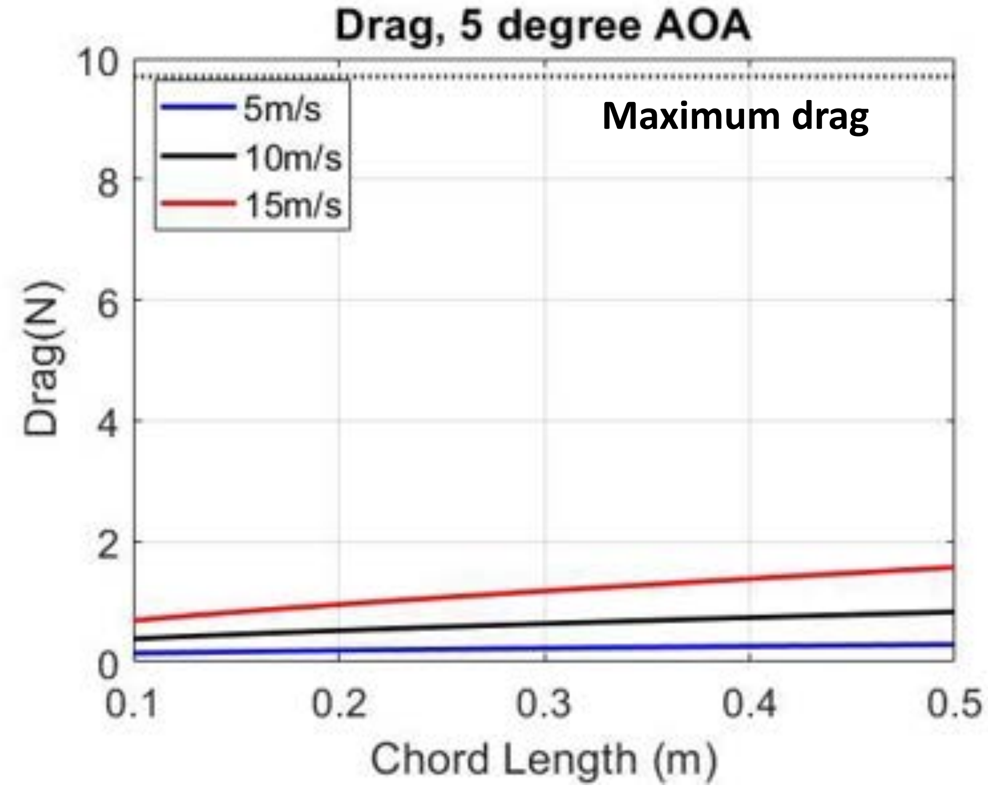
$$F = f\left(\frac{\rho\, u\, x}{\mu}\right) \rho\, u^2\, \frac{x}{2}$$

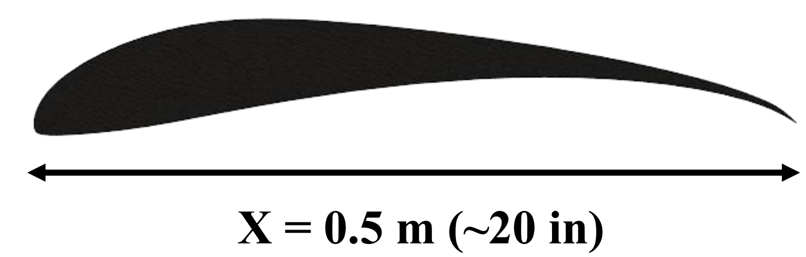
Prototyping and Analysis

❑ Chord vs lift and drag

- Assumed values for ρ, u, and μ.
- Compared against max. drag and min. lift for 7 ft of wing



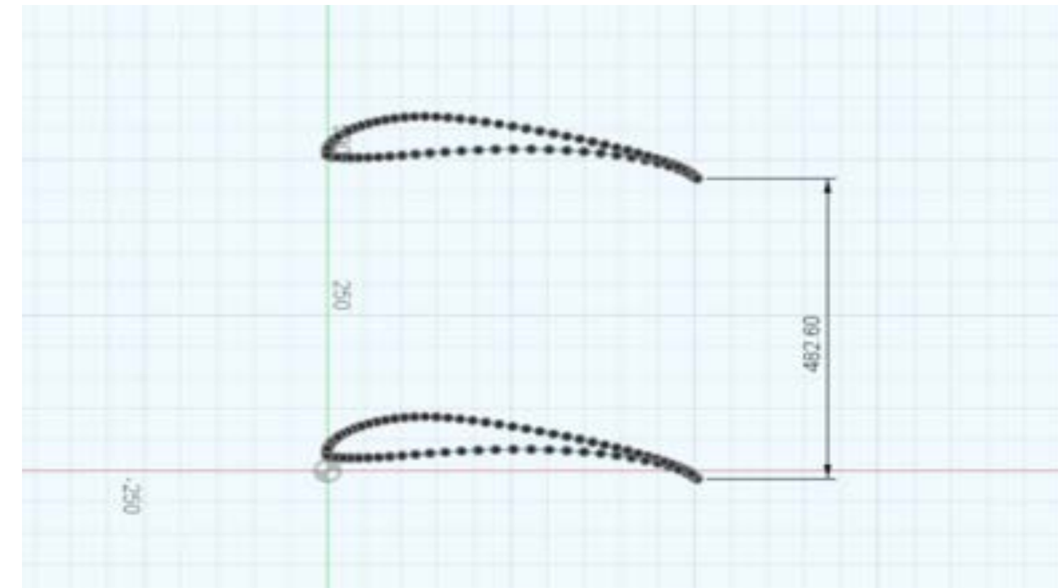




- A 0.5 m chord provides enough lift with acceptable drag

Prototyping and Analysis

- ❑ **Wing spacing?**
- ❑ **Maximize lift and decrease drag.**

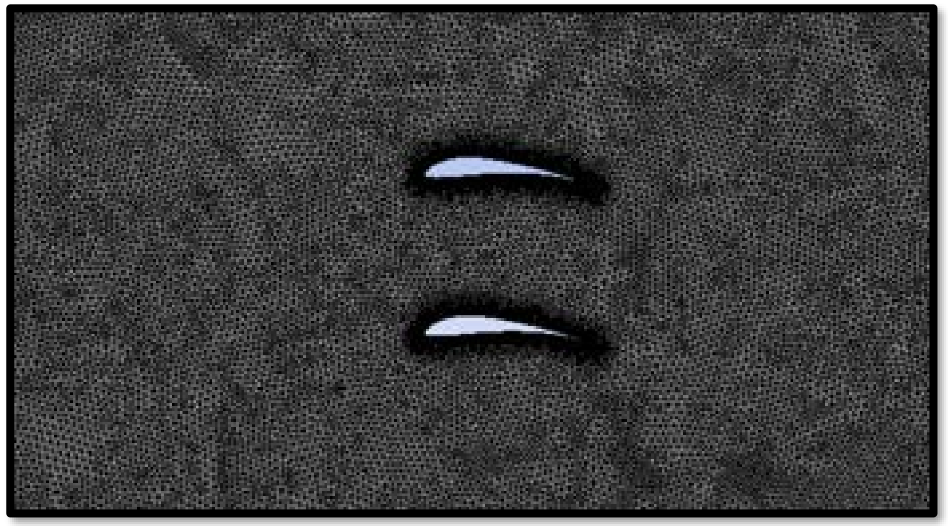


- ❑ **Rules of wing spacing:**
  - Too small = boundary layer interference.
  - Too large = loss of efficiency and flight characteristics.
    - "…above a gap of about 1.5 the max chord, each wing acts as a single monoplane wing with no inter-wing interference." (Nassise, 1951)

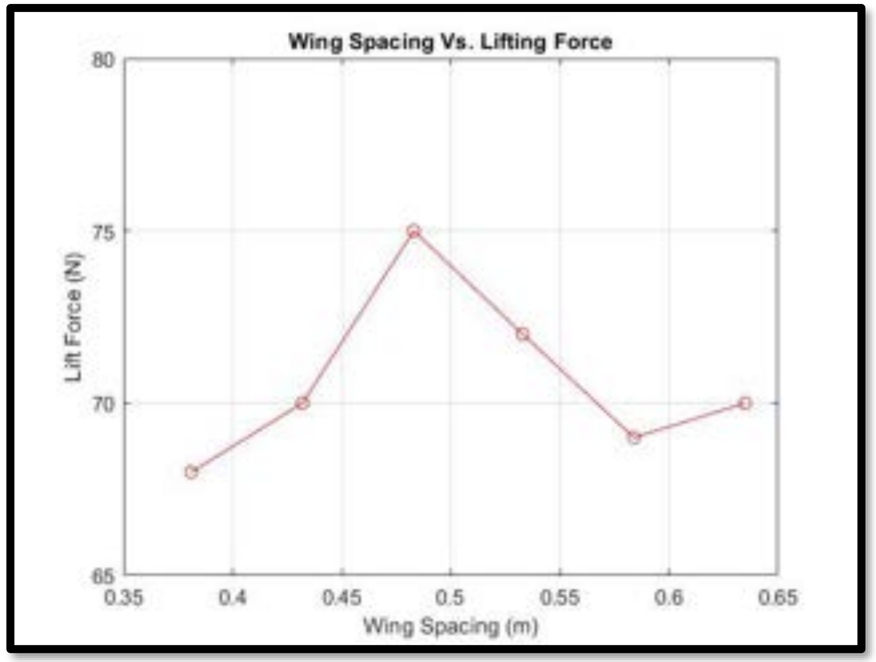
- ❑ **Conducted CFD Analysis over a range of 75% - 125% of chord length.**

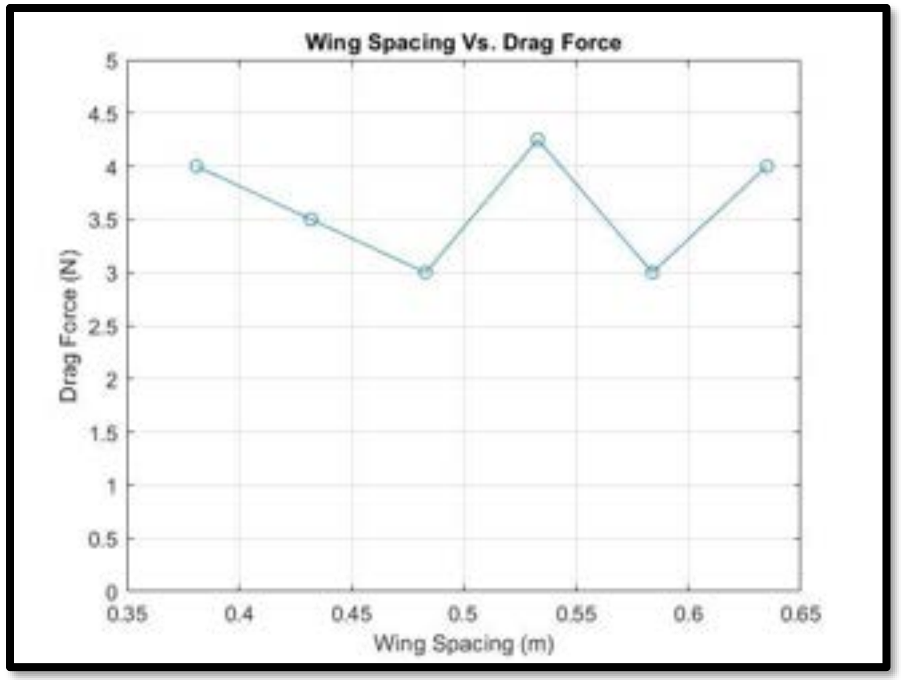
Prototyping and Analysis

- **Wing spacing vs. lift and drag**
  - Assumed:
    - steady-state
    - laminar flow
  - Boundary conditions:
    - inlet velocity = 10.5 m/s,
    - zero specified shear on edges
    - no slip on airfoils
  - Mesh granularity



- **Results**



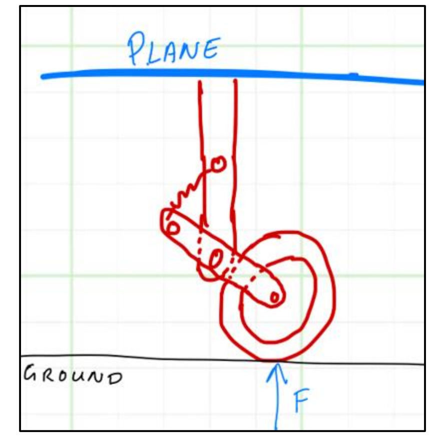


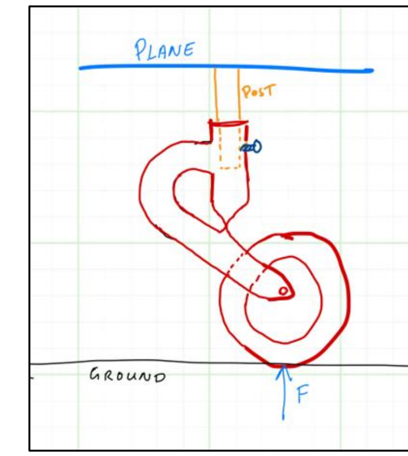
  - The wing spacing of 95% of the chord length exhibited the greatest lift force and least drag force.

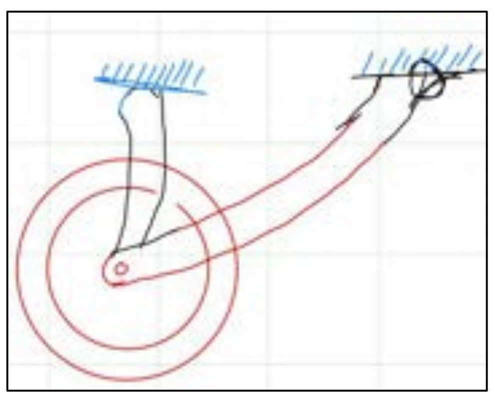
Prototyping and Analysis

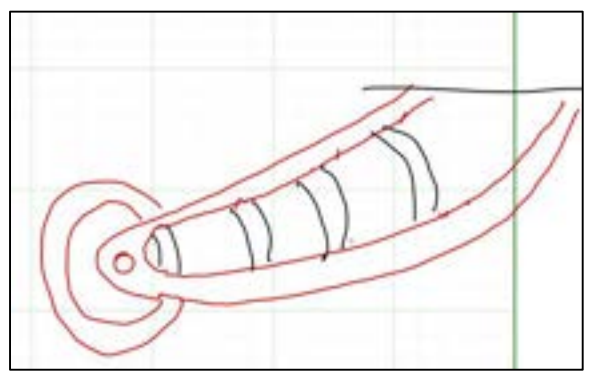
❑ Landing Gear

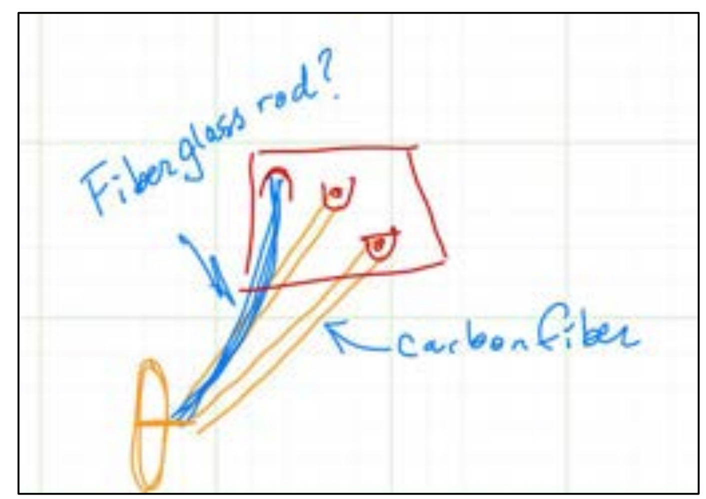
- Mitigate damage through deflection
- Lightweight

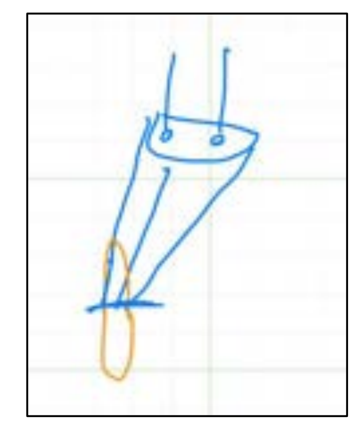


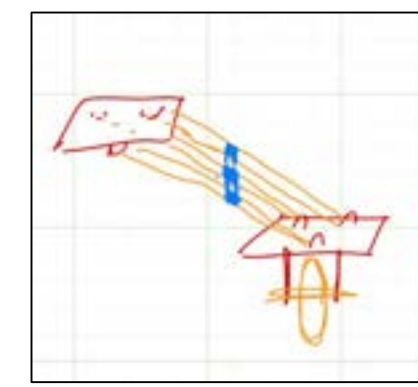


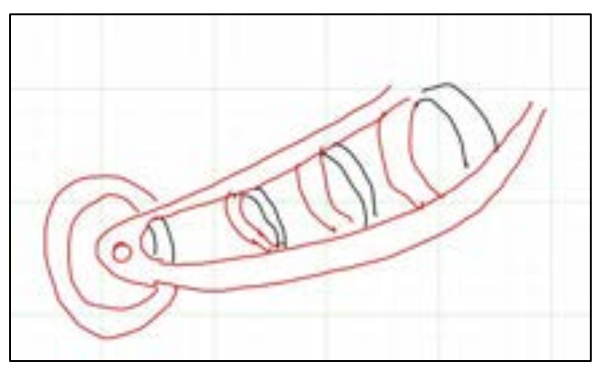


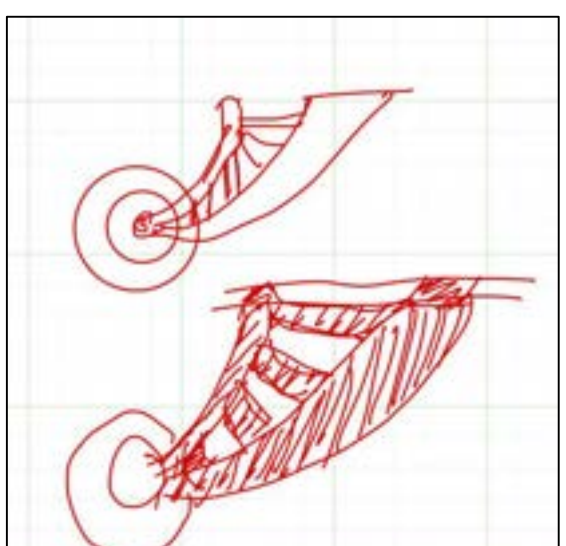


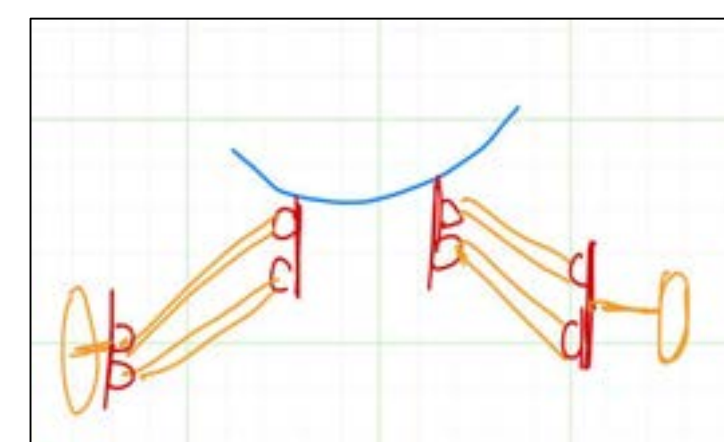


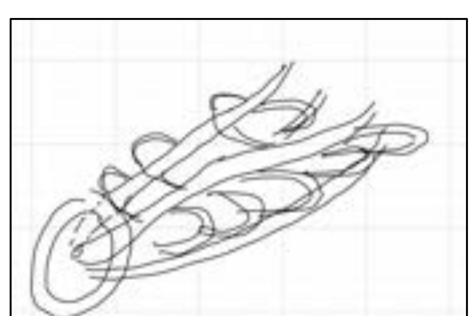


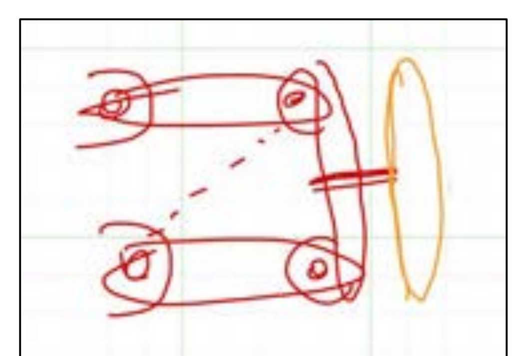




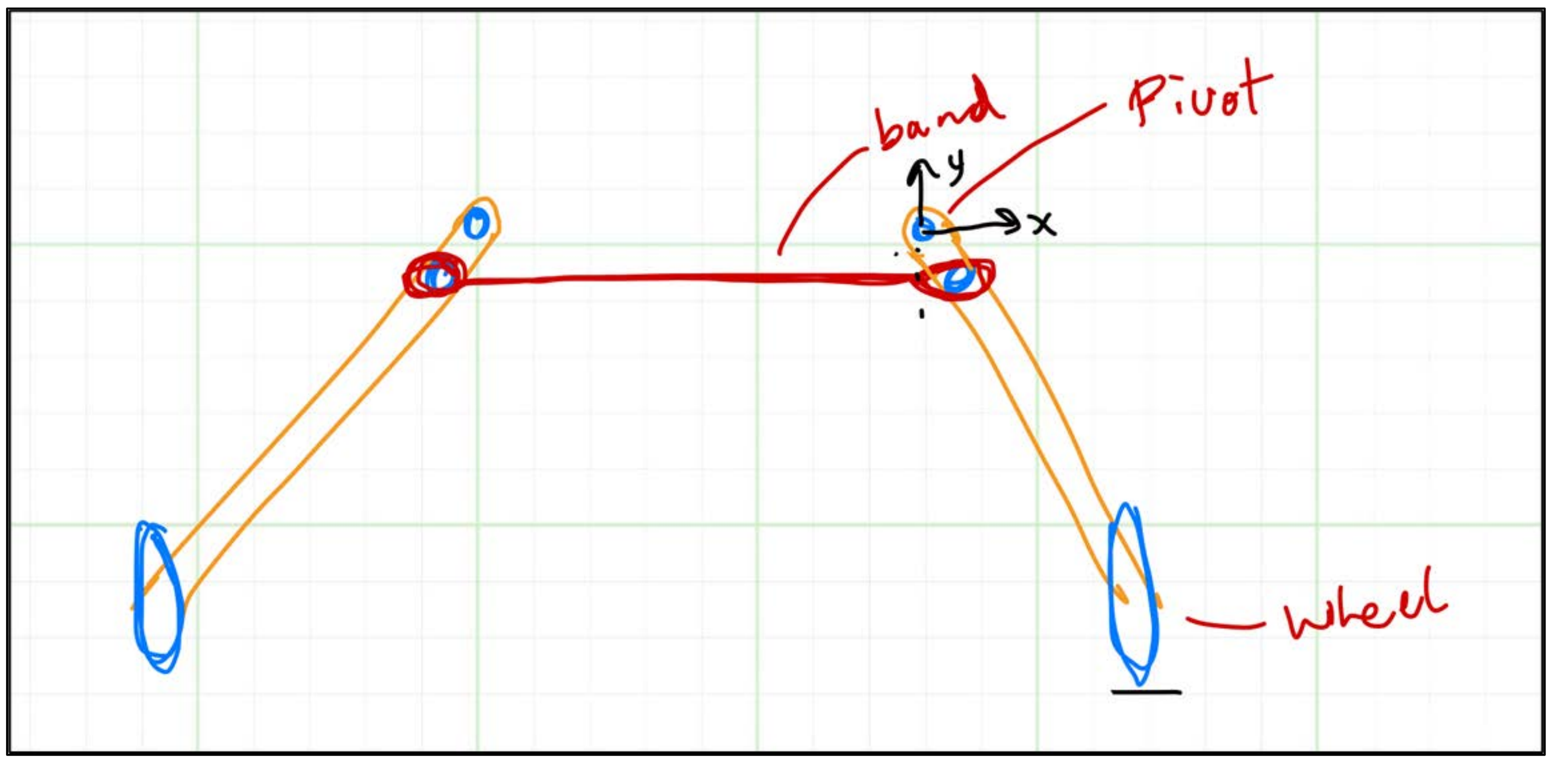


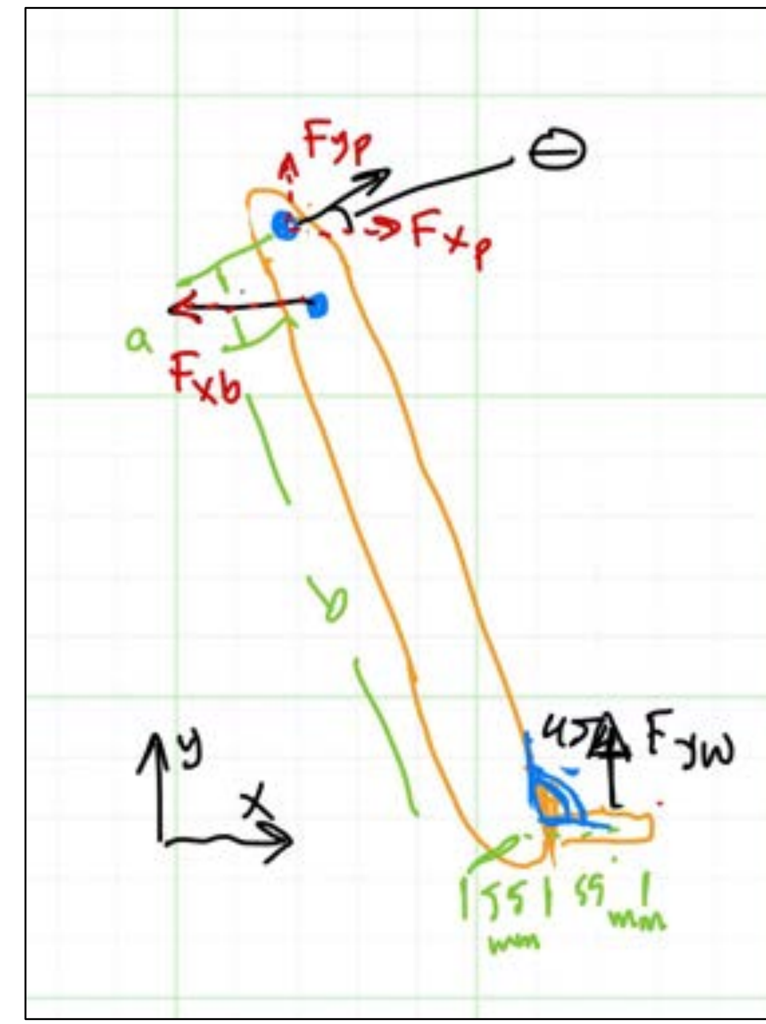






Prototyping and Analysis



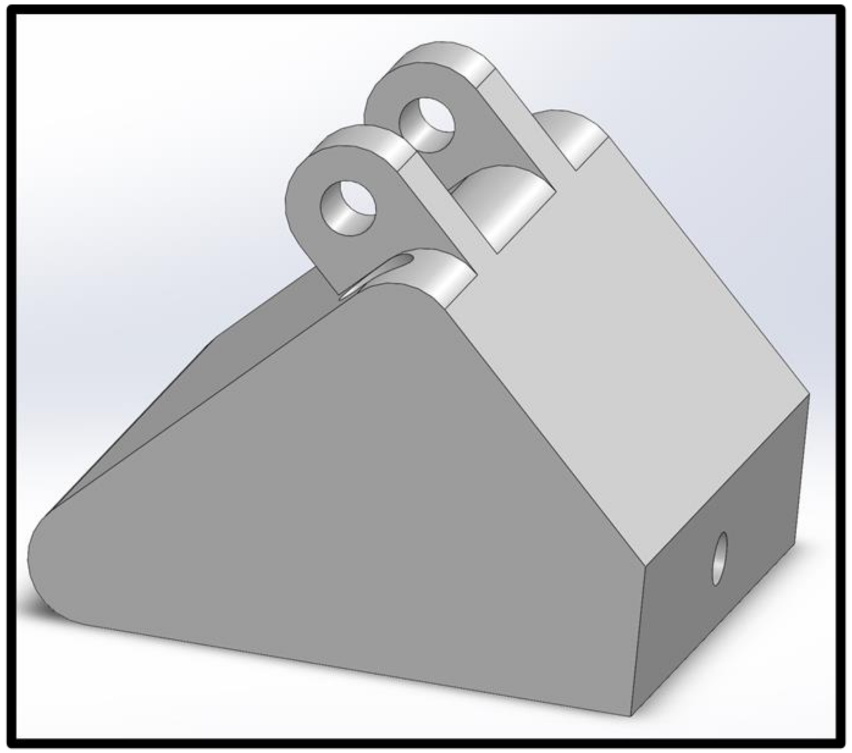


Find
- Locations of latex tubing
- Static loading on connections

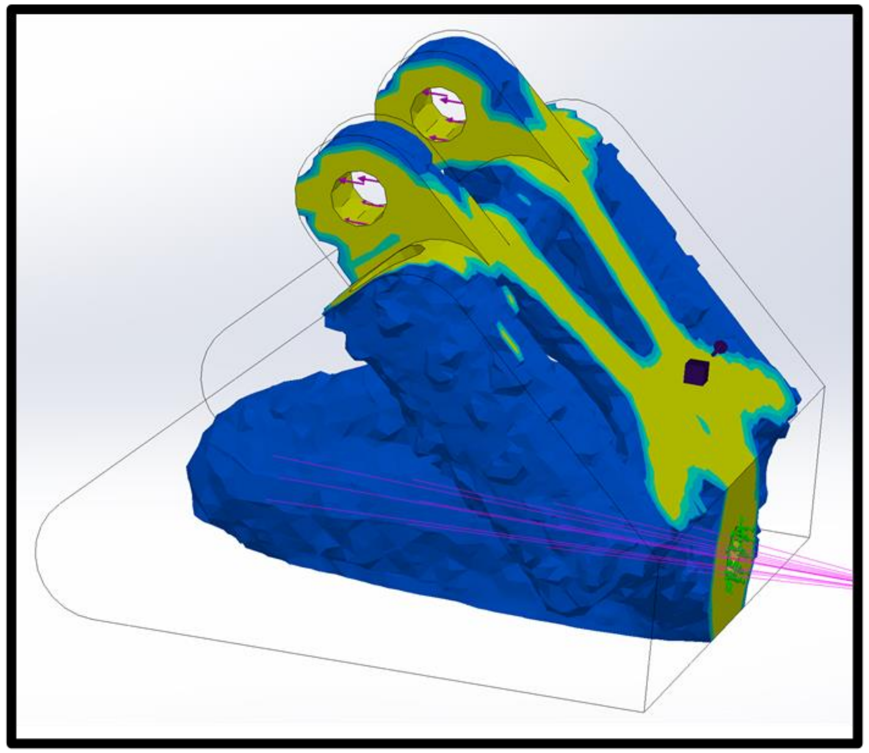
Found
- Maximize distance
- 2 strands ~30lbs at max deflection

Prototyping and Analysis

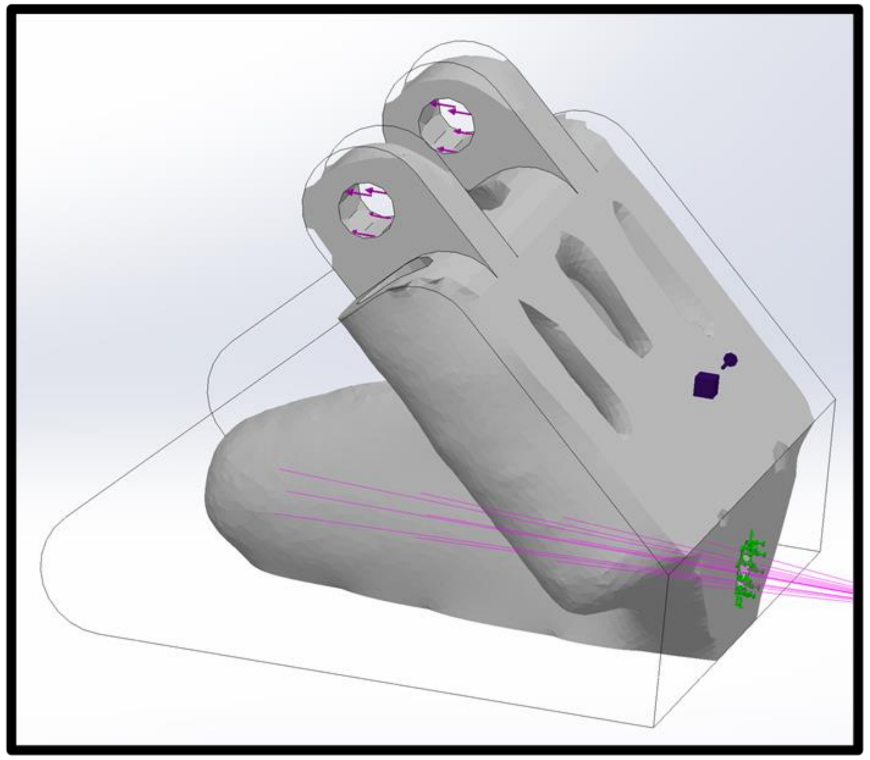
- **Wheel Connection**
  - Landing impact
  - Band resistance



Geometry Envelope



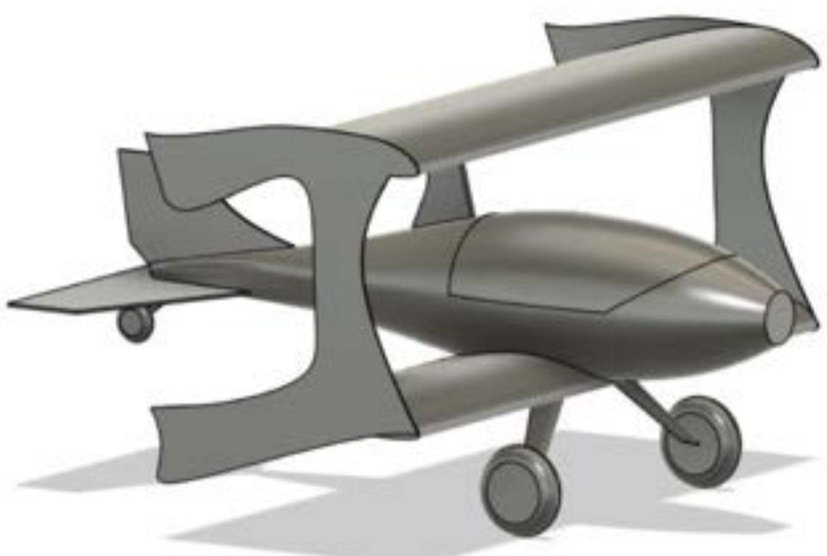
Topology Optimization



Final Geometry

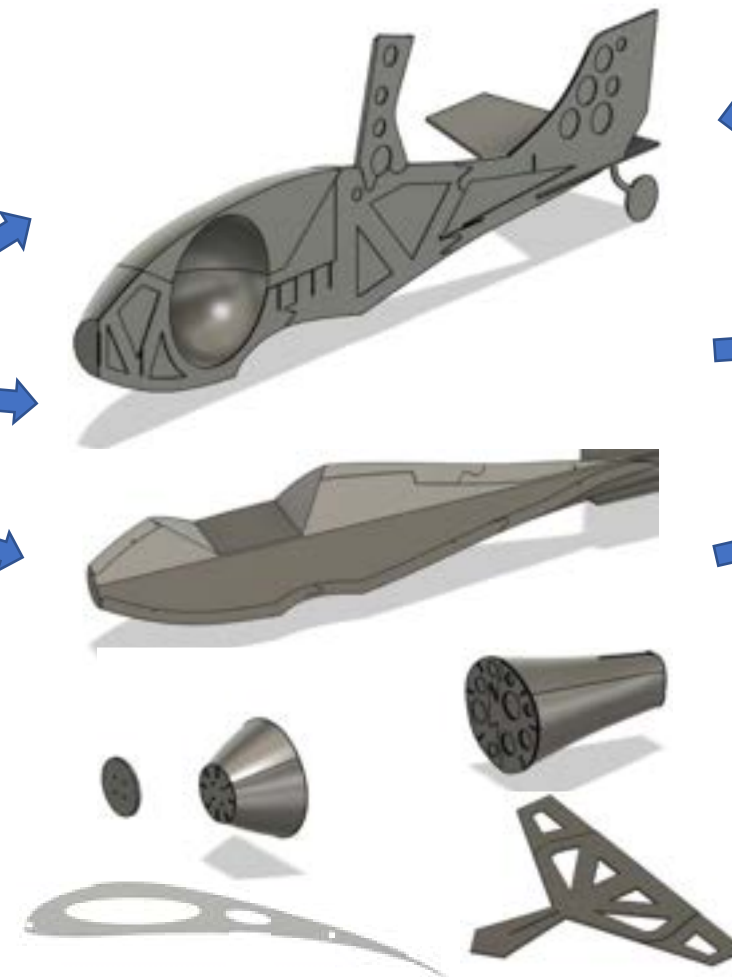
Final Design

AUTODESK® FUSION 360™



1. Design

SHAPER



2. Isolate Desired Components

glowforge

3. Laser Cut & Assemble

Final Design

Characteristics

- ❑ 48" wingspan
- ❑ 53" length
- ❑ ~20" chord length
- ❑ Emergency kill plug

Challenges

- ❑ Maximizing thrust
- ❑ Center of Gravity placement
- ❑ Ground handling

Flight Results

- Flight 1
  - <u>3 lbs. Payload</u>
  - Short Takeoff/Landing
  - Maintained heading
  - 2 circuits
  - Tail heavy
- Flight 2
  - Crashed on takeoff
- Flight 3
  - N/A

Flight Score

- **2022 Competition Results**
  - 31 participants
- **Our Score**
  - 21 Points
  - 11th Place if we had participated

Standings	University (Team)	Country	Sum of Top 3 Flight Scores
1	**044** - Polytechnic Univ of Puerto Rico (*Flying Beavers*)	United States	119.9575
2	**014** - Politechnika Poznanska (*White Eagle*)	Poland	86.3056
3	**034** - Wroclaw University of Technology (*JetStream Regular*)	Poland	84.4243
4	**015** - Univ of Cincinnati (*FITW*)	United States	76.2112
5	**058** - Polish Air Force Academy in Deblin (*Young Engineer's Team*)	Poland	68.7121
6	**056** - Czech Technical Univ of Prague (*Chicken Wings CTU*)	Czech Republic	68.3695
7	**021** - Alexandria Univ (*Alex Eagles*)	Egypt	51.7714
8	**049** - Louisiana State Univ (*Flying Tigers*)	United States	39.7696
9	**031** - Univ of Calif - Berkeley (*CAL Aero SAE*)	United States	39.3805
10	**029** - Polytechnic University of Valencia (*AD UPV*)	Spain	28.2774
11	**026** - College of New Jersey (*TCNJ Aero*)	United States	17.7030

$$FS = 120 * \frac{3 * S + W_{Payload}}{b + L} \Rightarrow FS = 120 * \frac{3 * S + W_{Payload}}{b + (3 + S * D_s)}$$

$$L = Length\,of\,CargoBay$$

$$D_s = Diameter\,of\,Soccer\,Ball$$

$$S = Number\,of\,Soccer\,Balls$$

$$b = Wingspan$$

$$W_{Payload} = Weight\,of\,Boxed\,Cargo$$

Specifications Met

- **Most specifications were met**
  - Green = Specification met
  - Yellow = Specification almost met
  - Red = Specification not met

Metric #	Need(s)	Metric	Imp	Units	Value
1	1	All electric powered	1	binary	Yes
2	2	Original Design	1	binary	Yes
3	4	Fixed wing aircraft	1	binary	Yes
4	5	Center of Gravity labeled	1	binary	Yes
5	6	Weight	1	lbs	≤55
6	7	Can stay in designated taxiways, runways, and airspace	1	binary	Yes
7	8	Uses radio control system	1	GHz	2.4
8	9	System shuts down when signal is lost	1	binary	Yes
9	10	Uses safety spinner nut	1	binary	Yes
10	11	Uses metal for propellor	1	binary	No
11	12	Uses lead	1	binary	No
12	13	Payload contributes to structer of UAV	1	binary	No
13	14	Payload plates must be secured to the cargo bay.	1	binary	Yes
14	15	Control surface slope	1	degrees	<10
16	17	Uses redundant clevis closure	1	closure methods	2
17	18	Motor is only source of power	1	binary	Yes
18	19	Battery is comercially available	1	binary	Yes
19	19	Battery is secured	1	binary	Yes
20	20	Power limiter is supplied from Neumoteros.com	1	binary	Yes
21	21	UAV has red arming plug to disarm propulsion system	1	binary	Yes
22	22	Aircraft is durable enough to stay intact	1	binary	Yes
23	23	Time to takeoff	1	s	≤180
24	24	Length to turn after start	1	ft	≤400
25	24	Takeoff length	1	ft	≤100
26	25	Landing length	1	ft	≤400
27	22,38,44	Time to unload payload	1	min	1
28	27	Wingspan length	1	ft	≤10
29	28	Uses Fiber Reinforced Polymer	1	binary	No
30	29	Uses Rubber bands	1	binary	No
31	30	Uses Gyroscopic stability	1	binary	No
32	31	Uses only one motor	1	binary	Yes
33	32	Uses 1:1 Gearing ratio	1	binary	Yes
34	33	Powered by a 6s 25c Defined capacity battery	1	mAh	≥3000
35	34	Uses a 2019 or newer 1000 Watt limiter	1	binary	Yes
36	35	External switch for servo power source	1	binary	Yes
37	36,39	Enclosed Payload	1	binary	Yes
38	37	Carries round and cubic cargo	1	binary	Yes
39	40,43	One cargo bay	1	binary	Yes
40	14,41	Payload is soley secured with tape, Velcro, rubber bands, container systems and friction systems	1	binary	no
43	45,46	Can be transported in a truck bed or smaller	2	Feet	≤10
44	47	Plane can withstand wind	2	mph	10
45	3,49	Meets FAA Regulations to fly recreationally in the US	1	binary	Yes
46	50	Time to manufacture	2	days	≤21
47	51	wingspan max length	1	ft	10
48	56,52	load weight minimum	1	lbs	20
49	56,53	load bay maximum length	1	in	15
50	56,54	one soccer ball	1	binary	yes
51	48	IP65 waterproof	2	binary	yes
52	55	Withstand wind gusts	3	mph	20

Flight Highlights

Questions?