POLYTECHNIC UNIVERSITY OF PUERTO RICO
GRADUATE SCHOOL: MASTER ENGINEERING IN MECHANICAL ENGINERING
ME 6400 – DESIGN PROJECT FOR MASTER IN MECHANICAL ENGINEERING SEC. 10 2019 FA

Optimization of a SAE Aero Design Aircraft

Enrique G. Méndez Cuevas Advisor: José R. Pertierra García

Abstract

The Polytechnic University of Puerto Rico (PUPR) has participated in SAE Aero Design for the previous years. SAE Aero Design is an international competition in which an airplane is designed by the students into one academic calendar year. SAE Aero Design have three classes of competition: Regular, Advance, and Micro. In 2018 PUPR participated in Regular Class with an aircraft called ORCA. The objective of Regular Class is designing an aircraft able to carry as much payload as possible fulfilling every requirement and limitations. ORCA was a good design, but the aircraft do not have the capacity to carry the payload predicted in the conceptual design. This project is based on the optimization of ORCA. This new design is bigger, lighter, and can carry the payload predicted fulfilling every requirement and limitations. The design method for the aircraft was based on a full weight analysis from various aircrafts designed for the same purpose, including ORCA.

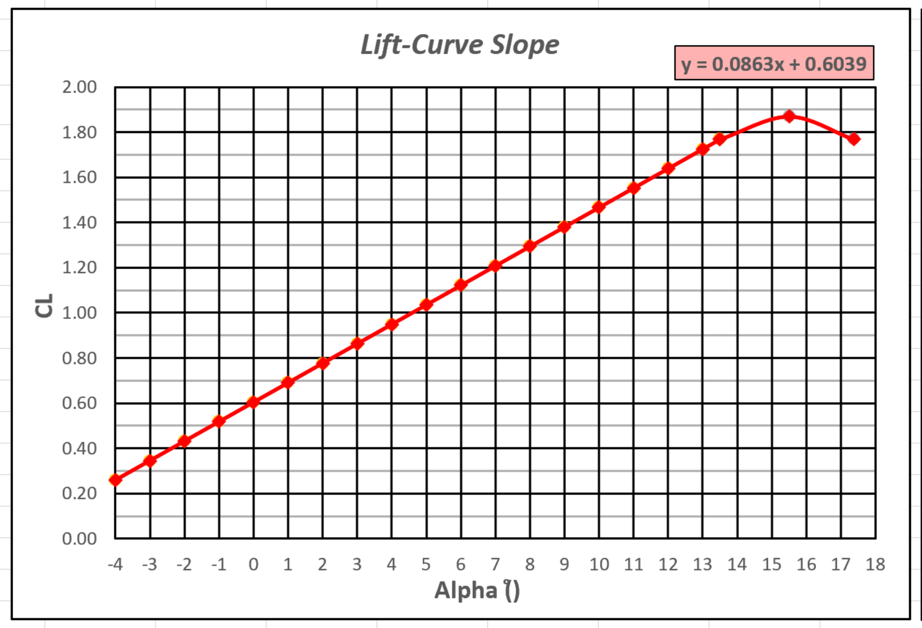
Introduction

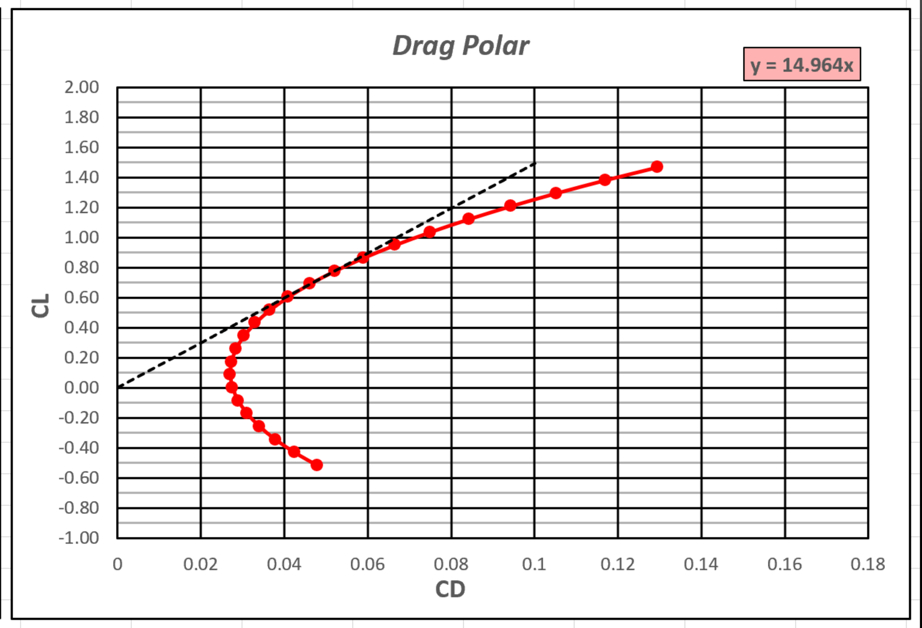
The design of the aircraft started from a weight analysis. This weight analysis was performed to the determination of weight fractions for every component for the aircraft. These weight fractions and assumptions like Vstall=30 ft/s, W/S=2.5, and AR=7 were necessary to make the initial sizing. After a few iterations considering aerodynamics and performance the aircraft was designed.

The Structure configuration of ORCA was very strong but at the same time it was heavy; this is due to the 2 g's used. For this new design just 1.2 g's and a safety factor of 5% was enough for the structure design to make it lighter. Also, another improvements for better performance and agility were the elimination of cabin bay, lighter wing and tail attachments, more wing area reducing wing loading, and using airfoil in vertical tail instead of flat plate. This modifications were the key for the optimization. For better maneuvering bigger control surfaces were applied with an increment in static margin to guaranties the stability.

Aircraft's structure it was completely designed in Basswood and Balsawood even the wheels were in basswood. This kinds of woods were selected to keep it lighter. Payload consist in 20 tennis balls and 20 metal plates making a total weight of 13lbs. which is around 66% of the Takeoff weight. The aircraft takeoff weight is 20lbs. with an empty weight below 7lbs. and just 140 feet of runway is enough to takeoff.

Aerodynamics





Empty Flight

Full Payload Flight

Project Cost

Propulsion	Motor	Cobra 3525/18 kv=430	$ 75.00
	Propeller	APC 15X6 E	$ 12.00
Electronics	Battery	Turnigy 3000mAh 6cell 22.2V	$ 50.00
	Receiver	Futaba R3006SB 2.4GHz	$ 83.00
	ESC	Skywalker 60A-UBEC 2-6S Lipo	$ 55.00
	Servos	TGY-811 (2)	$ 54.00
		Hitec HS-125mg (2)	$ 81.00
		Futaba S3010 (1)	$ 29.00
	Cables	Extensions Wires	$ 30.00
Structure	Basswood		$ 100.00
	Balsawood		$ 150.00
	Main gear		$ 25.00
	Nose gear		$ 12.00
	Glue	Cyanoacrylate	$ 25.00
	Skin	Monokote	$ 91.00
Payload	Passangers	Tennis Balls	$ 37.00
	Luggages	Metal Plates	$ 50.00
		Total =	$ 959.00

Center of Gravity

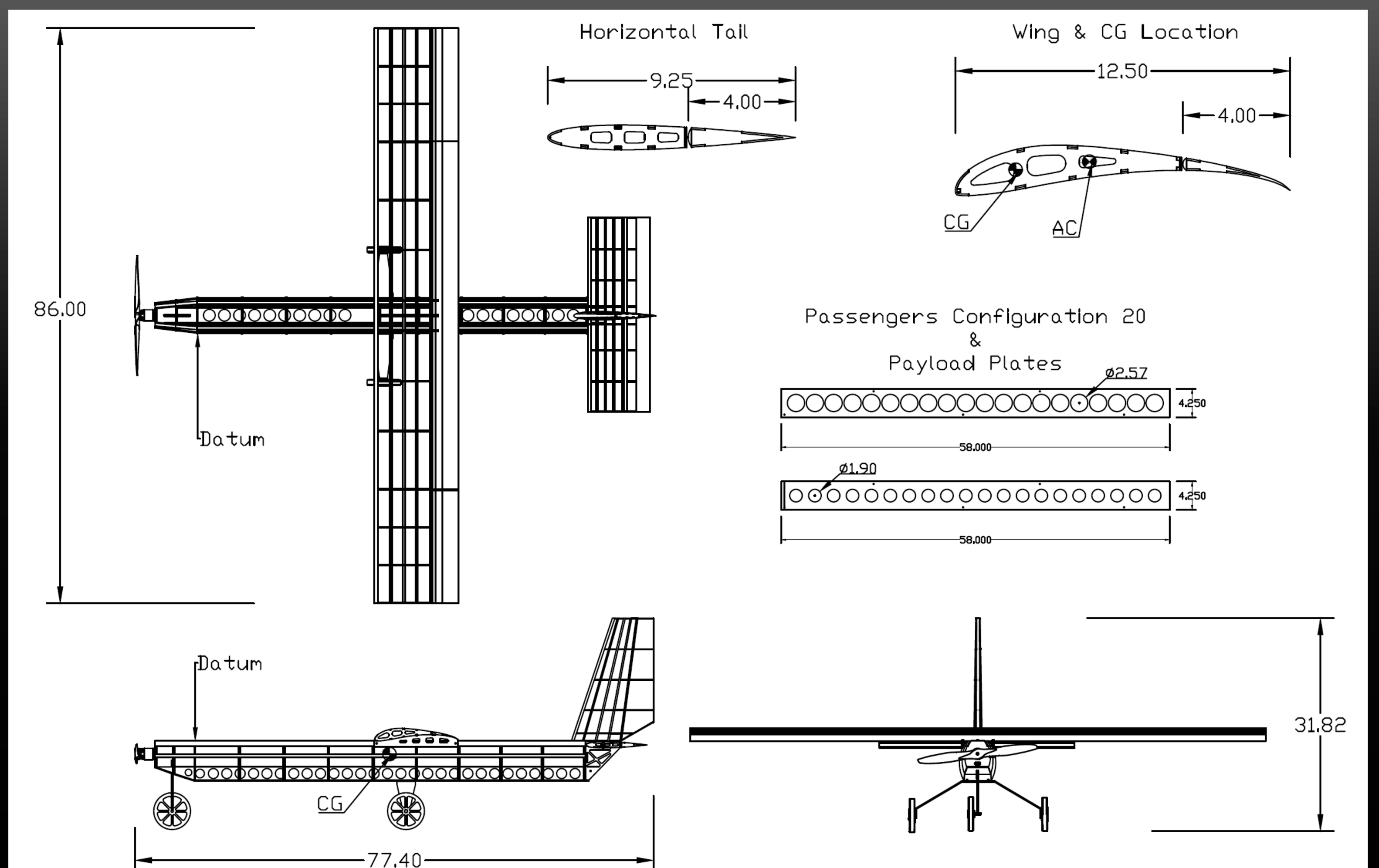
Without payload

Components	Weight (lbs.)	Arm (in.)	Moment (lbs. in.)
Tail	0.71875	61.00	43.844
Main Gear	0.7375	31.75	23.416
Nose Gear	0.3	-3.50	-1.050
Engine + Prop	0.66	-7.25	-4.785
Wing	1.25	32.50	40.625
Battery	1.02	42.00	42.840
Speed controler	0.097003	37.00	3.589
Receiver	0.000661	37.00	0.024
Payload	0	29.00	0.000
Fuselage	2.14	24.00	51.360
Power limiter	0.0375	36.00	1.3500
Σ =	6.961414	Σ =	201.2129
	X cg (in.) =	28.90403	
	X cg % chord =	17.23227	

With payload

Components	Weight (lbs.)	Arm (in.)	Moment (lbs. in.)
Tail	0.71875	61.00	43.844
Main Gear	0.7375	31.75	23.416
Nose Gear	0.3	-3.50	-1.050
Engine + Prop	0.66	-7.25	-4.785
Wing	1.25	32.50	40.625
Battery	1.02	42.00	42.840
Speed controler	0.097003	37.00	3.589
Receiver	0.000661	37.00	0.024
Payload	13	29.00	377.000
Fuselage	2.14	24.00	51.360
Power limiter	0.0375	36.00	1.350
Σ =	19.961414	Σ =	578.2129
	X cg (in.) =	28.96653	
	X cg % chord =	17.73226	

Drawing

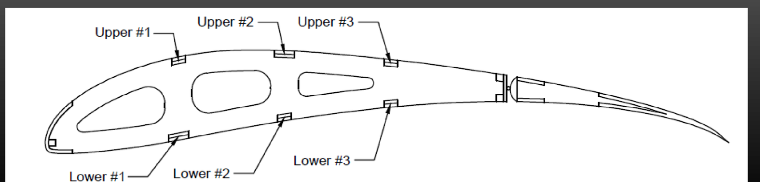


Aircraft Geometry Specifications

Wing S1223		Horizontal Tail NACA 0010		Vertical Tail NACA 0010	
Span (in.) =	86.00	Span (in.) =	29.10	Span (in.) =	18.41
C_R (in.) =	12.50	C_R (in.) =	9.24	C_R (in.) =	12.27
S (in^2) =	1075.00	S (in^2) =	268.75	S (in^2) =	169.49
AR =	6.88	AR =	3.15	AR =	2.00
C_T (in.) =	12.50	C_T (in.) =	9.24	C_T (in.) =	6.14
λ =	1.00	λ =	1.00	λ =	0.50
MAC =	12.50	MAC =	9.24	MAC =	9.55

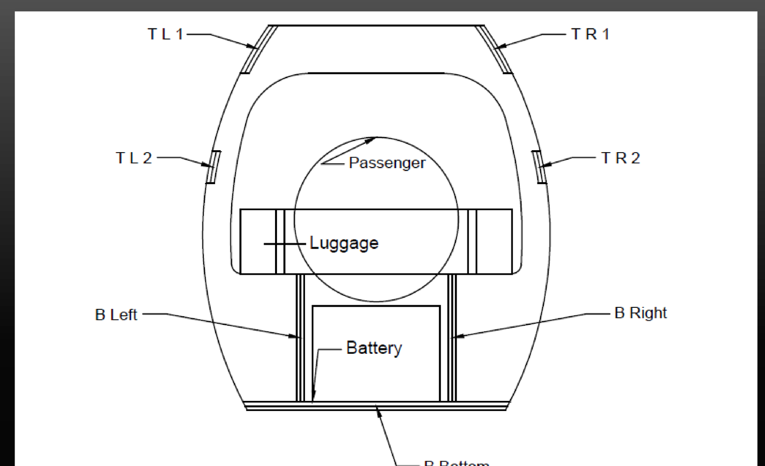
Ailerons		Elevator		Rudder	
Span (in.) =	16.99	Span (in.) =	29.10	Span (in.) =	18.41
C_R (in.) =	4.00	C_R (in.) =	3.99	C_R (in.) =	4.91
S (in^2) =	67.94	S (in^2) =	116.10	S (in^2) =	67.80
AR =	4.25	AR =	7.29	AR =	5.00
C_T (in.) =	4.00	C_T (in.) =	3.99	C_T (in.) =	2.45
λ =	1.00	λ =	1.00	λ =	0.50

Wing Structure



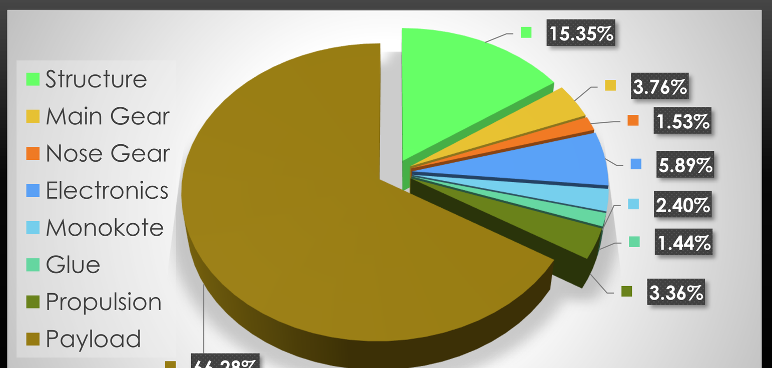
M (lb.in.)=265						
	ID	Ai	Ix	Pi	Pi * yi	Stress (psi)
Upper (Compress)	1	0.0313	0.0092	55.51	30.05	1776.25
	2	0.0469	0.0203	101.01	66.33	2154.93
	3	0.0313	0.0077	50.70	25.07	1622.35
Lower (Tension)	1	0.0469	0.0338	-130.55	110.79	-2784.96
	2	0.0313	0.0078	-51.10	25.46	-1635.15
	3	0.0313	0.0020	-25.54	6.36	-817.41
	Σ =	0.2188	0.0808	Σ =	264.07	

Fuselage Structure



M (lb.in.)=	135					
	ID	Ai	Ix	Pi	Pi * yi	Stress (psi)
Top Left	1	0.0938	1.5164	9.92	39.85	105.85
	2	0.0625	0.2956	3.57	7.76	57.20
Top Right	1	0.0938	1.5164	9.92	39.85	105.85
	2	0.0625	0.2956	3.57	7.76	57.20
Bottom	left	0.2500	0.1441	-3.25	1.60	-12.99
	right	0.2500	0.1441	-3.25	1.60	-12.99
	bottom	0.5000	1.2097	-20.49	31.87	-40.99
	Σ =	1.3125	5.1219	Σ =	130.29	

Weight Distribution



Results and Discussion

The total dimensions of the aircraft is a wingspan of 86", a length of 77.40", and a height of 31.82". The final aircraft design have a W/S=2.67 with a T/W=.38 and a takeoff weight around 20 pounds. A static margin of 0.21 it was necessary to guaranties the stability of the aircraft. With this properties and specifications got a take-off roll distance of 140 feet.

The V_{stall} is 30ft/s at AOA=15 degrees and the L/D_{max} is around 14.9 at AOA=1 degree. But at the operating flight conditions L/D is around 12.5, close to AOA=7 degrees.

A weight fraction (We/W0) of .348 which means that more that 65% of the aircraft is payload. Within that We/W0=0.348, just 15.35% of the aircraft is structure. Weight fraction analysis of every component: Wing 6.37%, Tail 3.66%, Fuselage 9.14%, Main Gear 3.75%, Nose Gear 1.52%, Engine 3.36%, Electronics 5.89%, Payload 66.3%.

Conclusions

The objective of design an aircraft with capacity to carry the payload predicted in the conceptual design was successfully performed and manufactured. The aircraft designed in this project meets all the requirements and limitations for Regular Class in 2018 Collegiate Design Series SAE Aero Design Rules. After this project, important factors to design this kind of aircraft is that the empty weight fraction should be between 0.24 and 0.34 and the thrust to weight ratio must be at least .40.

The weight fractions method used to design this aircraft could be used to develop aircrafts whose mission is carry as much payload as possible within their requirements and limitations. Also, could be used for future PUPR participation in SAE Aero Design.

Future Work

The structure design was one of the most studied areas in the project, so much so that the design is almost at the limit. Because this competition is very extreme a deeper analysis of structure is recommended to make it stronger "especially in the wing" keeping the same weights. This will be very helpful to flight in aggressive weather conditions; as it is where these competitions are held.

Use of telemetry to get info about the flight to corroborate the data assumed from the conceptual design. Also, implementation of sensors could be very useful to validate the aircraft's aerodynamics and performance.