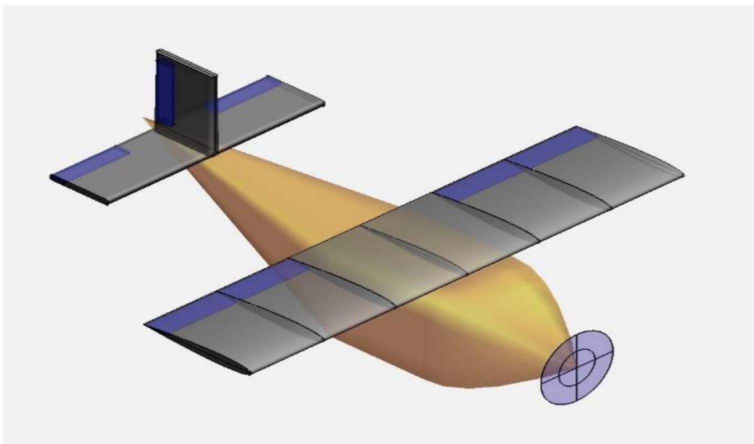
The WSU AE / Boeing
BRONZE PROPELLER COMPETITION
2018



Preliminary Design Report (PDR)

Team Tri Spectra

Team Members:

1. Anwar S. Jihan
2. Abdullah Sifat
3. Patrick Dinh

Table of Contents

1. Nomenclature

Aerodynamics

AoA = Angle of attack
c_{lmax} = Airfoil maximum lift coefficient
$C_{L\ max}$ = Wing maximum lift coefficient
e = Oswald efficiency factor
$C_{D,0}$ = Zero drag coefficient
t/c = Airfoil thickness ratio
AR = Aspect ratio
V_{stall} = Stall velocity
V_{cruise} = Cruise velocity
FF = Form Factor
L/D_{max} = Maximum lift to drag ratio
$C_{M\alpha=0}$ = Pitching moment coefficient at zero alpha
V_{climb} = Vertical climb Velocity
ρ = Density of air
b = span
c = chord
S = Area
S_{wetted} = Wetted area

Propulsion

Amp = Amps
C_D = Drag Coefficient
$C_{L,0}$ = Lift coefficient at cruise
$d_{propeller}$ = Propeller diameter
e = Oswald efficiency factor
E = Endurance
hp = Horsepower
I = Current
I_B = Battery Current
Kp = Propeller load factor
Kv = Motor Variable (RPM/Volt)
mAh = Milliamp hour (capacity)
nn = Propeller Rotation (Rev/s)
$P_{Available}$ = Power available
Pa = Max loaded power output
P_M = Motor Power
$P_{Required}$ = Power required
$q_\propto$ = Dynamic pressure
S = Wing area
T_R = Thrust required
V_∞ = Cruise Speed
V_L = Volts Loaded
V_z = Volts
W_0 = Gross Weight
W_a = Watts

W_{ap} = Arming Plug Weight
W_{awg} = Wire Weight
W_c = Connectors Weight (4x)
W_{esc} = Speed Controller Weight
W_{mo} = Motor Weight
W_p = Propeller Weight
W_{ps} = Propulsion System Weight
η = Propeller efficiency
ρ = Density

Stability and Control

C.G. = Center of gravity
A.C = Airplane aerodynamic center
Cm_α = pitch stiffness
Cm_0 = pitching moment at zero α_w
α_w = angle of attack of wing
δe = elevator deflection
$Cm_{\delta e}$ = change in pitching moment effectiveness with respect to elevator deflection
$CL_{\delta e}$ = change in elevator lift effectiveness with respect to elevator deflection
Xc.g. = c.g. x-distance from datum
Xa.c. = a.c. x-distance from datum
SM = Static margin

Structures

E = Young’s Modulus
I = Moment of Inertia
L = Length of half span
M = Bending Moment
σ_{max} = Maximum axial stress
P = Running load
V_o = Wing-tip deflection
n = Load Factor
TR = Torsional Rigidity

Others

C = Total aircraft cost
TSCR = Team score
MT = Mission time
PE = Planting Efficiency
ESC = Electronic speed controller
W/S = Wing loading
T/W = Thrust-to-weight ratio
AB = Automation Bonus

2.1. Propulsion (Abdullah Sifat)

2.1.1. Propeller Selection

Using the calculations done in conceptual design, the propeller diameter is fixed to be 9 inches. Three pitch values of propeller are considered for our design: 4.5-inch, 6-inch & 7.5-inch. Keeping the mission R&C's in mind, the APC Thin Electric 9x6 propeller is chosen because it can provide the required 2 lb of thrust for hand launch (at 12 ft/s) and it can achieve a top speed of 75 ft/s. The current consumption and thrust & power availability of the propeller are calculated at an RPM of 9,250. At this RPM, the 9x7.5 propeller draws more current than our target current limit of 14 A. The 9x4.5 propeller has a maximum efficiency close to our target J value, however, it does not produce enough thrust for hand launch and to reach the target maximum velocity. If the RPM is increased, the 9x4.5 propeller draws more current than our current limit of 14 A.

2.1.2. Propeller Selection

Great Planes ElectriFly LiPo 3S 11.1V 850mAh 25C battery is still considered because it has the maximum capacity and it is more reliable as it was already tested in WSU. At a 16 amps constant current the battery gives a very good performance. The discharge curve in the battery performance data shows a smooth graph in the middle. A constant current limit of 14 amps ensures good performance and longer endurance from the battery. However, the battery voltage seems to drop to 10.5V and so the voltage on the propeller performance calculations has been changed to 10.5V to better match the battery performance.

The motor selection is reconsidered in the preliminary design to reduce the weight of the propulsion system. Great Planes RimFire GTMG4560 motor is selected because it is lighter, and it can provide the required motor shaft power to reach all the R&C's. It has a constant current limit of 14 amps and a burst current limit of 20 amps. The burst current limit of the motor matches with the fuse current of 20 amps. The constant motor shaft power provided by this motor is 155 W which is more than the maximum required shaft power of the propeller (112 W at 9,250 RPM). Considering the RPM value used to find the propeller, the target Kv value for our motor was 900 and the chosen motor has a Kv value of 950. An exact match for Kv value could not be obtained because the constant current limit and the weight of the motor were also two important factors while choosing the motor for our vehicle.

2.1.3. Spinner & Motor Mount

A spinner improves the aerodynamic performance of the airplane. According to Raymer, [1] the spinner size should be below 25% of the propeller diameter, so a 1.5-inch spinner is considered to be used which can cover 17% of the propeller diameter. A larger spinner is heavier, so a small spinner is considered to reduce the weight buildup. Selection of the motor mount was simple. A mount with the same diameter as the motor is chosen, which is the 28mm Great Planes Rimfire backplate motor mount.

2.1.4. Calculations

The propeller performance data was calculated using the propeller thrust and power coefficient values obtained from the UIUC [2] website. The equations used to calculate thrust and power values were obtained from the "Propeller Performance Measurement for Low Reynolds Number UAV Applications" [3] paper in blackboard. All the necessary plots and tables are given in Figure 2.1.1 to 2.1.6, and Table 2.1.7 to 2.1.9.

2.1.5. Validation

The propeller performance calculating tool is validated using the data found in "Propeller & Preliminary Design paper". [4] RPM values and propeller coefficients found in that document is inserted into the tool to find the results and they are match with the given results in that document.

2.2. Aerodynamics (Patrick Dinh)

2.2.1. Wing and Tail Sizing

From conceptual design, the old wing area was calculated as 486 in^2 using a previously chosen W/S parameter. When iterating on the design, further revisions have put more effort in decreasing the estimated weight of the aircraft. The team also decided to select a new W/S parameter of 0.85 which set the new wing area to 252 in^2. Stall speed will be affected, increasing from 23 ft/s to 26.8 ft/s.

Tail sizing was also updated to satisfy the requirements from the S&C lead. The horizontal and vertical tail areas are now 72 in^2 and 33.3 in^2 respectively. These sizes greatly decreased from the CDR values for the horizontal and vertical, 144 in^2 and 114 in^2.

2.2.2. Fuselage Geometry

The CDR version of the fuselage did not have smooth transitions at each cross-section, resulting in corners which can cause additional drag. This lack of smoothness was not optimal but did simplify the calculation of wetted area by presenting distinct trapezoidal elements. For the sake of keeping the CAD design and build process relatively simple, the finalized fuselage shape will still have these corners along the length of the body which will likely have an impact on flight performance.

Now that the payload mechanism's geometry has been developed, the fuselage sizing has been decreased to the following general dimensions: length of 24 inch, max width of 5.25 inch, and max height of 5.25 inch.

2.2.3. Lift and Drag

Since the SD7062 airfoil's cl_{max} was 1.6, the 3D CL_{max} should be roughly $0.9cl_{max} = 1.44$ according to Nicolai [6]. Simulation of the wing in VSPAERO also shows a CL of approximately 1.4 at the corresponding angle of attack. Since the wing will not always be flying with the angle of attack for that CL_{max}, a more conservative CL_{max} value of 1.2 was considered for design purposes.

For the finalized design iteration, drag estimations from Nicolai's method[6] have decreased since the CDR. The model's total CD_{min} is now at 0.030, compared to the previous value of 0.035. The improvement was a result of reductions to wetted area and an increase in cruise speed to reach higher efficiency from the propulsion system.

A drag polar for the estimated CD_{min} versus CL at cruise is presented in Figure 2.2.1. The proportions of drag contributions from the complete aircraft are shown in Figure 2.2.2. It is shown that the wing and fuselage contribute to the majority of the overall drag on the vehicle.

2.2.4. Validation

Calculations from VSPAERO were used in the design process to estimate aerodynamics data for various aspects of the vehicle. The CL, CD, and pitching CM results from VSP were compared with Hagen's finite wing data [7] for an SD7062 wing with an aspect ratio of 6. The data was reasonably consistent between the experimental and VSP results.

The accuracy of the results from VSPAERO was also checked by replicating the "Calmodel" by Yrithu Pillay using VSP. Aerodynamics data for CL, CD, and pitching CM which were computed from the program was compared against the data provided by Pillay [8]. Our computed outputs were consistent with Pillay's results, which helped verify that VSP's simulation and Nicolai's drag estimation was reasonably accurate for use in our design.

2.3. Stability & Controls (Anwar Jihan)

The most critical goal during preliminary design is to firstly correct the previous SM and C.G calculation which results from resizing some important geometric feature's size to get higher accuracy in attaining the CG location from the updated weight table as listed in Table 2.3.7. Another important aspect, lateral stability analysis is performed to ensure accurate lateral derivatives which will lead to the aircraft is not only stable but also can perform a co-ordinate turn and can trim at various conditions.

2.3.1. Static Margin Revision and CG Optimization

The weight table was updated for more accuracy and the SM which was estimated in iPDR to be 10.26 and 10.27 respectively, have changed to 14.71% and 14,66% for Empty condition and fully loaded condition with the optimization in sizing. Optimization in sizing which changed the wing span to 3 ft. and fuselage length to 2 ft. resulted in CG to be about 7.635 and 7.630 inches from the fuselage datum. The updated trim data is listed in Table 2.3.3.

2.3.2. Control Surface and Empennage Optimization

In the preliminary design, the primary goal in control surface optimization was to get more accurate and optimal control surface. During initial preliminary design studies, it was found that the chord of the elevator was related to the sensitivity of controlling the airplane. For better controllability and performing a smoother maneuver the chord of elevator and rudder have been reduced to 30% of chord H-tail and V-tail which resulted in 0.104 ft. and 0.21 ft. chord, respectively. The V-tail was at a very early stage where excessive materials were used for keeping taper ratio 1. But, the fact that it restricts the deflection of elevator was overlooked. The V-Tail was optimized from 0.6 ft. span to 0.5 ft. span and the rudder with a taper ratio of 0.4 now has root chord of 0.5 ft. and the tip chord came down to 0.2 ft. The optimized sizing data are listed in Table 2.3.1.

2.3.2.1. Lateral Stability

In the preliminary design, the Lateral stability was studied and revised to ensure the optimization in sizing of control surface had no adverse effect on lateral control. Then, it was found that 35% chord for rudder was an over estimation and 30% chord of rudder provides smoother co-ordinate maneuver. The rudder size was also checked for cross-wind condition of 15 ft./s with 45% bank angle for turning. Static Lateral derivatives with assumptions of V_F/V is unity and the side-wash factor is 0.1 from historical trends, was calculated using methods described in Etkin[9]. The results are listed in Table 2.3.4. For checking the results OpenVSP was used and from moment coefficients the achieved derivatives of VSP validated the calculated derivatives.

2.3.2.2. Empennage Location

The Horizontal tail and Vertical tail location are paramount to ensure that there is no significant asymmetry and the horizontal tail's vertical location needed to be checked to ensure that at most critical points i.e. high angle of attack the H-tail has attached flow. Using Raymer[5] for locating both the tail, the V tail selection was trivial and is in the axis of symmetry and the H-tail was chosen to be at the fuselage surface which is 2 inches upward from the center line of the aircraft.

2.3.2.3. Cross-wind Handling Capability

With 25 degrees of rudder and aileron deflection in both positive and negative direction, the cross-wind conditions were checked against the fixed deflection and it was found that the airplane can handle 16 ft./s cross-wind without exceeding the deflection limit. Thus, the deflection limit is locked at 25 degrees of positive and negative deflection for both the rudder and the elevator.

2.3.2.4. Elevator deflection at 2-g pull up

Since the extreme load factor of 6 was decided in conceptual design, the elevator deflection per g for a 2-g pull up at different velocities were calculated using the methods in Etkin[9] and the result is listed in Table 2.3.2. it was estimated it would require -7.84 degrees of elevator deflection for a 2-g pull up.

2.4. Other Important Aspects

2.4.1. Payload Mechanism (Abdullah Sifat)

The payload system is planned to be made of two parts. A circular top with ten rods attached to it and a base to hold it. The base will be attached to the fuselage. The circular top is removable from the vehicle. This part is removed to load the payloads onto them. The darts are inserted on to the rods of the payload system. Initially the darts will be held in place by the rods and the bottom surface of the fuselage. A servo will be used to rotate the payload system. When each rod lines up with the hole on the bottom of the fuselage the darts will free fall towards the ground. The hole on the fuselage can also act as the air vent to cool the battery. The payload system is planned to be installed under the wing. It will be accessible by removing the wing. The payload mechanism is shown in the Figure 2.4.1 (Circular top), Figure 2.4.2 (Holder), and Figure 2.4.3 (payload system after assembly). The payload system is planned to be made by 3D printing. Since the circular top needs to have 10 rods attached to it, it will be stronger and lighter to make it by 3D printing.

More testing is necessary to figure out the accuracy of the payload system. A servo has to be modified to make it rotate 360 degrees. Since the payloads are being dropped into the air stream without any external force, the payloads might fall backwards. Timing for the payload drop needs to be calculated to ensure successful mission completion.

2.4.2. Hand Launch (Patrick Dinh)

Using the estimated values for the airplane’s weight and aerodynamic properties, an estimated flight path for a hand launch was computed using assumed take-off conditions. At the lowest point in the flight path, the height should be kept at around 2 ft to reduce the likelihood of contact with the ground. From the analysis, a safe set of minimum values for take-off that can be used for the airplane are: initial velocity of 11.5 ft/s, height of 6 ft, an angle of attack at 2 degrees, and 2.0 lb of thrust from the propulsion system. A plot for the estimated flight path of this set of conditions is shown in Figure 2.4.5.

2.5. Additional Discussion (Abdullah Sifat)

For the preliminary design our main goal was to reduce the size and weight of our plane. Every component of the propulsion system was reconsidered and changed accordingly to reduce the weight. The size of the airplane was reduced by changing the wing's aspect ratio to 5.15.

The 9x6 propeller changed our cruising speed to 60 ft/s since the propeller is most efficient at this speed. Higher cruising speed means the mission can be completed in less time and increasing the score. However, the accuracy of payload dropping might be affected by the higher cruising speed. The vehicle might need to slow down during payload drops which will increase the current consumption.

If the plane cruises at 60 ft/s, the mission time will be 84 seconds for a flight range of 5000 ft. This value is not accurate since the actual mission time will have other factors affecting it such as weather conditions, payload dropping time, flight altitude, and climb rate. However, at a 14 A constant current limit from the battery, the endurance is calculated to be 219 seconds which is more than double of the calculated mission time.

3. <u>Design Data Table (combined team effort)</u>

Parameter	**Design Prediction**
Wing Area	252 in^2
Wing Span	36 in.
$C_{D,0}$	0.030
$C_{L\ max}$	1.4
L/D_{MAX}	22.8
Wing Airfoil/s	SD7062
Aerodynamic Center Location	8.75 inches from nose of fuselage
$C_{M,0}$	0.02
$C_{M\text{-alpha}}$	-0.72
Static Margin	19%
Required Elevator Deflection for Trim at V_{Cruise}	1.4 degrees
Required Elevator Deflection for Trim at $1.2V_{Stall}$	-2.8 degrees
Required Elevator Deflection for Trim at Maneuver Point	6.3 degrees
Max Power Available	58.8 W
Propeller Diameter	9 inches
<u>Total</u> Propulsion System Weight (motor, battery pack, wires, connectors, fuse, prop, etc.)	0.62 lb.
Battery Pack (nominal volts, # of cells, & mAhr)	11.1 V, 3 cells, 850mAh
Maximum Current Draw	14 A
Endurance	219 seconds
Stall Speed	26 ft./s
Max Speed	75 ft./s
Corner Speed (V^*)	60 ft./s
Minimum Turn Radius	35 ft.
Take-off Distance	N/A
Landing Distance	N/A
Empty Weight (ready to fly, no payload)	1.64 lb.
Maximum Payload	1.66 lb.
CG Location	7.67 inch from Wing L.E. with payload
Wing Tip Deflection at V^*	0.63 inches
+/- n_{max}	+6 g, -2.5 g
Total Vehicle Cost	$452
Time to Build	20 hours
Other Critical (list below)	
a) Hand Launch Speed	12 ft./s
b) Mission Time	84 seconds

4. References

1. Raymer, D. P., “Aircraft design: a conceptual approach,” Washington (D.C.): American Institute of Aeronautics and Astronautics, 1992. pp 221.
2. “UIUC Propeller Data Site,” UIUC PDB - Vol 1 Available: http://m-selig.ae.illinois.edu/props/volume-1/propDB-volume-1.html.
3. Merchant, M. P., and Miller, L. S., “Propeller Performance Measurement for Low Reynolds Number UAV Applications,” 44th AIAA Aerospace Sciences Meeting and Exhibit, Jan. 2006.
4. Miller, L. S., “Propellers & Preliminary Design,” blackboard.wichita.edu
5. Raymer, D. P., “Aircraft Design: A Conceptual Approach,” Reston, VA: American Institute of Aeronautics and Astronautics, 2012.
6. Nicolai, L. M., “Estimating R/C Model Aerodynamics and Performance”, June 2002.
7. Hagen, Kevin. “Finite Wing Data,” AE 528 Blackboard, retrieved 2017.
8. Pillay, Yrithu. “Basic Aircraft Test Data,” AE 528 Blackboard, retrieved 2017.
9. Etkin, Bernard and Reid, Lloyd D., “Dynamics of Flight: Stability and Control,” 3rd edition, Wiley, 1996., pp 80.

5. CAD Drawings (Abdullah Sifat)

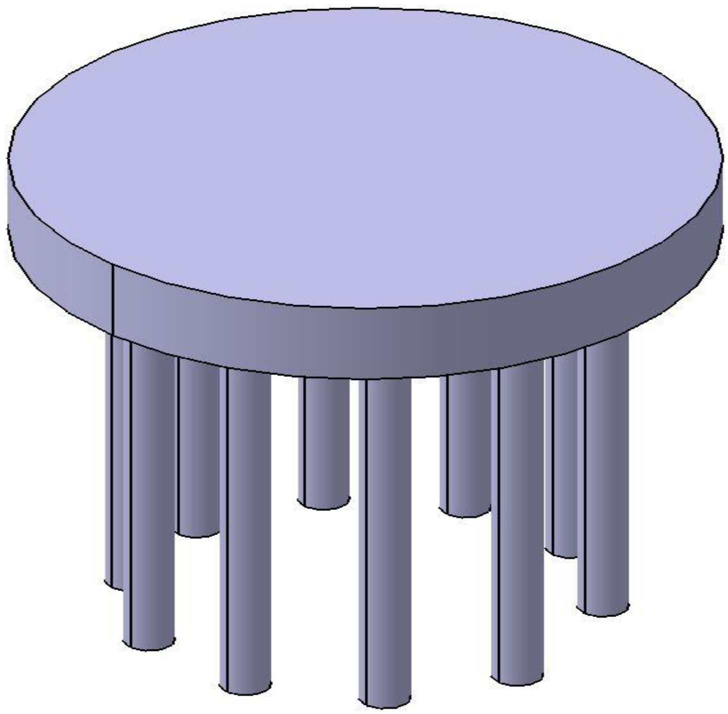


Figure 2.4.1: Circular part with rods of the payload system which is removable

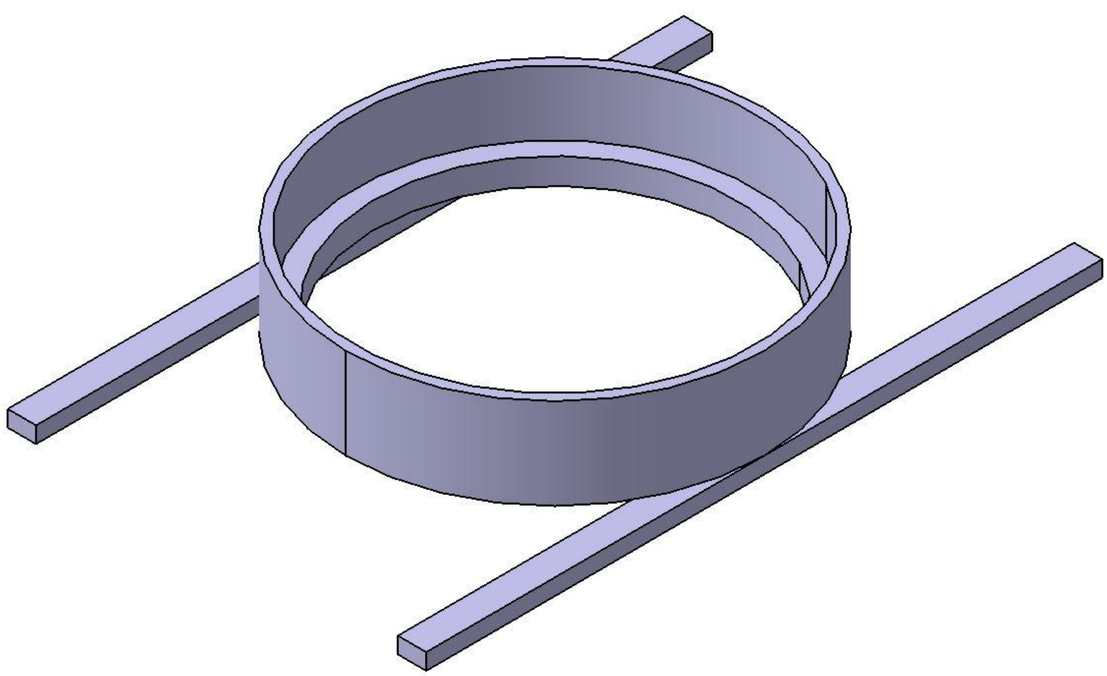


Figure 2.4.2: Payload system holder which will be attached to the fuselage

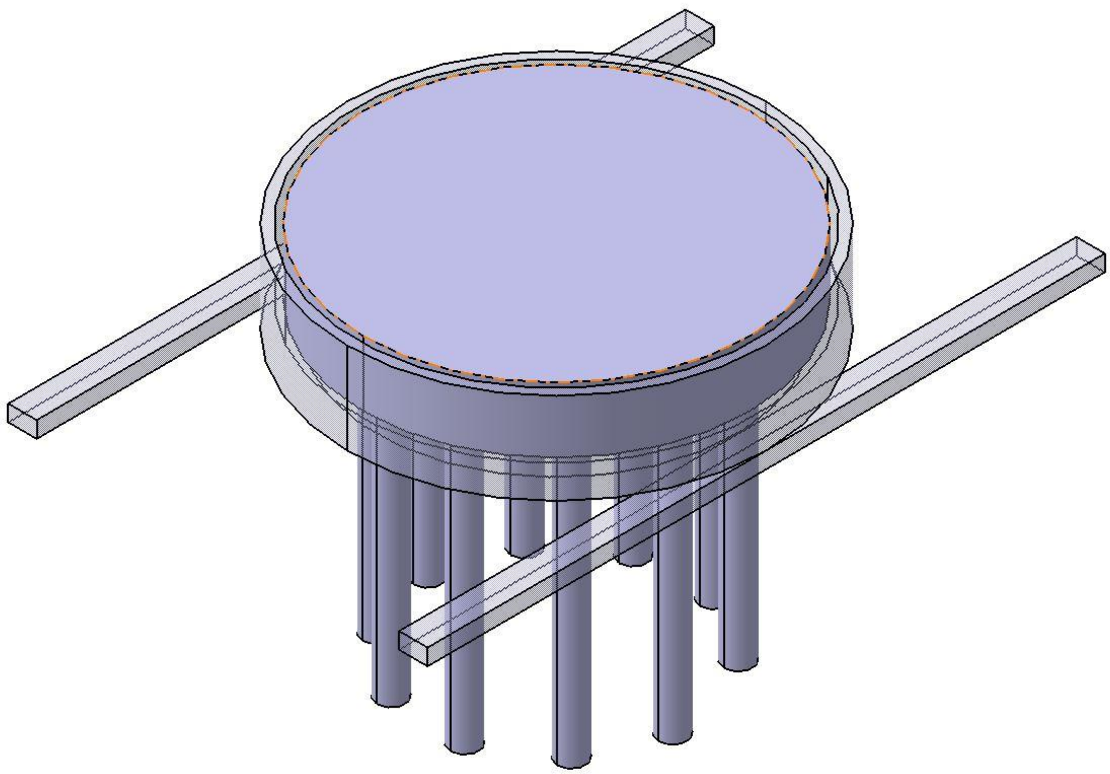


Figure 2.4.3: Payload System after assembly

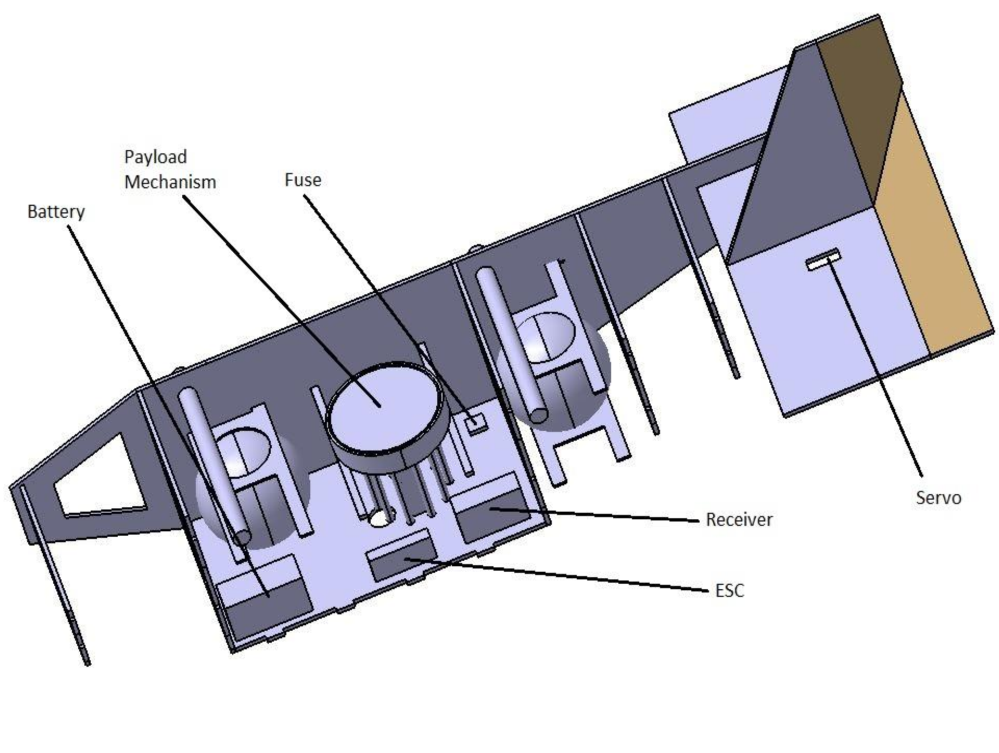


Figure 2.4.4: Layout Drawing

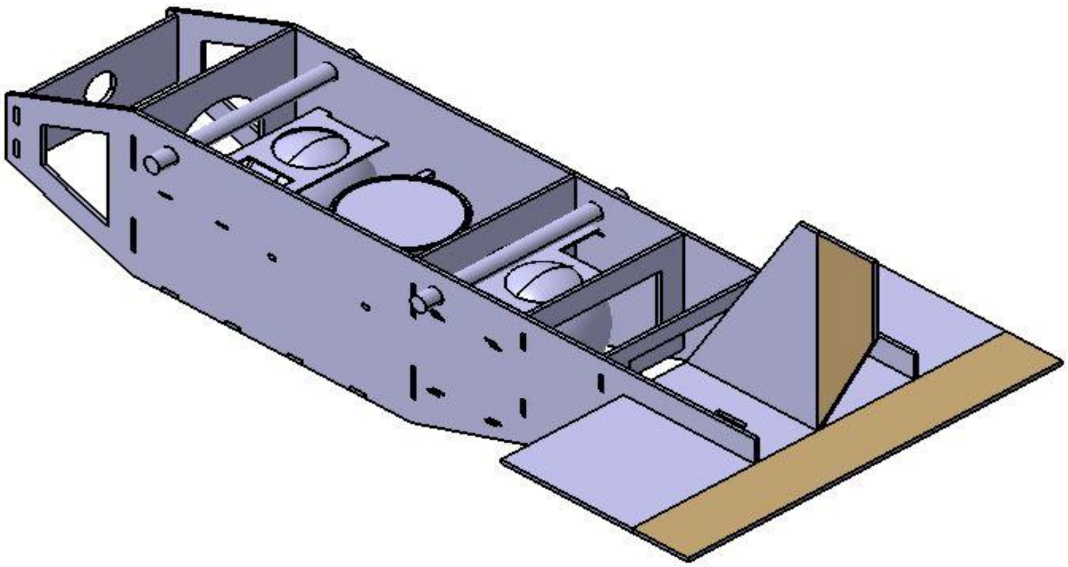


Figure 2.4.5: Fuselage with horizontal and vertical tail

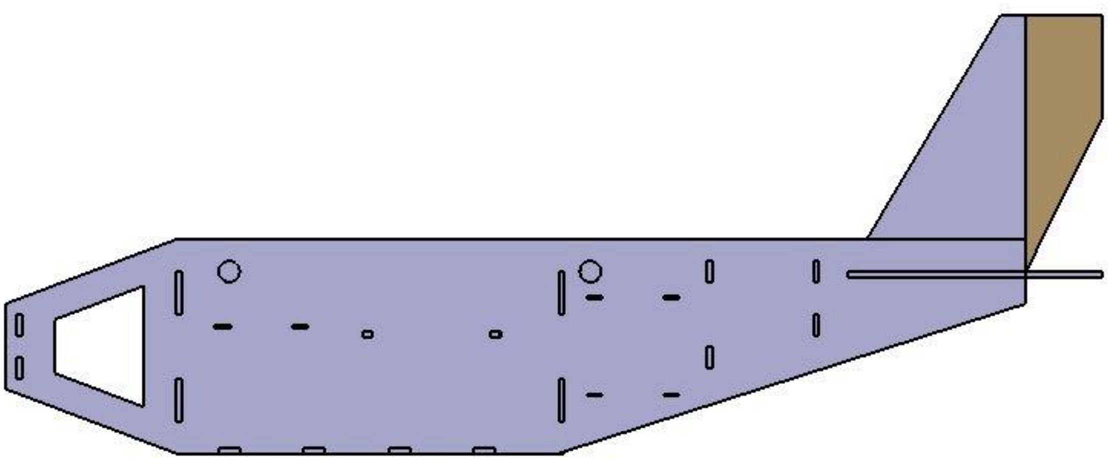


Figure 2.4.6: Side View of the Fuselage

6. Plots and Data

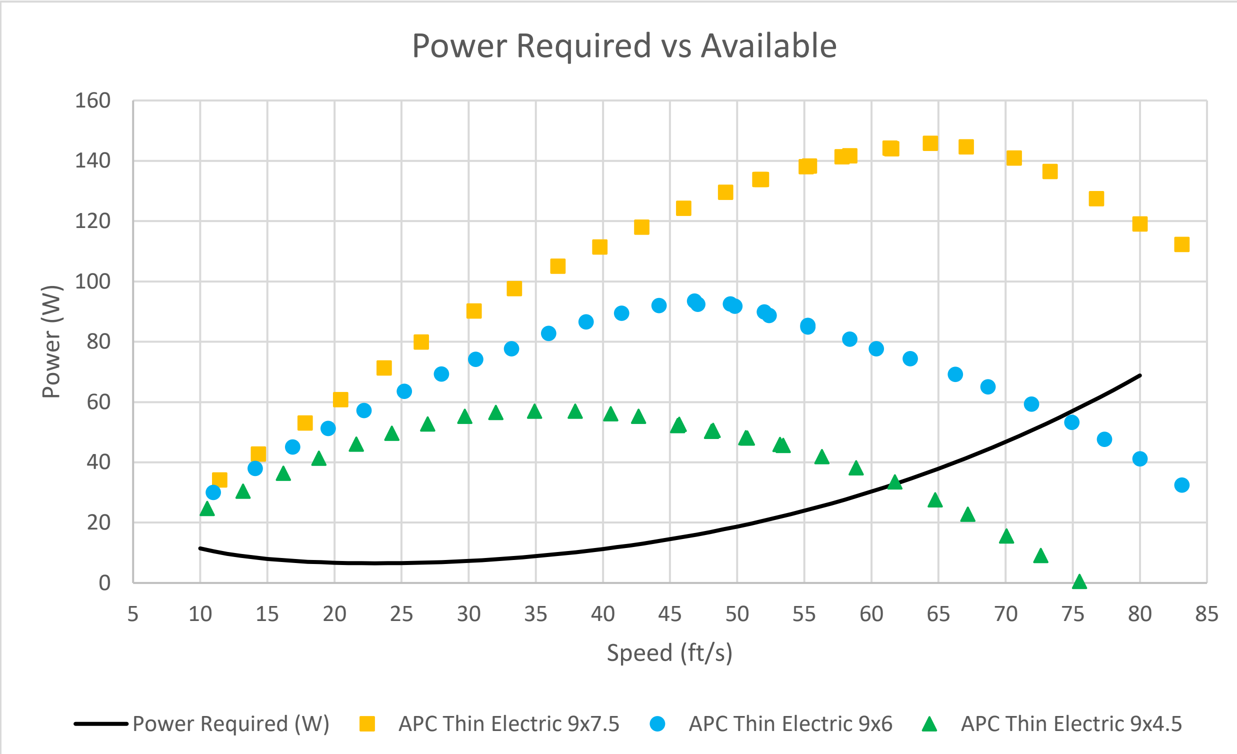


Figure 2.1.1: Power Available & Power Required comparison of APC Thin Electric Propellers

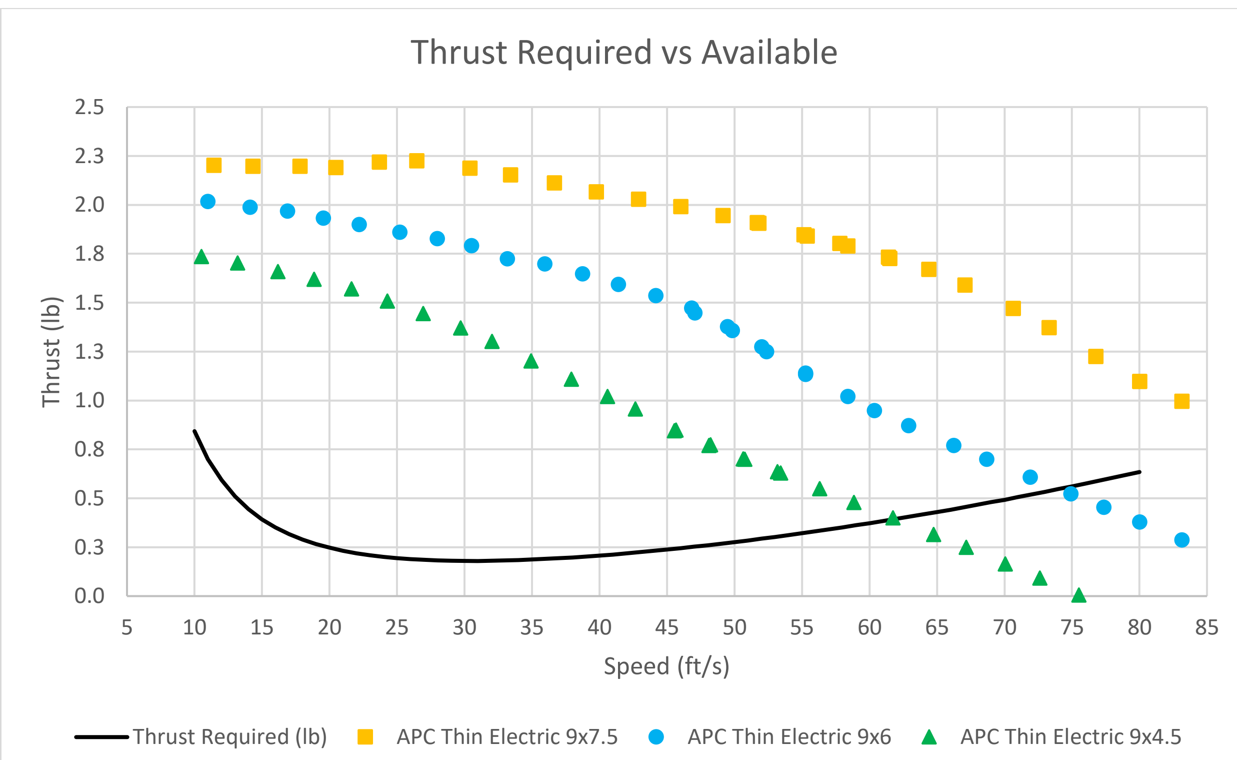


Figure 2.1.2: Thrust Available & Thrust Required comparison of APC Thin Electric Propellers

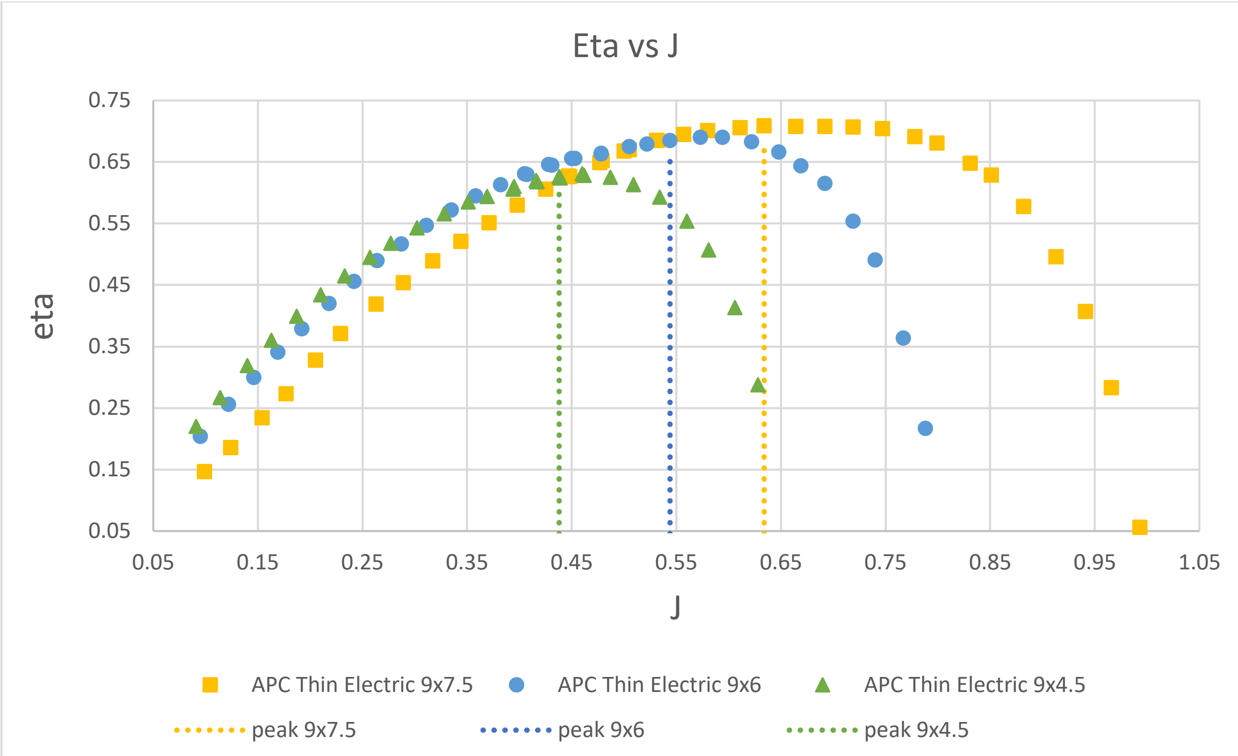


Figure 2.1.3: Comparing the advance ratio at maximum efficiency of 9-inch APC Thin Electric Propeller

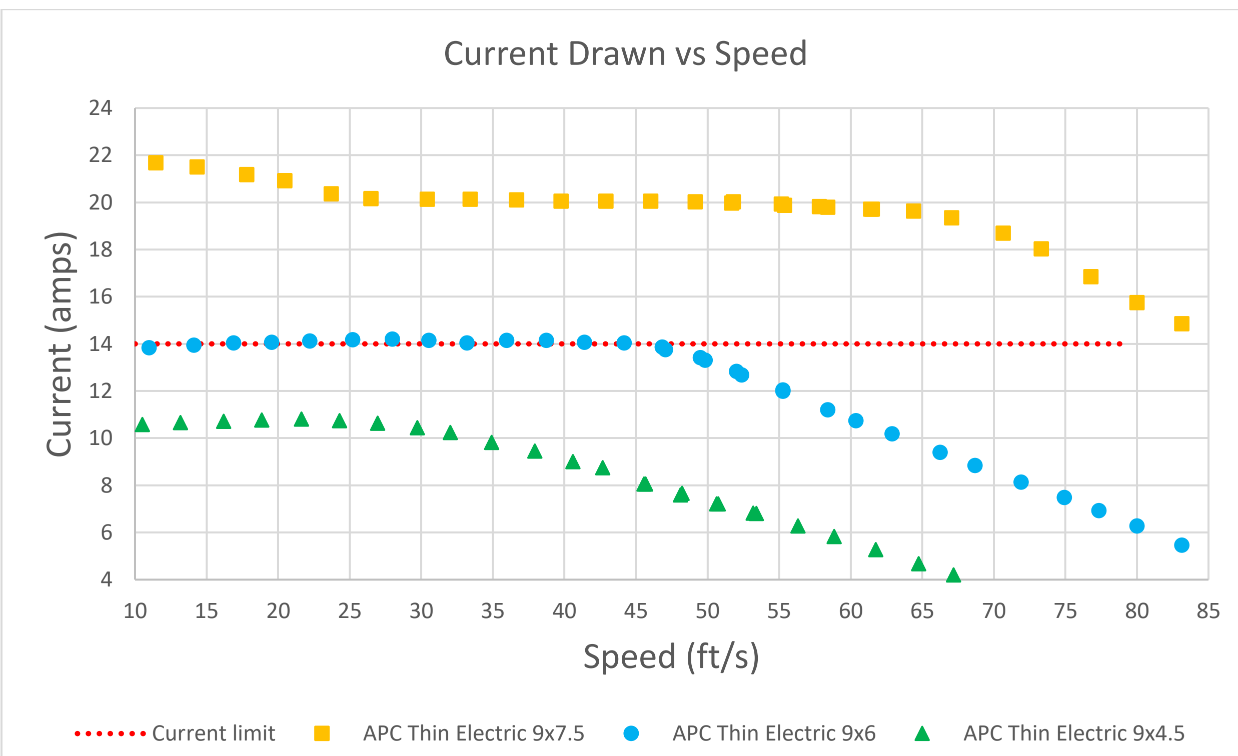


Figure 2.1.4: Comparing the current drawn by 9-inch APC Thin Electric Propeller

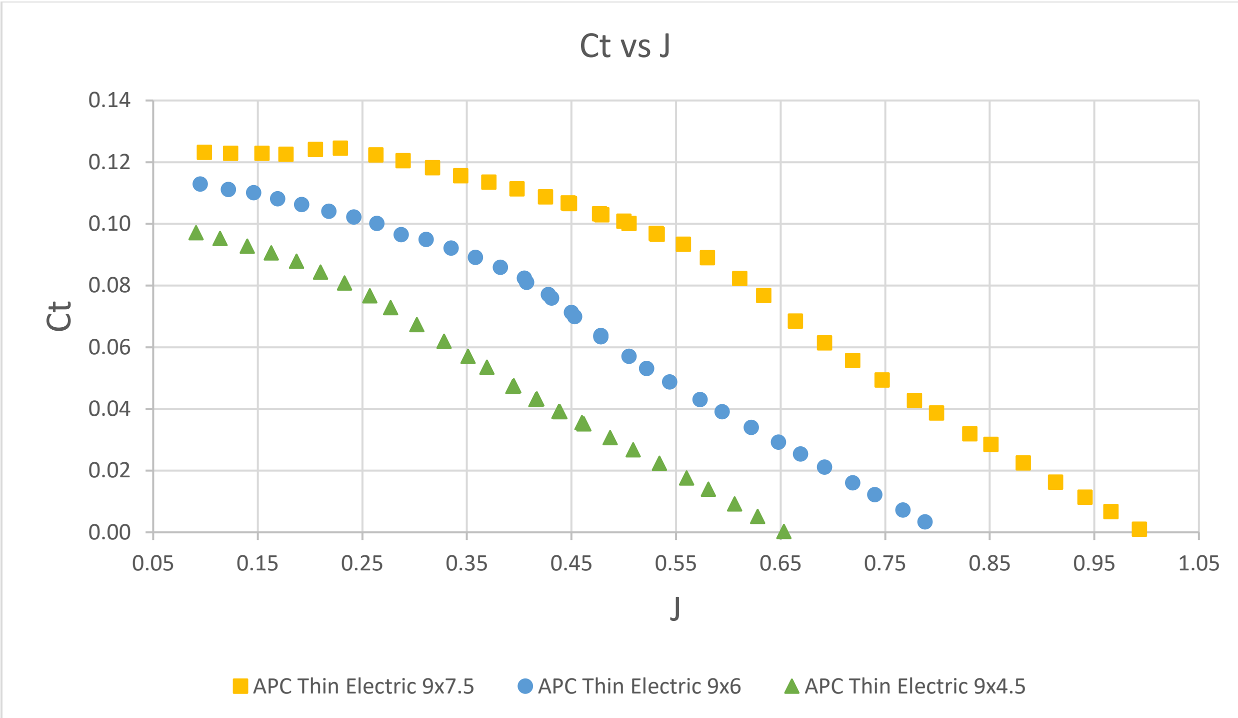


Figure 2.1.5: Comparing thrust coefficient vs advance ratio of 10x5 and 10x7 APC Thin Electric Propeller

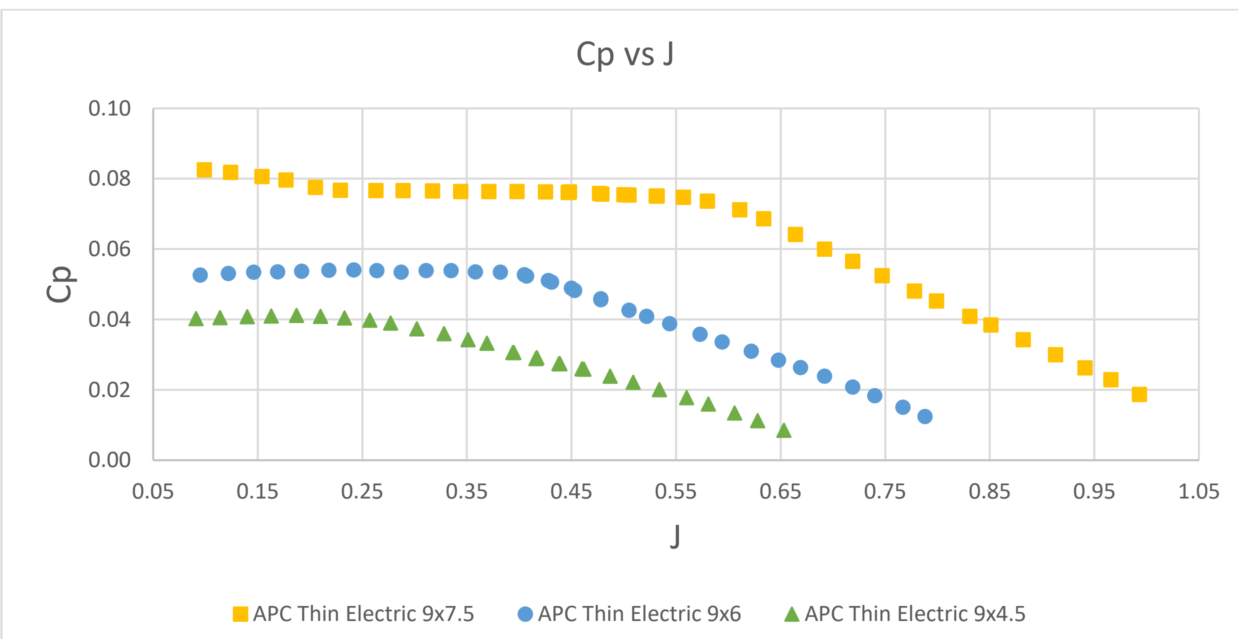


Figure 2.1.6: Comparing power coefficient vs advance ratio of 10x5 and 10x7 APC Thin Electric Propeller

Component Name	**Weight (oz)**	**Weight (lb.)**	**Cost**	**Propulsion system components**
Battery	2.8	0.175	$20	Great Planes Electrifly LiPo 3S 11.1V 850mAh 25C Star Battery
Motor	1.91	0.119	$50	Great Planes RimFire GPMG4560
Propeller	0.63	0.039	$3	APC Thin Electric 9x6 Propeller
ESC	0.63	0.039	$45	Great Planes Silver Series 25A Brushless ESC
Servo (5)	1.4	0.088	$75	Futaba S3114 Servo
Receiver	0.58	0.036	$40	RX-FrSky G-RX8 Receiver
Mount	0.2	0.013	$4	Great Planes Rimfire Motor Mount 28mm
Spinner	0.18	0.011	$8	Great Planes E-Spinner 1.5"
Wire	1.6	0.100	$5	
	9.93	**0.62**	**$250**	

Table 2.1.7: List of Propulsion System Components

Motor Name	**Kv**	**RPM**	**Constant Current (amps)**	**Burst Current (amps)**	**Voltage (V)**	**Power (W)**	**Weight (oz)**	**Propeller Diameter (in)**
Great Planes RimFire GPMG4525	1,000	10,500	12	15	7.4 - 11.1	135	1.4	9x4.5 - 10x4.5
Great Planes RimFire GPMG4560	**950**	**9,975**	**14**	**20**	**7.4 - 11.1**	**155**	**1.91**	**8x6 - 10x4**
Scorpion SII-2215-900KV (V2)	900	9,450	16	16	7.4 - 14.4	237	2.42	11x3.8 - 11x8
E-Flite Park 400 EFLM1300	740	7,770	7	10	7.2 - 12	111	2	10x4.7 - 12x3.8
SuperTigre 370 SUPG8030	1,000	10,500	11.5	13	7.4 - 11.1	125	1.4	9x3.5 - 11x4
E-Flite Park 450 EFLM1400	890	9,345	14	18	7.2 - 12	200	2.5	9x6 - 11x3.8

Table 2.1.8: List of Motors Considered

Propeller	Flight Condition	Velocity (ft/s)	Thrust (lb.)	Shaft Power (W)	Power Available (W)	Current (amps)	RPM (rev/min)
APC TE 9x7.5	Hand Launch	11	2.08	157.20	31.5	20.0	9,000
	Stall	26	2.11	146.21	73.6	18.6	
	Cruise	60	1.64	142.97	132.8	18	
	Turn	65	1.51	140.31	133.3	17.8	
APC TE 9x6	Hand Launch	11	2.02	108.9	30.1	13.8	9,250
	Stall	26	1.86	111.6	63.6	14.2	
	Cruise	60	0.95	84.5	77.7	10.7	
	Turn	65	0.77	74.00	69.2	9.4	
APC TE 9x4.5	Hand Launch	11	2.19	118.38	35.2	15.0	10,400
	Stall	26	1.91	120.14	70.6	15.3	
	Cruise	60	0.80	76.08	64.8	9.7	
	Turn	65	0.61	65.21	54.3	8.3	

Table 2.1.9: Propeller Performance Data

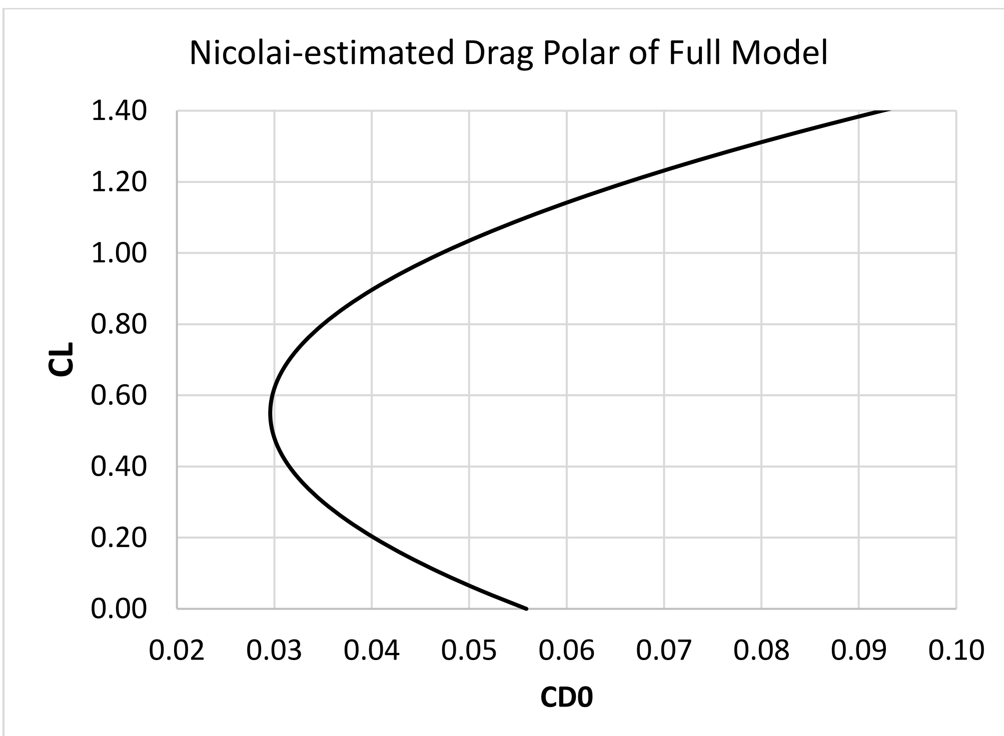


Figure 2.2.1: Drag polar of the full airplane using Nicolai's drag estimation

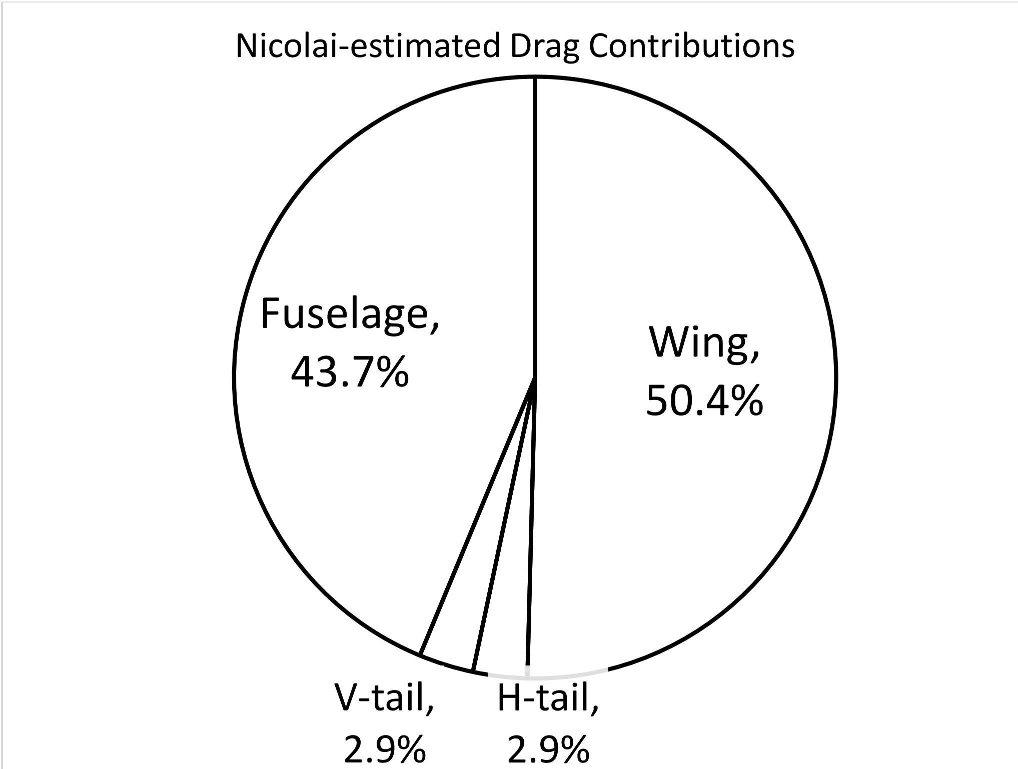


Figure 2.2.2: Percentages of drag contributions from the Nicolai estimation

Empennage Sizing Data						
	Span	Root Chord	Tip Chord	Area	MAC	Taper Ratio
Horizontal Tail (ft)	0.92	0.5	0.5	0.5	0.5	1.0
Vertical Tail (ft)	0.5	0.5	0.2	0.231	0.371	0.4

Table 2.3.1: Aircraft tail sizing

Velocity (V) ft/s	Cw	(Δδe)/(n-1)	(Δα)/(n-1)
35	0.7120405	-0.3130078	0.1859097
45	0.4307405	-0.1893504	0.1124639
55	0.2883470	-0.1267552	0.0752857
65	0.2064496	-0.0907537	0.0539028
75	0.1550666	-0.0681661	0.0404870
85	0.1207266	-0.0530705	0.0315210

Table 2.3.2: Elevator coefficients

Trim angle of elevator at Cruise and Stall condition (Degrees)				
Weight	α_trim Cruise	δ_trim Cruise	α_trim Stall	δ_trim Stall
Empty weight	2.64	-1.04	14.09	-20.11
Take-off Weight	1.92	5.85	13.36	-13.16

Table 2.3.3: Elevator trim angles

Derivatives	V_{cruise}	$1.2V_{stall}$	V_{turn}
Cmα	-0.66	-0.59	-0.66
Cℓβ	-0.93	-0.80	-0.93
Cnβ	0.04	0.04	0.04
Cℓp	-0.45	-0.43	-0.45
Cnp	-0.11	-0.11	-0.11
Cnr	-0.37	-0.37	-0.37
Cℓδr	0.11	0.11	0.11
Cnδr	-0.27	-0.27	-0.27
Cℓδa	-0.06	-0.06	-0.06
Cnδa	0.010	0.03	0.02
CLδe	1.02	1.02	1.02
Cmδe	-1.32	-1.32	-1.32
All values shown in 1/rad			

Table 2.3.4: Stability derivatives

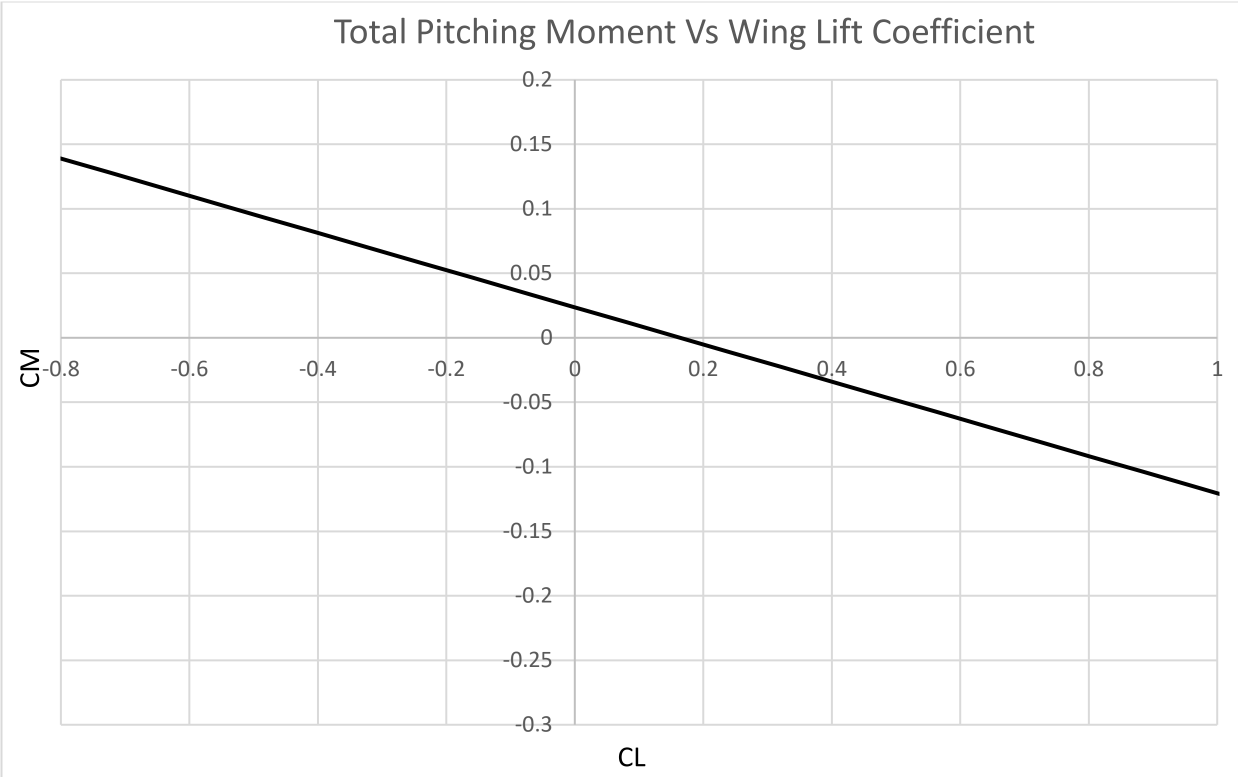


Figure 2.3.5: Pitching moment vs wing lift coefficient

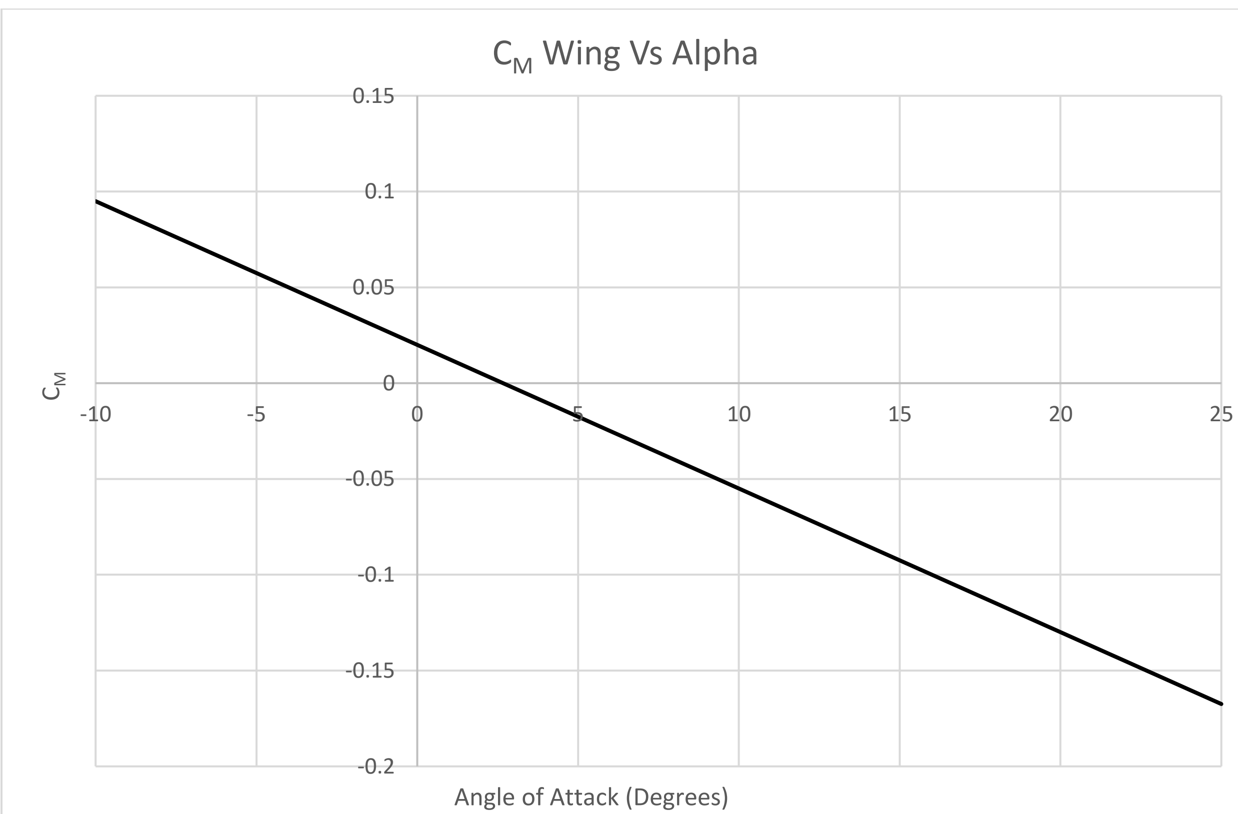


Figure 2.3.6: Pitching moment vs angle of attack

Component	Weight (oz)	Arm (ft. aft datum)	Arm(in.)	Moment
Fuselage	3.500	1.17	14.00	49.00
H-Tail	0.700	1.92	23.00	16.10
V-Tail	0.400	1.88	22.50	9.00
Wing	4.150	0.60	7.18	29.78
Propeller	0.630	-0.08	-1.00	-0.63
Motor	1.910	-0.08	-1.00	-1.91
ESC	0.630	0.29	3.50	2.21
Battery Pack	2.800	0.29	3.50	9.80
Mount	0.600	-0.08	-1.00	-0.60
Servos	1.400	0.58	7.00	9.80
Reciever	0.580	0.29	3.50	2.03
Fuse	0.150	1.00	13.00	1.95
Wiring	1.600			0.00
Spinner	0.180	-0.08	-1	-0.18
Tennis Ball	2.000		14.75	29.50
Tennis Ball	2.000		6	12.00
Payload Mechanism	2.000	0.83	10	20.00
Servo 2	0.560		18	10.08
Adhesive	1.000			
TOTAL	**26.8**	oz.		
	1.67	lbs		197.92

Table 2.3.7: Total aircraft weight build-up

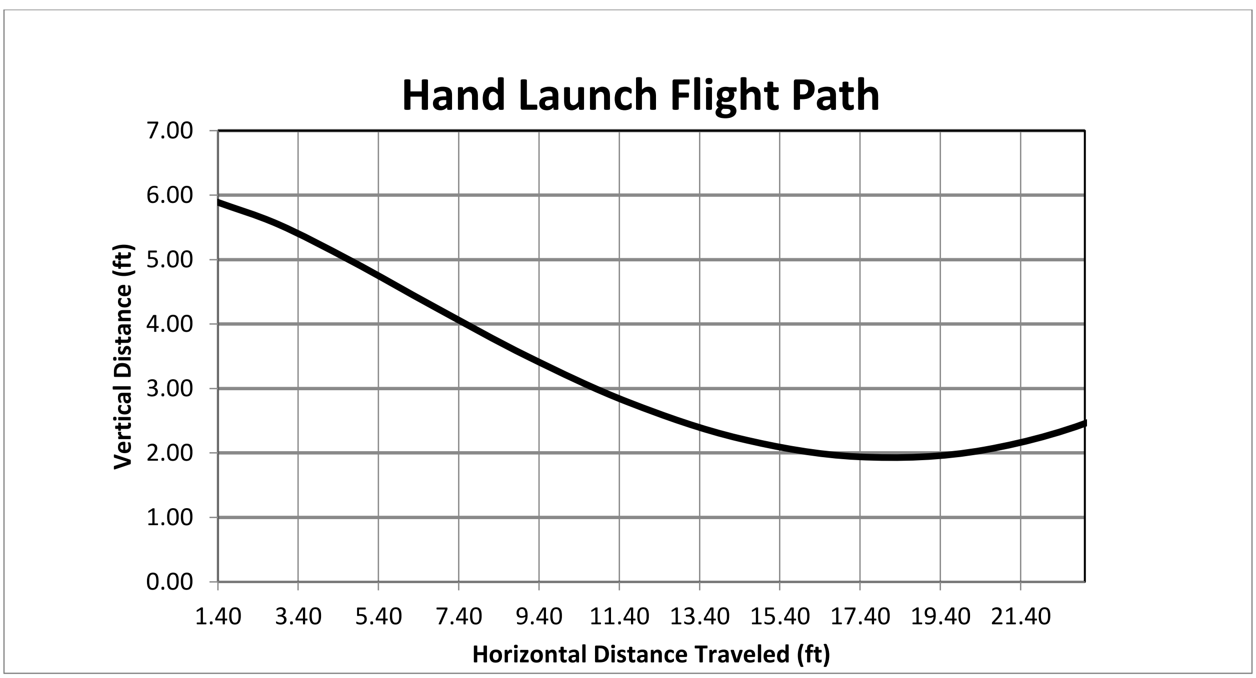


Figure 2.4.7: Estimated flight trajectory using the minimum launch conditions