REPORT 3

DEPARTMENT OF AEROSPACE ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, MADRAS

DESIGN OF UAV

UDAAN

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Weight Estimation

1.1 Introduction

To develop UDAAN - a lightweight, energy efficient, inflatable drone capable of vertical Take off, Stand By and Landing, which can deliver payloads and is self rechargeable. Drones allows for a wide variety of missions, however with the weight of the sensors increasing, the drones able to carry such payloads are cumbersome and difficult to transport.That is why we are trying to develop India's first inflatable drone.The drone has inflatable structure, is at the same time will be easy to transport and rugged because of the flexible structure. Moreover, the drone would be waterproof and can land and take-off on water surface because of compressed Helium gas used in the inflatable structure.

1.2 Novelty Features

1.2.1 Fast

The UDAAN will unfold in a few seconds and can be operated by a single person.

1.2.2 Compact

The UDAAN will be easily transportable thanks to its compact and foldable inflatable structure

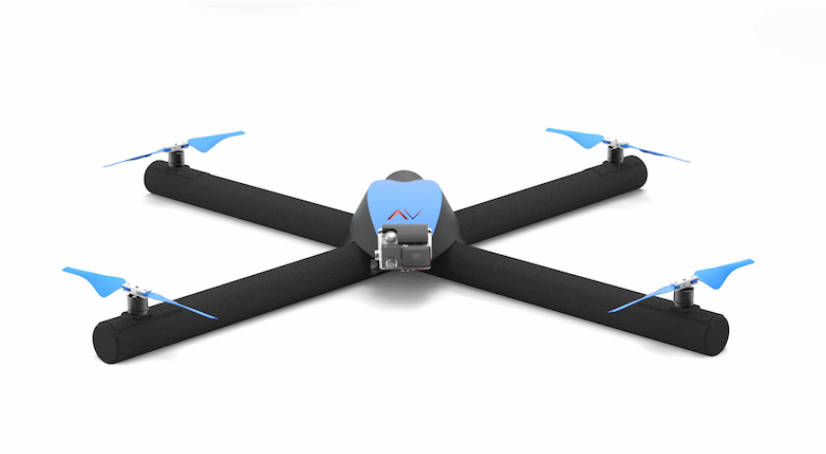

Figure 1.1: Inflatable drone

1.2.3 Amphibious

The UDAAN is waterproof, therefore deployable under heavy rain or even on water.

1.2.4 Payload and Surveillance

UDAAN is capable of carrying a Payload and hence can be utilised for delivery of items via e-commerce channel.

1.2.5 Self Rechargeable

UDAAN would be equipped with self rechargeable capabilities.We are trying to develop and incorporate a mechanism to recharge the battery using renewable energy sources.

1.3 Mission Profile

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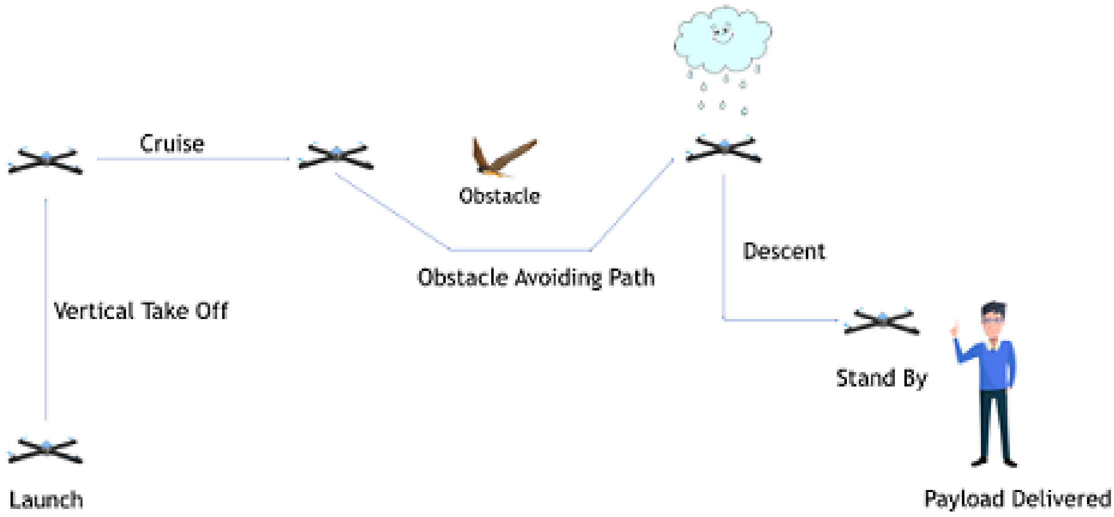

Figure 1.2: Mission Profile

1.4 Estimated Data

1.4.1 Dimensions

Available Payload : Camera, Parcel

Folded : 300x300x150 mm

Unfolded : 800x800x150 mm

Endurance : up to 60 min

1.4.2 Common Characteristics

Waterproof

Wind resistance : 37 kmph

Unfolding time : 60s

Folding time : 60s

1.4.3 Weight Estimate

Components	Weight(grams)	Quantity	Total Weight(grams)
Propeller	5	4	5*4=20
Motor	20	4	20*4=80
Flight Control Board	50	1	50*1=50
Electronic speed controller	75	4	75*4=300
Base weight	100	1	100*1=100
Camera weight	120	1	120*1=120
Battery	200	1	200*1=200

Table 1.1: First Weight Estimation

Total weight = 20+80+50+300+100+120+200=870 grams

Data given in the table are initial guesses and actual weight might vary from this approximation.

Chapter 2

Second Weight Estimation

2.1 Weight Estimate

Components	Weight(grams)	Quantity	Total Weight(grams)
Propeller	7.5	4	7.5*4=30
Motor	23	4	23*4=92
Flight Control Board	60	1	60*1=60
Electronic speed controller	100	4	100*4=400
Base weight	200	1	200*1 = 200
Camera weight	120	1	100*1=100
Battery	160	1	160*1=160
Bolts	20	-	20
Locking nuts	20	-	20
Wires	30	-	30

Table 2.1: Second Weight Estimation

Total weight = 30+92+60+400+200+100+160+20+20+30 = 1112 grams

2.2 Thrust Calculation

2.2.1 Sample Calculation

The analytical calculations need to be done initially to verify whether the data obtained is feasible or not.We have done a sample calculation by considering an approximate weight of 1000 grams.Let us consider a thrust to weight ratio of 2 as is the general trend while designing drones.Head space is taken as 20 % and hence the thrust to weight ratio finally changes to 2.4

Therefore, the net thrust that the motors need to provide is 1000 * 2.4 = 2400 grams.The thrust required per motor and thereof for one propeller is 2400/4 = 600 grams. For different size of propeller, with different rpm values we can achieve above thrust.

Let us consider the propeller size to be 8*4 and motor rpm around 10500,which is generally used with quadcopters of the frame that we have thought of.Here 8 is the diameter in inches and 4 is the pitch.Pitch is defined as the linear movement it will travel in 1 second.The thrust obtained is 605 grams if we are using the above propeller with the mentioned motor speed, from the formula that is given in Figure 2.1.For obtaining 10500 rpm the KV rating which is given by rpm per volt is 2570.Now in most quadcopters we are using a 3cell 11.1V Lithium Polymer battery.Therefore the net rpm of motion is 28527 rpm

If propeller diameter is 10 inchess then motor rpm becomes 1/3rd that is 9509 rpm. Similarly, when 5 inch diameter is chosen the rpm is reduced by 50 %, that is it becomes 14263.5 rpm which is more than required.

Therefore, a propeller of size 8*4 is analytically feasible to be used to get a net thrust of approximately 1000 grams.

The battery weight for the given configuration is 160 grams and the motor weight is 23*4 = 92 grams.The net weight of 4 propellers is 30 grams.Now, considering the weight that we have obtained which is 1112 grams.The required thrust per propeller will be (1112*2.4)/4 which is 670 grams.The corresponding rpm is 11000 rpm. Hence, 8*4 propeller with selected motor and battery can give us required rpm and the thrust needed.

- The analytical calculations are as follows:
- Estimated Weight of drone = 1112 grams
- Thrust/Weight = 2
- Headspace given for thrust = 20 %
- Net thrust required = 2.4 * 1112 grams = 2669 grams
- Net thrust required per motor = 670 grams
- Specification of propeller:
    1. Diameter = 8 inches
    2. pitch = 4 inches

2.2.2 Motor Specification

- Motor: Avionic M2226/18 KV2570 MICRO brushless motor
- KV (rpm/v): 2570
- Power: 80W
- Winds: 18
- Resistance: 327 mOhm
- Idle current: 0.8 A
- Weight: 23 gms

2.2.3 Formula used for thrust calculation

$$F = 1.225\frac{\pi(0.0254\cdot d)^2}{4}\left[\left(RPM_{prop}\cdot 0.0254\cdot pitch\cdot\frac{1min}{60sec}\right)^2 - \left(RPM_{prop}\cdot 0.0254\cdot pitch\cdot\frac{1min}{60sec}\right)V_0\right]\left(\frac{d}{3.29546\cdot pitch}\right)^{1.5}$$

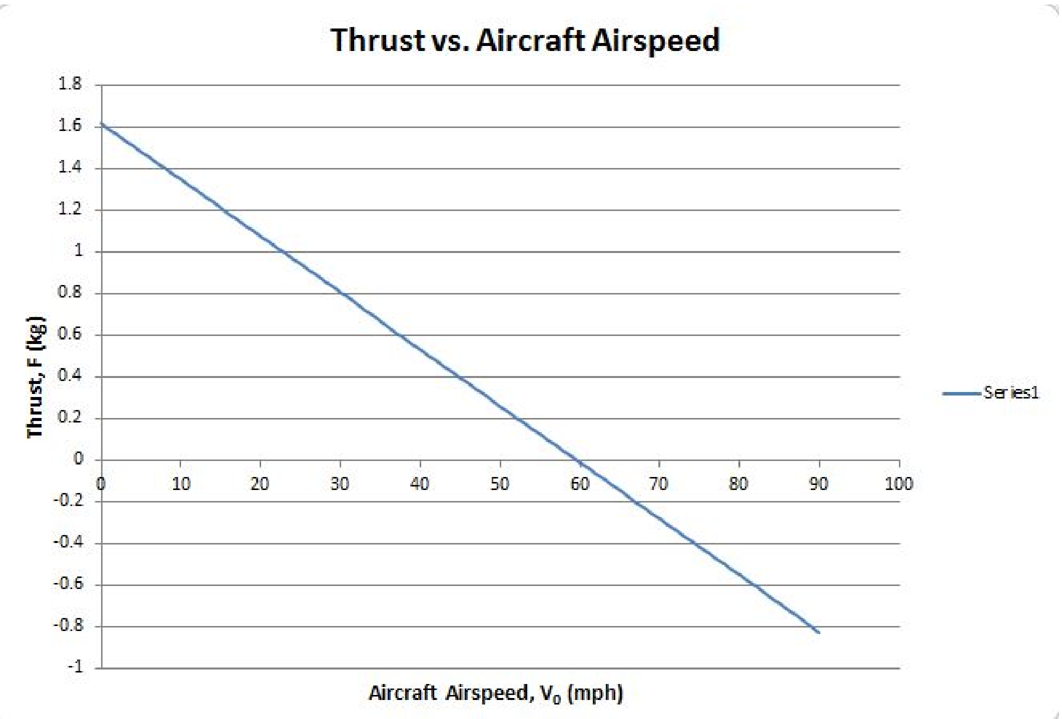

Figure 2.1: Thrust v/s Speed

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2.2.4 Battery Specification

- Minimum Capacity: 2200mAh
- Configuration: 3S1P / 11.1v / 3Cell
- Constant Discharge: 25C

- Peak Discharge (10sec): 35C

2.3 Procedure

- Decide appropriate dimension of propeller.
- Choose suitable RPM of motor.
- Get the required static thrust from the table.
- Iterate the dimensions until you get the required thrust which is 672 g of thrust.
- After fixing the dimension and RPM of motor, find suitable LiPo battery
- RPM = KV * Battery voltage RPM = 2570 * 11.1 = 28500
- This is the RPM of motor without propeller.After using propeller RPM reduces by 2.5 times approximately.
- Net RPM = 11410 (estimated)
- After finalizing the battery, fix the Electronic speed controller.

2.4 Conclusion

The weight of the inflatable drone is estimated to be around 1112gm.The estimated static thrust produced is 6.636 N.In the next phase, after performing successive iterations we will finalize the weight of the drone and perform dynamic thrust calculations.

Chapter 3

Propeller Design

3.1 Introduction

A relatively simple method of predicting the performance of a propeller (as well as fans or windmills) is the use of Blade Element Theory. In this method the propeller is divided into a number of independent sections along the length. At each section a force balance is applied involving 2D section lift and drag with the thrust and torque produced by the section. At the same time a balance of axial and angular momentum is applied. This produces a set of non-linear equations that can be solved by iteration for each blade section. The resulting values of section thrust and torque can be summed to predict the overall performance of the propeller. The theory does not include secondary effects such as 3-D flow velocities induced on the propeller by the shed tip vortex or radial components of flow induced by angular acceleration due to the rotation of the propeller. In comparison with real propeller results this theory will over-predict thrust and under-predict torque with a resulting increase in theoretical efficiency of 5% to 10% over measured performance. Some of the flow assumptions made also breakdown for extreme conditions when the flow on the blade becomes stalled or there is a significant proportion of the propeller blade in windmilling configuration while other parts are still thrust producing. The theory has been found very useful for comparative studies such as optimising blade pitch setting for a given cruise speed or in determining the optimum blade solidity for a propeller. Given the above limitations it is still the best tool available for getting good first order predictions of thrust, torque and efficiency for propellers under a large range of operating conditions.

3.2 Blade Element Subdivision

A propeller blade can be subdivided as shown into a discrete number of sections. For each section the flow can be analysed independently if the

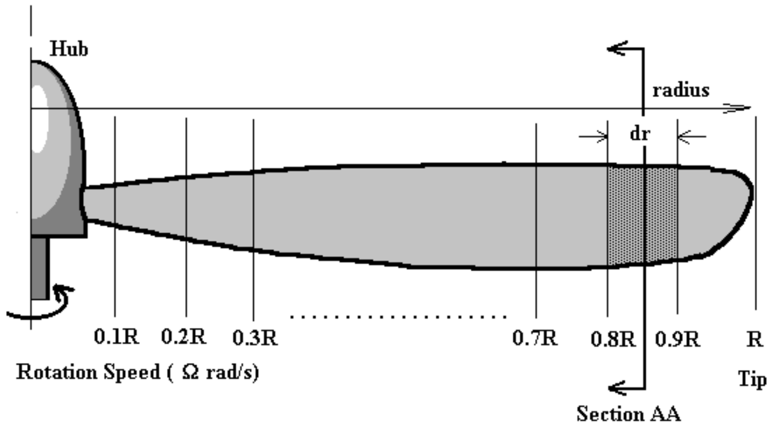

Figure 3.1: propeller

assumption is made that for each there are only axial and angular velocity components and that the induced flow input from other sections is negligible. Thus at section AA (radius = r) shown above, the flow on the blade would consist of the following components.

V_0 - axial flow at propeller disk. V_2 - Angular flow velocity vector.

V_1 - section local flow velocity vector, summation of vectors V_0 and V_2.

Since the propeller blade will be set at a given geometric pitch angle, the

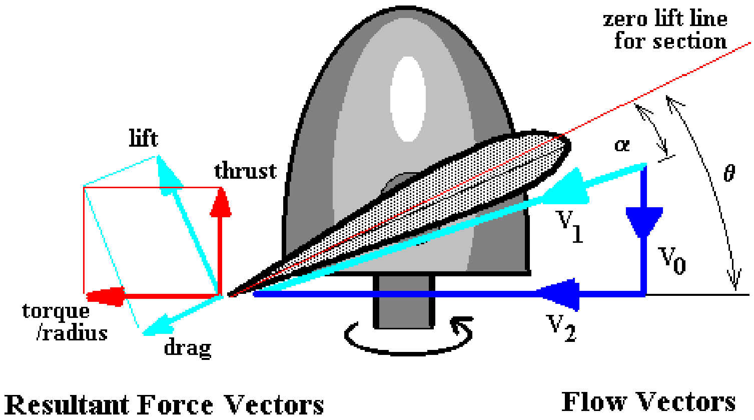

Figure 3.2: propeller

local velocity vector will create a flow angle of attack on the section. Lift and drag of the section can be calculated using standard 2-D aerofoil properties. (Note: change of reference line from chord to zero lift line). The lift and drag components normal to and parallel to the propeller disk can be calculated so that the contribution to thrust and torque of the compete propeller from this single element can be found.

The difference in angle between thrust and lift directions is defined as $\phi = \theta - \alpha$

The elemental thrust and torque of this blade element can thus be written as

$$\Delta T = \Delta L \cos \phi - \Delta D \sin \phi$$

$$\frac{\Delta Q}{r} = \Delta D \cos \phi + \Delta L \sin \Phi$$

Substituting section data (CL and CD for the given) leads to the following equations. per blade where is the air density, c is the blade chord so that the lift producing area of the blade element is c.dr. If the number of propeller blades is (B) then,

3.3 Inflow Factors

A major complexity in applying this theory arises when trying to determine the magnitude of the two flow components V_0 and V_2. V_0 is roughly equal to the aircraft's forward velocity (Vinf) but is increased by the propeller's own induced axial flow into a slipstream. V_2 is roughly equal to the blade section's angular speed (r) but is reduced slightly due to the swirling nature of the flow induced by the propeller. To calculate V_0 and V_2 accurately both axial and angular momentum balances must be applied to predict the induced flow effects on a given blade element. As shown in the following diagram the induced flow components can be defined as factors increasing or decreasing the major flow components.

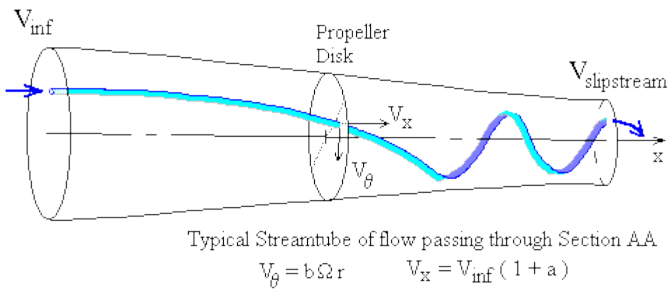

Figure 3.3: Streamtube of flow

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3.4 Different Parameters

3.4.1 Coefficient of Thrust

$C_{To}=\dfrac{T}{\rho * n^2 * D^4}$

Where

- C_{To} = Coefficient of Thrust

- T = Thrust
- ρ = Density of air
- D = Diameter of propeller

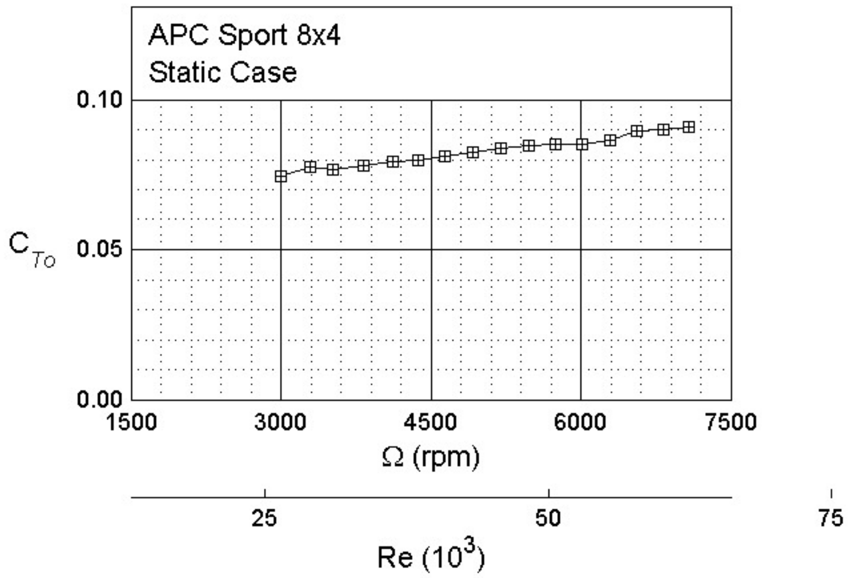

Figure 3.4: C_{T_0} Vs RPM

3.4.2 Coefficient of Power

$C_{Po}=\frac{P}{\rho * n^3 * D^5}$

Where

- C_{Po} = Coefficient of Power
- P = Thrust
- ρ = Density of air
- D = Diameter of propeller

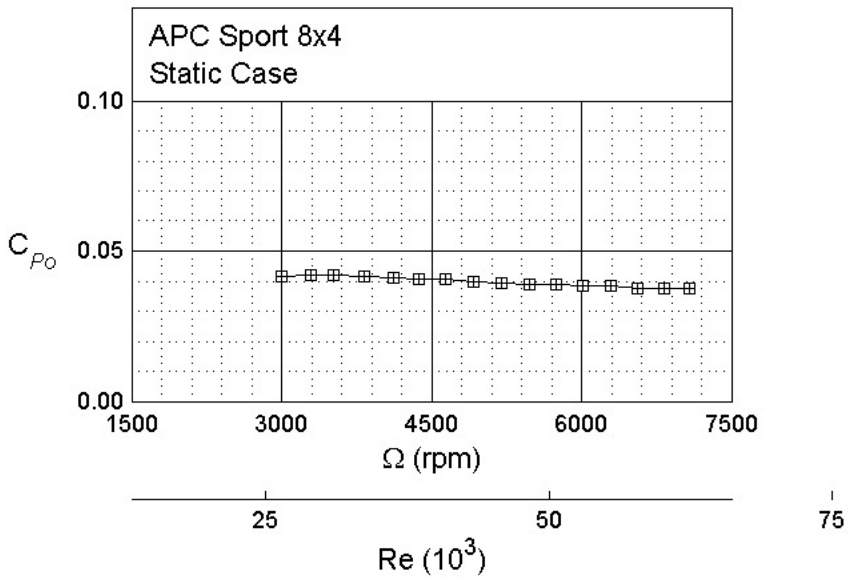

Figure 3.5: C_{p_0} Vs RPM

3.4.3 Coefficient of dynamic thrust

Where

J=$\frac{V}{nD}$

V = velocity of Drone

n= Rotation per Second

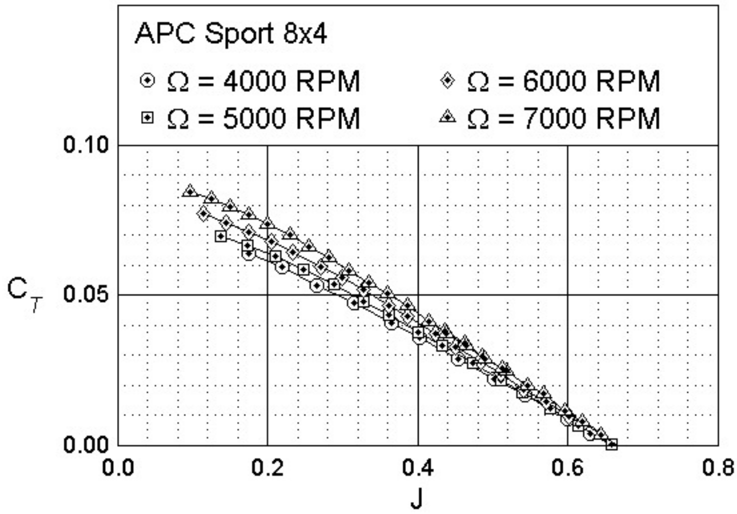

Figure 3.6: C_T Vs J

3.4.4 Efficiency v/s Advance Ratio Graph

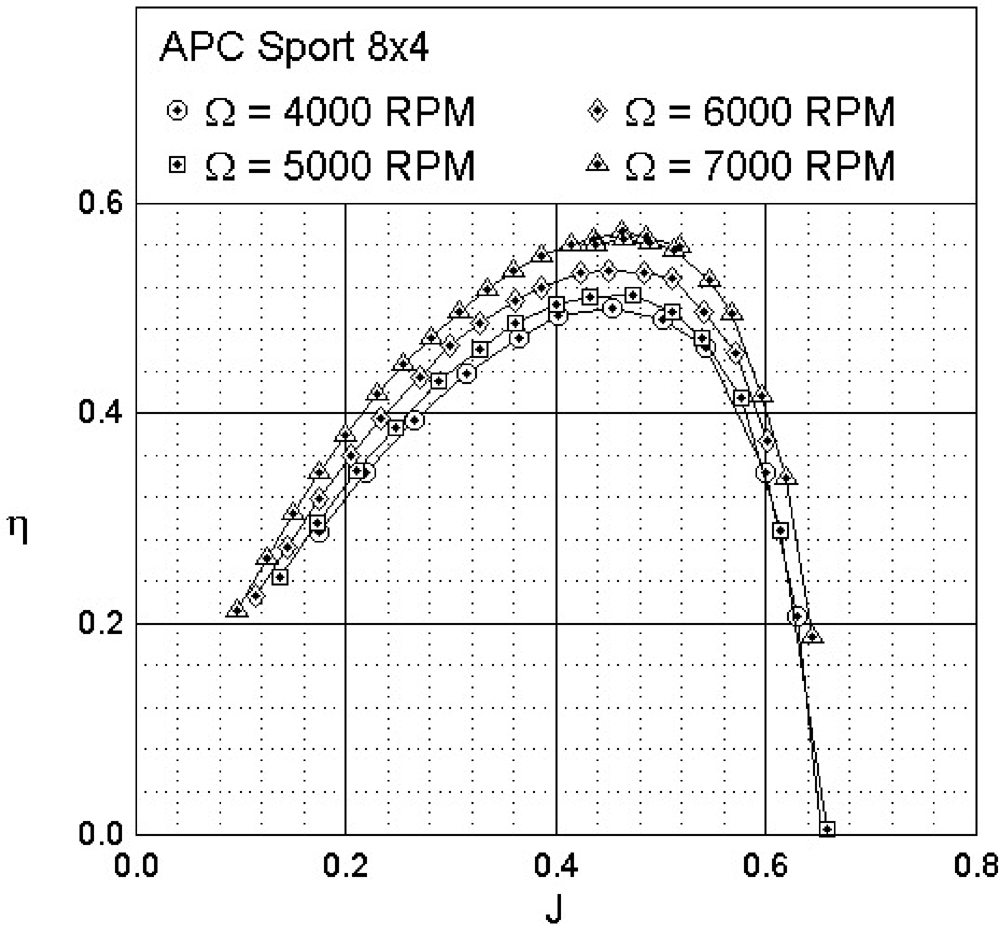

Figure 3.7: η Vs J

3.4.5 Coefficient of dynamic power v/s Advance ration Graph

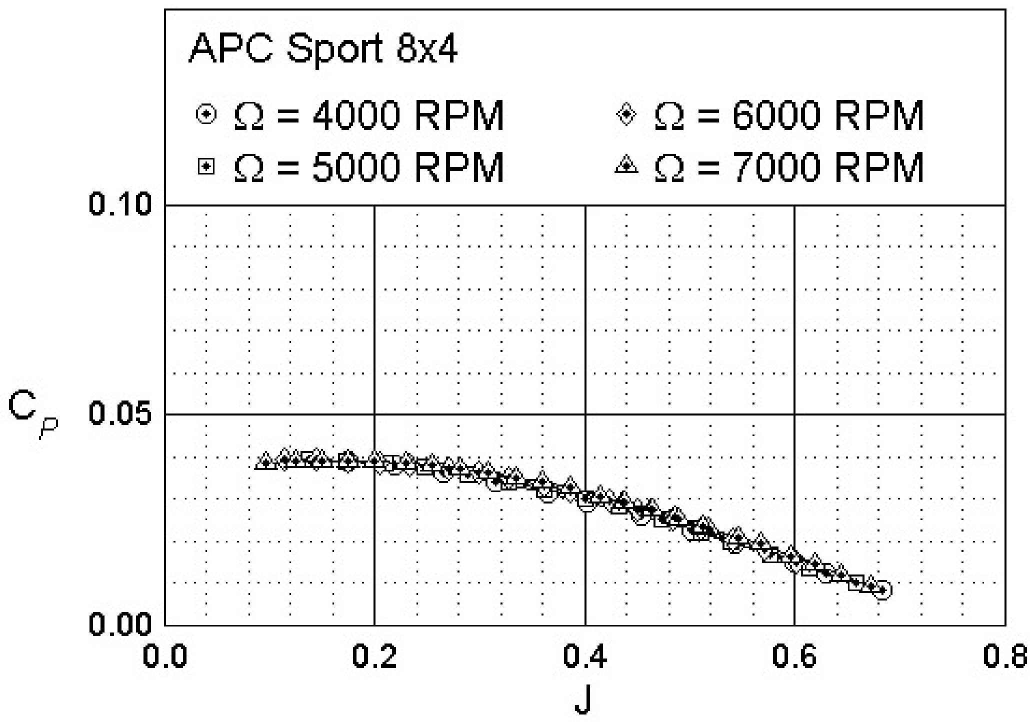

Figure 3.8: C_P Vs J

3.5 Sample Calculation

Required Thrust = .284 * 9.81 = 2.786 N

Density of Air = 1.225 Kg/m^3

RPS (n) = 120

Diameter = 0.2032 m

$C_T = \dfrac{2.786}{1.225 * 120^2 * 0.2032^4} = 0.0926$

$C_P = 0.039$

$C_{Po} = \dfrac{P}{\rho * n^3 * D^5}$

Hence P = 28.59 Watt

3.6 Conclusion

After performing several iterations and doing analytical calculations, we came to a conclusion that the propeller dimension for our quadcopter is 8*4 with the diameter of the propeller being 8 inches and the pitch of a propeller to be 4 inches.The claims were justified with the graphs which were between non-dimesnional parameters of thrust,power,discharge and efficiency with the advance ratio and rpm respectively,obtained by doing wind tunnel testing.

3.7 References

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