Helicopter Preliminary Design Report

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Design Summary

In order to achieve the desired specifications from the brief, the priority of this design effort was focused on to procure most of the design constraints mentioned in the specification brief. A considerable amount of statistical data was collected initially. A MATLAB program was developed to perform a constraint analysis for initial design. After much iteration, pre-final coordinates for the rotorcraft were chosen. This led to understanding the variables much better than just empirical calculations.

A 7-seater mid-sized helicopter to be used for transportation was aimed. This design gives a good room for a well-equipped 7 seats cabin and also comes with a skid landing gear just because of its simplicity of operation. Using a skid landing gear makes it easy for a transport aircraft to land easily on many surfaces even in an inoperable region. The design solution gives a maximum take-off weight of 3,400 Kg. The total power requirement to fly this rotorcraft would be slightly above 578 kW and to meet its power a Turbomeca Arriel-2C2 providing the rotorcraft with a maximum take-off power of 704 kW.

The design enables the reader to get an idea on the various parameters and the variables that the preliminary design depends upon. There are comparisons shown when and where required together with charts comprising of the actual calculations that were done during the design. As we know, that the rotor is one of the principle components of a helicopter which enables it to stay in air, a complete aerodynamic analysis to choose the airfoil for main rotor and tail rotor was performed using XFLR5 software. All the variables where then understood which led to the selection of the most optimal airfoil for this design. Performance charts are made from the calculated values and are added in the report wherever required. They have been iterated several times to reach the most optimum values matching other conventional helicopters from the statistical data.

Physical sizing was done with the help of sequential approach with the help of empirical formulae. The fuselage is sized in accordance with the main rotor blades, its smooth shape for a good flow and the number of seating required. From all the statistical data collected for a similar mission of helicopters it was iterated and formulated using constraint analysis. The tail arm distance is calculated by the amount tail arm moment about the centre gravity that needs to drive the torque produced by the main rotor and the tail rotor is sized accordance to the tail arm distance. It is observed that the longer the tail arm lesser is the anti-torque requirement. The fuselage width and height sizing is determined to accommodate the payload with respect to centre of gravity and the main rotor diameter.

Finally, this transport helicopter is developed out of the commitment to fulfil every basic parameter of a preliminary design. Hence, a brief cost analysis is presented at the end of the report to get an idea of what is takes to own, operate and maintain a helicopter.

Nomenclature

α	Angle of Attack
Ω	Rotational Speed
C	Rotor Chord
r	Rotor Radius
ρ	Air Density
V_{tip}	Tip Velocity
W	Net Weight
V_h	Induced Velocity at Hover
n	Number of Blades
MTOW	Maximum take-off Weight
C_d	Coefficient of Drag
μ	Inflow Ratio
σ	Main Rotor Solidity
FM	Figure of Merit
λ_h	Induced Velocity Ratio at Hover
AR	Aspect Ratio
B	Tip-loss Factor
V_i	Induced Velocity
P_o	Profile Power
P_p	Parasite Power
Cl_{mean}	Mean Lift Coefficient
C_t	Coefficient of Thrust
M	Mach Number
a	Speed of Sound
T	Temperature
γ	Gas Constant
D	Main Rotor Diameter
D_{tr}	Tail Rotor Diameter
Ω_{tr}	Tail Rotor Speed
R_{tr}	Tail Rotor Radius
T_{tr}	Tail Rotor Thrust
$C_{T(tr)}$	Coefficient of Thrust Tail Rotor
C_{tr}	Chord of Tail Rotor
σ_{tr}	Tail Rotor Solidity
A_{tr}	Tail Rotor Area
AR_{tr}	Aspect Ratio of Tail Rotor

1. Our Mission:

The design of this helicopter aims to provide convenience and save time of busy passengers who wish to travel from Birmingham to Manchester and vice-versa. Moreover, this helicopter can be used to ferry passengers between airports and central business districts of cities and there is a good chance to utilize this aircraft for short city tours.

Furthermore, there is spacious cabin for passengers which are 5.5 meters in length and 2.01 meters in width to accommodate seven seats. The helicopter is flying at the maximum speed of 67m/s which makes the passenger reach their destinations quickly. For the safety of the passengers and the helicopter in case of an engine failure the pilot may still make a safe landing even at a parking lot. Also, it has an excellent hovering capacity (Figure of Merit 0.74) which makes the helicopter fly lower to have a better view of the location while flying.

Also, when the Mach number at the tip is taken into consideration, it is kept low to reduce the rotor noise which makes flying more convenient. Such very little careful thoughts make flying comfortable.

2. Introduction:

In this era of supersonic aircrafts, jumbo-jets and luxurious chartered aircrafts the helicopter has still survived being neither supersonic and nor quite simple to handle. For over 70 years helicopters have played an important role in both military as well as in civilian air transportation. Today helicopter is used for almost every such mission which was thought to be just a fantasy before few years ranging from obvious military purpose, aerial photography, construction, medical transport, short tours, fire-fighting, search and rescue among others. Due to its wide-ranging operating characteristics, it has been chosen by almost everyone in the world to perform task which are nearly impossible for a fixed wing aircraft. There are more than to be counted advantages for the uses of helicopters but few of them will be its mobility to fly in almost all the environment conditions, many number of terrains, can transport people to remote location where there are no transport modes available. It can carry payloads internally as well as externally using slings and winches.

The scope of this report is to complete a preliminary design of a helicopter hence much of the importance is given to the physical sizing, calculations of the individual components, its basic aerodynamics and a brief cost analysis. This transport helicopter is like every other conventional helicopter which is capable of hovering for prolonged period, fly at low altitudes, safely take-off and land on various surfaces and enable quick transport of payload for short distances. All equations used in the report are used for the purpose of performance calculation, physical sizing and weight estimation have been authentic literature obtained in public domain.

1. Table of Physical Dimension:

Weights:

MTOW (Kg)	3400
Empty Weight (Kg)	1961.4
→→Max. Payload (INTERNAL) (Kg)	1000
→→Fuel (Kg)	438.6
→→Main Rotor Blades (Kg)	207.8
→→Hub (Kg)	55
→→Fuselage (Kg)	411.8
→→Control System (Kg)	117
→→Electrical System(Kg)	117
→→Other Systems (Kg)	920

Engine Data :

Engine Model	Turbomeca Arriel 2C2
Max. take-off Power (kW)	704
Dimension (m)	1.01 x 0.576 x 0.498
Weight (Kg)	131.5
Emergency Power (kW)	713
Max. Power at Take-off (kW)	636

Performance Data :

Maximum Forward Speed (m/s)	67
Never to Exceed Speed (m/s)	74
Ferry range (Km)	851
Hover Service Ceiling (m MSL)	2500
Passengers	7
Pilot	2
Endurance (h)	1.5

Main Rotor Data :

Radius (m)	5.8
Chord (m)	0.28
Number of Blades	4
Solidity	0.061
Disk Loading (Kg/m^2)	32.17
Tip Speed (m/s)	212.5
Shaft RPM	350
Airfoil	NACA 63a010

Tail Rotor Data :

Radius (m)	0.52
Chord (m)	0.1
Number of Blades	10
Solidity	0.636
Disk Loading (Kg/m^2)	275.46
Tip Speed (m/s)	183.42
Shaft RPM	3360
Airfoil	NACA 0012

2. Main Rotor Design:

- **General Sizing:**

This sizing was done using the given MTOW in the specification requirements as 3500 Kg. This weight is taken as primary consideration and it is estimated to be 80% of the MTOW. In order to achieve a given high speed of 67m/s, the Mach number at the tip is kept at an optimal value of 0.65. refer Appendix [E]

Hence we get,

$$Vmax_{tip} = M_{tip} * a$$

$$Vmax_{tip} = 212\ m/s$$

The graph -Refer Appendix [B]- represents the MTOW .Vs. Disk-loading. Here, the disk-loading is estimated to be 30Kfg/m^2. We know that the radius is selected as 6.0078m.

$$Disk\ Loading = \frac{Weight}{\pi R^2}$$

Though the larger radius gives higher hovering efficiency and better auto-rotational characteristics it adds up to the weight and cost to the helicopter. After this calculation we can obtain the coefficient of thrust which is given by the formula:

$$C_t = \frac{W}{R * A * \rho * {Vmax_{tip}}^2} = 0.0023$$

And

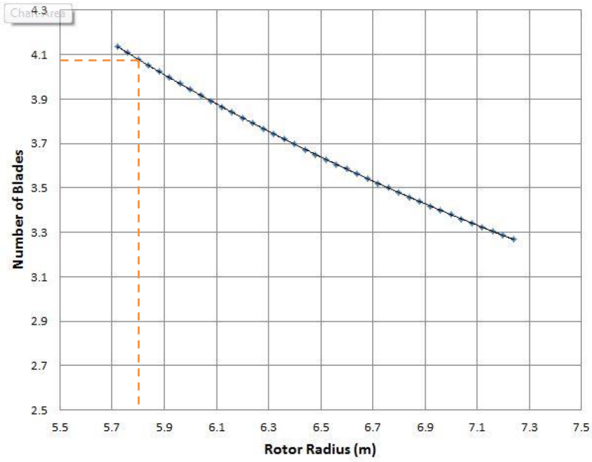
$$\sigma = 6 * \frac{C_t}{Cl_{mean}} = 0.0194$$

- **Blade Planform:**

Rotor blade tip loss factor could be assumed as 0.98 [1] that helps in obtaining number of blades approximately and blade chord.

- **Blade Airfoil**: It is explained in detail in the section 5 of this report.

However, the blade solidity could be adversely used to obtain a number of blades and understand the relationship between number of blades and radius of blades.



Through the graph above, the radius is chosen to be as 5.8m and hence the design does not exceed the number of blades as four.

3. Tail Rotor and Vertical Fin Design:

The tail rotor is design to counteract the torque produced by the main rotor. Initial sizing of a tractor type tail rotor was made in accordance with the main rotor diameter and the amount of moment produced by the main rotor. To reduce the loss of thrust due to the blockage of vertical fin, a ducted fan method known as fenestron is used. Though it adds weight and complexity of its design but often this trade-off are acceptable when its advantages are considered [2]. This system has an advantage in terms of the power required to drive it as the diameter if the rotor reduces to about half of the conventional tail rotor. Hence, the solidity of the blade becomes higher as it has many numbers of blades which increases its overall weight. The length of the tail boom is calculated with the assumption that it is 20% longer than the main rotor radius [3].

The vertical fin provides better directional stability as it even offloads tail rotor in forward flight. This provides a good casing to mount the fenestron to it which directly attached to the tail boom [1].

4. Horizontal Stabilizer:

$$S_{HT} = 0.021 W_o{}^{0.758}$$

$$a_{HT} = 0.4247 W_o{}^{0.327}$$

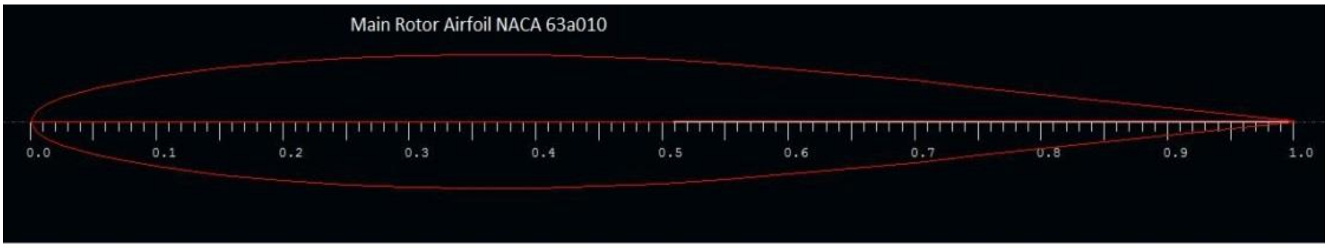
The horizontal surface gives pitch stability of the helicopter [2]. Since the main rotor and fuselage are inherent negative stability in pitch, it helps in better handling of the helicopter. The surface area of the horizontal stabilizer is calculated by the gross weight of the helicopter which is 0.86m and also has an effect on the centre of gravity of the rotorcraft. An inverted airfoil is chosen to create a downwash in forward flight to keep the fuselage angle of attack to the lowest parasite drag. The position of the horizontal stabilizer is 5.69m from the centre of the main rotor which is in the downwash of the main rotor the forward fixed stabilizer is to avoid sudden changes in downwash caused by rotor wake. The area of the stabilizer is larger as it is inside the wake which increases the weight [1].

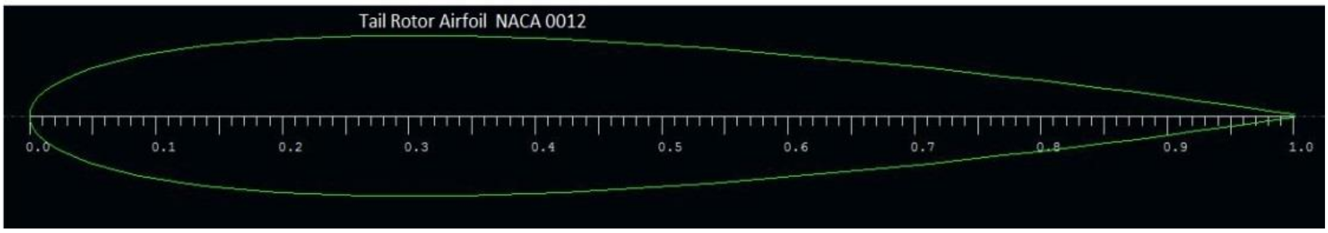
5. Airfoil Selection for the Main and Tail Rotor:

- Aerodynamic analysis was performed using XFLR5 software on a set of Airfoils which are used for General Utility Helicopters. Refer to Appendix [F]

Airfoil	Cl	Cd	Cl/Cd	Cm
HQ 0/10	1.84	0.08	22.8	-0.4825
NACA 63a010	1.83	0.0797	23	-0.4782
NACA 64A010	1.699	0.06	24.94	-0.4053
NASA SC(2)-0010	1.963	0.09	21.32	-0.5504
RAE 101	1.852	0.08	22.73	-0.48

- There were many varied conditions used while performing the analysis such as a range of Mach number from 0.05-0.2, using different alpha values and for different chords.
- There are few critical areas which need to be addressed while selecting an Airfoil for the helicopter as the helicopter blades operate in wide-range of environment and in multifarious conditions making the Airfoil to perform well in all situations. Few of them are [1] :
    1. Having high CL_{max} which enables a rotor with having a low weight as well as solidity.
    2. Having a high L/D ratio in a range of operating Mach numbers
    3. A low value of C_m enables the rotor blades to minimize torsional moments and vibrations.



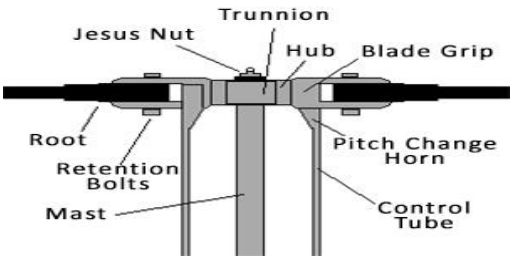


- Noting all these conditions, the most optimum Airfoil from the list above was **NACA 63a010** which behaved considerably well in many conditions. This Airfoil was iterated for many chords and the data is as follows :

(While a more advance designed Airfoil may achieve a better performance, this selection was made using the Airfoils available in Public Domain)

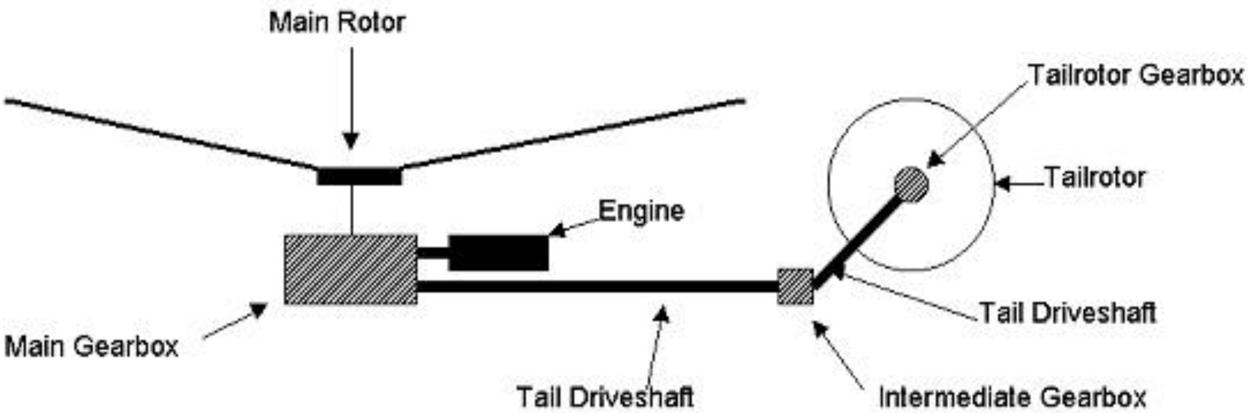
6. Gearbox and Transmission:

A conventional (or) fully articulated main rotor hub is used. This type of rotor hub allows each blade to lead/lag, flap independent of the other rotor blades. Each rotor blade is attached to the rotor hub by a horizontal hinge called flapping hinge which permits the blade to flap up and down [4]. Each blade can then move up and down independently. The flapping hinge may be located at varying distances from rotor hub and there may be more than one such hinge in the hub. The position is chosen by each manufacturer primarily with regard to stability and control. Each rotor blade is also attached to the hub by a vertical hinge called drag hinge (or) lag hinge that permits each blade to move back and forth in the plane of rotor disk. Dampers are normally incorporated in the design of this type of rotor system to prevent excessive motion about drag hinge.



The purpose of drag hinge and dampers is to absorb the acceleration and deceleration of rotor blades. The blades of a fully articulated rotor can also be feathered (or) rotated about their span-wise axis. In other words, feathering means the changing of pitch angle of rotor blades. Rotor blades have high span-to-chord ratio and thus severe stresses can be transmitted to the hub if the blades are not permitted to flap. However, if the blades are aero-elastically soft, the hub stresses can be kept to a minimum and both types of hinges can be eliminated.

For the transmission of power from the turbine engine to the helicopter rotor a speed reduction gearbox should always be used [5]. As the turbine output shaft rotates at speeds of 5,000 to 50,000 RPM's. Usually in all modern helicopters two-stage main reduction gearboxes are used but as we have chosen to fly the helicopter with single gas turbine engine, one stage speed reduction gearbox is used and is presented below.



7. Fuel Capacity and Tank Sizing:

Price/litre	1.74
Litres/hour	191.43
Price/hour	333.08

Fuel Tank size (Litres)	545.5
Weight of Fuel (kg)	438.6
Fuel Volume (m^3)	0.5

8. Centre of Gravity:

The maximum weight of the rotorcraft is counted as 3400 kg with all other objects added together. A reference plane in order to locate the C.G is taken at 4.08m forward from centre of rotor. the weights of all components and their location from the reference plane are tabulated. The weight of the relative object is multiplied by the arm distance, to find its moment.

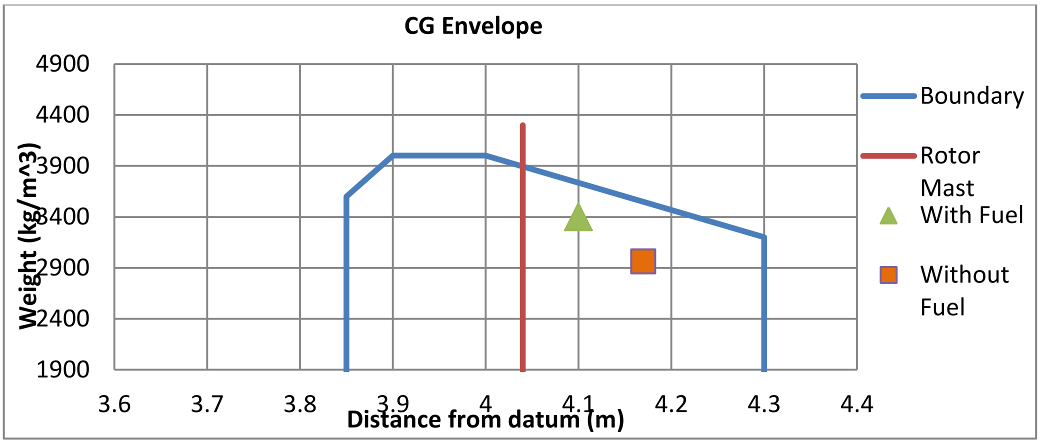
$$Moment = weoght * Arm$$

From the calculation C.G of the rotorcraft is located at 4.1m from the reference plane.

$$C.G = \frac{Moment}{Weight}$$

The forward and aft movement of the C.G is calculated and a C.G envelope is drawn to find the maximum workable C.G range. The limit of C.G lies from 3.8m to 4.2m. The maximum forward limit of C.G for 1900 kg is located at 3.85m aft of reference plane and the max aft limit of the C.G lies at 4.2m aft of the reference line. The forward C.G limit for 3400kg lies at 3.9m aft of reference plane and aft C.G position falls on 4.17m aft of the reference plane. The lateral C.G limits has the maximum deviation right/left is 0.2m as the reference plane is the fuselage median plane.

	Weight (kg)	**Longitudinal Arm(m) From nose**	**Longitudinal Moment (kg.m)**
Basic Empty Weight	1961.4	4.04	7924.056
Pilots (2)	200	2	400
Passengers (7)	700	5.5	3850
Baggage and miscellaneous	100	7	700
Fuel	438.6	3	1315.8
Total	3400	4.173487059	14189.856
C.G lies between 3.8m – 4.3m			



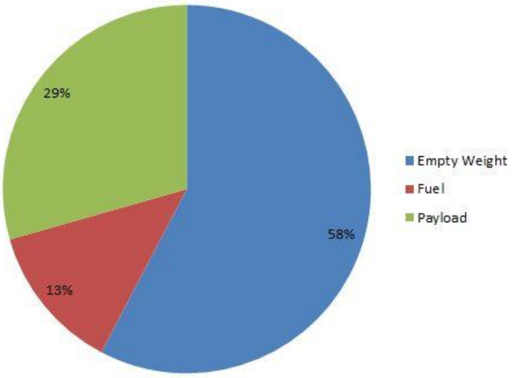
9. Weight Estimates:

$W=W_e+W_{PAY+}W_f$

$3400=W_e+1000+438.60$

$W_e=1961$ kg

Empty Weight comprises of weight of blades, hub, propulsion unit, fuselage, control systems, electrical equipment's and any other fixed equipment's.



Main rotor blades are made up of carbon composites, whose density could be assumed as 1600 kg/m^3 that gives mass of the blades as 207.872 kg.

Weight of Hub = 0.0135 x Empty Weight x $R^{0.2}$ = 55.4 kg

Propulsion Unit weight= 131.5 kg

Fuselage Weight = 0.21 x Empty Weight =411.89 kg

Controls Weight = 0.06 x Empty Weight =117.684 kg

Electrical Systems Weight = 0.06 x Empty Weight =117.684 kg

Fixed Equipment Weight = 0.28 x Empty Weight =1042.028 kg

10. Vertical Flight:

The design of this helicopter started with the main rotor, assuming maximum takeoff weight of 3400 kg. The next step is to get the solidity of the rotor which will be able to carry this weight.

Solidity provides a means to measure the potential for a rotor system to provide thrust. It is the ratio of total blade area over disk area.

$$\sigma = \frac{nc}{\pi r}$$

In order to calculate this, we need first to obtain the dimensions of the blades. In this design, we used four blades with rotor radius of 5.8m and chord of 0.28m. The induced velocity made by the rotor is also taking into consideration and calculated from the following equation.

$$V_h = \sqrt{\frac{W}{2\rho A_{Disk}}}$$

To get the power required to take this helicopter weight of the ground, the ideal power is calculated as a first estimation from this equation.

$$P_{Ideal} = \sqrt{\frac{W^3}{2\rho A_{disk}}}$$

Induced power is the power required to produce lift which is very close to the ideal power. Also there is rotor profile power which is the power required to overcome the weight and aerodynamic drag force of the blades. Another power parameter which should be calculated is the parasitic power. It is the power to move the rest of the airframe through the air.

$$P_{parasitic} = \frac{1}{8} \sigma\, C_D\, \rho A_{\,disc}\, V_{tip}^3$$

Hence, the total power required for hover is the summation of induced power and parasitic power. Two parameters are important to indicate the performance of the helicopter is the power and thrust coefficients.

$$C_T = \frac{W}{\rho\, A_{disk}\, V_{tip}^2}\ , \qquad C_p = \frac{P_{total}}{\rho\, A_{disk}\, V_{tip}^3}$$

The ideal power which is calculated previously is not the actual power required for the helicopter as there are some losses. Those losses are all combined in what is called 'Figure of Merit'. It is an indicator on how efficient the helicopter is.

$$FM = \frac{C_T \sqrt{\frac{C_T}{2}}}{C_P}$$

Most of the helicopters have a figure of merit between 0.7 – 0.8. Our design had been optimized to get a figure of merit of 0.74.

The engine had been selected according to the total power required as shown in Appendix [D]

After selecting the engine, the fuel tank capacity had been calculated. The most important parameter to know is the specific fuel consumption (SFC) which depends on the engine power. Hence, the fuel tank size is obtained which is 439kg. The endurance is given from this equation.

$$Endurance = \frac{W_{fuel}}{\dot{m}}$$

Then the range can be obtained.

$$Range\ (nmi) = Endurance\ x\ Cruise\ Speed$$

11. Forward Flight:

The total power required for the forward flight is given by:

$$P = P_i + P_0 + P_p + P_{tr} + P_t$$

The induced power cannot be obtained through direct relations hence the formula for induced velocity ratio in forward flight can be taken as [6]:

$$\lambda = \mu tan\alpha_t + (\lambda)/(\sqrt{(\mu^2 + +\lambda^2)}$$

$$\lambda_h = \sqrt{\left(\frac{C_t}{2}\right)}$$

Assuming α_T=2° and following the Newton Ralphson method induced forward velocity id obtained at different velocities. $\mu = \frac{U}{Vmax_{tip}}$. Furthermore, through incudes forward velocity ratio and using the relation $\frac{P}{P_h} = \frac{\lambda}{\lambda_h}$

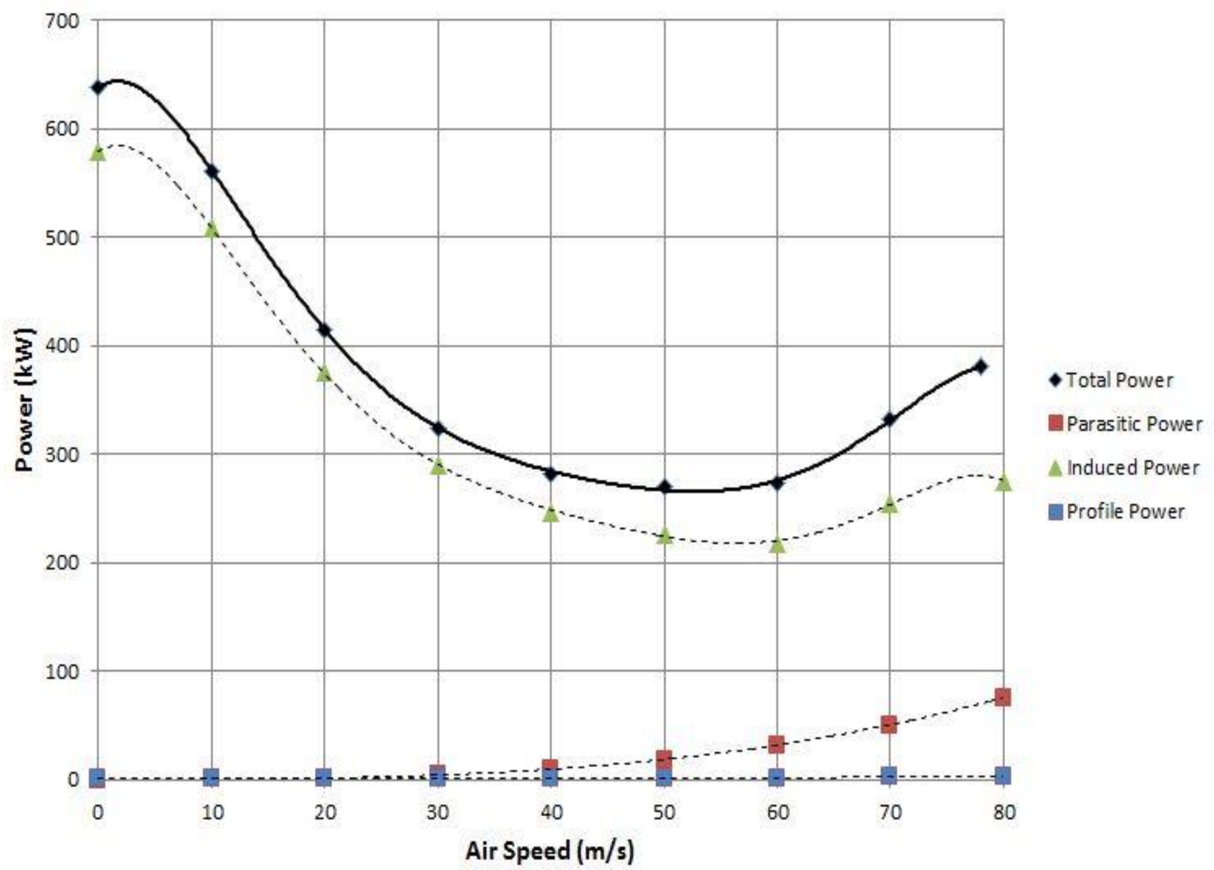
12. Profile Power:

The blade profile power at forward flight $P_o = \frac{1}{4}\rho\sigma\overline{C_D}\Omega^3 R^3(1 + 3\mu^2)$. The power increases parabolically with "µ". The tail rotor power can be assumed to be 10% of induced power and transmission losses as 5% of total power [6].

13. Parasite Power:

Parasite power is the power to overcome the parasite drag of the vehicle. The drag includes fuselage drag and interference drag between main rotor, tail rotor, fuselage and skids. The airframe drag could be either found from the wind tunnel tests or through computations but also in a simpler way the coefficient of drag could be assumed according to the historical data [1] and correspondingly drag can be calculated at various free stream velocities.

The induced, profile, parasite and total power with respect to velocities is plotted below:



14. Hover Ceiling:

The hover ceiling OGE effect is reached when the engine power at a certain altitude matches with the hover power. The engine power varies according to the altitude, hence the available engine power is $P_e\sigma^{1.35}$ and σ is in SI units at a certain altitude is

$$\frac{P}{P_o} = e^{\left(\frac{-0.00296h}{304.8}\right)}$$

Comparing available engine power at 2500m at mean sea level at hover power of 578.9 kW, the climb rate of 0.2316 is obtained. This shows that the service ceiling of 2500m is achieved. Refer Appendix [E]

15. Flight Controls:

The flight control linkage connects three separate inputs. The cyclic stick is connected to linkage that connects s to the rotor blades which change the pitch angle of the rotor blades. A collective lever positioned either side of each pilot functionally interconnected to the swashplate by bell cranks and relays. Anti-torque pedals are connected to the tail rotor hub via linkage rods that runs through the tail-boom. The application of the pedal changes the pitch of tail rotor to increase and decrease the thrust introduced by tail rotor which controls the yaw according to the direction of the pedals. The swashplate is driven by a control channel through a hydraulic servo which provides the required actuating force. Refer Appendix [H]

12. Payload Range Diagram:

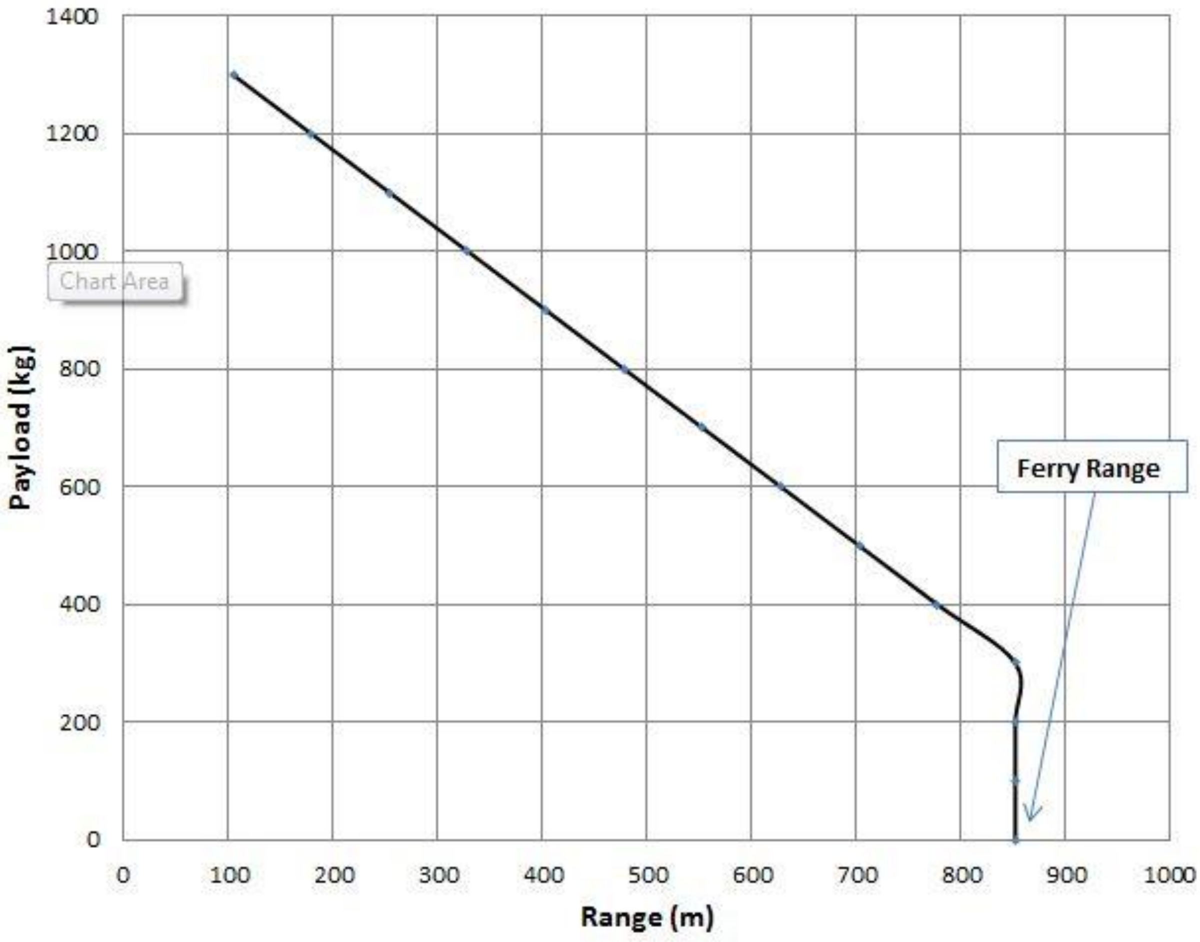
As the helicopter is designed to accommodate passengers and carry them from one point to another hence it is crucial to understand the effect of payload on the range which needs to be achieved.

$$R = \frac{U}{P}\frac{\left(W - W_e - W_{pay}\right)}{SFc}$$

$\frac{U}{P}$ is obtained from the plot of forward power .Vs. velocity, where at one certain point we get the velocity for high range and correspondingly for power. Refer to Appendix [I]

$$U = 65\ m/s$$

$$P = 262\ kW$$

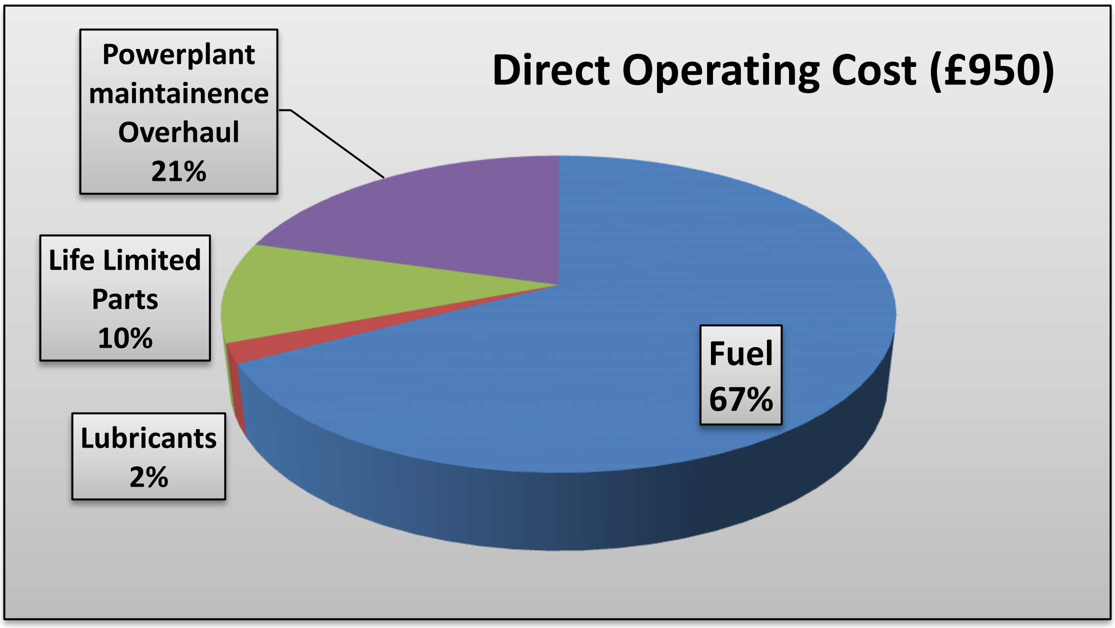


13. Autorotation

In the case of engine failure, the helicopter gets into an autorotation state. Autorotation is when the main rotor is driven by the air moving up unlike the normal powered flight where the engine draws the air above the rotor. When the engine fails, the rotor is allowed to rotate freely through a freewheeling unit which disengages it from the engine. This is the only hope for the helicopter to survive from engine failure. Refer to Appendix [G]

14. Cost Estimation:

The total cost of the aircraft was estimated to be £4,000,000 approximately. This assumption was made with respect to the cost of the engine being 40% of the cost of the entire helicopter. Furthermore, the direct operating cost has been estimated for this helicopter as follows:



The maintain cost can be estimated with a general idea of considering the total cost of the aircraft and the retirement hours. Hence if we suppose that the helicopter will run for 10,000 hours before retirement then the maintenance cost would be as follows:

$$Maintainance\ Cost(£/hour) = \frac{Total\ Cost\ of\ the\ Helicopter}{RetirementHours}$$

$$Maintainance\ Cost(£/hour) = \frac{£6,000,000}{10,000} = £600$$

15. Conclusion and Recommendation:

The designed helicopter satisfies the given requirements of the weight, range, payload, hover ceiling and maximum speed. Moreover, a high figure of merit of 0.74 is achieved which indicates a good overall performance of the helicopter. However, better aerodynamic optimisation techniques and experimental procedures rather than statistical data would lead to an efficient design and thereby giving you a higher figure of merit and efficiency.

An effective mission dependant trade-off has to be made between the carried fuel and the payload. Increasing number of fuel tanks increases the range. A ferry range of 851.8Km can be obtained with the current design. The power required to hiver is higher than the power required for forward flight by again a factor of 1.74. Thus, it depends on the mission. Finally, the FAA recognises the designed helicopter in the group B and it satisfies the regulations of 27.1.

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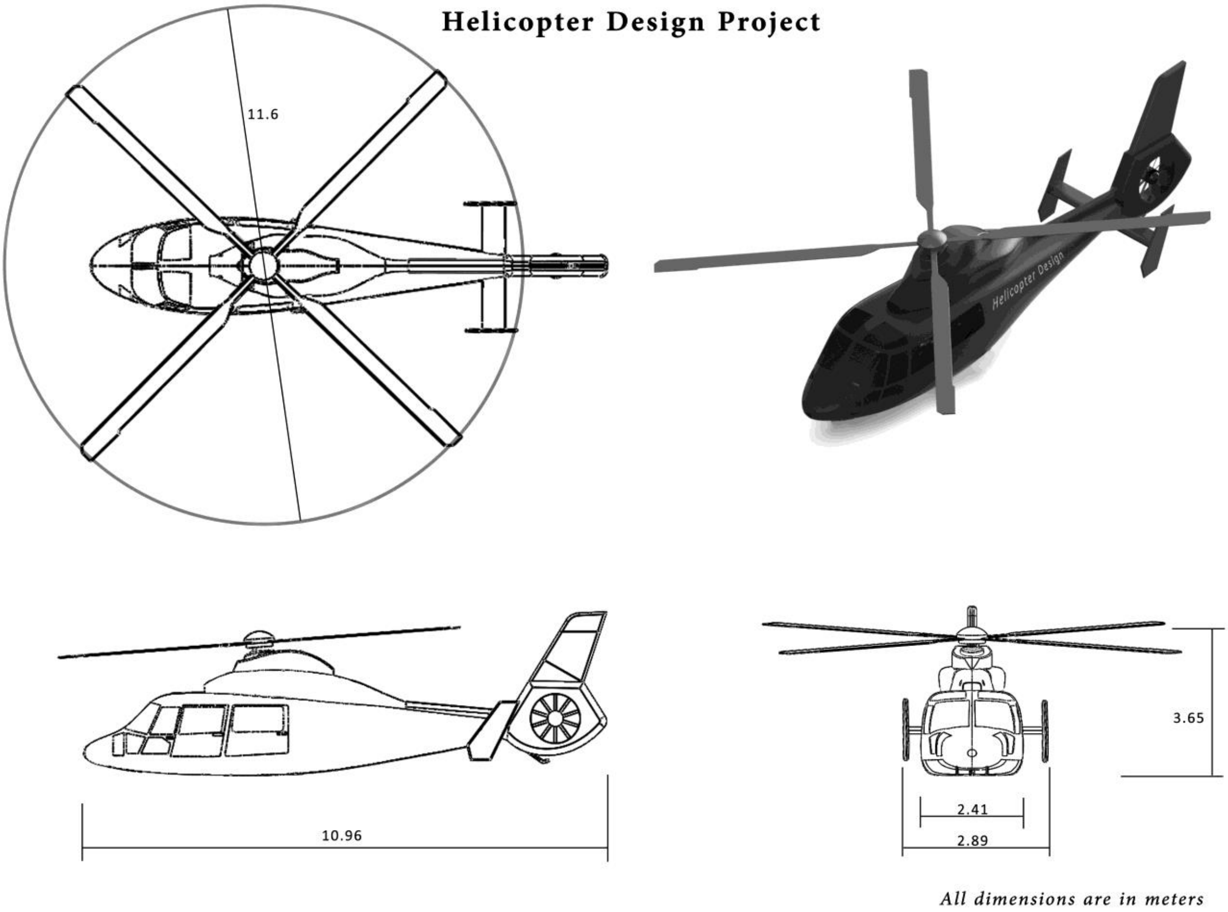
[16] A. Brocklehurst and G. N. Barakos, Progress in Aerospace Sciences, Liverpool: ELSEVIER Ltd.#, 2012.

[17] A. R. S. Bramwell, The Longitudinal Stability and Control of the Tandem-Rotor Helicopter, London: Ministry of Aviation, 1961.

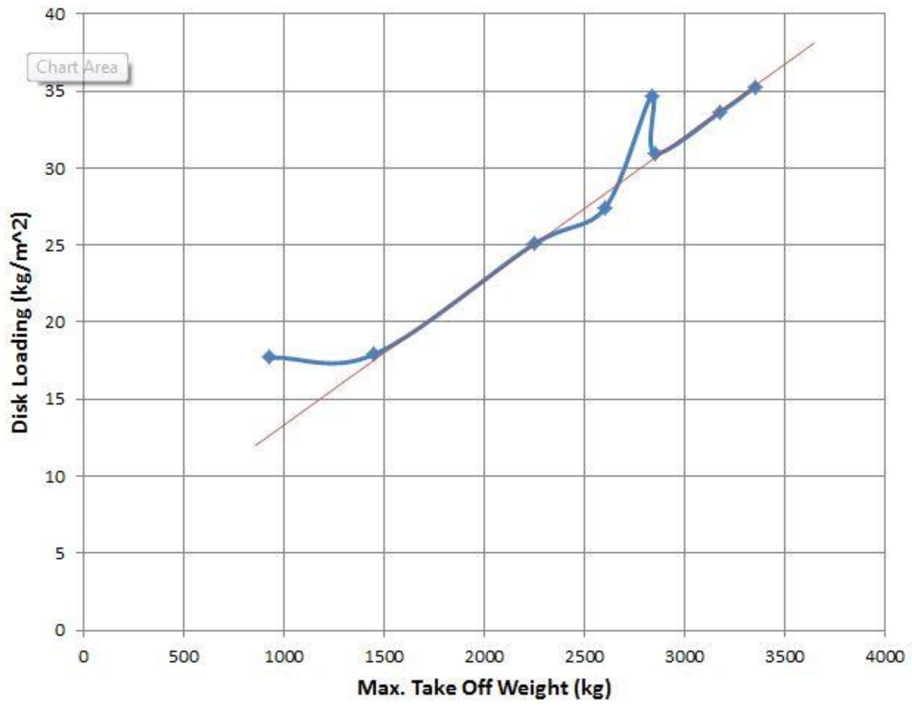
[18] N. Apetre, S. Sarkar, N. Iyyer, P. Kang and N. Phan, Innovative Methods to Estimate Rotorcraft Gross Weight and Cener of Gravity, EU: 6th European Workshop on Structural Health Monitoring, 2009.

[19] E. A. S. Agency, Type-Certificate Data Sheet, EU: EASA, 2010.

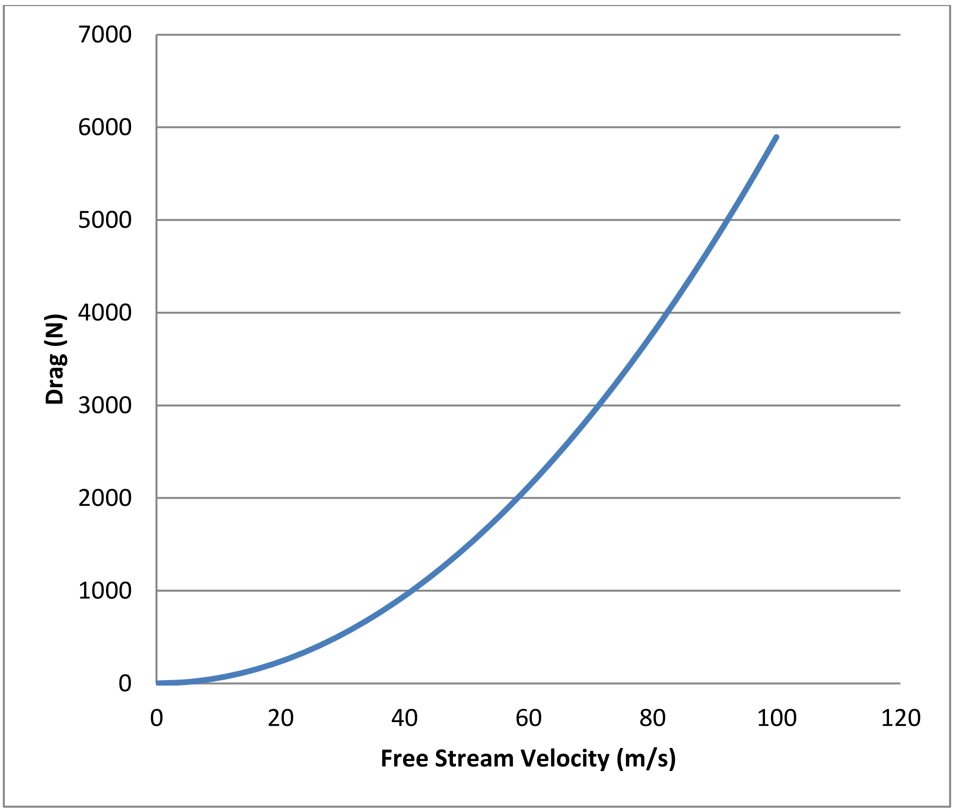
Appendix [A] 3D Sketch



Appendix [B] MTOW Vs Disk Loading



Appendix [C] Fuselage Drag



Appendix [D] Engine Selection

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BUYER'S GUIDE

Turbine Engines	Model	Application (# of engines)	Maximum Takeoff Rating (shp)	Maximum Continuous Power (shp)	Fuel Consumption (lbs/shp)	Weight (lbs)	Dimensions (inches) (LxWxH or LxD)	Remarks
Turbomeca	TM 333 2B2	DHRUV (2)	1105	986	.517	367	41.1/19.3/29.7	
Turbomeca	Ardiden 1H1	DHRUV (2)	1373	1151	.46			
Turbomeca	Makila 1A	Eurocopter AS 332	1663	1515				
Turbomeca	Makila 1A1	Eurocopter AS 332L1/AS 532	1820	1185	.484	518	82.8/19.4/26.8	
Turbomeca	Arriel 2C2	Eurocopter EC 155 (2)	944	853	.545	282	39.9/18.2/22.7	
Turbomeca	Makila 2A	Eurocopter EC 725/ EC 225 (2)	2097	1892	.469			EC 725 - Mitary Version EC 225 - Civil Version

Appendix [E] Matlab Codes

Program-1

```
g=9.81; %acceleration due to gravity
Maxspeed=66.87;
MTOW=3500; %Maximum take-off weight is 3500kg
MgrossN=3500*g; %Maximum gross weight in Newton
Egross=3400; %Estimated gross weight in kg
EgrossN=Egross*g; %Estimated gross weight in Newton

%Calculating Tip Velocity
gamma=1.4;
R=8.314; %gas constant
Td=15; %temperature in degress
Tk=273+Td; %temperature in kelvin
a=sqrt(gamma*g*R*Tk);
Mmaxtip=0.65; %maximum mach number at the tip
Vmaxtip=Mmaxtip*a;

%Calculating Rotor Radius

Diskloading=30;
rotorradius=sqrt((Egross)/(Diskloading*3.14))
disp(rotorradius);
%Calculating Rotational Velocity
Rvelocity=Vmaxtip/rotorradius;
rotorarea=3.14*(rotorradius^2);
%Calculating Coefficient of thrust
Ct=Egross/(rotorarea*0.954*(Vmaxtip^2));

%Calculating Rotor blade solidity
advanceratio=Maxspeed/Vmaxtip;
mrliftcoeff=0.7; %mrliftcoeff is mean lift coefficient which falls between 0.4 to
0.7
    bladesolidity=6*(Ct/mrliftcoeff);
    bladeload=Ct/bladesolidity; %through this blade loading can be calculated



%Calculating Number of Blades
lambda_i=sqrt(Ct/2); %Inflow ratio
 B=0.98; %tip loss factor and it varies between 0.95 to 0.98
    Nb=sqrt(2*Ct)/(1-B); %Number of blades

%Calculating blade chord and aspect ratio
bladechord=(bladesolidity*3.14*rotorradius)/(Nb);
```

Program 2

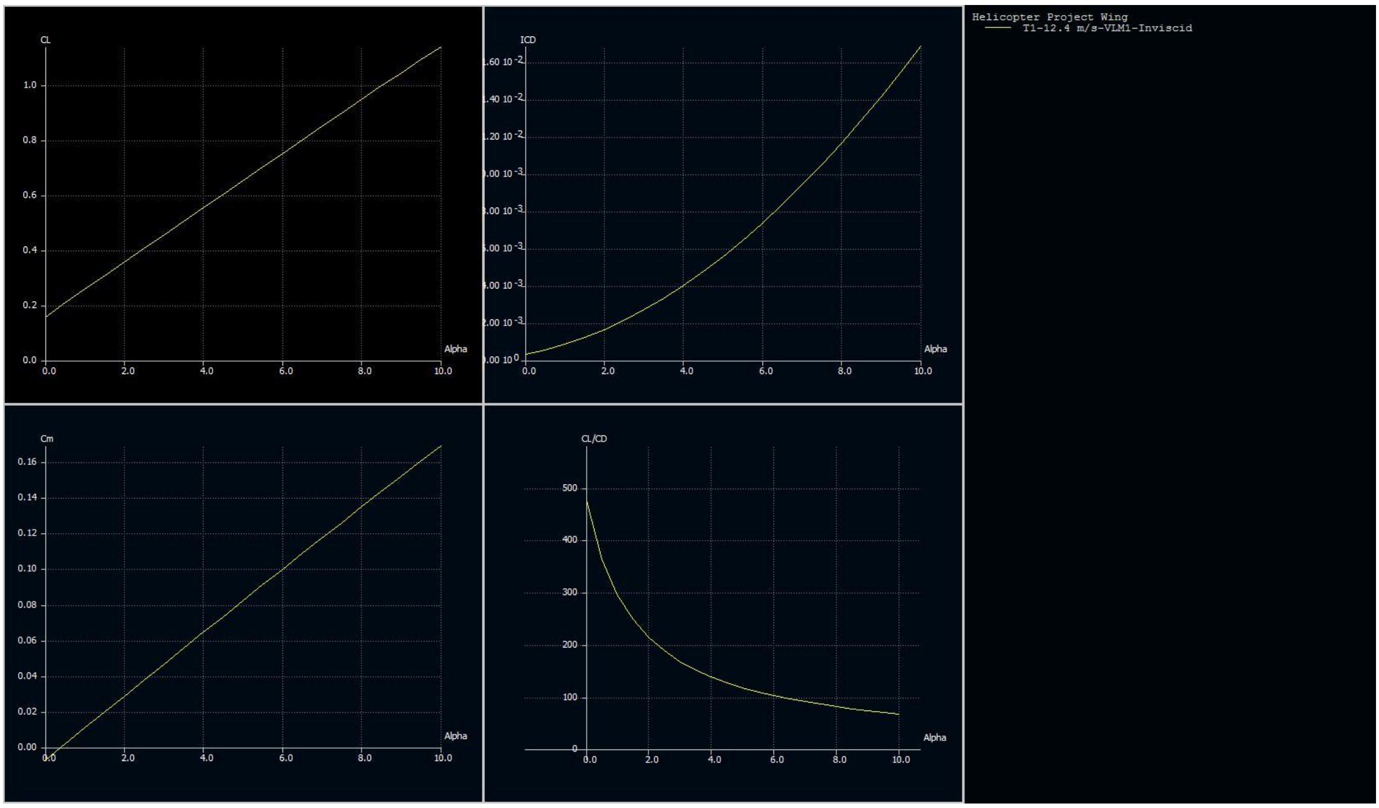
```
%Program to calculate induced velocity ratio at forward speed by
%Newton-Raphson Method

j=1;
lambdah=0.060495; %Induced velocity ratio at hover
Vmaxtip=212.58; % Maximum Velocity at the tip
Maxspeed=0; %Free Stream Velocity
alfa=2; %Tilt Angle
mu=(Maxspeed*cosd(alfa))/Vmaxtip;
```

```
lambda=lambdah;

alpha1=tand(alfa);
disp(Maxspeed);
    while(j<10) % Loop for performing Newton Raphson Iterations
    f=lambda-(mu*alpha1)-((lambdah^2)/(sqrt(mu^2+lambda^2)));

    df=1+((lambdah^2)*lambda)/(((mu^2)+(lambda^2))^(3/2));

    lambda=lambda-(f/df);
    j=j+1;
   disp(lambda);
    end
```

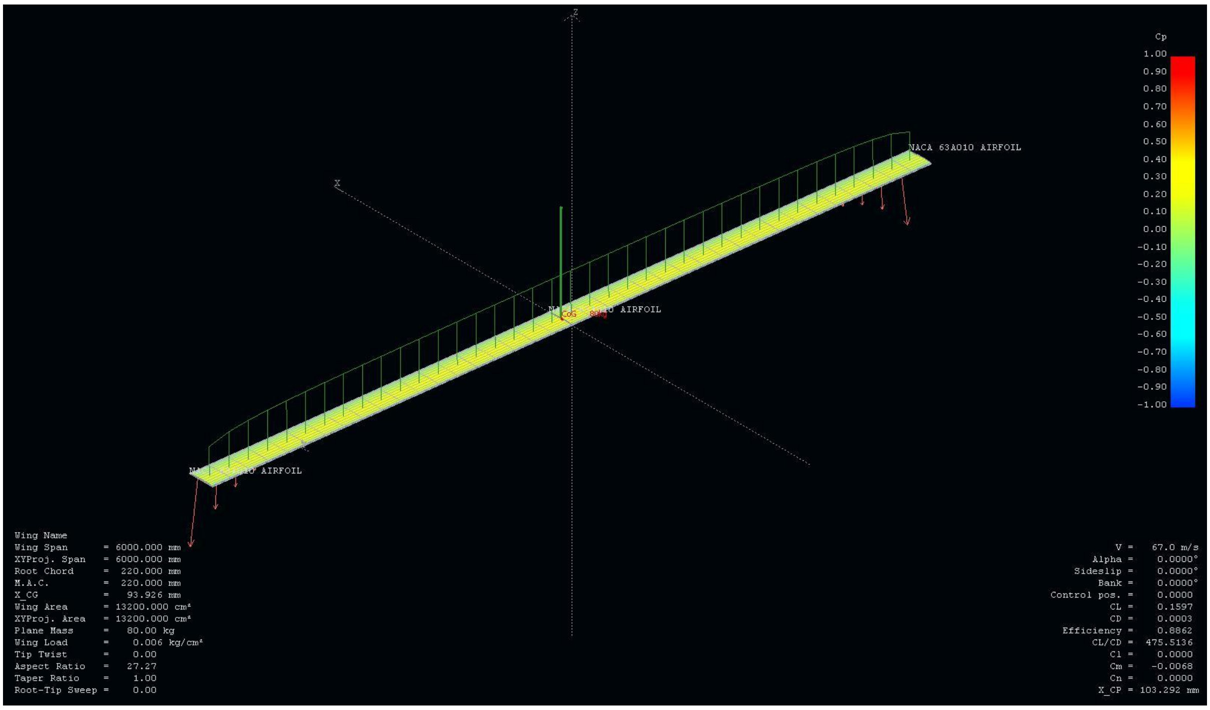
Program-3

```
a=-0.0296*2500;
b=a/1000;
c=exp(b);
disp(c);
d=0.940*c;
disp(d);
e=d^1.35;
P=(704*e); %Engine power according to characterisitics of certain altitude
disp(P);
Climbrate=((P*1000)-(578900))/(3400*9.8); % Calculated Climb Rate
disp('Climb Rate');
disp(Climbrate);
```

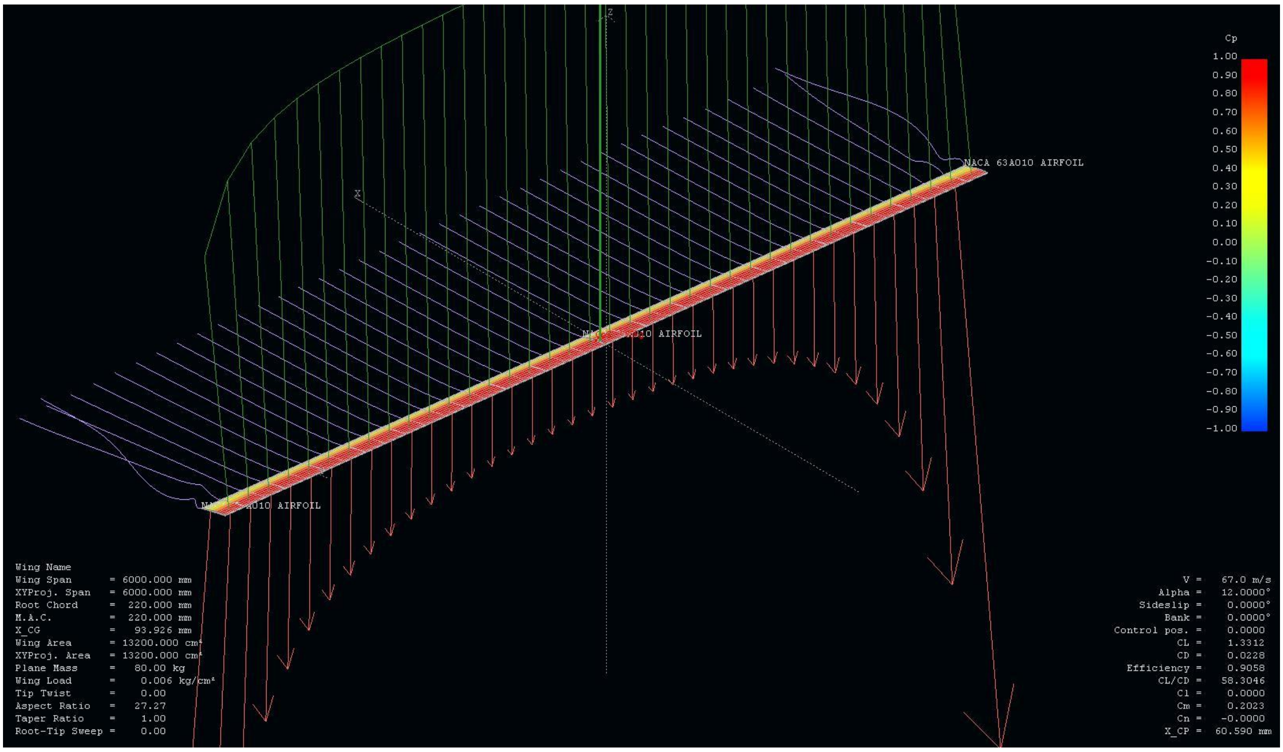
Appendix [F] Airfoil Selection Data:



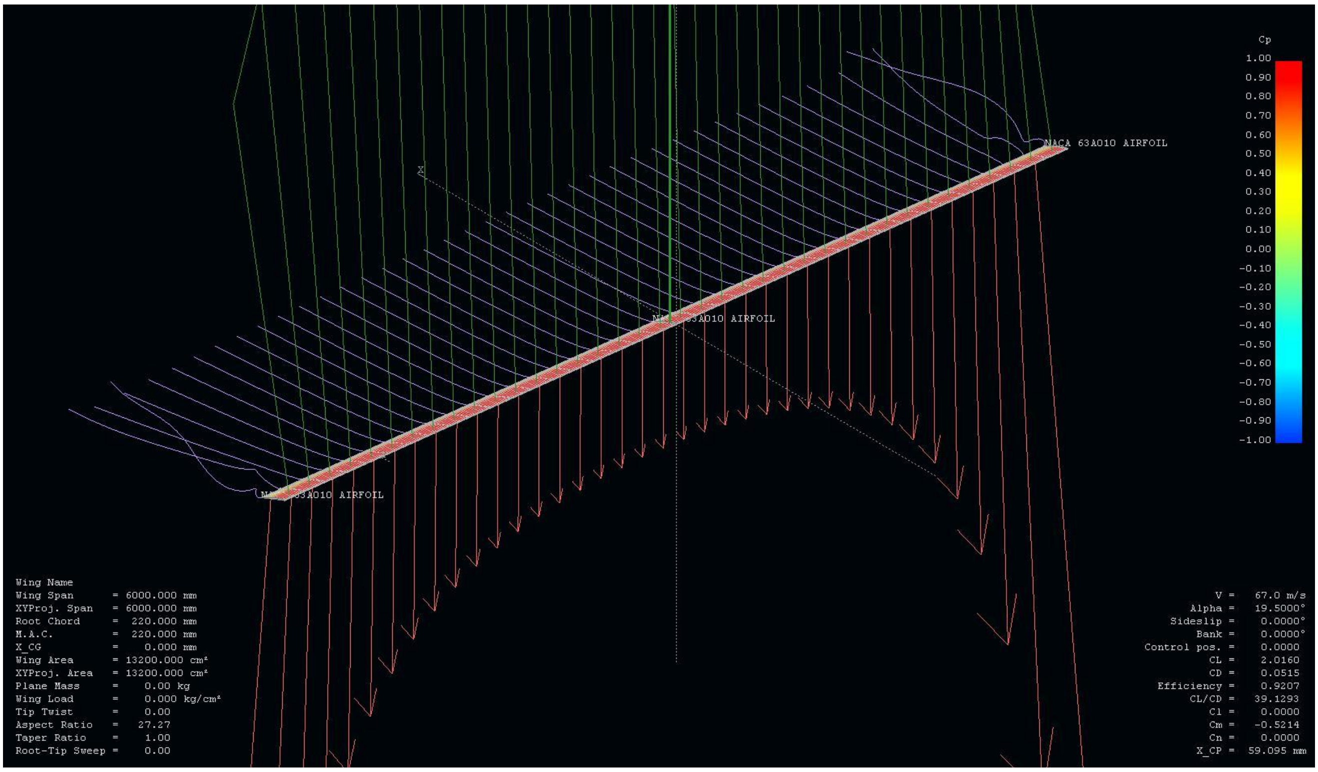
(At 0 degree angle of attack)



(At 12.5 degree angle of attack)

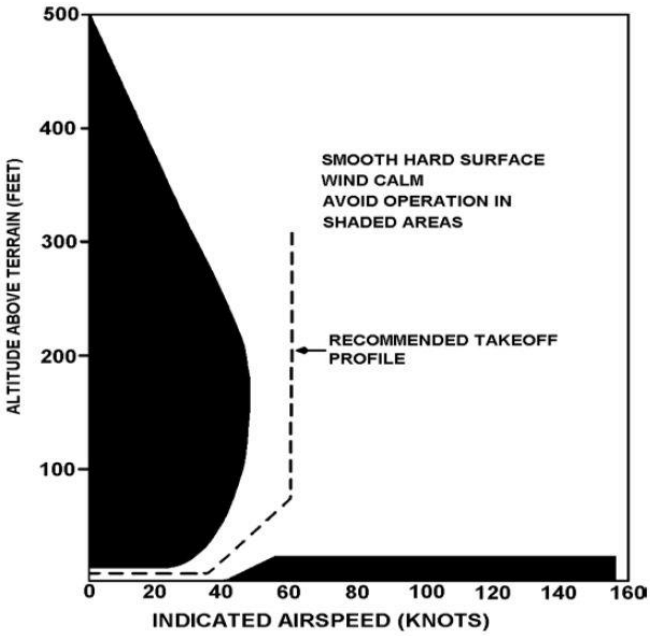


(At 19.5 degree angle of attack)

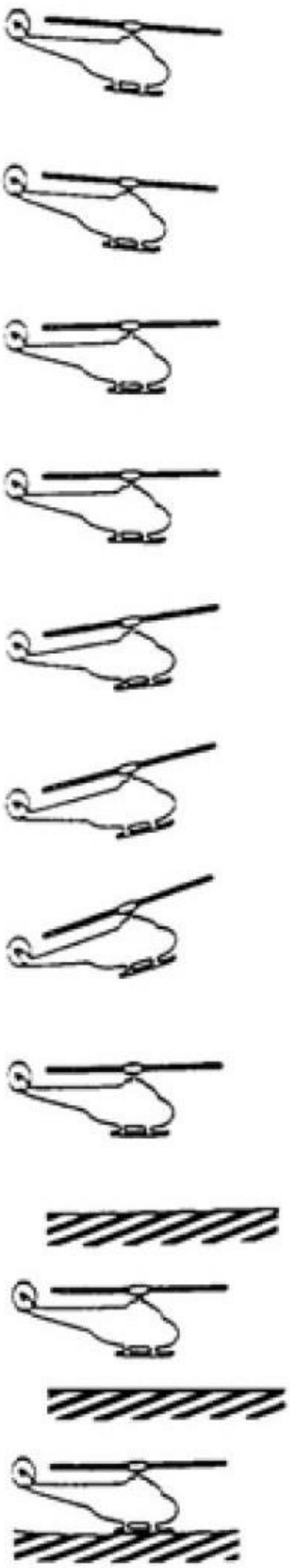


Appendix [G] Height-Velocity Diagram and Autorotation

Safe autorotation landing is not an easy job no matter how well trained the pilot is. The Height-Velocity Diagram shown in figure () –also known as the Deadman's Curve– identifies the portions of the flight envelope indicating where a safe landing can be performed in the event of an engine failure. The H-V diagram generally depicts two areas to be avoided; the low airspeed/high altitude region and the high airspeed/ low altitude region. Each helicopter has its own H-V diagram. They are found in their respective NATOPS Manuals and pilots should be familiar with these diagrams.

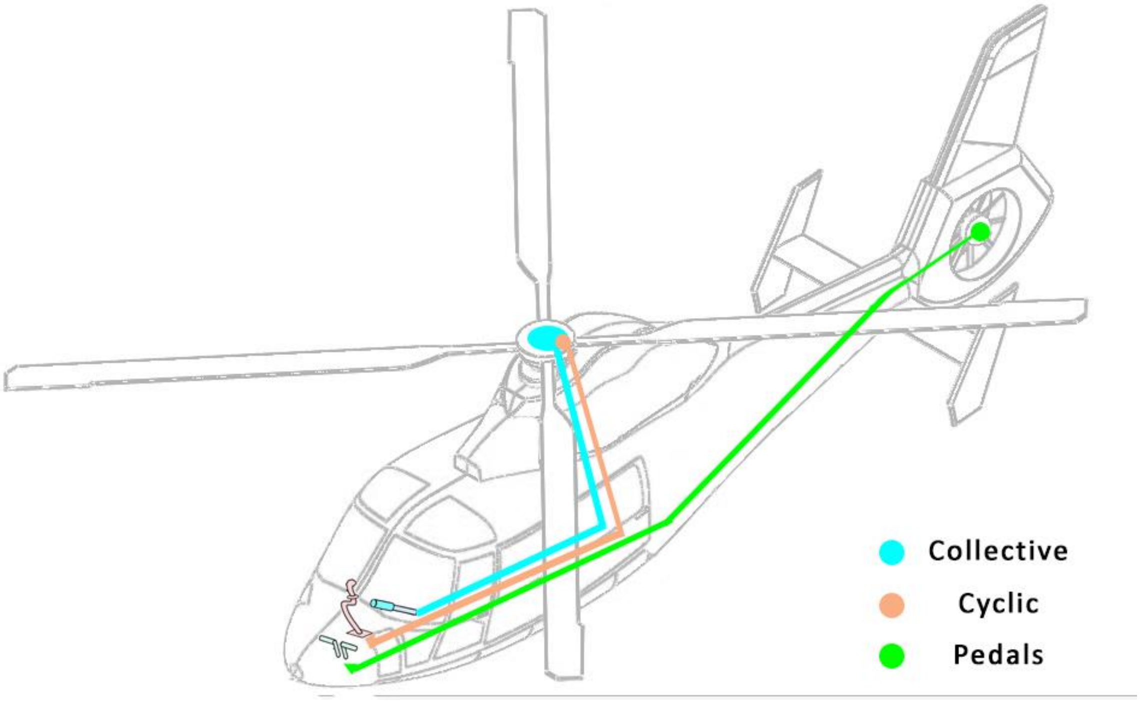


LANDING AFTER A POWER FAILURE

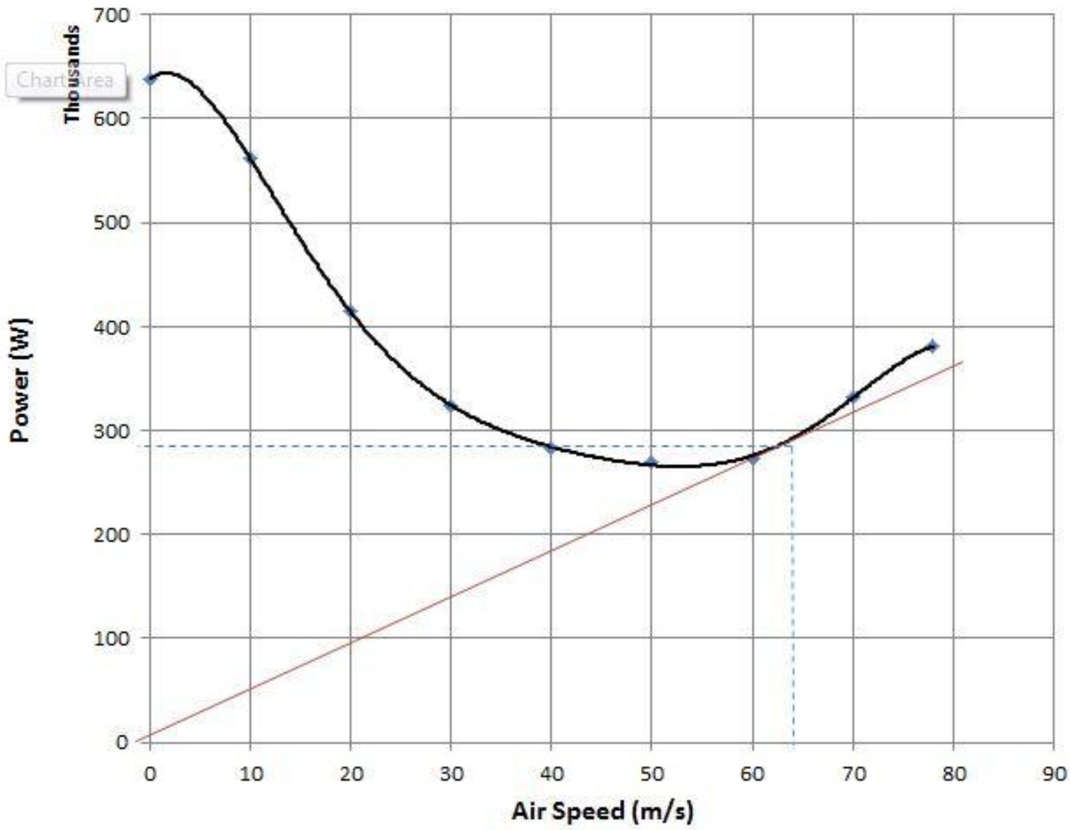


1. STEADY FLIGHT; ALL SYSTEMS WORKING
2. OOPS! ENGINE QUITS; RPM STARTS DOWN
3. LOWER COLLECTIVE TO STOP RPM DECAY; GET STARTED DOWN
4. STEADY AUTOROTATION AT POWER BUCKET SPEED; RPM MAY BE HELD LOW TO STRETCH GLIDE
5. START CYCLIC FLARE: LET ROTOR OVERSPEED UP TO REDLINE
6. MILK CYCLIC FLARE TO KILL FORWARD SPEED AND RATE OF DESCENT
7. INCREASE COLLECTIVE; LET RPM DECREASE
8. LOWER NOSE TO LEVEL ATTITUDE
9. PULL IN LAST OF COLLECTIVE PITCH
10. TOUCH DOWN LIKE A FEATHER; A PERFECT 10!

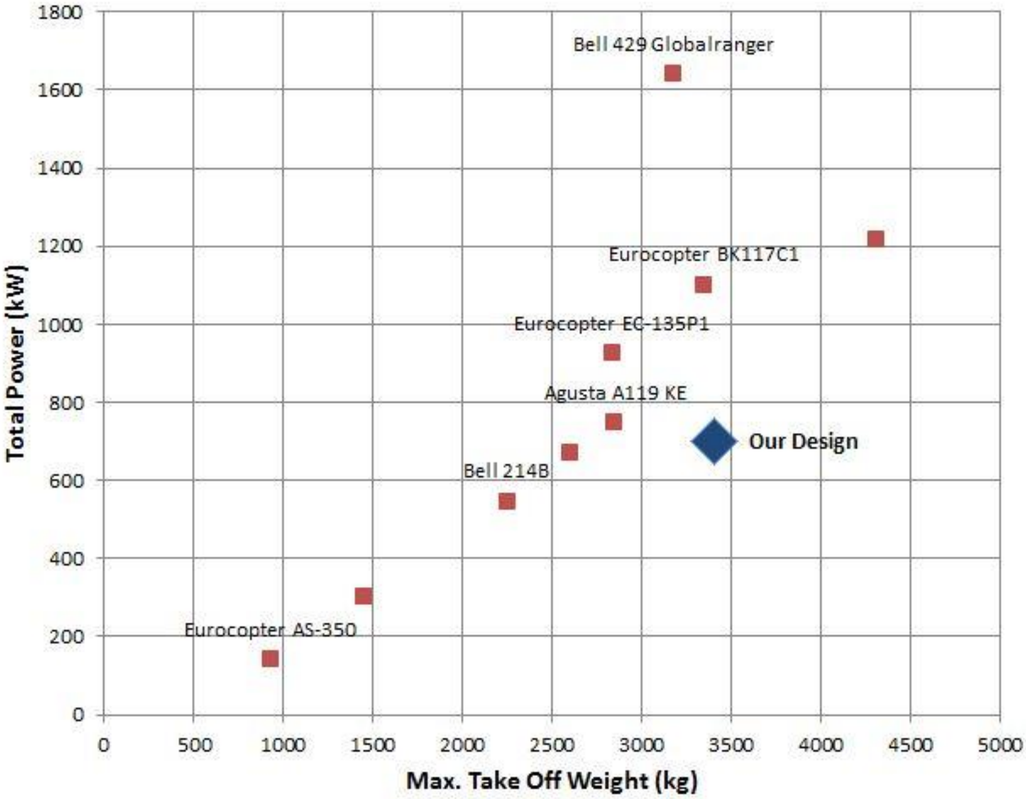
Appendix [H] Flight Controls

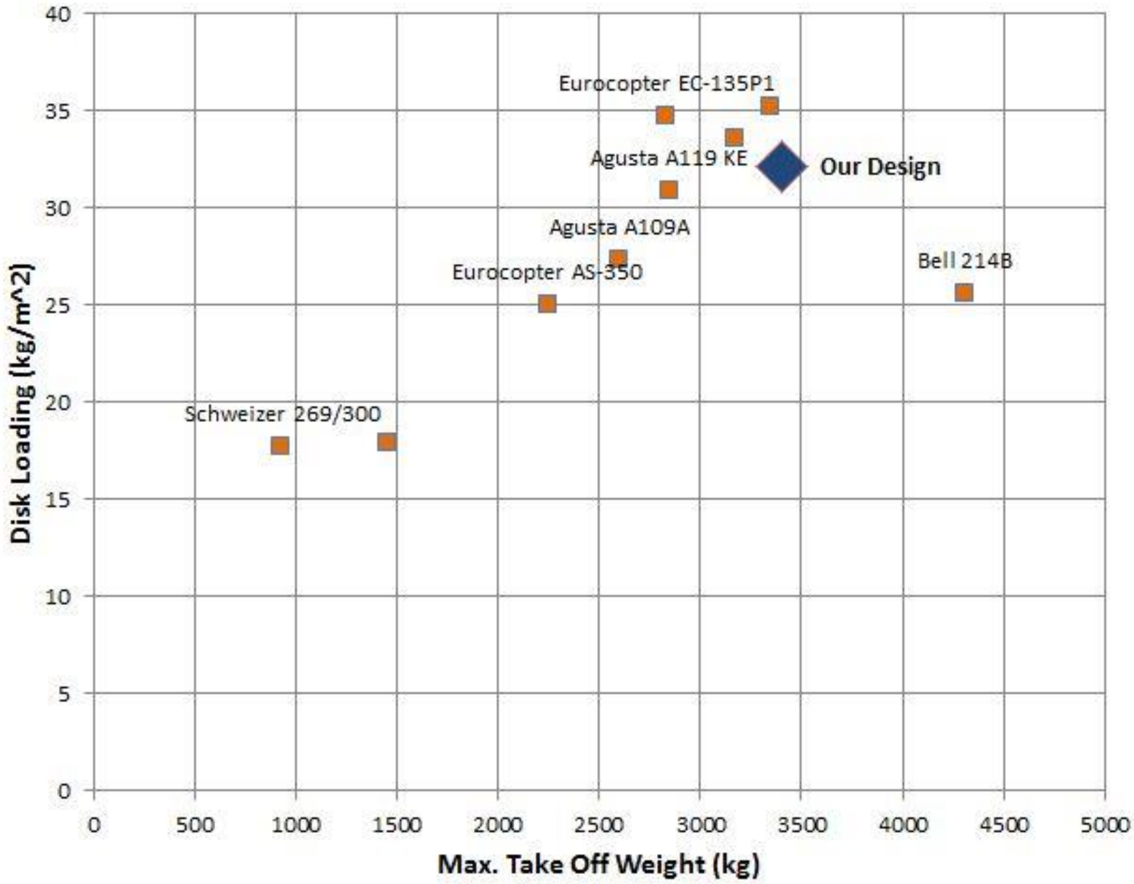


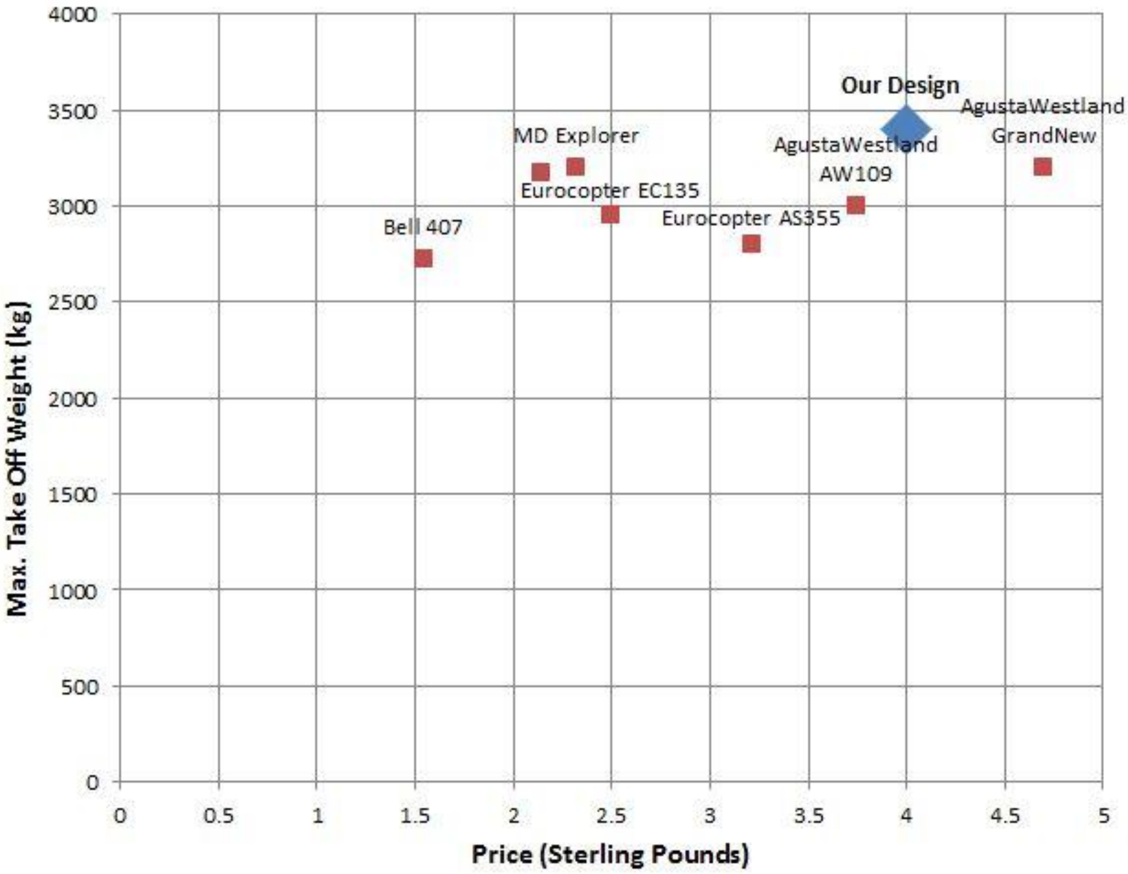
Appendix [I] Total Power Vs Airspeed

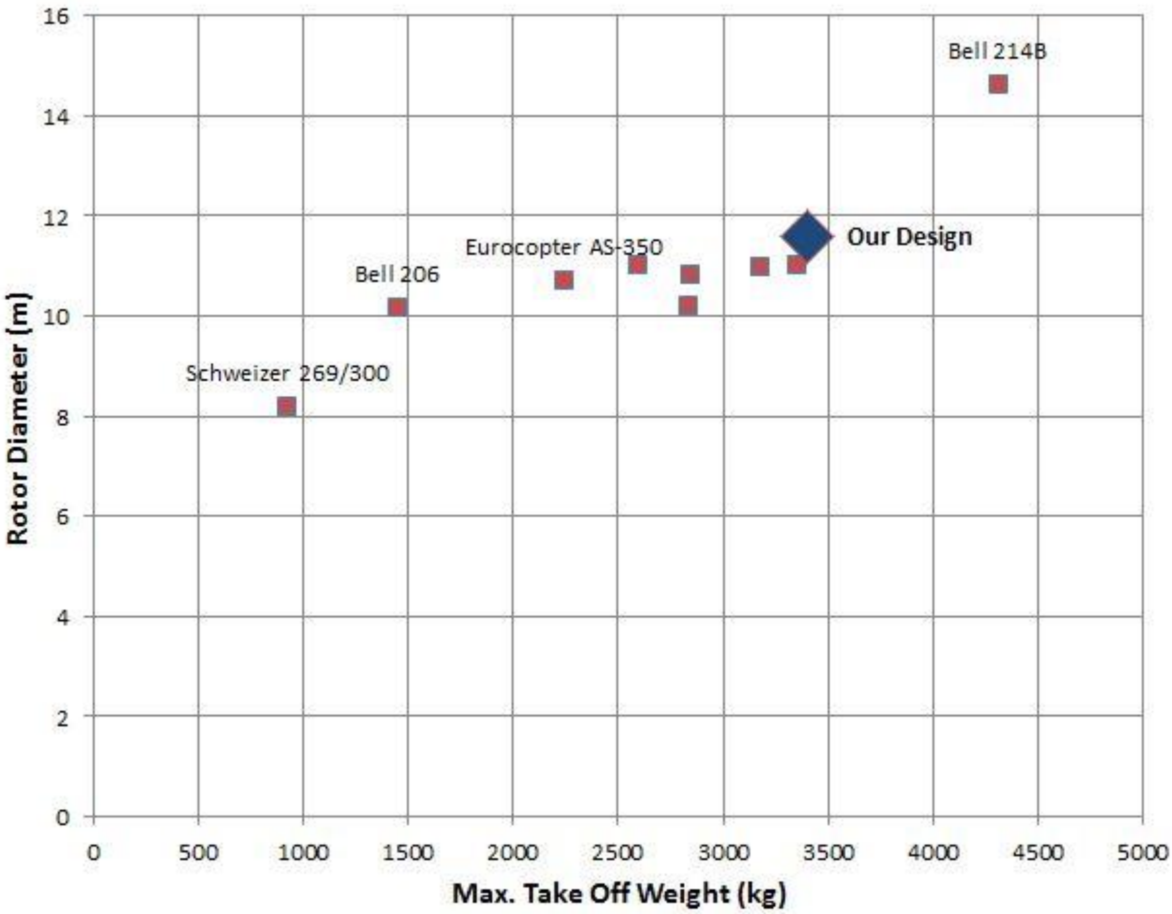


Appendix [J] Comparison Graphs






Our Design
AgustaWestland GrandNew
MD Explorer
AgustaWestland AW109
Eurocopter EC135
Eurocopter AS355
Bell 407
Max. Take Off Weight (kg)
Price (Sterling Pounds)
0
500
1000
1500
2000
2500
3000
3500
4000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Bell 214B
Our Design
Eurocopter AS-350
Bell 206
Schweizer 269/300
Rotor Diameter (m)
Max. Take Off Weight (kg)
0
2
4
6
8
10
12
14
16
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000