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Submitted by
Kübra Çınar - 2328177
Emin Tolukan - 2388080
Melih Çimen - 2083848

Table of Contents

Nomenclature

v_i	Induced Velocity
σ_{MR}	Main Rotor Solidity
σ_{TR}	Tail Rotor Solidity
T	Thrust
$C_{D,0}$	Profile Drag Coefficient
k, K	Correction Factor
f	The equivalent flat-plate Area
V	Forward Speed
A	Disc Area of Main Rotor
A_{TR}	Disc Area of Tail Rotor
ρ	Air Density
$v_{tip} = \Omega R$	Tip Velocity
N_b	Number of Blades
c	Chord length
P_i	Induced Power
P_A	Power Available
P_0	Profile Power
P_P	Parasite Power
P_R	Required Power
P_M	Miscellaneous Power
R_{MR}	Main Rotor Blade Radius
W_e	Empty Weight

W_R	Main Rotor Group Weight
W_{TR}	Tail Rotor Group Weight
W_T	Power Plant Group Weight
W_{PS}	Power Plant Section Group Weight
W_{DS}	Mechanical Drive System Group Weight
W_{FC}	Flight Control Group Weight
W_{LG}	Landing Gear Group Weight
W_F	Fuselage Group Weight
W_P	Forward Propulsion Group Weight
$W_G/TOGW$	Gross Weight
DL	Disc Loading
V_c	Cruise Speed
PL	Power Loading
$W_{payload}$	Payload Weight
W_{fuel}	Fuel Weight
W_{other}	Other weights
hp	Horsepower
θ_{tw}	Twist Rate
RPM_{tail}	Tail rotor revolutions per minute
SFC	Specific fuel consumption

Introduction

The main objective in this project is to design an affordable rotorcraft that would permit commutes through big cities. The rotorcraft must be fast, light and must satisfy certain requirements, both physical; like size, weight, and cabin capacity, and technical; like cruise speed, range, noise, and power requirements. Design includes not only technical specifications but also the engineering drawings with dimensions and seat configurations. Calculations of several technical parameters are performed using both the empirical methodology, like the weight estimation, and appropriate mathematical formulations related to helicopter aerodynamics, such as momentum theory. Since the sole purpose of this vehicle is to allow cheap and fast transportation, the focus in the design process was mainly put towards making the helicopter light, comfortable for passengers, easy to handle for the pilots and aerodynamically and technically suitable for the mission.

Chapter 1. Design requirements

The purpose of this section is to introduce the design requirements for this vehicle and chosen technical configurations. As for any personal aerial vehicle project, design and technical considerations for this helicopter are chosen to be consistent with the requirements of the mission. The goal is to design a four-seat helicopter capable of vertical take-off and landing that will meet the following requirements.

Table 1.1: Given requirements.

Useful payload	1 pilot + 3 passengers + baggage allowance
Cruise speed	> 61.1 m/s
Hover ceiling OGE	2500 m ISA
Range (no reserve at cruise speed at 15,000 m ISA)	> 500,000 m
Main rotor tip speed	< 195 m/s
Tail rotor tip speed	< 180 m/s
Handling	Cooper Harper rating of 3.5 or less (Level I Handling Qualities)

Table 1.2: Chosen requirements.

City of operation	Istanbul
Rotorcraft configuration	Conventional
Cruise speed	63.8 m/s
Range	600,000 m
Baggage allowance per person	17 kg
Average passenger weight	75 kg
Main rotor tip speed	194 m/s
Tail rotor tip speed	175 m/s

Chapter 2. Competitor Study

Disc loading values of the helicopters are calculated using

$$DL = \frac{T}{A} \, . \qquad \textbf{(2.1)}$$

- $T = W_G$, which depends on each helicopter's gross weight.
- $A = \pi \cdot {R_{MR}}^2$, which depends on each helicopter's main rotor radius.

Below are the results obtained from competitor study and market research.

Table 2.1: Performance characteristics of competitor helicopters.

Parameter	Competitor Helicopter 1 Robinson R44 (RAVEN II) [10][11][12]	Competitor Helicopter 2 Eurocopter AS350 Écureuil [3][5]	Competitor Helicopter 3 Eurocopter EC120 Colibri [6][7]	Competitor Helicopter 4 AgustaWestland AW109 [1][2]	Competitor Helicopter 5 Bell 206 L4 [4][15]
Cruise speed	56.1 m/s	68 m/s	62.8 m/s	79.2 m/s	55.8 m/s
Max. speed	66.7 m/s	79.7 m/s	77.8 m/s	86.4 m/s	61.1 m/s
Range	404000 m	662000 m	727000 m	932000 m	693000 m
Service ceiling IGE @MTOW	------	4600 m	2820 m	5974 m	4100 m
Rate of climb	>5.08 m/s	8.5 m/s	6.1 m/s	9.8 m/s	6.9 m/s
Max. operating altitude	4627 m	------	------	4937 m	-----
Disc loading (MTOW)	140 $\frac{\mathrm{N}}{\mathrm{m}^2}$	65 $\frac{\mathrm{N}}{\mathrm{m}^2}$	54 $\frac{\mathrm{N}}{\mathrm{m}^2}$	78 $\frac{\mathrm{N}}{\mathrm{m}^2}$	46 $\frac{\mathrm{N}}{\mathrm{m}^2}$

Table 2.2: General characteristics of competitor helicopters.

Parameter	Competitor Helicopter 1	Competitor Helicopter 2	Competitor Helicopter 3	Competitor Helicopter 4	Competitor Helicopter 5
Crew+ passenger capacity	1+3	1+5	1+4	1 or 2+6 or 7	1+4
Length	11.6 m	10.93 m	11.52 m	11.448 m	12.09 m
Width	2.18 m	2.17 m	1.35 m	1.61 m	2.38 m
Height	3.28 m	3.145 m	3.4 m	3.50 m	2.84 m.
Main rotor diameter	10.05 m	10.7 m	10 m	11 m	10.16 m
Number of blades	2	3	3	4	2
Empty weight	658 kg	1174 kg	960 kg	1590 kg	1057 kg
Maximum gross weight	1134 kg	2370 kg	1715 kg	3000 kg	1520 kg
Power plant	1 × Lycoming IO-540-AE1A5 6-cylinder	1 × Turbomeca Arriel 2B turboshaft engine	1 × Turbomeca TM 319 Arrius 2F	2 × Pratt & Whitney Canada PW206C Turboshaft engine	1 × Allison 250-C20J turboshaft engine
Horsepower	245 hp	848 hp	504 hp	560 hp	726 hp
Fuel capacity	120 L main+ 70 L auxiliary	540 L main+475 L auxiliary	416 L	837 L	416 L
Unit cost	$412,000	$2.4 million	$895,000	$6.3 million	$1.6 million

Chapter 3. Sizing and performance analysis

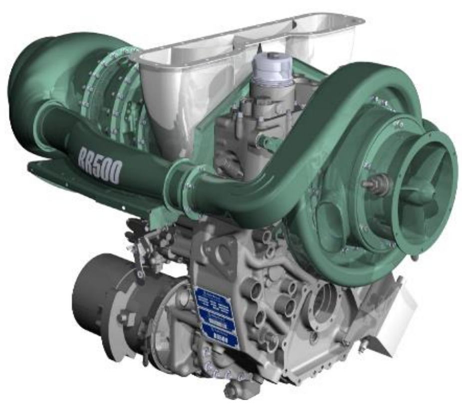
3.1. Engine selection.

In this section, the engine selected for this helicopter is introduced and the reasons for selection of this exact engine are explained. Once the engine and its power capabilities are established, gross weight estimation for this helicopter is performed. Power requirements for the mission, and the power performance of this helicopter are summarized, and performance analysis is included.

The engine for this helicopter must satisfy the following parameters

- It must be light
- It must provide necessary power for cruise flight
- It must have enough excess power for good climbing capabilities
- It must be efficient to provide power for the entire range of 600 km.

To meet these needs, RR500 turboshaft engine by Rolls Royce is chosen.



[13]

Figure 3.1.1: 3D model of RR 500 turboshaft engine.

Table 3.1.1: The main performance characteristics of this engine. [14]

Type	Turboshaft
Length	1.09 m
Diameter	0.59 m
Compressor	Single-stage centrifugal
Available power (special order)	350 hp
SFC	$1.12 \cdot 10^{-6} \frac{\mathrm{N}}{\mathrm{W} \cdot \mathrm{s}}$

3.2. Gross weight estimation.

Gross weight estimation of the helicopter is performed using empirical correlations by integrating them into an iterative algorithm. As a result of computations, not only the gross weight of the overall rotorcraft but also the weights of individual groups and the radius of the main rotor are obtained. The individual weight groups included into computation of the gross weight are main rotor group, tail rotor group, power plant group, power plant section group, mechanical drive system group, flight control group, landing gear group, fuselage group and forward propulsion group. The scheme of the algorithm used for computations of the gross weight and main rotor radius is shown below.

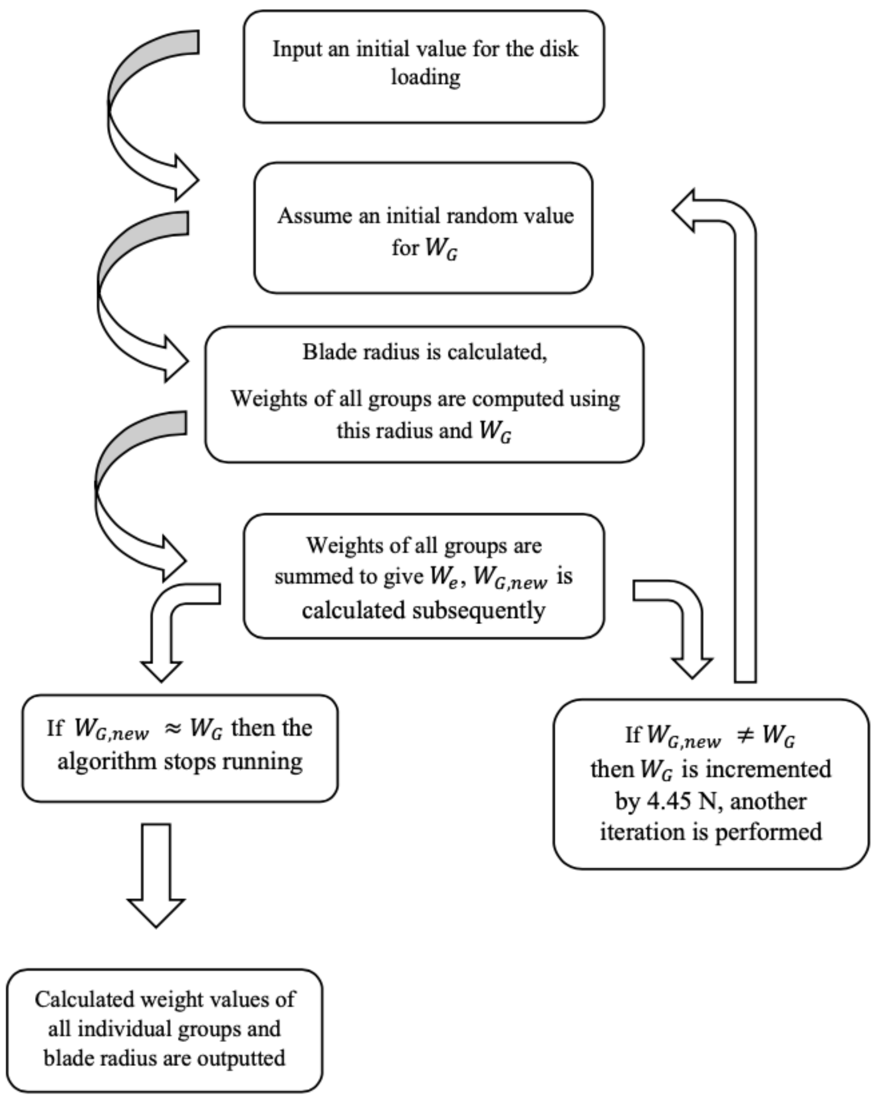


Figure 3.2.1: Algorithm scheme for weight estimation.

The design takeoff gross weight of the helicopter is calculated using

$$W_G = W_e + W_{payload} + W_{fuel} \, , \tag{3.1}$$

where empty weight is found using

$$W_e = W_R + W_{TR} + W_T + W_{PS} + W_{DS} + W_{FC} + W_{LG} + W_F + W_P + Wother, \tag{3.2}$$

where other weights can be calculated using

$$W_{other} = 0.2 \cdot W_e \tag{3.3}$$

where each weight groups are calculated using following formulas

$$W_R = 1.7 \cdot {W_G}^{0.342} + {R_{MR}}^{1.58} \cdot {\sigma_{MR}}^{0.63}, \tag{3.4}$$

where σ is calculated using

$$\sigma = \frac{N_b \cdot c \cdot R}{A} \tag{3.5}$$

$$W_{TR} = 7.12 \cdot \left(\frac{W_G}{1000}\right)^{0.446} + {R_{TR}}^{1.62} \cdot {\sigma_{TR}}^{0.660} \, , \tag{3.6}$$

$$W_T = 0.166 \cdot hp \, , \tag{3.7}$$

$$W_{PS} = 0.00155 \cdot (W_G)^{1.07} \cdot DL^{0.54}, \tag{3.8}$$

where DL is found using

$$DL = \frac{T}{A} \, , \tag{3.9}$$

$$W_{DS} = 42.4 \cdot \left(\frac{P_A \cdot R_{MR}}{v_{tip}}\right)^{0.763} \, , \tag{3.10}$$

$$W_{FC} = 0.0226 \cdot {W_G}^{0.712} \cdot {V_c}^{0.653}, \tag{3.11}$$

$$W_{LG} = 0.0475 \cdot {W_G}^{0.975} \tag{3.12}$$

$$W_F = 0.21 \cdot {W_G}^{0.598} \cdot {R_{MR}}^{0.942} \, , \tag{3.13}$$

$$W_P = 0.146 \cdot \frac{W_G}{PL} \ . \qquad \textbf{(3.14)}$$

Knowing the desired range, V_c and SFC of the engine and using an approximate required power for cruise flight (this can be determined approximately from Fig. 3.4.1) the appropriate fuel weight can be calculated by rearranging equation

$$Range = W_{fuel} \cdot \frac{V_c}{P_R \cdot \text{SFC}}$$

Where Range is in meters, W_{fuel} is in Newtons, V_c is in meters per second and P_R is in Watts. Plugging all known parameters,

$$W_{fuel} = 2670 \text{ N} \approx 272.2 \text{ kg}$$

The following values are used in calculations:

- $W_{payload} = 368$ kg , which consist of 1 pilot, and 3 passenger each having average weight of 75 kg, and luggage allowance of 17 kg per passenger.
- Horsepower = 350 hp, as provided by the engine.
- V_c = 64 m/s (≈124.8 knots).

Three different values of disk loading are chosen for comparison. The criteria to satisfy while choosing a disk loading value is the tip speed limit, appropriate main rotor radius and lowest possible gross weight.

Table 3.2.1: TOGW and main rotor radius results for three disk loading values.

DL (N/m^2)	76.15	167.65	225.14
$\boldsymbol{R_{MR}}$ **(m)**	8.171	5	4.203
$\boldsymbol{W_G}$ **(kg)**	1628	1339	1273

First two values of disk loading are chosen such that they are close to disk loadings of competitor helicopters. The largest disk loading is chosen for the sake of comparison and to see if the weight output will be smaller. According to the results above, it is reasonable to choose disk loading as 225.14 N/m^2, as it gives the lightest weight while at the same time resulting in a main rotor radius such that tip speed limit is not exceeded. Knowing that the main rotor rotates at 440 rpm, the value of tip speed can be easily found using

$$v_{tip} = \Omega \cdot R_{MR} \quad \textbf{(3.15)}$$

The following values are used in calculations

- $\Omega = \frac{440 \text{ rpm}}{60} \cdot 2 \cdot \pi = 46.08 \text{ rad/s}$.
- $R_{MR} = 4.20$ m.

Tip speed for the main rotor can be found by plugging these values into **(3.15)**, this yields $v_{tip} \approx 194 \text{ m/s}$

The results of weights of individual groups and total empty weight obtained for the chosen disk loading are summarized below.

Table 3.2.2: Calculated values for weights of all groups.

Weight group	**Weight result (kg)**
Main rotor group	104.9389
Tail rotor group	4.2415
Power plant group	22.2273
Power plant section group	7.9325
Mechanical drive system group	90.3534
Flight control group	95.6959
Landing gear group	49.0540
Fuselage group	130.0769
Forward propulsion group	23.1799
Empty weight	633.2404

3.3. Power requirements.

Knowing approximate power values at different flight regimes is important for the performance analysis of a helicopter. Upon these estimations, one can judge the helicopter's capabilities and predict useful parameters. The power estimation for this helicopter is performed for a range of forward speeds starting from 0 m/s (assuming hover) to 250 km/h. Required power for a given flight speed includes profile power,

$$P_0 = \left(\frac{1}{8}\right) \cdot \sigma \cdot C_{D,0} \cdot \rho \cdot A \cdot (\Omega \cdot R_{MR})^3 \cdot [1 + K] \cdot \left(\frac{V}{\Omega \cdot R_{MR}}\right)^2, \qquad \textbf{(3.16)}$$

parasite power,

$$P_P = \frac{1}{2} \cdot \rho \cdot V^3 \cdot f, \qquad \textbf{(3.17)}$$

induced power,

$$P_i = k \cdot v_i \cdot T, \qquad \textbf{(3.18)}$$

where induced velocity is found using

$$v_i = \sqrt{-\frac{1}{2} \cdot V^2 + \frac{1}{2} \cdot \sqrt{V^4 + 4 \cdot \left(\frac{T}{2 \cdot \rho \cdot A}\right)^2}}\ , \qquad \textbf{(3.19)}$$

and thrust is approximated from $T \approx W = DL \cdot A$,

and lastly, miscellaneous power,

$$P_M = 0.15 \cdot (P_0 + P_P + P_i). \qquad \textbf{(3.20)}$$

Finally, total power is calculated using

$$P_{total} = P_0 + P_P + P_i + P_M. \qquad \textbf{(3.21)}$$

The following values are used in the calculations

- $\sigma = 0.0454$
- $C_{D,0} = 0.01$,
- $\rho = 1.225 \frac{\text{kg}}{\text{m}^3}$,
- $R_{MR} = 4.2029$ m,
- $A = 55.4943 \text{ m}^2$,
- $\Omega = 46.0767 \frac{\text{rad}}{\text{s}}$,
- $K = 4.65$,
- $f = 0.8879 \text{ m}^2$,
- $k = 1.15$.

Knowing that the available power for our custom RR 500 engine is 350 hp, all calculations are performed for the established range of forward speeds. The plots for power values are shown below.

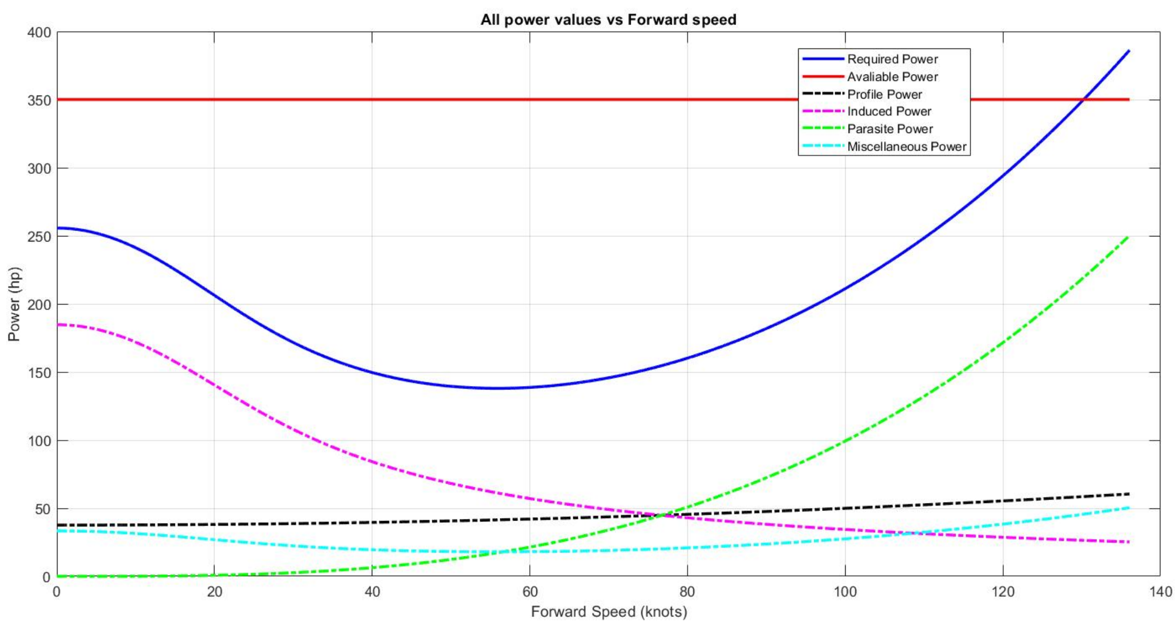


Figure 3.3.1: Required, available, profile, induced, parasite and miscellaneous power plots with respect to forward speed ranging from 0 to 136 knots (0 to 250 km/s).

3.4. Performance analysis.

For a helicopter in forward flight, it is important to know maximum velocity that is allowed by the available power of the engine. It is also useful to know maximum range speed, to fly as far a distance as the engine power allows, and the maximum endurance speed, to stay in air for as long as possible. These speeds are estimated using the formulations from Section 3.3. By plotting the required power with respect to the range of forward speeds, the values for these speeds are obtained below.

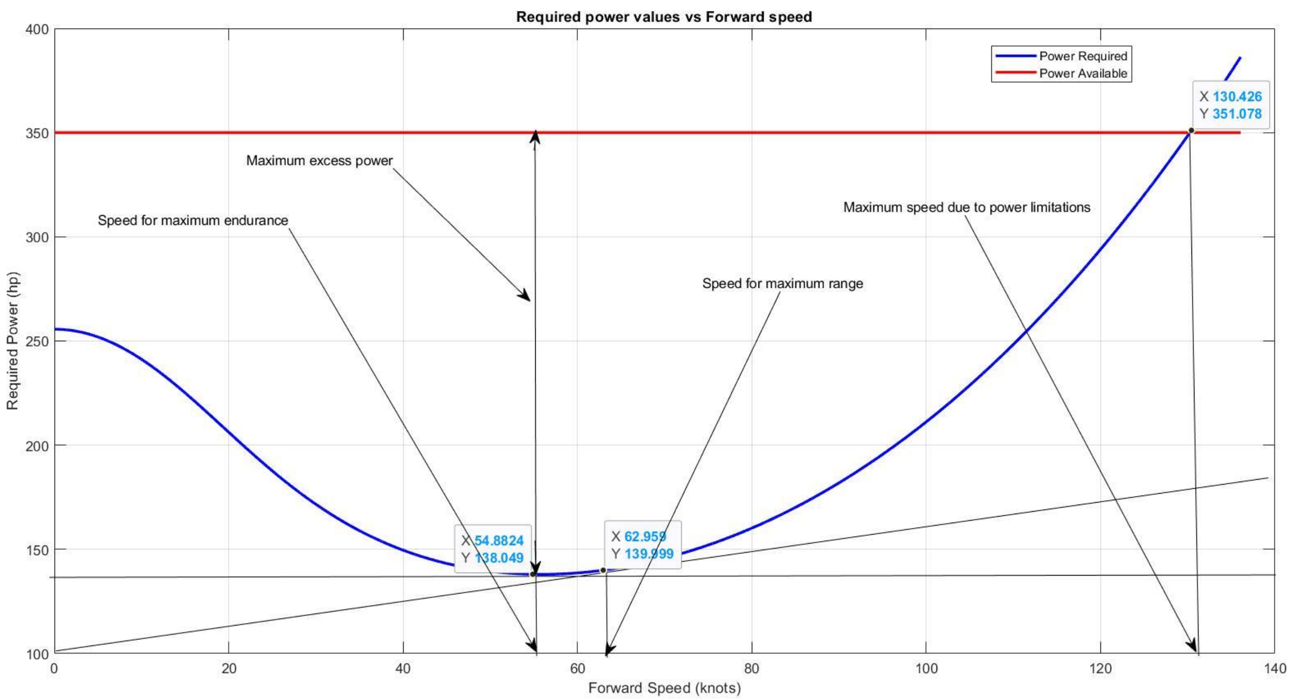


Figure 3.4.1: Required power plot with respect to forward speed ranging from 0 to 136 knots, with speed for maximum endurance, speed for maximum range and maximum forward speed indicated.

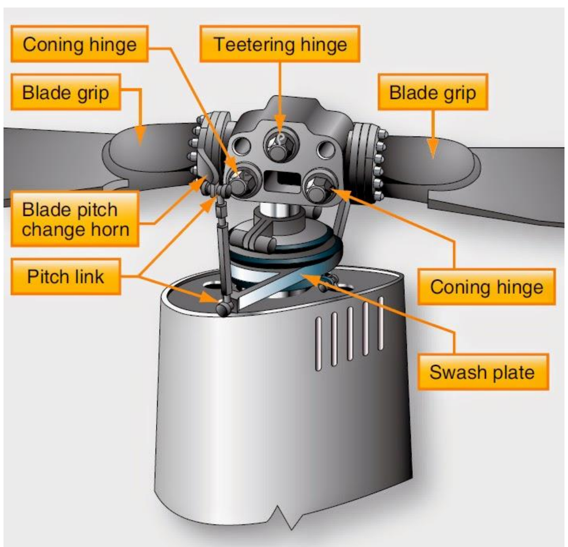
Chapter 4. Additional design aspects.

When designing a rotorcraft, everything begins with its primary mission. The mission of this helicopter is cheap and fast transportation of passengers in a big city. Cities like Istanbul are densely populated, and commutes with cars are not a good option for busy citizens, both for the in-city routes, and for the inter-city trips. This helicopter is designed for efficient operation in the skies of Istanbul, where with its relatively low tip speed it will not disturb citizens with loud noise, and with its good excess power it will be able to maneuver and change altitude as needed. Weight, power, and engine specifications are established in the previous chapters. Further details on rotorcraft configuration, main and tail rotor sizing, empennage design and avionics suite are provided in this chapter.

4.1. Rotorcraft configuration.

4.1.a. Hub

Hub of a helicopter is the bridge between aerodynamics and control. Teetering rotor hub configuration is chosen for this helicopter. This is because this helicopter has only two blades. Teetering hubs are aerodynamically more efficient than fully articulated hubs. Also, the simplicity of structural design of this hub configuration eliminates maintenance issues and costs.



[8]

Figure 4.1.1: Teetering (semi-articulated) rotor hub scheme with names of individual components.

4.1.b. Tail rotor type

A two-bladed tail rotor is chosen as the anti-torque system. This configuration is aerodynamically efficient and permits a good yaw control.

 **[9]**

Figure 4.1.2: Two-bladed tail rotor configuration for a conventional rotorcraft configuration.

4.1.c. Landing gear type.

As much as it is important to have a good landing gear to improve aerodynamic efficiency of a helicopter and ensure smooth landing, it is important for this helicopter to be light and easy to maintain. Landing skids are chosen as landing gear for this vehicle because they ensure structural integrity, light weight and eliminate the need for complex maintenance.

Figure 4.1.3: Landing skids for a conventional transport helicopter

4.1.d. Door locations

Although the full 3-view drawing is included in Chapter 5, in this section more details are given about the sizing and configuration of the doors. The helicopter includes four doors, two on the right and two on the left of the fuselage. The front seat doors are outward opening while the back row doors are laterally sliding doors. Such a configuration is chosen for the ease of boarding and comfort of the passengers. The back row doors can also be opened during flight for aerial photoshoots under certain safety requirements.

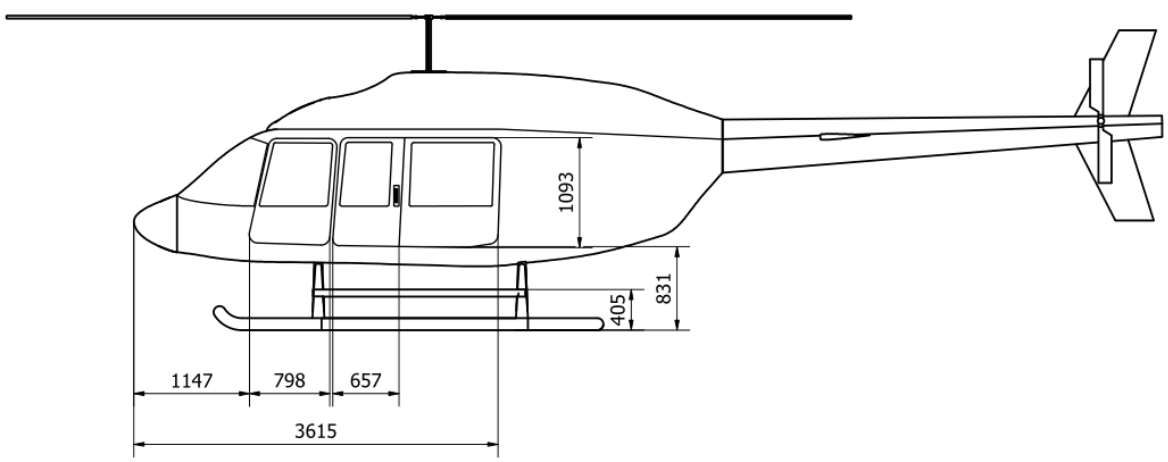


Figure 4.1.3: Door configuration and dimensions indicated in mm.

4.2. Main and tail rotor sizing.

4.2.a. Main rotor

For the simplicity of design, blade geometry is chosen to be rectangular, with a linear twist of $\theta_{tw} = -10°$. Such a twist rate is chosen to provide a better figure of merit for hover, and overall better lift distribution along inner sections of the blade. Higher magnitude of twist rate is also possible, but this may adversely affect performance in forward flight. The main rotor has two blades attached to the semi-articulated (teetering) hub. The blade tip has no sweep to avoid complexity and additional cost. Angular rate for the main rotor is chosen to be 440. At this rate, the tip speed requirement is satisfied and much less profile drag is generated. This is also the optimum rpm for RR 500 engine available power and helicopter's cruise speed requirements as shown in Fig. 3.4.1. Airfoil used for this helicopter is a four-digit NACA 0012 airfoil. This symmetric airfoil proves to have better hover performance than many cambered airfoils, hence is a better choice for this helicopter. The chord length of the main rotor blade is 0.3 m.

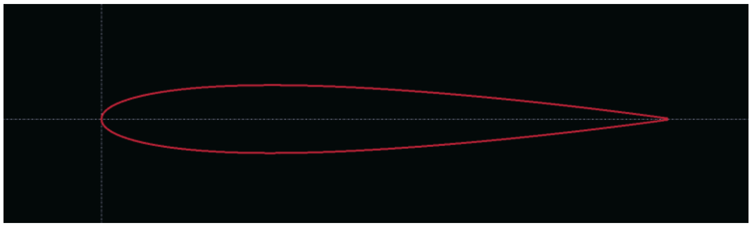


Figure 4.2.1: NACA 0012 airfoil plot from XLFR5 software package.

4.2.b. Tail rotor

Radius of the tail rotor is chosen such that it is 6.84 times shorter than the radius of the main rotor blade. This ratio is taken from a similar helicopter in the market, "Bell 206". Therefore, tail rotor radius is 0.6145 m long. By rearranging equation **(3.15)**, with the known value for tip speed for the tail rotor, the tail rotor angular rate is found using

$$RPM_{tail} = \frac{V_{tip}}{R} \cdot \frac{\text{rad}}{\text{s}} \cdot \frac{\text{revolution}}{2 \cdot \pi \cdot \text{rad}} \cdot \frac{60\ \text{s}}{\text{min}} = \frac{175\,\frac{\text{m}}{\text{s}}}{0.6145\ \text{m}} \cdot \frac{60\ \text{s}}{2 \cdot \pi} = 2719.5\ \text{RPM}$$

This is a reasonable value for a tail rotor angular rate and can be easily provided by the engine using the right transmission and gearing. When it comes to the tail rotor blades' cross-section, same NACA 0012 airfoil is chosen for this helicopter.

4.3. Empennage arrangement.

Empennage design is extremely important in terms of aerodynamic efficiency and capabilities of a helicopter. Forward mounted horizontal stabilizer is added to this design to improve lateral stability of this helicopter. A double fin is attached at the back of the tail boom to provide yaw stability.

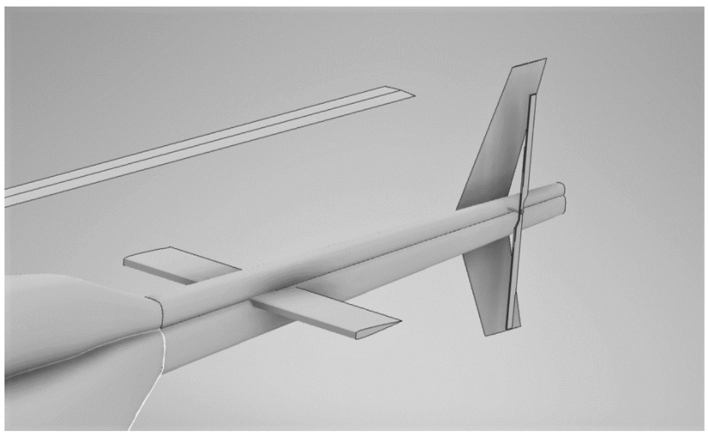


Figure 4.3.1: Empennage design of the helicopter

4.4. Avionics suit.

Modern day aviation is more digital and ergonomic than ever before. The avionics of a helicopter make it easy for pilots to operate it by providing amazing features like easy navigation, warning systems, terrain awareness systems, high frequency radios, communications systems etc. This helicopter is suited with IFR avionics from THALES **[16],** tailored for light weight and safe flight. IFR is the abbreviation for “instrumental flight rules”, this implies that the aircraft is intended to operate in even the worst meteorological conditions.

The suite includes:
- Integrated Display Unit
- Primary Flight Display & Navigation Display
- Synthetic Vision System
- Digital Map
- Basic Flight Management System
- Flight Warning System
- Centralized Maintenance System
- Standby Instrument
- Flight & Voice data recorder
- Tablet Universal Adaptor
- Satellite Communication
- Global Navigation System
- Radio Altimeter & antennas
- Terrain Awareness Warning System
- Traffic Collision Avoidance System
- Very High Frequency Radio Terminal

Chapter 5. Helicopter layout.

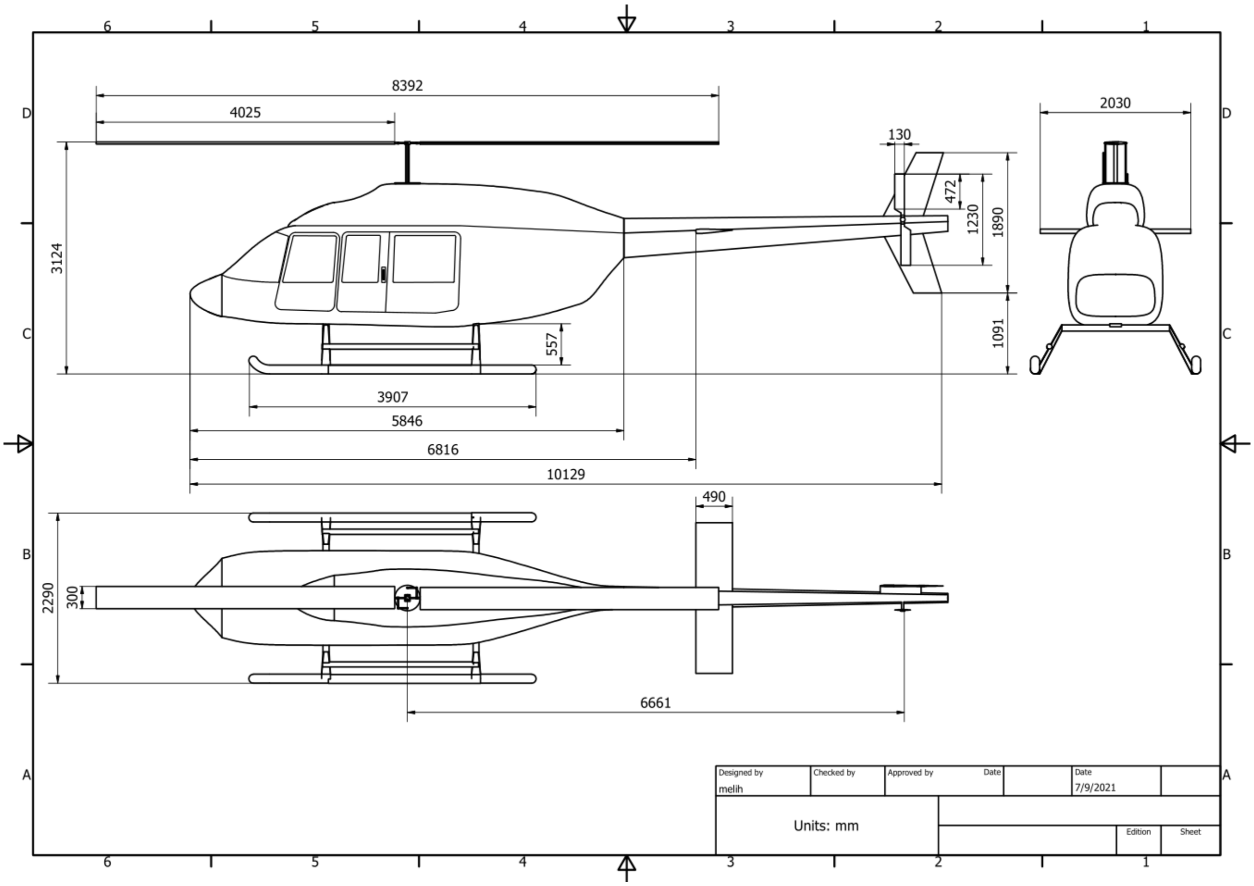


Figure 5.1.1: Helicopter 3-view layout: side, front, and top views with annotated dimensions

The layout of the helicopter is designed and drawn using Autodesk's Inventor professional 2022 3-D drawing package. This layout includes all calculated dimensions. A more detailed view of the seat configuration is included below.

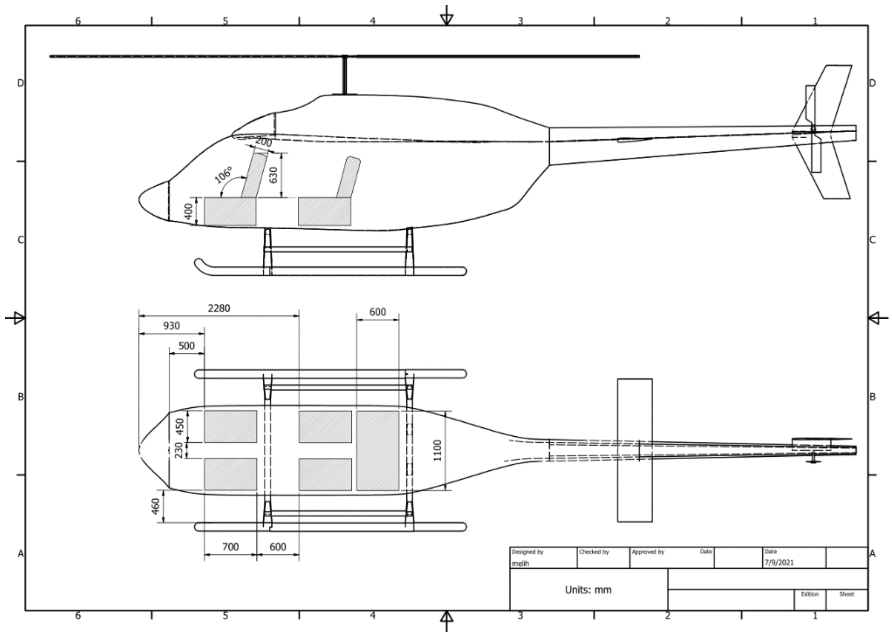


Figure 5.1.2: Helicopter floor and seat configuration with annotated dimensions

Table 5.1.1: Tabulated dimensions of external and internal components

Parameter	Dimension (mm)
Disk diameter	8392
Total height	3124
Total length of the body	10129
Total length of the fuselage	5846
Total length of the empennage	4283
Skid width	2290
Fin height	1890
Fin ground offset	1091
Horizontal stabilizer chord	490
Horizontal stabilizer length	2030
Seat width	450
Seat length	700
Passenger leg room	600
Seat lateral offset	230
Seat height	400
Seat back height	630
Baggage compartment width	600
Baggage compartment length	1100

Conclusion

Although different independent methodologies are used in this project, all of them are connected to one aim – design of a light, powerful and modern transportation helicopter. With the current – day standards in mind, the overall design and avionics of this helicopter prove to be up to date. Physically, the empty weight of the helicopter is superior to the majority of competitors. Of course, the empty weight is approximated, and many components are not taken into account, but the approximation used in this project has proven to yield reliable results therefore it is reasonable to conclude that weight requirement of the project is satisfied. When it comes to the internal design, a lot of attention is paid to the comfort of seat layout. Spacing between the front and back seat rows allows plenty of leg room. The baggage compartment behind the back row allows passengers to bring up to 17 kg of baggage which should be enough for intercity or in city trips. Many considerations are put into the aerodynamic design of the helicopter, the smooth engine and mast casing increases the efficiency in flight at high forward speeds by decreasing the parasite drag. Symmetric airfoils used for blades decrease profile drag, while blade twist allows uniform lift distribution and better hover performance. RR 500 engine provides good excess power for climbing and sudden maneuvers and powers the helicopter with enough shaft horsepower to cruise at 64 m/s. Maintenance wise, this helicopter is relatively cheap to maintain, this is said in line with simplified design choices. There are no mechanical complications in the landing gear, and the teetering hub design is chosen deliberately to reduce maintenance issues. Briefly, this design suits the mission from all perspectives.

REFERENCES

[1] *Agusta Westland AW109*. (n.d.). Retrieved from Charter Advisory: https://www.charteradvisory.cz/en/agusta-westland-aw109

[2] *AgustaWestland AW109*. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/AgustaWestland_AW109

[3] *AS350*. (n.d.). Retrieved from HELIAIRSWEDEN: https://www.heliairsweden.com/en/as350

[4] *Bell 206*. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Bell_206

[5] *Eurocopter AS350 Écureuil*. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Eurocopter_AS350_Écureuil

[6] *Eurocopter EC120 Colibri*. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Eurocopter_EC120_Colibri

[7] *Eurocopter EC120B*. (n.d.). Retrieved from Global Air: https://www.globalair.com/aircraft-for-sale/Specifications?specid=221

[8] *Helicopter Structures*. (n.d.). Retrieved from Aeronautics Guide: https://www.aircraftsystemstech.com/p/helicopter-structures.html

[9] *Helicopter Tail Rotors*. (n.d.). Retrieved from Pilot Teacher: https://pilotteacher.com/helicopter-tail-rotors-the-different-types-explained/

[10] *Kiralık ve Satılık Helikopter*. (2021). Retrieved from Helikopter: https://satilikhelikopter.com/

[11] *Robinson R44*. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Robinson_R44

[12] *Robinson R44 Raven II Specifications*. (2018). Retrieved from Premier Jet Aviation: http://jetav.com/robinson-r44-raven-ii-specifications/

[13] *Rolls-Royce RR500*. (n.d.). Retrieved from WIKIPEDIA: https://en.wikipedia.org/wiki/Rolls-Royce_RR500

[14] *RR500*. (n.d.). Retrieved from Yumpu: https://www.yumpu.com/en/document/read/25834284/rr500-turboshaft-rolls-royce

[15] *The Fundamental Guide to the Bell 206 Helicopter*. (n.d.). Retrieved from WinAir: https://winair.ca/blog/fundamental-guide-bell-206-helicopter/

[16] *Ultimate FlytX*. (n.d.). Retrieved from THALES: https://www.thalesgroup.com/en/markets/aerospace/flight-deck-avionics-equipment-functions/flytx-new-generation-avionics-suite

MATLAB CODES

```
%power estimation

clc
clear all
close all
format short

%% dfine parameters
%all parameters are converted to si units
k_small    =  1.15
K_capital  =  4.65
%thrust coefficient is equal to value at hover
Dl         = 225.1390  %%variable from pt2
c          = 0.3
R          = 4.2029    %%variable from pt2
A          = pi*(R)^2
W          = Dl*A
T          = W
Nb         = 2
solidity   = (Nb*c*R)/A
Cd_0       = 0.01
Rho        = 1.225
Rpm        = 440
Rps        = Rpm/60
Omega      = 2*pi*Rps
Vtip       = Omega*R


f          =  0.016*A



V = (0:0.001:70);
% power equations

vi = sqrt( (-1/2).*(V.^2)+(1/2)* sqrt((V.^4)+4*(T/(2*Rho*A))^2)  );

%induced power
Pi = k_small*vi*T;

%profile power
Ppr = (1/8)*solidity*Cd_0 *Rho* A *((Vtip)^3)*(1+ K_capital* ((V./Vtip).^2) )
;

%Parasite power
Ppa = (1/2)*Rho*(V.^3)*f;
%miscellaneous power
Pm = 0.15*(Pi+Ppr+Ppa);

Ptotal = Pi+Ppr+Ppa +Pm;



%conversion to knots and hp
```

```
V = 1.94384*V;
Ptotal = Ptotal*0.00134102;
for i = 1:70001
    Pavailable(i) = 350;
end




 figure(1)

 plot(V,Ptotal,'b','LineWidth',2)
 hold on
 plot(V,Pavailable,'r','LineWidth',2)
legend('Power Required','Power Available')
title('Required power values vs Forward speed')
xlabel('Forward Speed (knots)')
ylabel('Required Power (hp)')
grid on



% idnividual powers in HP
Ppr = Ppr *0.00134102;
Pi  = Pi*0.00134102;
Ppa = Ppa*0.00134102;
Pm = Pm*0.00134102;

figure(2)
plot(V,Ppr,'k','LineWidth',2)
hold on
plot(V,Pi,'r','LineWidth',2)
hold on
plot(V,Ppa,'g','LineWidth',2)
hold on
plot(V,Pm,'c-.','LineWidth',2)

legend('Profile Power','Induced Power','Parasite Power','Miscellaneous
Power')
grid on
xlabel('Forward Speed (knots)')
ylabel('Individual Powers (hp)')
title('Individual powers vs Forward speed')



figure(3)
plot(V,Ptotal,'b','LineWidth',2)
hold on
plot(V,Pavailable,'r','LineWidth',2)
plot(V,Ppr,'k-.','LineWidth',2)
hold on
plot(V,Pi,'m-.','LineWidth',2)
hold on
plot(V,Ppa,'g-.','LineWidth',2)
hold on
```

```
plot(V,Pm,'c-.','LineWidth',2)
grid on
legend('Required Power','Avaliable Power','Profile Power','Induced
Power','Parasite Power','Miscellaneous Power')
ylabel('Power (hp)')
xlabel('Forward Speed (knots)')
title('All power values vs Forward speed')
```

```
%weigth estimation

clc
clear all
close all
format short

%% define parameters in british units (ft and lb)
Dl          = 4.7%variable



Wg = 5; % initial value to start off the iteration
Wgross_output = 2 ; % initial value to start off the iteration
while abs(Wg-Wgross_output)>1


R           = sqrt(Wg/(pi*Dl));
Rt          = (1/6.84)*R;
A           = pi*(R)^2;
At          = pi*(Rt)^2;
c           = 0.984252;
Nb          = 2;
solidity    =(Nb*c*R)/A ;
c_tail      = 0.4265092;
solidity_t  =(Nb*c_tail*Rt)  /At ;
Rpm         = 440;
Rps         = Rpm/60;
Omega       = 2*pi*Rps;
Vtip        = Omega*R;
Gw_assumed  = Dl*A;
T           = Gw_assumed;
HP          = 350     ;      %% Allison Model 250
Vc          = 209     ;       %Cruise speed in ft/s (124.1899372 Knots) 230kmh
Lp          = T/(HP)  ;       %power loading
Wbaggage    = 150;
Wfuel_max   = 600;  %%small because ov vtip
Wcrew_passengers = 661.61  ;
Wpayload    = Wbaggage+Wcrew_passengers;




%% 1 main rotor group

Wr = 1.7*(Wg^0.342)*(R^1.58)*(solidity^0.63);

%% 2 Tail rotor group

Wtr = 7.12*((Wg/1000)^0.446)*(Rt^1.62)*(solidity_t^0.660);

%% 3 Power plant group
Wt = 0.140*HP ;    %% changed

%% 4 power plant section group
```

```
Wps = 0.00155*(Wg^1.07)*(Dl^0.54);

%% 5 Mechanical drive system group
Wds = 42.4*((HP*R)/Vtip)^0.763;

%% 6 Flight control group
Wfc = 0.0226*(Wg^0.712)*(Vc^0.653);

%% 7 Landing gear group
Wlg = 0.0470*(Wg^0.975);

%% 8 Fuselage group
Wf = 0.21*(Wg^0.598)*(R^0.942);

%% 9 Forward propulsion group
Wp  = 0.146*(Wg/Lp);


Wempty = Wr+Wtr+Wt+Wps+Wds+Wfc+Wlg+Wf+Wp;

Wempty = 1.2*Wempty;

Wgross_output = Wempty + Wpayload + Wfuel_max;

Wg = Wg+1;

end
Wg = (Wg-1)*4.45

Empty_weight_excluding_other_parts =  4.45* Wempty/1.2 /9.81
Total_empty_weigth = Wempty *4.45 /9.81


main_rotor_group_weigth = Wr *4.45 /9.81

Tail_rotor_group_weigth = Wtr*4.45/9.81

Power_plant_group_weigth =Wt*4.45/9.81

power_plant_section_group_weigth = Wps*4.45/9.81

Mechanical_drive_system_group_weigth = Wds*4.45/9.81

Fligth_control_group_weigth = Wfc*4.45/9.81

Landing_gear_group_weigth = Wlg*4.45/9.81

Fuselage_group_weigth = Wf *4.45/9.81

Forward_propulsion_group_weigth = Wp *4.45/9.81



Wgross_output =Wgross_output *4.45/9.81
Wbaggage = Wbaggage*4.45/9.81
Wfuel_max= Wfuel_max*4.45/9.81
Wcrew_passengers = Wcrew_passengers*4.45/9.81
```

```
Wpayload = Wpayload*4.45/9.81
R = R/3.28
c = c/3.28
Rt = Rt/3.28
c_tail = c_tail/3.28
Dl = Wgross_output*9.81/(pi*R^2)
Vtip = Omega*R


Wgross_output
```

3-DModel