Jurnal Mekanikal
December 2008, No. 27, 78 - 90

POWER ESTIMATION FOR FOUR SEATER HELICOPTER

Ahmad Azlan Shah B. Ibrahim
Mohammad Nazri Mohd Jaafar*

Faculty of Mechanical Engineering
University Technology Malaysia
81310 UTM Skudai, Johor
Malaysia

ABSTRACT

In helicopter design, generally there are three types of condition of interest, which are hover, vertical climb and forward flight. This paper describes the method for first estimation of power required for four-seater helicopter. The objective of this study is to estimate power for four-seater helicopter. Among the factors that affect the power required are the density effect of air at various altitudes, induced velocity along the blade, and horizontal force due to the fuselage, but only some of them will be studied in this paper. Methods used in this study to estimate the power is the momentum method. A parametric study on present helicopters in the market was performed to obtain initial specifications for the proposed helicopter. Based on these specifications, the weight estimation was determined according to Prouty method [1]. Using the momentum method and the specification for the helicopter, the power required was estimated. A computer program using MATLAB was also developed to expedite the power estimation calculations.

Keywords: *Power Estimation, Gross Weight, Parametric Study, MATLAB*

1.0 INTRODUCTION

A helicopter is an aircraft which is lifted and propelled by one or more horizontal rotors – each of two or more rotor blades [2]. Helicopters are the most versatile flying machines in existence today. This versatility gives the pilot complete access to three-dimensional space in a way that no airplane can. Helicopters are classified as rotary-wing aircraft to distinguish them from fixed-wing aircraft. This is because for helicopter, the rotor blade creates the lift. Therefore, the rotor blade diameter is one of the main design requirements in helicopter. The rotor blade gains the power to rotate from the helicopter propulsion system. There are two types of engine available in the helicopter market, piston engine and turbo shaft engine. The engine is chosen based on power available, performance required, fuel consumption and other factors.

* Corresponding author: E-mail: nazri@fkm.utm.my

2.0 PARAMETRIC STUDY

2.1 Parameter Study

Sizing is the first and most critical stage in helicopter preliminary design process. Design trends analysis is a technique in which helicopter configurations are analyzed in order to conclude or identify a trend which is common to many configurations, and may represent physical constrains which is not clear and evident at the early stages [3]. Design trends analysis is useful for the geometrical sizing and preliminary sizing of performance, power required and other parameters.

A survey on current four-seater helicopters was done. Then all the data are gathered into a table to obtain the early ideas on the initial configuration of the intended design for the helicopter. Data obtained was used to determine the new specification of the helicopter.

Below is the list of helicopters that were gathered during the survey. All the specifications are obtained from books and internet based on the latest configuration for each helicopter:

1. Robinson R44
2. Enstrom 480
3. Schweizer 333SP
4. Mil-34
5. Kamov Ka-18
6. Vertical Aviation Technologies Hummingbird
7. Cessna CH-1 Skyhook
8. Agusta 115
9. MD 500C
10. Sikorsky S-51

Based on this study, the most suitable helicopter for light utility/transport purpose is Robinson R44, and is chosen as base helicopters. R44 is the most popular light utility helicopter for four-seat helicopter and is thus chosen as a model for reference in the preliminary design. Specifications for current helicopters in the market are shown in Table 1, whereas, Table 2 shows the specification for the proposed four-seater helicopter for this study.

2.2 Steps In Parameter Study And Sizing

Firstly, the value of gross weight and power were taken from the Robinson R44 helicopter as a reference, which are GW = 1089 kg and P_a = 235 Hp. Then using the fuel weight equation obtained from Prouty, [1]:

$$\text{Fuel Weight} = \text{Specific Fuel Consumption} \times \text{Installed Power} \times \text{Mission Time}$$

In this fuel weight calculation, specific fuel consumption and installed power are determined initially from existing helicopters again, but they will be updated further from the engine design results. When the fuel weight is calculated, the useful load can be calculated easily.

Useful Load = Crew + Fuel Weight + Payload

After obtaining the useful load, the intended gross weight can be found. Then, the gross value is compared with the original estimate. If the two gross weights are significantly different, modify the estimated fuel and installed power. The disk loading value is used to calculate the main rotor radius using the equation below:

$$D.L = \frac{T}{\pi R^2}$$

Table 1: Data of 4-seater Helicopter in the Market

Model	Rotor Diameter (m)	Powerplant	PA	Empty Weight (kg)	Max T/O Weight
Mil-34	10.01	Vedeneev M-14V-26 9-cylinder radial,	240 kW	800	1,350
Kamov Ka-18	10	Ivchenko AI-14VF radial engines	200 kW	1015	1,502
Enstrom 480	9.75	Allison 250-C20W turboshaft	212kW	671	1202
Robinson R44	10.05	Textron Lycoming O-540	167 kW	645	1,089
Schweizer 333SP	8.38	Rolls-Royce 250-C20W turboshaft,	315 kW	549	1156
Sikorsky S-51	14.93	Pratt & Whitney R-985 AN-5 Wasp Jr	450 HP	1728.19	2494.76
Hummingbird	10.05	LYCOMING 260 H.P.FSO-526-A	270hp	816.5	1,224.72
Cessna CH-1 Skyhook	10.67	Continental FSO-526-A flat-four engine	270hp	944	1406
Agusta 115	11.33	Turbomeca Astazou II turboshaft	480hp	730	1350
MD 500C	8.03	One Allison 250-C20 Turboshaft	207 kW	493	1,157

2.3 Specification for Proposed Helicopter

The specifications for the proposed helicopter are shown in Table 2 [4].

Table 2: Specification of the proposed helicopter [4]

GENERAL		MAIN & TAIL ROTOR	
Type of aircraft	Light Utility/Transport	Blade shape (main)	Symmetrical
Regulation	FAR Part 27	Airfoil type	NACA 0012
No of seat	4	Disk loading	13.69 N/m^2
No of engine	1	Blade shape (tail)	Symmetrical
Function	Pilot Training, Recreation, Transport	Airfoil type	NACA 0012
ENGINE CONFIG.		**DIMENSION EXTERNAL**	
Type	Piston engine	Main rotor diameter	10.10m
Model	Lycoming IO-540-AE15	Tail rotor diameter	1.6m
Power Rating	240 hp (flat rating)	Length overall	9.09m
Fuel Consumption	14 gal/h	Height overall	1.8m
WEIGHT		**PERFORMANCE**	
Empty, W_e	587.97kg	Cruise velocity, V_{cr}	197.5km/h
Gross, W_o	1060.41kg	Velocity never exceed, V_{NE}	206.94km/h
Fuel, W_f	106.59kg	Service ceiling	9876 ft
Crew, W_{crew}	308.44kg	Range	604km
$\frac{Empty}{Gross}$	0.55	Endurance	3.02 hours

2.4 Weight Estimation

Weight estimation for the proposed helicopter was done using the equation by Prouty [1]. The parameters used are based on the specifications given in Table 2 and the results are presented in Table 3.

Table 3: Data for Weight Estimation

Component Weight	Equation	Value
Main Blade Weight, W_{bm}	$W_{bm} = 0.026 b^{0.66} c R^{1.3} (\Omega R)^{0.67}$	108.84 lb

Table 3: Data for Weight Estimation *(continued)*

Main rotor hub and hinge, W_{hub}	$W_{hub} = 0.0037b^{0.28}R^{1.5}(\Omega R)^{0.43}\left(0.67W_{bm} + \frac{gJ}{R^2}\right)$	61.46 lb
Fuselage, W_F	$W_F = 6.9\left(\frac{G.W}{1000}\right)^{0.49} L_F^{0.61}(S_{wetf})^{0.25}$	383.81 lb
Tail Rotor, W_t	$W_T = 1.4R_T^{0.09}\left(\frac{Transmisssion\ h.p\ Rating}{\Omega_M}\right)^{0.9}$	7.07 lb
Avionics, W_{av}	$W_{AV} = 150\ lb\ (avg)$	150 lb
Empty weight, W_e	$W_e = W_{engine} + W_{bm} + W_{hub} + W_{AV} + W_F +$	1227.78 lb
Gross weight, W_o	$W_o = W_e + W_{crew} + W_{fuel} + W_{payload}$	2213.21 lb
Weight Ratio	$\frac{W_e}{W_o} = \frac{726.92}{1297.92} = 0.56$	0.554

2.5 Weight Balance

The location of the center of gravity was determined as shown below. The locations of these items are based on the proposed helicopter design.

Table 4: Location of Center of Gravity Calculation

Weight Group	Weight(lb)	Fuselage station(m)	Moment
Fuselage	383.81	2.4	921.144
Engine	447	2.75	1229.25
Blade	108.84	2.4	261.216
Rotor Hub	61.46	2.4	147.504
Tail Rotor	7.07	8.29	58.6103
Avionics	150	1.1	165
Landing Gear	69	2.4	165.6
∑ Empty Weight=	1227.18	∑moment =	2948.3243
Crew	280	1.4	392
Crew	280	2.25	630
Fuel	293.75	3	881.25
Payload	132.28	3.45	456.366
∑Gross Weight =	2213.21	∑moment =	5307.9403

$$C.G_{empty} = \frac{\sum Moment}{\sum Empty\ weight}$$

$$= \frac{2948.3243}{1227.18} = 2.403m\ \ from\ helicopter\ nose$$

$$C.G_{takeoff} = \frac{\sum Moment}{\sum Takeoff\ weight}$$

$$= \frac{5307.9403}{2213.21} = 2.403m\ \ from\ helicopter\ nose$$

3.0 COMPUTER PROGRAM DEVELOPED FROM MATLAB TO ESTIMATE POWER REQUIRED

The analysis to estimate the power required for each flight condition, i.e. hover, vertical climb and forward flight, are done through the program developed using *Matlab 7.0*. This program is able to provide a quick estimate for power requirement by just keying in certain values. The data from the program can be used to determine the power required for specific value on each flight conditions.

3.1 The Computer Program Developed Using MATLAB

The program will start when the user run the main.m (main page as shown in Figure 1). Then, the user can select whether to calculate in English unit or in S.I unit. The choices are made because usually all the helicopter parameter is in Imperial Unit, however in Malaysia, S.I unit is commonly used. User can choose which one is more suitable for their calculation. There is also help command in the main page to help the user familiarize with the feature.

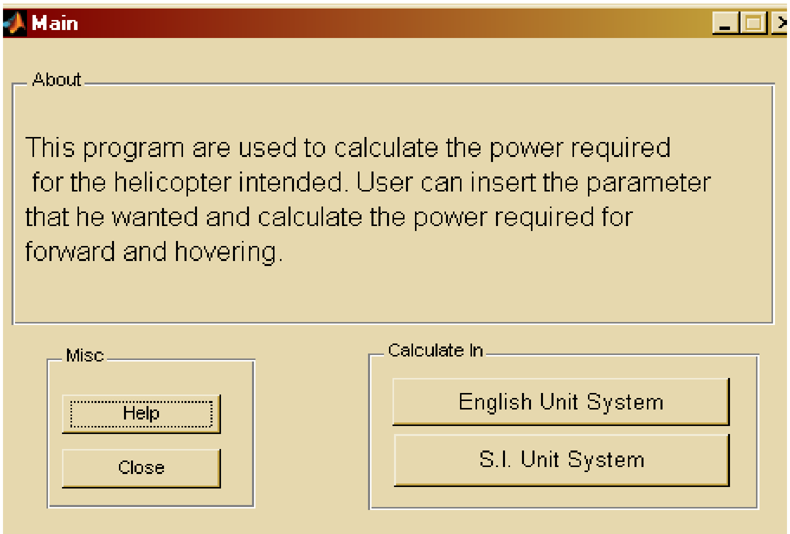

Figure 1: Main Page

After the user selected the unit to be used, a new dialogue box will appear (see Figure 2). In this page, the user can input the parameters of the helicopter. When the calculate button is pressed, Matlab will automatically calculate all the parameter inserted and using the equations as mentioned in help. Note that this program was developed for first estimation of power required based on the maximum forward speed. The graph plotted will show the minimum continuous power required to achieve the forward speed required (the straight line in Figure 3). This means that the power available calculated must provide continuous power that is greater than the required power to achieve the speed specified before.

Figure 2: Calculating In S.I Unit

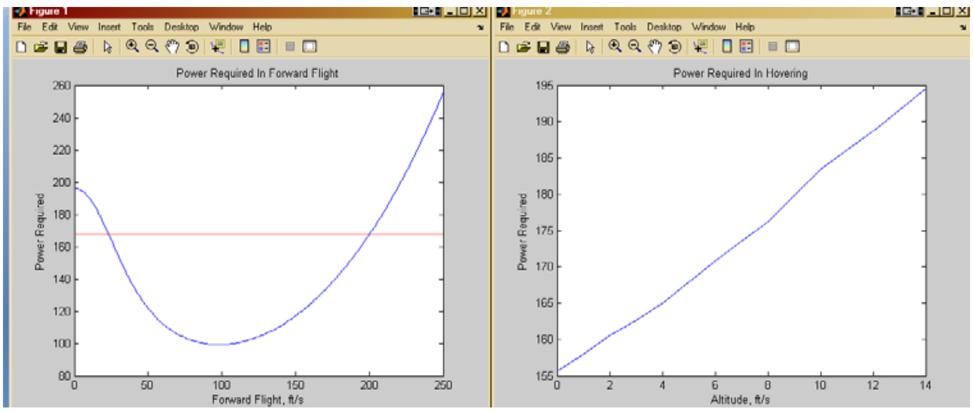

Figure 3: The Program Output

4.0 RESULTS AND DISCUSSION

Using the weight and the parameters seized before, the power required for the helicopter was calculated. The power required were different in three flight conditions which is hovering, forward flight and vertical climb. Note that the installed power was chosen based on forward flight condition [5]

4.1 Power Loss in Transmission

Assuming a cemented-belt-joint efficiency of 98 % [6], the shaft is rigid, the power losses in the transmission is mainly due to the gearboxes and gears [1]

Power Losses per Stages = K [Design Max Power + Actual Power]
With K = 0.0025 for spur/bevel gears
= 0.00375 for planetary gears

Power Losses = K [Design Max Power + Actual Power] $_{\text{per stages}}$
= 0.00375 (300 + Main rotor) + 2* 0.0025 (300 + Engine power)
+ 0.00375 (80 + Tail power) + 0.04 (Engine power)

**assuming that Engine power ≈ Tail Power + Main Rotor Power*

Total Losses = 0.04875 [Main Rotor Power] + 0.04875 [Tail Rotor Power] + 3.325 Hp

4.2 Power Analysis

The results are presented in graphs to describe the power required for the main rotor for each flight conditions. Each flight conditions have different methods to analyze the total power required by the helicopter to fulfill the requirement for the flight condition.

4.2.1 Power Required During Hovering

Figure 4 shows that the power required to hover are increasing with altitude. Therefore, the higher the helicopter hovers, more power required.

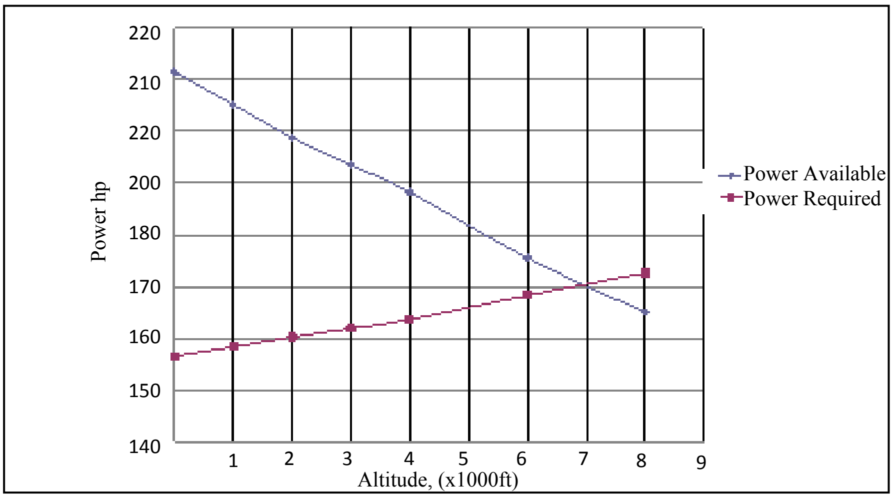

Figure 4: Power Required For Hovering Versus Altitude

However, as the power available is decreasing with altitude (lower density), it can be seen that the helicopter reached the hover ceiling at approximately 7000 ft (2134 m). This is reasonable since it is over the expected height of 6000 ft (1829 m). However, if the figure of merit is increased further, the helicopter will hover better. However, this will affect the forward flight performance [1]. The graph shows that the Lycoming IO-540-AE1A5 engine installed is more than enough for the helicopter to achieve the desired performance.

4.2.2 Power Required During Forward Flight

The cruise power required is maximum at sea level, ISA conditions. With increase in altitude or in air temperature, air density is reduced, leading to a reduction in parasite drag and in the power required to fly at a given speed. However, since the power available by the engine decreases with density, the maximum continuous power available to the helicopter also decreases. Note that the available power at any density altitude also depends on how much the engine is de-rated from its maximum uninstalled rating.

Figure 5 shows the values for maximum velocity, V_{max}, endurance velocity, V_{en}, and range velocity, V_R. Initially, the power available is close to the power required. The power is used to gain speed to allowable altitude. Velocity for minimum power is 92 ft/s (101 km/h) while for maximum range is 151 ft/s (166 km/h).

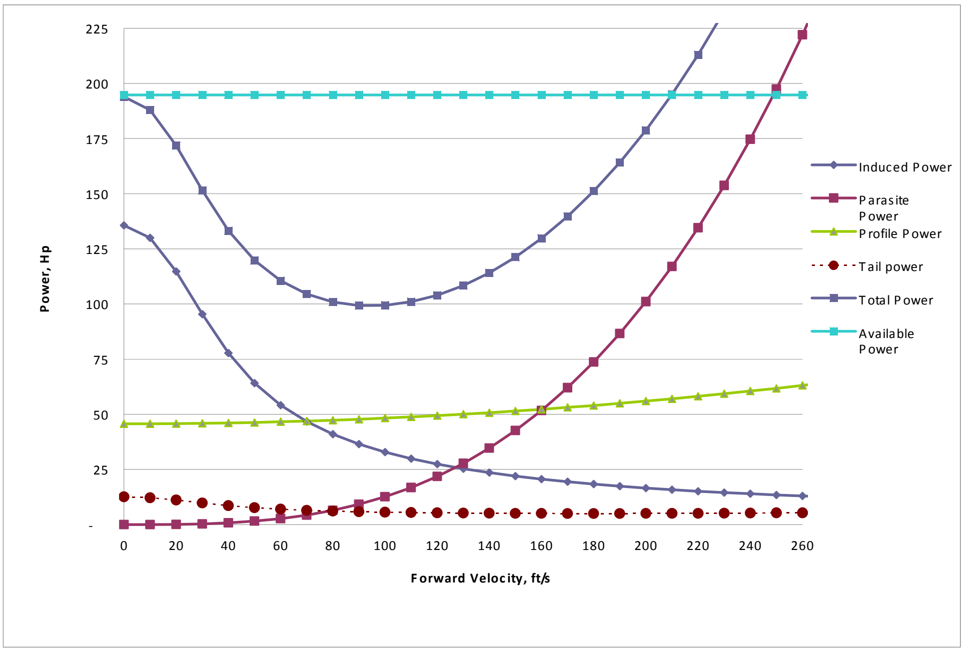

Figure 5: Power Required for Forward Flight versus Velocity

Nowadays, maximum velocity is often used as a requirement for designing helicopter. For transport helicopter, cruising velocity is between velocity for maximum range and maximum velocity. The minimum continuous power to achieve desired maximum velocity is around 180 hp (134kW).

From Figure 6, it can be seen that the power required at sea level is slightly lower than other altitude at lower speed. At higher velocities, the power required is lower when attitude increases. This is due to the effect of density to the power required especially the parasite power. It is more efficient to cruise at a higher altitude but at higher altitude, the power available is less. Therefore, the optimum altitude must be calculated to achieve both power available and cruise power efficiency.

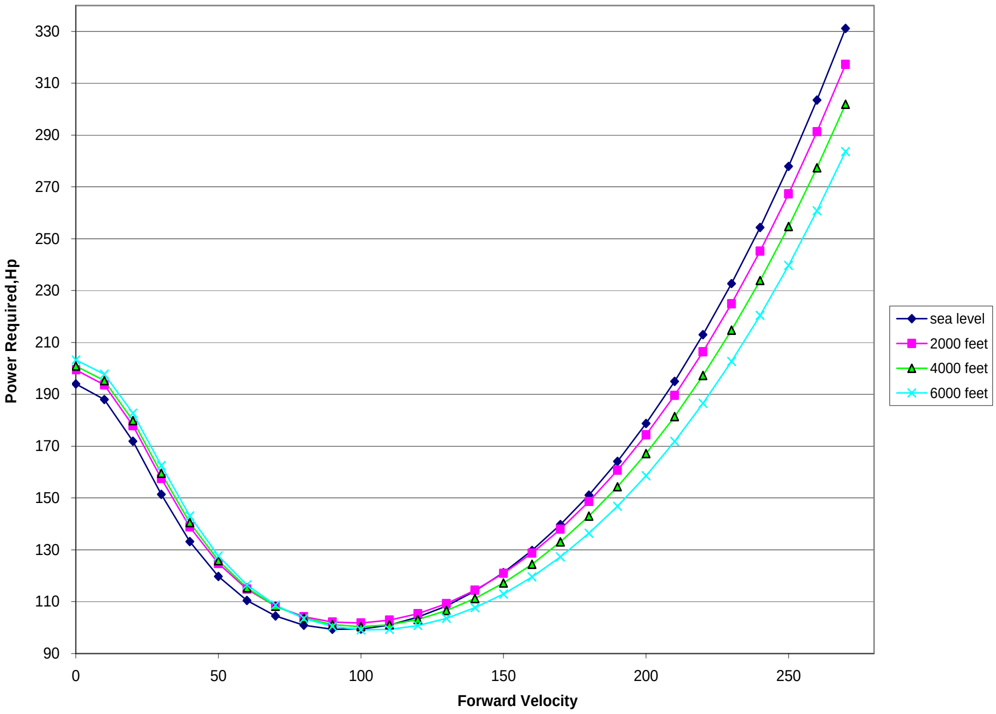

Figure 6: Power Required for Forward Flight versus Velocity at Different Altitude

4.2.3 Power Required During Vertical Climb

Power required for climbing is calculated from hovering excess power. Figure 7 shows that the higher the rate of climb, the more power will be needed. The maximum Vertical Climb Rate is 22 ft/s which is very fast. However, the climb rate will become lower as the helicopter climb. This is because the higher the altitude is, the higher the power needed to climb.

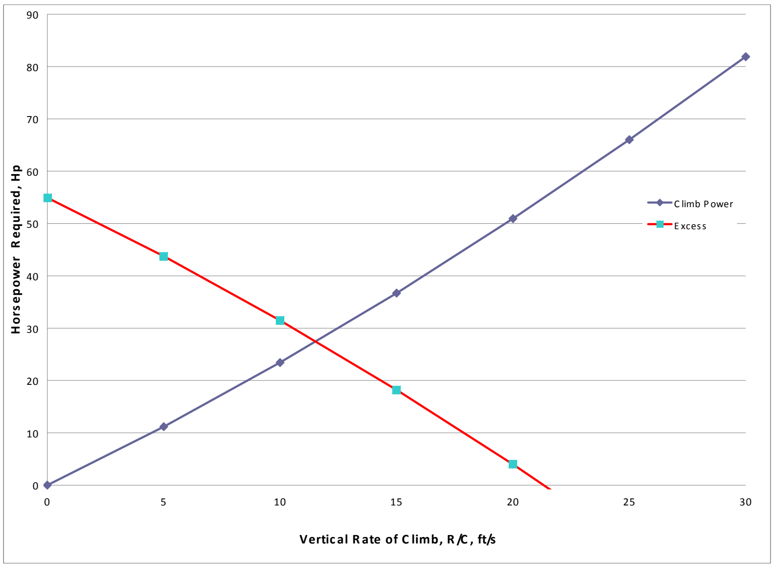

Figure 7: Graph Power Required Versus Climb Rate

4.2.4 MATLAB Program

After running the 'PowerEstimation' program using the proposed helicopter parameters and specifications, the program automatically plotted Figures 8 and 9. The results were similar to that when performing manual calculation. The straight horizontal line shows the minimum power to achieve the velocity needed which is 200ft/s (220km/h).

Figure 8 shows that the power required at 0 ft/s is around 195hp (145kW) and to achieve 200 ft/s , the maximum continuous power needed is 170hp (127kW). These values are almost similar with manual calculation. This proved that the program is valid subjected to some limitations.

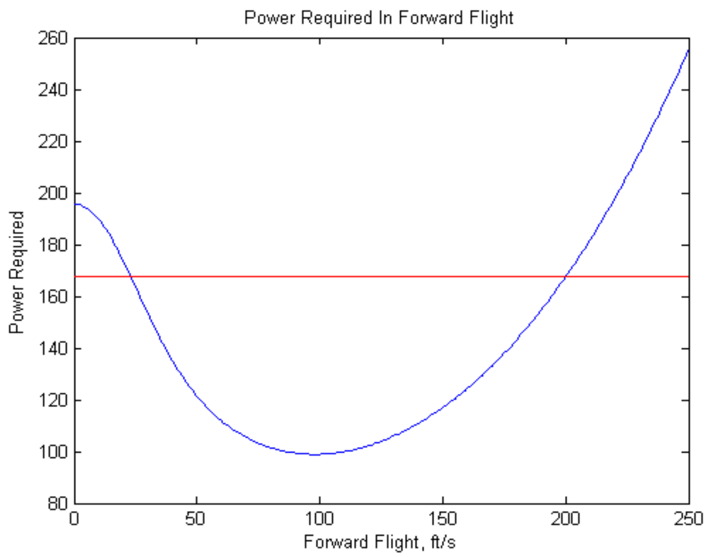

Figure 8: Forward Flight Power Graph plotted from Matlab

Figure 9 shows the power required for hovering. The power required value is almost the same from manual calculation. At ground level, the power required for hovering is 155hp (116kW). This shows that the program is also valid for hovering condition.

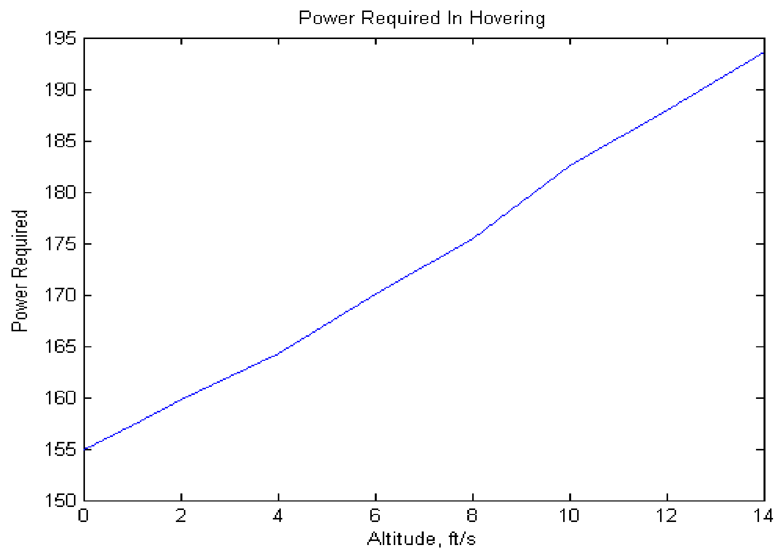

Figure 9: Hovering Power Graph plotted from Matlab

4.2.5 Overview

Overall, the power delivered by the Lycoming IO- 540 engine is enough for the helicopter to achieve good performance. However, if more engine power is used, the helicopter can perform better in hovering, climbing and vertical flight. The result of the analysis is shown in Table 5.

Table 5 : Performance Result

Parameter	**Value**
Pr For Hover at ISA	156 hp (116kW)
Hovering Ceiling	7000 ft (2134m)
Maximum Velocity	210ft/s (230km/h)
Endurance Velocity	92ft/s (101km/h)
Maximum Range Velocity	150 ft/s (165km/h)
Maximum Vertical Climb	22 ft/s (24km/h)

5.0 CONCLUSION

This paper presented the capability of the developed MATLAB program to estimate the power of a 4 seater helicopter. The program is able to cut short the manual calculation time and is also able to plot the important graphs such as the power required versus forward flight graph. However, due to the limitation of the momentum theory applied, the estimated power may be less than the actual power required.

This program concentrates more on forward flight since it required more power than during hovering and vertical climb. This program requires further development and additional features to make it more user-friendly.

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