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Power Estimation for a Two Seater Helicopter

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Abstract

The paper describes the methods to estimate power required by two seater helicopter at three flight conditions: hovering, vertical climbing and forward flight. Factors that affect the power required by the helicopter include induced velocity along the rotor blade, various altitudes, horizontal force due to the fuselage and others are discussed in this paper. Methods analyzed in this study to estimate the power are momentum method, blade element method and combined method. The initial specification of the helicopter was done by studying the present helicopter configuration in the market. All related data were then plotted against gross weight. The study on weight estimation was done according to the Prouty method and based on some assumptions. The helicopter specification as studied in this paper was found closely similar to the specification of existing helicopter in the market.

Keywords: Power estimation, gross weight, develop programming, preliminary helicopter design

1. INTRODUCTION

Helicopter is a useful and popular air vehicle nowadays. There are many types of helicopter in present market, which can be divided into light and heavy type [1]. An example of light helicopter (capacity of 2 crews) is Robinson R22, while the heavy types (capacity of 12 crews) are mostly for a military purpose such as Black Hawk [2]. By definition, helicopter is an aircraft which is lifted and propelled by one or more horizontal rotors; each with two or more rotor blades [3]. Helicopters can also be classified as rotary-wing aircraft to distinguish them from fixed-wing aircraft [4]. 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 [5]. The engine is chosen based on power available, performance required, fuel consumption and other factors. This research focused on two-seater helicopter to estimate the power and weight for this type of helicopter.

2.PARAMETRIC STUDY

2.1 Preliminary Sizing

Sizing is the first and an important stage in helicopter preliminary design process. Design trends analysis is a well-known technique, in which flying configurations are analysed in order to conclude or identify a trend which is common to many configurations. Therefore, it may represent physical constrains which are not clear and evident at the early stages [6]. Design trends analysis is useful for the sizing stage in its broad sense: geometrical sizing and preliminary sizing of performance, power required and other parameters [7].

In this study, for the initial estimate of sizing, the historical surveys of similar helicopter were searched. Then, all the data were tabulated to compare the specifications of all helicopters chosen. This is important to obtain early ideas on the initial configuration of the intended design for the helicopter. Information obtained from the data was then used to determine the new specification of the helicopter. Below is the list of the helicopters that were studied. All the specifications are the latest configuration obtained from the internet.

1. Enstrom F28a
2. Enstrom F28f
3. Brantly B2b
4. Bell 47j
5. Baby Elle
6. Robinson R22
7. Bongo
8. Schweizer 300cb
9. Th-28 Eagle
10. Na 42 Barracuda
11. Mosquito
12. Exec 162f
13. Dragon Fly

Based on the data gathered, the most suitable helicopter as base two-seat helicopters is Robinson R22 [8]. Moreover, R22 is the most popular two-seater helicopter as training helicopter and it is also available in Malaysia. Thus, this helicopter had been chosen as a model for reference in the preliminary design for the proposed helicopter specification.

Based on the gathered data, graphs of the main parameters of the helicopter specifications were plotted as shown in Figure 1 and 2. The following trade studies included parameters such as Tail Rotor Diameter, V_{cruise}, Fuselage Length and Height, etc. The proposed specification for the helicopter is shown in Table 1.

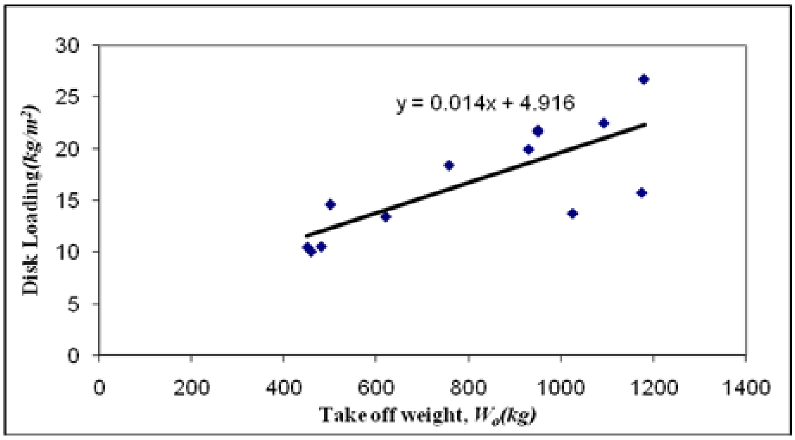

Figure 1. Disk Loading Vs Take Off Weight

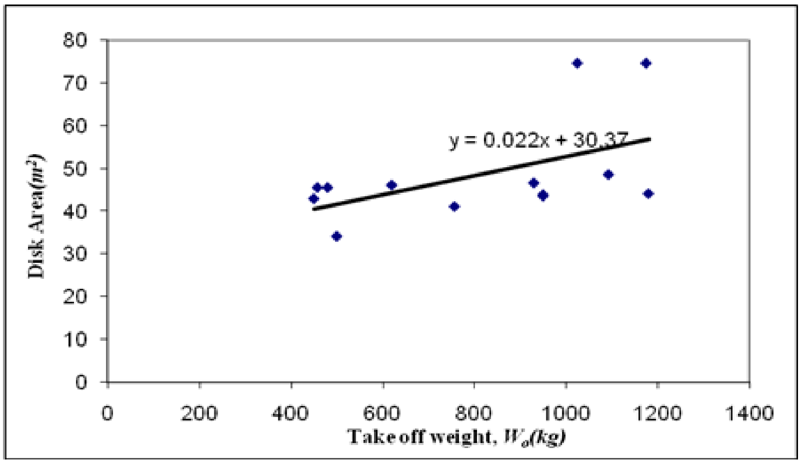

Figure 2. Disk Area Vs Take Off Weight

Table 1. Specification for Proposed Helicopter

GENERAL	
Type of aircraft	Light Helicopter
Regulation	FAR Part 27
No of seat	2
No of engine	1
Function	Pilot Trainer, Recreation, Surveillance
ENGINE CONFIGURATION	
Type	Piston engine
Model	Lycoming O-320-B2C
Thrust Power	131 hp
Fuel capacity	19.2 gal
WEIGHT	
Empty, W_e	793.9 lb
Gross, W_o	1364.9 lb
Fuel, W_f	131 lb
Crew, W_{crew}	340 lb
$\frac{Empty}{Gross}$	0.58
MAIN & TAIL ROTOR	
Blade shape (main)	Symmetrical
Airfoil type	NACA 0015
Disk loading	2.784 lb/ft^2
Blade shape (tail)	Symmetrical
Airfoil type	NACA 0015
EXTERNAL DIMENSION	
Main rotor diameter	29.48 ft
Tail rotor diameter	2.78 ft
Length overall	34.65 ft
Height overall	12.14 ft
PERFORMANCE	
Cruise velocity, V_{cr}	529.13 ft/s
Velocity never exceed, VNE	608.47 ft/s
Service ceiling	10861.94 ft
Range	1336.34 ft
Endurance	2.91 hours

2.2 Weight Estimation and Weight Balance (Based On Robinson R22 Beta)

There are two ways to estimate helicopter weight. The first method is by observing the trend of the present helicopter in the market. From the graphs shown before (Figure 1 and Figure 2), the main parameter to obtain other parameters is the gross weight or maximum take-off weight.

This important parameter can be obtained from these two graphs as an initial estimate. This is called the parametric study for one to start the design of a new helicopter. The second method is by referring to the *Prouty Weight Estimation* [9]. Table 2 shows the data for weight estimation and Table 3 shows the data for weight balance.

2.3 Main Rotor Design

The main rotor is the most important component of the helicopters. Proper design of the rotor is critical to meeting the performance specifications for the helicopter as a whole [10]. Below are the required parameters to design the main rotor, which are summarized in Table 4:

a) Helicopter Weight
b) Induced velocity
c) Number of Blades
d) Inflow Ratio
e) Airfoil type
f) Optimum Angle for the particular airfoil of (C_l /C_d)
g) Zero lift drag coefficient

Table 2. Parameters for Weight Estimation

Component	Equation for Weight Estimation	Weight
Main Blade Weight, W_{bm}	$W_{bm} = 0.026b^{0.66}c\,R^{1.3}(\Omega R)^{0.67}$	51.14 lb
Main rotor hub and hinge, W_{hub}	$W_{hub} = 0.0037b^{0.28}R^{1.5}(\Omega R)^{0.43}\left(0.67W_{bm} + \frac{gJ}{R^2}\right)$	$29.15lb$
Fuselage, W_F	$W_F = 6.9\left(\frac{G.W}{1000}\right)^{0.49} L_F^{0.61}(S_{wetf})^{0.25}$	$178.48\ lb$
Tail Rotor, W_t	$W_T = 1.4R_T^{0.09}\left(\frac{Transmisssion\ h.p\ Rating}{\Omega_M}\right)^{0.9}$	$3.15\ lb$
Avionics, W_{av}	$W_{AV} = 150\ lb\ (avg)$	$150\ lb$
Empty weight, W_e	$W_e = W_{engine} + W_{bm} + W_{hub} + W_{AV} + W_F + W_T + W_{L.G}$	$726{,}92\ lb$
Gross weight, W_o	$W_o = W_e + W_{crew} + W_{fuel} + W_{payload}$	$1297.92\ lb$
Weight Ratio	$\frac{W_e}{W_o} = \frac{726.92}{1297.92} = 0.56$	0.56

Table 3. Parameters for Weight Balance

Component	Weight(lb)	Fuselage station(ft)	Moment
Fuselage	178.48	8.3	1481.384
Engine	246	9.2	2263.2
Blade	51.14	8.8	450.032
Rotor Hub	29.15	8.3	241.945
Tail Rotor	3.15	3.4	510
Avionics	150	4.5	310.5
Landing Gear	69	20	63
∑ Empty Weight=	726.92	∑moment =	5320.061
Crew	340	7.8	2652
Fuel	131	9	1179
Payload	100	3	300
∑Gross Weight	1297.92	∑Moment	9451.061

Table 4. Parameters For Determining Main Rotor

No.	Parameter	Specification
1	Helicopter weight, W	620 kg
2	Induced velocity, v_i	6.25m/s
3	No of blades, b	2
4	Inflow Ratio, μ	0.0015
5	C_{do}	0.006
6	Airfoil type	NACA 0015

Table 5 shows the proposed specification of the main rotor design.

Table 5. Proposed Specification of Main Rotor

Component	Equation	Value
Solidity	$\sigma_{rotor} = \frac{b \times \overline{C}}{\pi R}$	0.041
Thrust Coefficient	$C_T = \frac{\sigma C_{\ell\max} B^2}{4}$	5.74 x 10^{-3}
Torque coefficient	$C_Q = \frac{\sigma C_{do}}{8} + \frac{C_T^{3/2}}{\sqrt{2}}$	3.38 x 10^{-4}
Figure of Merit	$M = 0.707\frac{C_T^{3/2}}{C_Q}$	0.9096
Disc Loading	$DL = W/A$	96.3 N/m^2
Power Loading	$PL = \frac{38M}{\sqrt{DL}}$	3.52

3.DEVELOPED SOFTWARE FROM MATLAB

The power required by each flight condition (hovering, vertical climbing and forward flight) has been estimated using the software developed using *Matlab 7.0*. This software can give a quick solution to the analysis by just keying the values in the software [11]. The data required from the developed software can be used to determine the specific power required for each flight condition.

3.1 Developed Software Using Matlab

To use the software, the user only needs to key in the data into the empty box in the software and by clicking the calculate button, the parameters such as powers and coefficient for each type flight condition can be obtained easily. The data obtained from the software can be used to calculate the specific value for the analysis. Figures 3, 4 and 5 show the interface of the software.

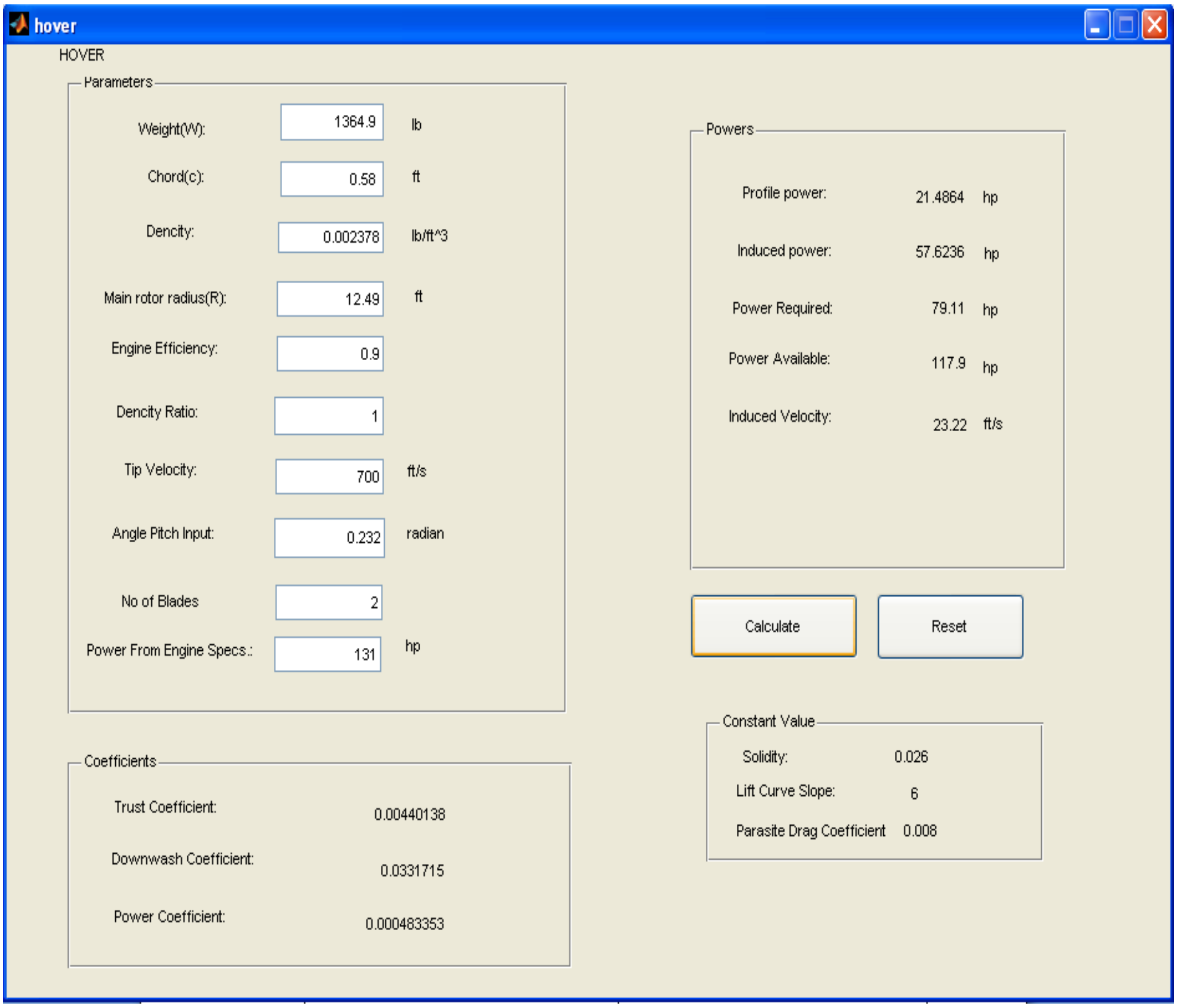

Figure 3. Interface for Estimating Required Power for Hovering

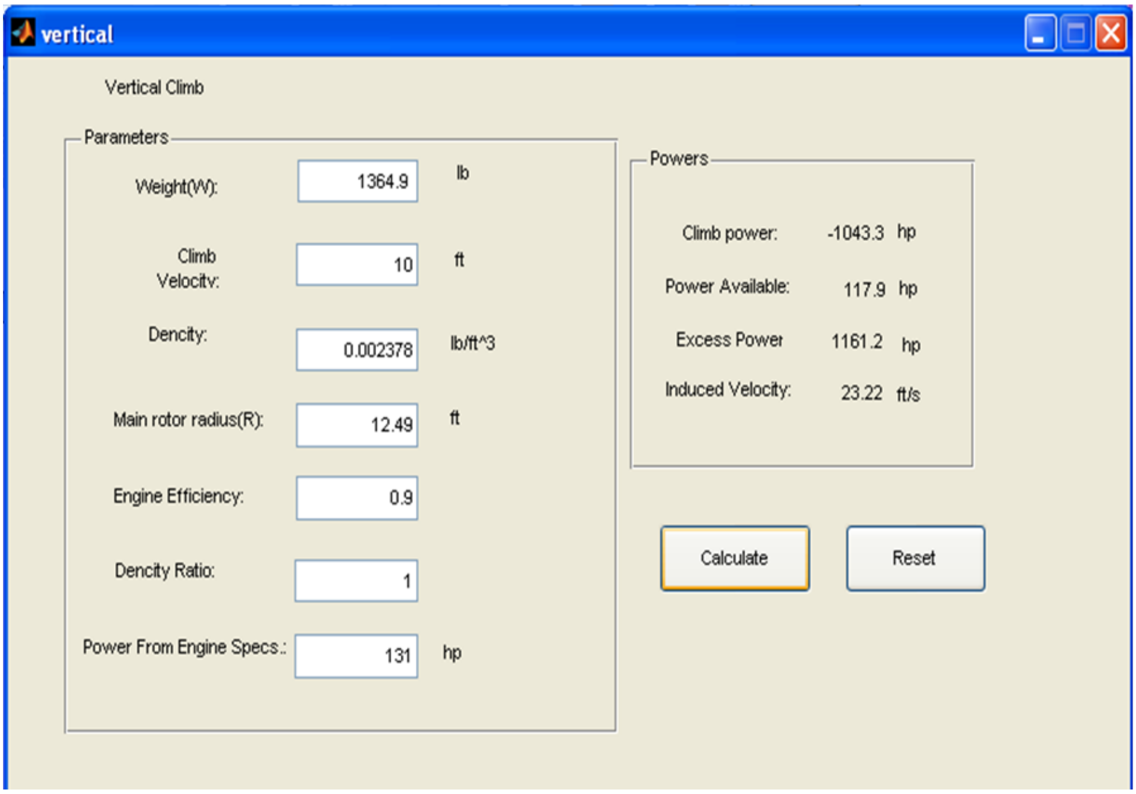

Figure 4. Interface for Estimating Required Power for Vertical Climbing

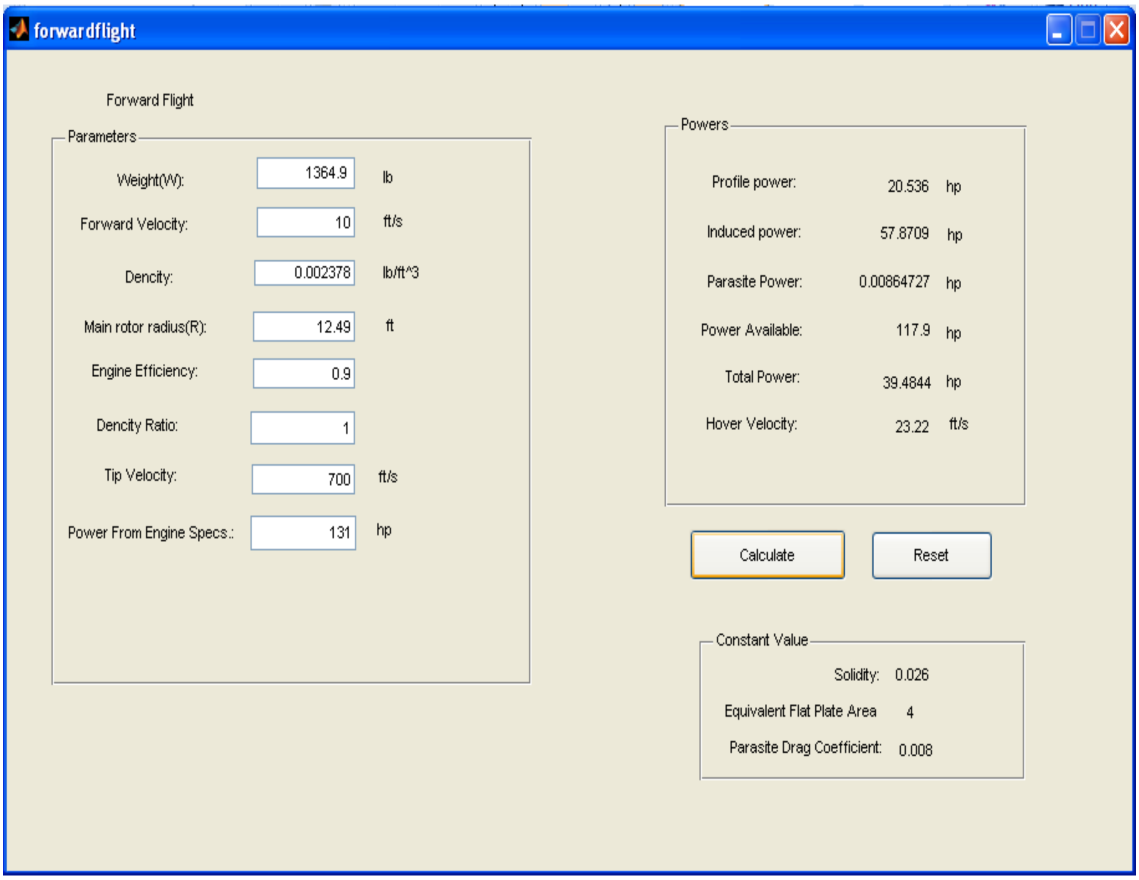

Figure 5. Interface for Estimating Required Power for Forward Flight

4.RESULTS AND DISCUSSION

The analysis focused on determining two main parameters, i.e. to identify the weight of the components and to estimate the power required by the helicopter for hovering, vertical climbing and forward flight. The results of this study can provide guide to estimate power for two seater helicopter.

4.1 Weight Estimation

For preliminary design, *Prouty Weight Estimation* method had been used to do the analysis for weight estimation. Although weight estimation for the proposed helicopter can also obtained through the trend analysis graphs, the Prouty Method would give the best estimation. The steps to obtain weight estimation have been explained in the parametric study. From the analysis, the gross weight of the proposed helicopter was *1297.2 lbs* and its empty weight was *726.92 lbs*. Other weights that had been considered in this analysis were weights of theMain Blade, Main rotor hub and hinge, Fuselage, Tail Rotor, and Avionics.

From the analysis, it was found that the gross weight of the proposed helicopter with the other two-seat helicopter in the market only had slight difference, even after weight balancing for each component had been allocated to certain places on the helicopter. From the calculation, the center of gravity for takeoff was *7.28 ft* for gross weight and was *7.42 ft* for empty weight, both determined from the helicopter nose.

4.2 Trend Data Analysis

From the parameter study, graph of each parameter had been plotted. The analysis included the study on trend, sequence and economical trend of helicopter in the market. The graphs indicate the portion that influence weight of the helicopter to estimate the take off weight. Other parameters regarding this initial estimation were also obtained. Lastly the criteria for purposed helicopter obtained through out this process.

4.3 Power Analysis

The results are represented in graphs to describe the power required by the main rotor for each flight condition of hovering, vertical climbing and forward flight. Different method is used to estimate the power for each flight condition. It is important to determine the total power required for the proposed helicopter to estimate the overall performance, known as power analysis, so that the helicopter will have enough thrust to fly. The power analysis was conducted for hovering, vertical climbing and forward flight conditions.

4.3.1 Hovering Condition

In this study, four graphs representing the power analysis for hovering condition had been plotted, as follows:

1. Thrust Coefficient Vs Collective Pitch
2. Downwash Coefficient Vs Collective Pitch
3. Power Coefficient Vs Collective Pitch
4. Power Vs Altitude

The results were obtained using the momentum method, blade element method and combined method, as explained in the literature review. Each result (graph) shows the relation between the parameter and power required by the proposed helicopter to hover. The graphs also indicate the factors that affect the total power required in hovering condition. Total power required is defined as the sum of profile power and induced power.

Figure 6 shows the results of thrust coefficient versus collective pitch. The graph indicates a quadratic relation between thrust coefficient and collective pitch. It can also be seen that the thrust coefficient increased quadratically with collective pitch. There are other factors that caused the increasing value, which were rotor solidity, angle of attack and downwash coefficient. Relating these parameters with power required clearly shows that for a given thrust and collective pitch, there was also an increment in total power required by the proposed helicopter.

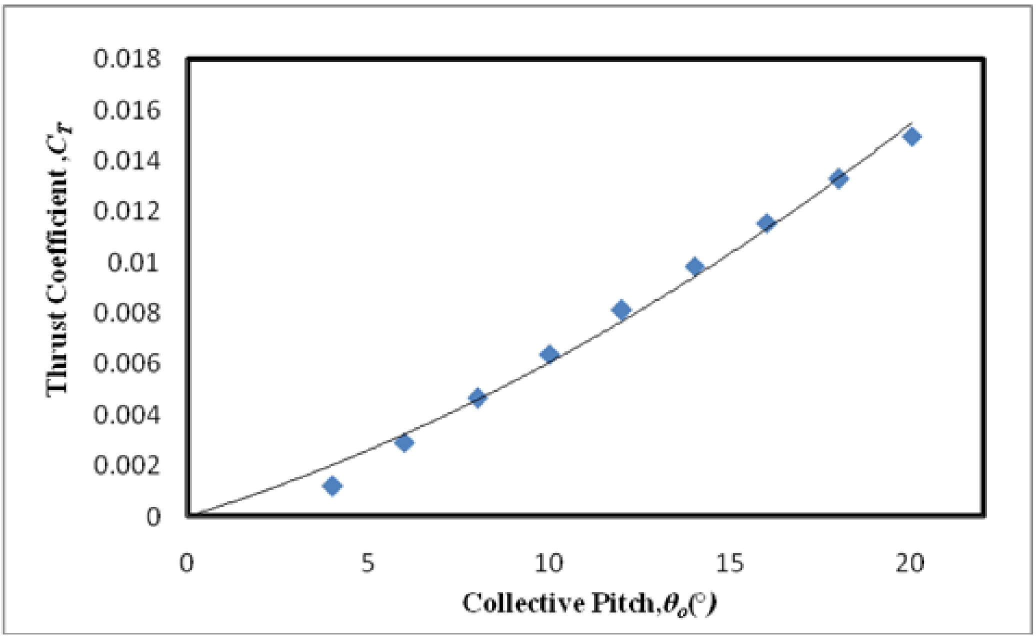

Figure 6. Plot of the Thrust Coefficient at various Collective Pitch

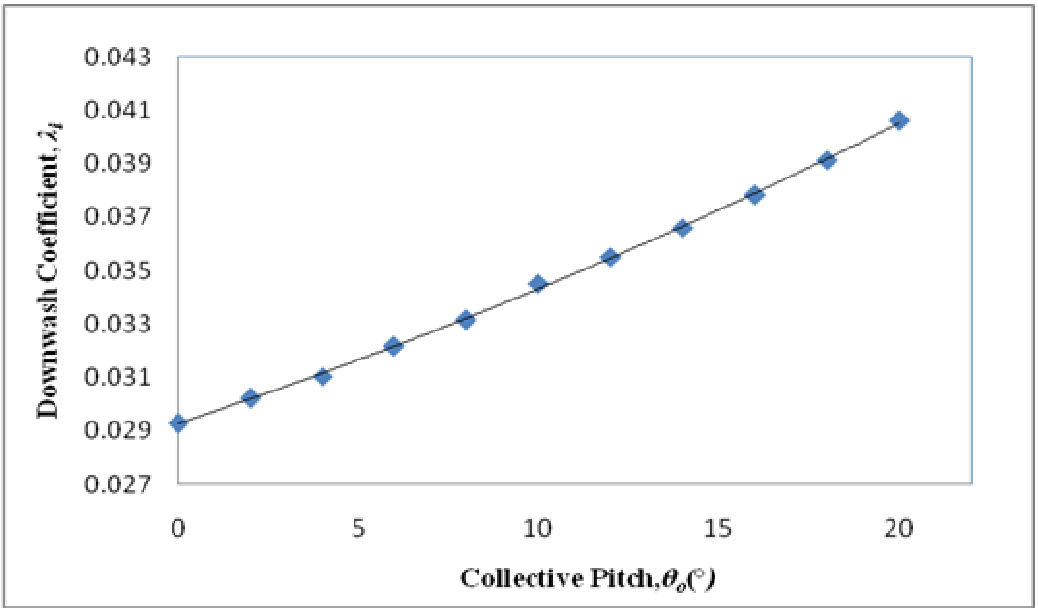

Figure 7. Plot of Downwash Coefficient at various Collective Pitch

Figure 7 shows the relation between downwash coefficient and collective pitch. The downwash coefficient increased gradually with collective pitch. This was because the thrust coefficient increased in a similar manner. Both parameters were related to estimate minimal power required by the proposed helicopter to fly. The figure also indicates that there was a value for zero collective pitch. It was because when there was no collective pitch input from the cockpit, due to the effect of the induced velocity due to rotating rotor to the blade.

Figure 8 shows the relation between power coefficient and collective pitch. The value for power coefficient also increased gradually with collective pitch. The increment of power coefficient depends on the induced velocity in hover condition. For this analysis, it was assumed that the inductionwas constant along the blade. This theory does not apply to the real condition because induced power varies continuously along the blade. For an increased collective pitch given by the pilot, the power coefficient would also increase, followed by increment of thrust coefficient.

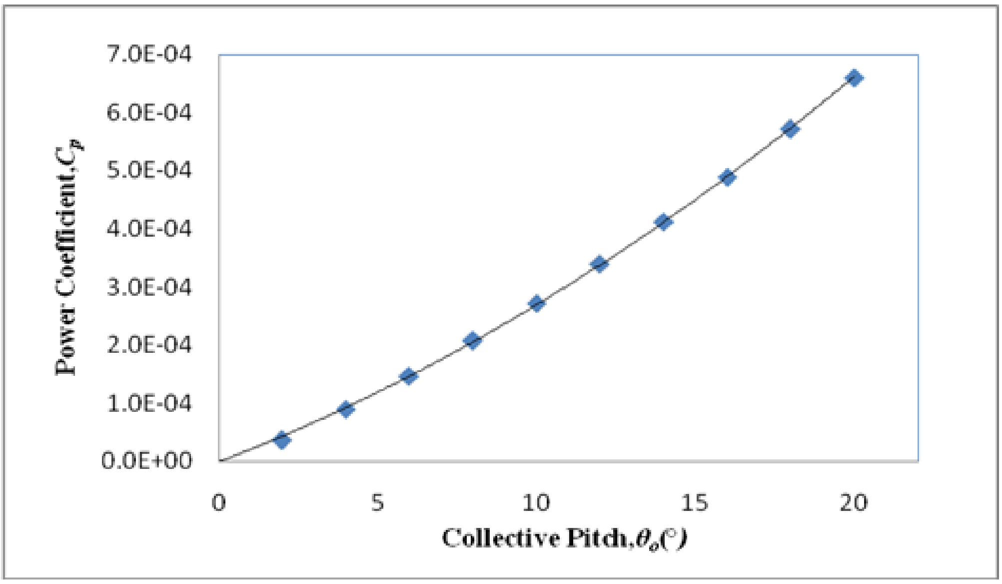

Figure 8. Plot of Power Coefficient at various Collective Pitch

Figure 9 shows the relation between total power required and power available in hovering condition. The power available was found decreasing as the altitude increased, while the power required increased with respect to the variation of air density. There were factors that affected the power required to maintain the hovering condition, which were tip speed, blade profile and induced velocity. The intersection between line of power available and power required would give the value for maximum altitude for hovering, which was 13 200 ft. Power available depends on the engine horsepower and engine efficiency, which in this study was considered as 0.9.

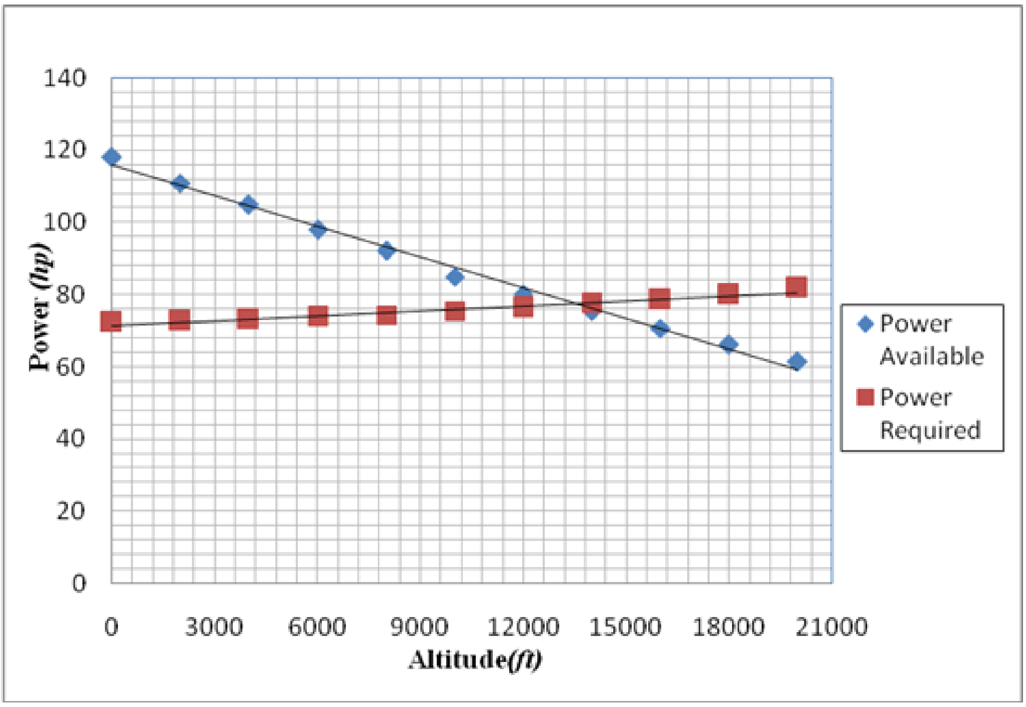

Figure 9. Plot of Power Available and Power Required at various Altitude

4.3.2 Vertical Climb

Figure 10 shows the relation between power and vertical rate of climbing for vertical flight condition. There were two types of power that affected the vertical climb, which were power required and power available. According to the graphs, the power required increased rapidly as it was the total power that generated enough power to maintain the helicopter in vertical flight. The situation inversely happened to the power available as it decreased because it depended on the power generated by the engine and air density. The intersection between the two lines of power gave a maximum vertical rate of climb whose value was *48 ft/s*. It was important to make sure that the vertical rate of climb remain below the maximum value because stall could occur after this value.

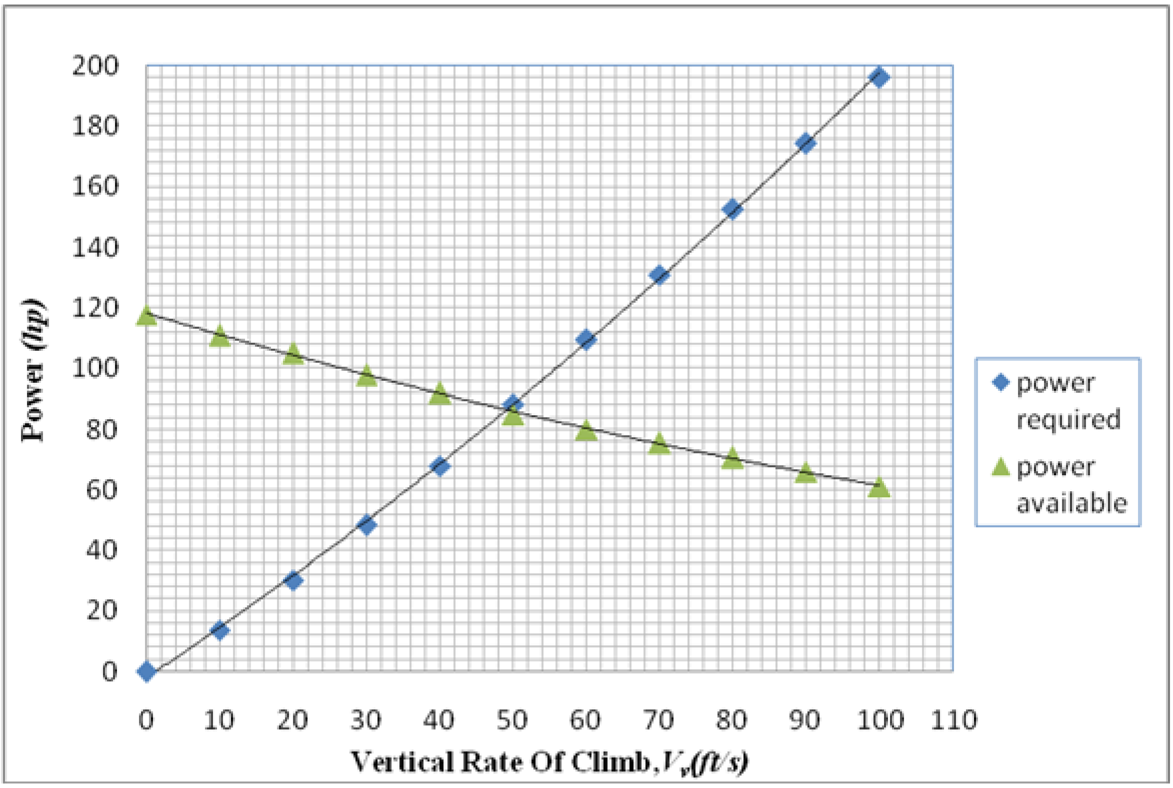

Figure 10. Power vs Vertical Rate of Climb

4.3.3 Forward Flight

Figure 11 shows the relation between power and forward velocity in forward flight condition. Four types of power were studied to estimate the total power required for forward flight conditions, which were the sum of induced power, profile power, parasite power and power available.From the graphs, it can be seen clearly that induced power decreased as the forward velocity increased, followed by a steady increase of parasite power and moderate increase of profile power. The power available was constant with respect to the thrust generated by the engine. The total power, or sum of each power, depended on several factors which were difference in altitude change, air density and induced velocity produced along the blade. Cruise speed was determined from the max continuous power of the designed engine, while take-off power forward speed value was determined as max speed for the helicopter. The comparisons for the same gross weight at different altitudes are shown in the following figures.

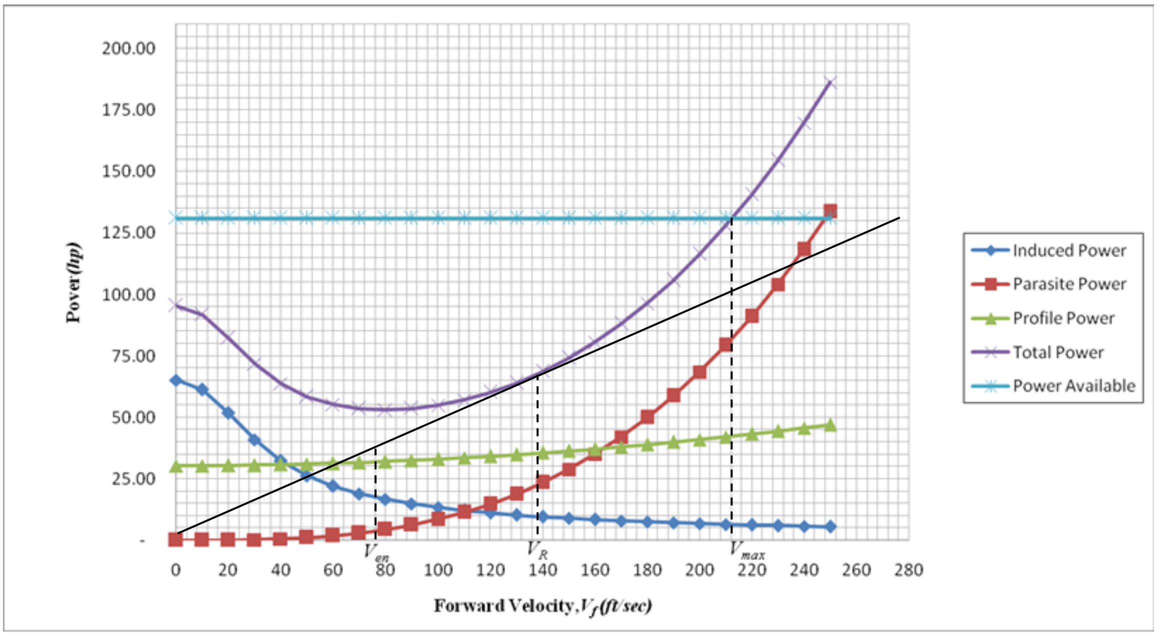

Figure 11. Power vs Forward Velocity

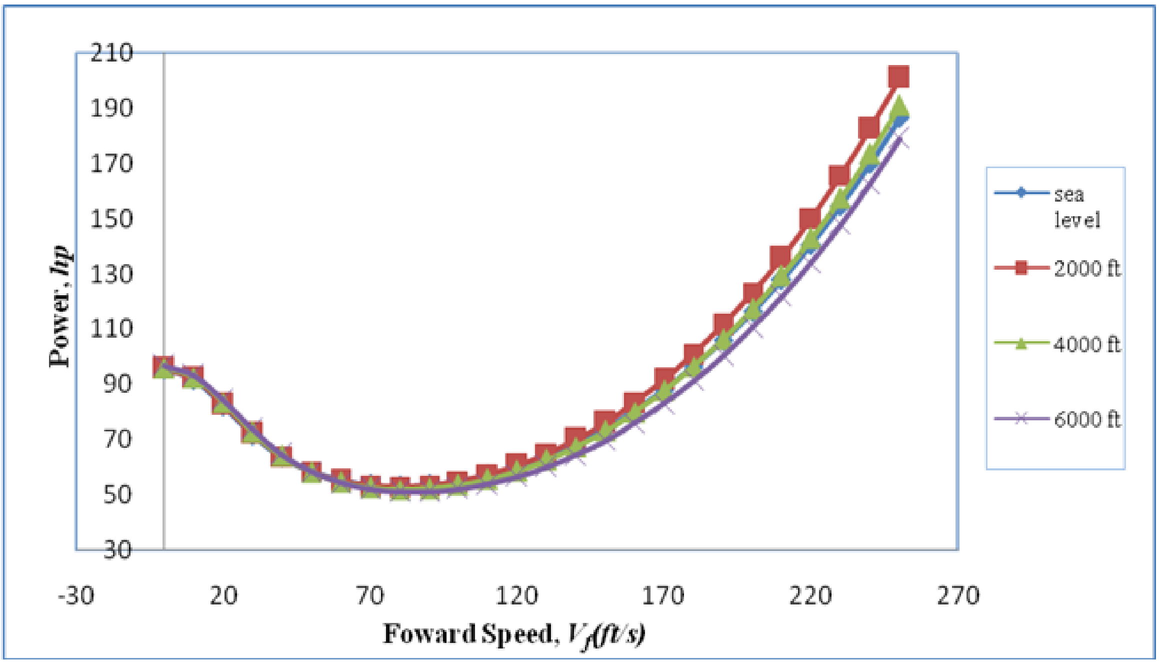

Figure 12. Comparison of Power at Different Altitude

For the proposed design, the cruise speed was defined to be the speed at which the power required is equal to the maximum continuous power that could be obtained from the engine. Although not exactly equal to the speed for maximum range, it was found that the cruising and maximum-range speeds were close enough to each other that almost the same range was achieved with either, as indicated by the specific range trends shown in Figure 12. For most helicopters, the power required to hover is greater than the power required to cruise. Therefore, the transmission and consequently the engine is sized by a maximum continuous power requirement rather than by a transient (take-off) rating requirement.

Cruise power required is maximum at sea level, according to 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 deliverable by the engine in reality 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.

From Figure 12, the following values are obtained for the proposed helicopter:

1. Maximum Velocity, V_{max} =212 *ft/s*
2. Endurance Velocity, V_{en} =80 *ft/s*
3. Range Velocity, V_R =140 *ft/s*

5. CONCLUSION

As there are many light helicopters present in the market, the main factors for best selection are the design and purpose of mission. This paper has briefly explained power estimation method for light two-seat helicopter. The proposed design follows closely the actual specification of present helicopter in the market for light helicopter type. As for the gross and empty weight analysis, the obtained values had been compared to those of present helicopter, which are in an ideal range, in which this helicopter has a gross weight of about*1365 lb*. Although there are many assumptions that have been made in the analysis for estimating the power required by the helicopter in various conditions, the result can provide a general insight on power estimation required for future light helicopter.

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