# Developing of the computational tool for preliminary project of helicopter of the conventional configuration

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# ABSTRACT

In this work is presented the project and implementation of the computational tool for the evaluation of the energetic requirements of helicopters. In other words, what is the power of motor (motors) to install? The mission parameters are the main input to this program. From this data, using statistical trends (obtained by analyzing a great amount of available helicopter data) principal parameters are evaluated in the preliminary definition of the helicopter (conventional configuration): main and secondary rotor diameter, tip speed, rotors chord, structure weight and others. Next, there is the direct possibility of evaluating the power of motor. Two different theories may be used: Linear Momentum Theory and Blade Element Momentum Theory. The power may be evaluated for three different modes of operation: hovering at fixed altitude, horizontal speed at fixed altitude and climb speed at fixed altitude. Finally, there is the possibility of choosing the motor from the database. There is a possibility of analyzing the graphic of required power vs forward speed. The developed tool may be used in a preliminary helicopter project or for the educational purposes.

Keywords: helicopter, project of aircraft, computational tool, power, mission parameters.

## 1. INTRODUCTION

Nowadays there are various tools of different complexity for preliminary design of aircraft. But for the helicopter project only one tool is known: RAPID/RaTE: Rotorcraft Analysis for Preliminary Design / Rand Technologies & Engineering ([4]). This tool is very complete, but is not of free access.

The goal of this thesis is developing of the computational tool with GUI for the preliminary project of helicopter of the conventional configuration, having mission parameters as input.

## 2. THEORETICAL BACKGROUND

### 2. 1 Linear Momentum Theory

The general equation for the required power of the helicopter is:

$$P = P_i + P_0 + P_p + P_{TR} + P_C, \qquad \textbf{(1)}$$

where $P$ is the total power, $P_i$ the induced power, $P_0$ the parasitic power, $P_p$ the power corresponding to fuselage horizontal drag, $P_{TR}$ is the power consumed by the tail rotor and $P_C$ is the climb power.

Finally a total power at Sea level (SL) is calculated, using the next equation ([1] page 216):

$$P_{SL} = P \cdot \frac{1.225}{\rho(h)} \tag{2}$$

This equation is valid for reciprocating engine. For a turboshaft engine the power output at altitude follows a more complicated relationship.

## 2. 2 Blade Element Momentum Theory

Based on the example in [1] page 126, the following the exponential distribution of the velocity was assumed:

$$\lambda(r) = \lambda_{tip} \cdot r^n \tag{3}$$

with $n \geq 0$ (as the main value $n$ = 1.1 was chosen, because 1.1 is value that corresponds to the recommended value of 1.15 for the coeficient of the induced power), $\lambda_{tip}$ is an inflow velocity on the tip of the main rotor blades and $r$ is the nondimentional position along the main rotor blades.

### 2.2.1. **Complex $C_{D_v}$**

In this case a fuselage is divided in three parts. The user can define the length of each part. $C_{D_v}$ is assumed to be a constant for each part, but the value of $C_{D_v}$ depends of the fuselage shape. Calculation of the fuselage $C_{D_v}$ is made by numerical integration of eq.(6.34) from [1] page 308:

$$dD_v = \frac{1}{2} \cdot \rho \cdot \bar{v}^2 \cdot C_{D_v} \cdot Width \cdot dl, \tag{4}$$

where $\bar{v}$ is fully developed wake velocity

Having the force, obtaining of the coefficient of the force is simple.

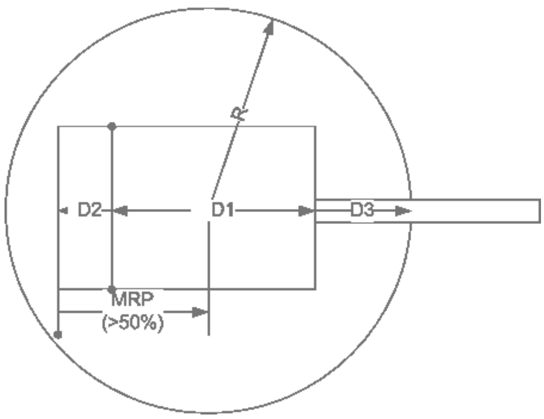


**Figura 2.1 – Integration intervals (D1, D2, D3 are the forces that correspond to the inegration intervals)**

Defining:

$$B(l) = \frac{1}{2} \cdot \rho \cdot \overline{v}^{2}(l) \cdot C_{D_v} \cdot Width \tag{5}$$

For the case of numerical integration:

$$D_{vertical} = 2 \cdot \sum_{e \cdot R}^{(1-MRP)\cdot Length} B(l) \cdot \Delta l + \sum_{(1-MRP)\cdot Length}^{MRP \cdot Length} B(l) \cdot \Delta l + \sum_{(1-MRP)\cdot Length}^{R} B(l) \cdot \Delta l \tag{6}$$

### 2.2.2. **Horizontal flight with fixed velocity and at the fixed altitude**

Calculation of the powers is analogous to the previous section, when Linear Momentum Theory was applied. There is one exception: $P_0$. Because of the horizontal velocity of helicopter, the velocity distribution on the main rotor is changed with the appearance of a zone with reversed flow and another zone where compressibility effects became significant. Assuming there are neither a reversed flow region, nor a region with compressibility effects, $P_0$ can be calculated using ([1], 5.27):

$$C_{P0} = \frac{\sigma \cdot C_{d0}}{4 \cdot \pi} \cdot \int_{0}^{2\cdot\pi} \int_{e}^{1} (r + \mu \cdot \sin(\psi))^3 \cdot dr \cdot d\psi, \tag{7}$$

where $\psi$ is an azimutal position of the main rotor blades.

To take into account the reversed flow region, the next term is needed to be added to (7) ([1], 5.42):

$$C_{\text{Preverseflow}} = -\frac{\sigma \cdot C_{d0}}{2 \cdot \pi} \cdot \int_{\pi}^{2\cdot\pi} \int_{0}^{(-\mu \cdot \sin(\psi))} (r + \mu \cdot \sin(\psi))^3 \cdot dr \cdot d\psi \tag{8}$$

To take into account the compressibility effects method of Gessow & Crim (1956) described in [1] on page 220 is used:

$$\frac{\Delta C_{P0compressibility}}{\sigma} = 0.007 \cdot \Delta M_{dd} + 0.052 \cdot \Delta M_{dd}^{2}, M_{1,90} \geq M_{dd}, \tag{9}$$

where $M_{1,90}$ is a local Mach number for $r$ = 1 and $\psi$ = 90º, $\Delta M_{dd}$ represents a difference between a local Mach number and a critical Mach number assumed to be 0.8.

# 3. IMPLEMENTATION

## 3. 1 Introduction

The present project had as starting point a user friendly interface based on a simple GUI. As such the programming language AutoIt was used. For repetitive calculations a dynamic link library was programmed using C language, containing appropriate numerical functions.

## 3. 2 Helicopter sizing by Statistics

The tool allows the sizing of the main parameters of the helicopter (the main and secondary rotor chord, the main and secondary rotor angular speed, the main and secondary rotor tip speed, fuselage length, width and height, empty weight, etc.) based on the statistical methods. Statistical regressions and graphics were obtained from [4]. For example, for the main rotor diameter (m) was used:

$$D = K \cdot 9.133 \cdot W^{0.380} \cdot V_{\max}^{-0.515} \qquad (10)$$

where $V_{\max}$ is the maximum helicopter speed (km/h), $W$ is a takeoff weight (kg).

# 4. APRESENTATION OF THE TOOL

## 4. 1 Graphical user interface

A main window of the computational tool looks like this:

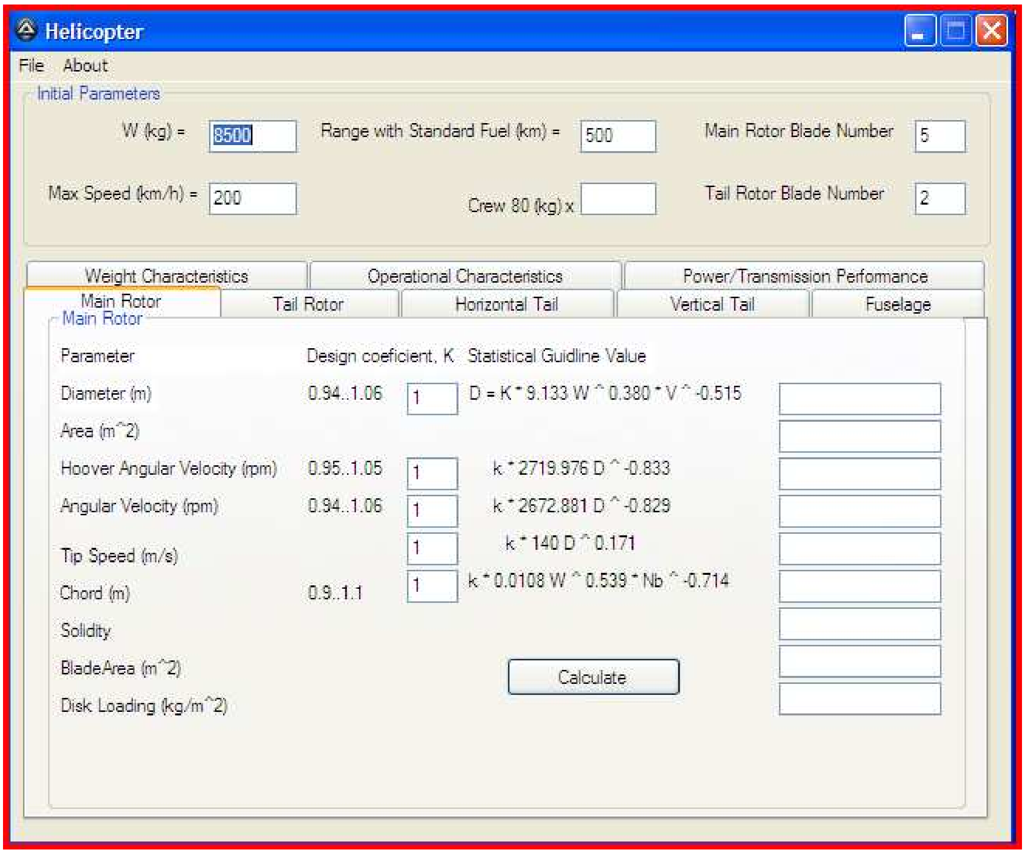


**Figure 4.1 – Main window**

The main window is divided in various compartments. The first compartment "Initial Parameters" contains the mission parameters. Below the mission parameters there are various tabs, used for grouping the helicopter parameters. There are groups such as: "Main Rotor", "Tail Rotor", "Horizontal Tail" "Vertical Tail", "Fuselage", "Weight Characteristics", "Operational Characteristics", "Power/Transmission Performance.

The next window is named “Power Analysys”. In this window on the left side appears a column with parameters evaluated previously. There is possibility to correct these values. On the right side of the window there are controls to define three types of mission:

- Hover at constant altitude
- Flight with fixed horizontal speed at fixed altitude
- Climb speed at the fixed altitude

There are three buttons “Calculate Power”, “Select Motor” and “Draw Power Graph.”. “Calculate Power” is used for calculate required power to satisfy all missions requirements defined by user. Two different theories are used for calculations: Linear Momentum Theory and Blade Element Momentum Theory.

“Select Motor” activate mode of selection of the motor that satisfy all energetic requirements calculated previously.

“Draw Power Graph.” draws power graphic. This plot can be used for calculate the horizontal velocity for minimize the power or to calculate the velocity for maximum range.

## 4. 2 Power graphic

The presented tool has the possibility to visualize the required power in function of the horizontal velocity on the interval of most relevance ($0.1 \le \lambda \le 0.5$).

The power graphic window looks like this:

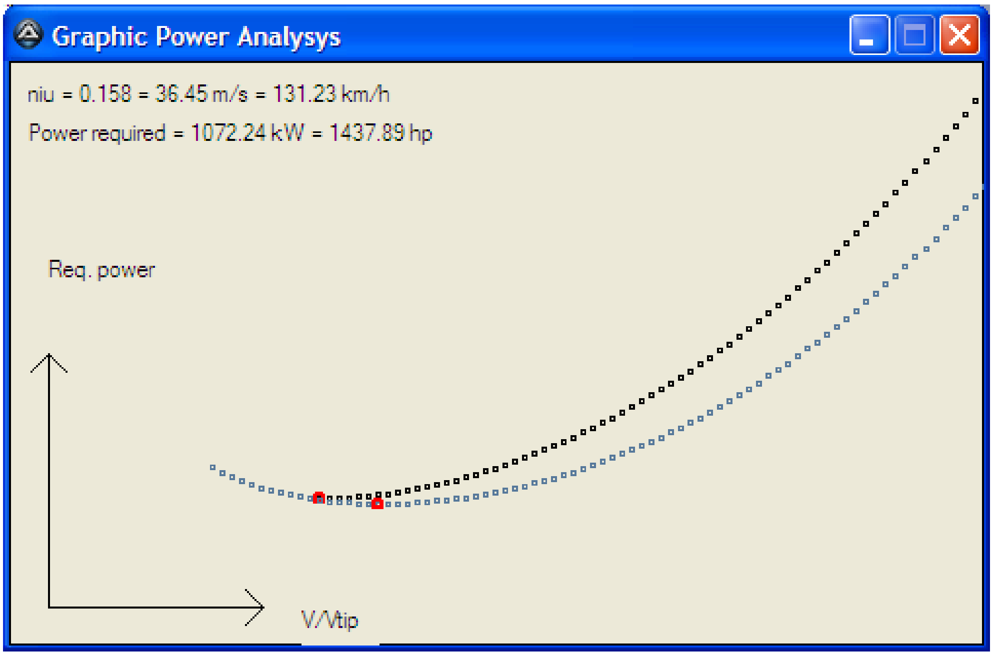


**Figure 4.2 – Power graphic for two different regimes**

The axes are positioned on the left bottom side and the red point corresponds to the minimum of power. The power variation is given at discrete values for forward velocity.

#### 4.2.1. **Additional functionalities**

Additional functionalities of the tool are:
- Calculation and visualisation of the point corresponding to minimum of required power
- Visualisation of the horizontal line corresponding to the engine power, chosen previously. The intersection of this line with power required establish the limits of the velocity interval in which helicopter can operate.
- Maximum range velocity calculation (is a point, where the line passing through the origin, is tangent to the power graphic)

# 5. RESULTS OBTAINED (PRESENTATION AND ANALYSIS)

## 5. 1 Parts of the total required power

Different calculations were performed with the developed tool for various helicopter configurations and mission parameters. After analysing the results obtained, some conclusions can be made. In hover the main contribution to the total power is from the induced power (70-80%). 10% corresponds to a tail rotor and remain corresponds the parasitic drag of the main rotor.

In horizontal flight: $P_0 = 40\% - 30\%, P_i = 30\%, P_p = 20\%$.

In the climbing mode with maximum speed of climb, the maximum contribution is from $P_c$. The contribution of $P_i$ and $P_0$ have approximately the same value of 15-20%. Contribution of the fuselage drag is 4-5%.

Based on this analysis, the most important contributions may be selected for defining which parts of helicopter must be optimized firstly, depending on the main mission.

#### 5.1.1. **Components of $P_0$ in horizontal flight**

Based on calculations of the previous section, was concluded that a fraction of $P_0$ relative to the compressibility effects represent significant part of $P_0$. The value of this contribution grows up with horizontal speed of helicopter. A part of $P_0$ corresponding to the reversed flow is not significant for the total interval of operational speed.

## 5. 2 Other parameters

#### 5.2.1. **Comparison of the power graphics obtained with Linear Momentum Theory and with Blade Element Momentum Theory with and without compressibility effects**

It was concluded that power graphics, obtained with LMT and BEMT, present the same trends. But the BEMT graphic present the lower values of the power. This observation corresponds to the fact that LMT presents higher values of required power, in general, during calculation.

Graphic obtained with BEMT with compressibility effects present a different trend. This graphic coincides with BEMT graphic before approximately the minimum. After this point compressibility effects grow, with higher power consumption therefore leading to a higher slope of the power vs. forward velocity curve.

### 5.2.2. **Airfoil section influence**

Two different airfoils were used in calculation: VR-7 and NACA0012. The calculated power vs. forward velocity presents the same trend (Figure 5.1). Nevertheless the graphic corresponding to VR-7 airfoil present lower values of the required power. The reason is that the VR-7 airfoil was specially projected for helicopter.

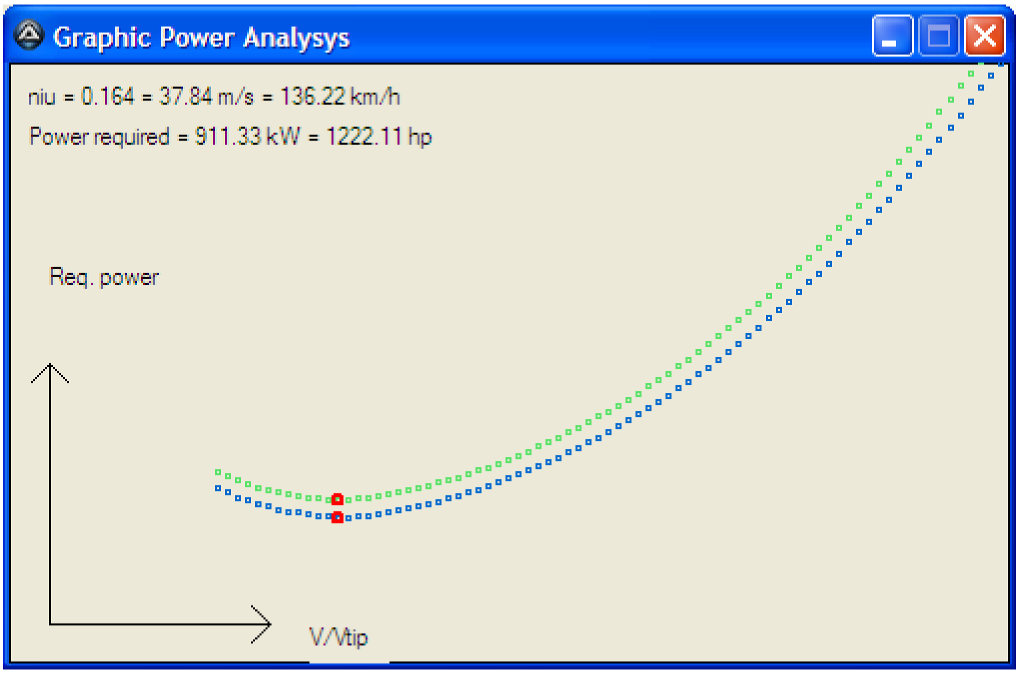


**Figure 5.1 – Power graphic for two different airfoils, blue: VR-7, green: NACA0012**

### 5.2.3. **Main rotor blade taper ratio influence**

Taper ratio influence positively the required power: the required power decreases, but this effect is not infinitely scalable:

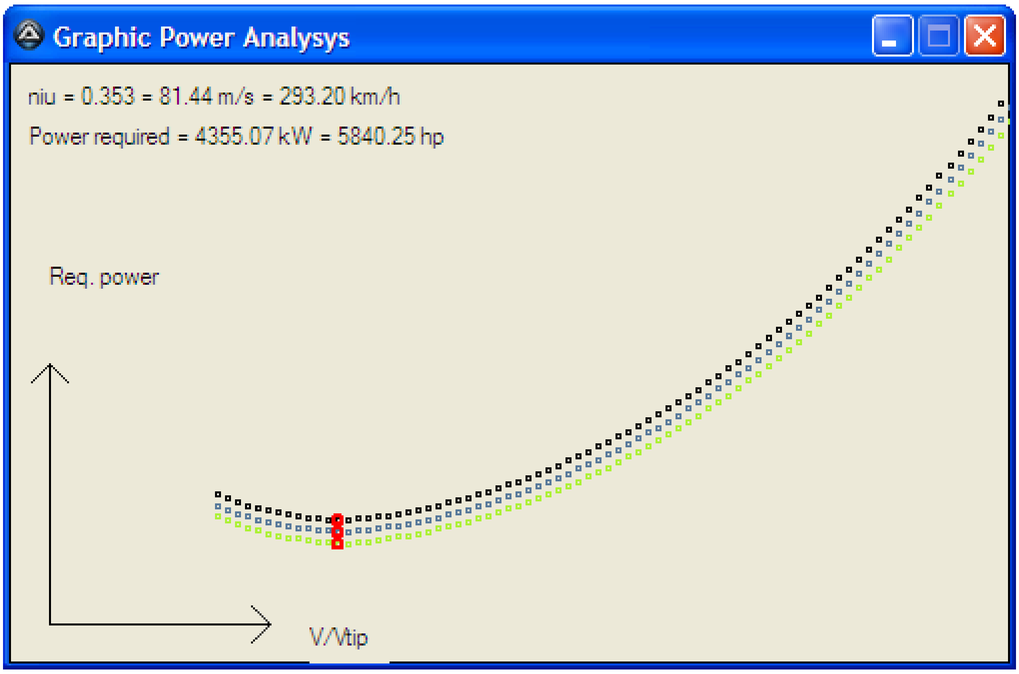


**Figure 5.2 - Main rotor blade taper ratio influence on power graphic, $\lambda = 1$: black, $\lambda = \frac{1}{2}$: dark blue, $\lambda = \frac{1}{5}$ :yellow**

### 5.2.4. Fuselage $C_{D_{vertical}}$ influence

$C_{D_{vertical}}$ is a coefficient responsible for the apparent increase of the helicopter weight caused by the interaction of the main rotor inflow and helicopters fuselage. The difference in required power due limit values of these coefficients is small.

# 6. PRACTICAL EXAMPLE (MI - 2)

As an example the helicopter Mi – 2 was chosen. Sizing by statistics using the developed tool show results very close to real parameters of the helicopter Mi-2.

### 6.1.1. Linear Momentum Theory

Calculations were made for the following technical requirements: hover at 1000 m, maximum speed of horizontal flight of 58 m/s at 500 m and climb speed of 4.5 m/s at SL. The calculated value of the required power is 870.58 hp.

### 6.1.2. Blade Element Momentum Theory

The calculated value of the required power is 800.07 hp for the same conditions as in the previous section.

It is not difficult to see that values of required power obtained with the two different theories are similar. Comparing obtained values with real project of Mi-2 (2 x 400 hp), can be concluded that the developed tool gives good results. Comparison of other initial parameters gives similar results: 6.7 m for the radius of the main rotor (real value is 7.25 m), 41 cm for the main rotor chord (real value is 40 cm), etc.

## 7. CONCLUSIONS AND FUTURE WORK

In this thesis a computational tool for preliminary project of helicopter of the conventional configuration was presented. GUI and internals were described, because the user need to know internal function of the tool for taking the right decisions and know program limitations.

Presented tool can be used for preliminary estimation of the different parameters of helicopter and for educational purposes. It is obvious that this tool is not ideal and has limitations. So the user always needs to have critical spirit when using this tool.

The presented computational tool could be further developed in a number of ways. The first one is to expand the functionalities of the tool. For example add control toolbox, enlarge databases, add possibility of structural and vibration analysis, etc. The second one is to port the tool to the Object Oriented languages, Java for example. It makes possible to adapt this tool to portable devices, such as smartphones and tablets with OS Android.

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