# Preliminary Design of Conventional Helicopter using Genetic Algorithm

*A thesis submitted in partial fulfilment of the requirements*

*for the degree of Master of Technology*

*by*


Anant Goel

*Y9227083*

Department of Aerospace Engineering

Indian Institute of Technology Kanpur


August 2014

# Certificate

It is certified that the work contained in this thesis entitled 'Preliminary Design of Conventional Helicopter using Genetic Algorithm', by Anant Goel, has been carried out under my supervision and that this work has not been submitted elsewhere far a degree

Signed: ______________________________

(Abhishek)

Assistant Professor

Department of Aerospace Engineering

IIT Kanpur



Date: 30/7/14

# *Abstract*

This thesis describes the development of a design code for preliminary design of conventional helicopter with single main rotor and tail rotor. An existing emperical methodology by Prouty for approaching helicopter design is explored. It is generally suited for design of medium and light weight helicopters.

The calculation of Power changed from emperical formula to calculation by Blade Element Momentum Theory. This allows the method to work for a wider range of weight of Helicopters. The classical approach of design trade study using graphical method (Carpet Plots) is given. Finally Genetic Algorithm is used to obtain optimal designs for best range, minimum disc loading and minimum weight for two different types of helicopters.

# *Acknowledgements*

First and foremost, I would like to thank my supervisor, Dr. Abhishek for his invaluable support and guidance. Talking to him has always been an inspiring and motivating experience. It is due to his generous help and excellent guidance at all stages that I have been able to perform any kind of research work. I found in him an always accessible and friendly mentor.

I would also like to thank my colleagues Palash Jain and Sumeet Kumar and my wing-mates Anupam and Shrikant for all the encouragement, criticism and insightful discussions I shared with them.

Finally, I will always be thankful to god for my parents and my brother whose understanding and patient nature, motivation and support in every difficult situation have been the mainstay of my existence.

Anant Goel

# Contents

# List of Figures

# List of Tables

# Symbols

| | |
|---|---|
| $W_{to}$ | Gross Take-off Weight |
| $z_{MRBL}$,$z_{TRBL}$ | Number of Main and Tail Rotor Blades |
| $c$ | Main Rotor Blade Chord |
| $R_{MR}$,$R_{TR}$ | Main and Tail Rotor Radius |
| $\lambda_{MRBL}$,$\lambda_{TRBL}$ | Main and Tail Rotor Blade Aspect Ratio |
| $\sigma_{MR}$,$\sigma_{TR}$ | Main and Tail Rotor Solidity |
| $g$ | Acceleration due to gravity |
| $L_f$ | Length of fuselage |
| $S_{wet_f}$ | Wetted Area of fuselage |
| $S_{wet_n}$ | Wetted Area of nacelles |
| $n_{leg}$ | Number of Landing gear legs |
| $P_{trans}$ | Transmission Power required |
| $A_h$ | horizontal stabilizer area |
| $AR_h$ | horizontal stabilizer Aspect Ratio |
| $V_{tot}$ | Fuel Tank Capacity |
| $A_v$ | Vertical Stabilizer Area |
| $AR_v$ | Vertical Stabilizer Aspect Ratio |
| $n_{gb}$ | Number of Gearboxes |

| | |
|---|---|
| $rpm_{eng}$ | Engine RPM |
| $rho$ | Density of Air |
| $rho_0$ | Density of Air at Sea level |
| $W_{pl}$ | Payload Weight |
| $t_{mission}$ | Mission Time |
| $C_{L_\alpha}$ | Lift Coefficient |
| $C_d$ | Drag Coefficient |
| $\theta_{tip}$ | tip deflection of main rotor blade |
| $e$ | root cut off |
| $DL$ | Disk Loading |
| $C_{T_\sigma}$ | Blade Loading coeffient |
| $FM_{MR}$ | Main rotor figure of merit |
| $FM_{TR}$ | Tail rotor figure of merit |
| $f_{SH}$ | Transmission shaft torque overload factor |
| $n_{SH}$ | shaft RPM |
| $P_{DC}$ | Power consumption of pump, generator and other devices |
| $T_{RES}$ | Time Reserve |
| $t_{MR}$,$t_{TR}$ | Thrust loss of main and tail rotor |
| $V_{CR}$ | Cruise Velocity |
| $\eta_{PR}$ | Main Rotor Propulsive efficiency |
| $v_{tip}$,$v_{tip_t}$ | Main and Tail Rotor blade tip speed |
| $\zeta_{CR}$ | Main Rotor Cruise Power conversion efficiency |
| $\zeta_{MGB}$ | Main Transmission efficiency |
| $\zeta_{MR}$,$\zeta_{TR}$ | Hover Power conversion efficiency main and tail rotors |
| $C_e$ | Engine Specific Fuel Consumption |

| | |
|---|---|
| $E$ | Vehicle Energy efficiency |
| $k_{MRBL}$,$k_{TRBL}$ | Weight coefficients of main and tail rotor blades |
| $k_{1APU}$,$k_{2APU}$ | Weight coefficients of auxiliary power unit |
| $k_{1BCS}$,$k_{2BCS}$ | Weight coefficients of Booster Control System |
| $k_{1ENG}$,$k_{2ENG}$ | Weight coefficient of Engine |
| $k_{1FUS}$,$k_{2FUS}$,$k_{3FUS}$ | Weight coefficient of fuselage |
| $k_{1SP}$,$k_{2SP}$ | Weight coefficient of swashplate |
| $k_{ELSYS}$ | Weight coefficient of electrical systems |
| $k_{EMPEN}$ | Weight Coefficient of Empennage |
| $k_{FS}$ | Weight Coefficient of Fuel Systems |
| $k_{IGB}$ | Weight Coefficient of Intermediate Gear Box |
| $k_{LG}$ | Weight Coefficient of Landing Gear |
| $k_{MGB}$,$k_{TGB}$ | Weight Coefficient of Main and Tail rotor gear boxes |
| $k_{MRHUB}$,$k_{TRHUB}$ | Weight Coefficient of Main and Tail Rotor Hubs |
| $k_{PIS}$ | Weight Coefficient of Powerplant Installation System |
| $k_{SH1ROT}$,$k_{SH2ROT}$ | Weight coefficients of main rotor shaft |
| $k_{GHE}$ | Weight Coefficient of Ground Handling Equipment |
| $\frac{L}{D}$ | Lift to Drag Ratio |
| $W_{MRBL}$ | Main Rotor Blades Weight |
| $f_{ZMRBL}$,$f_{ZTRBL}$ | Factor to account for main and tail rotor influence on hub weight |
| $N_{CFMRBL}$,$N_{CFTRBL}$ | Centrifugal forces of main and tail rotor blades |
| $z_{ENG}$ | Number of Engines |
| $P_{ENG}$ | Engine Power required |
| $D_{FIX}$ | Reference diameter for fuselage weight estimation |
| $k_{WE}$ | Weight efficiency |

*Dedicated to my Parents*

# Chapter 1

# Introduction

## 1.1 Background

The rotorcraft design process is an exercise of compromise of various design parameters to meet an optimised configuration. The design parameters can be broadly classified as mission capabilities, flight performance, handling qualities, reliability, maintainability and cost.

The process starts with conceptual and preliminary design phase wherein lots of theoretical estimations with appropriate analysis tools are needed to come up with the desired helicopter configuration in a shorter time and reduced cost. Coceptual design is focused on understanding the problem, weighting the customer requirements, generating feasible alternatives, and comparing alternatives in order to make major preliminary design decisions. In the preliminary design phase design choices are made about sizing of the concept. It is desired to obtain more and more information about the system at its early design phases. A poor design decision, discovered at late stages of preliminary design becomes very expensive to change, and may hinder the timely completion of the project.

## 1.2 Motivation

The different versions of rotorcraft preliminary design programs being used in industries and research institutes across the globe are not commercial in nature and thus have limited availability. This motivates the development of an indigenous analytical tool to help the rotorcraft research industry in India.

Also, since most methods available for preliminary design are emperical in nature they are very specific to the weight class of the concept. It becomes difficult to compare various design concepts and many design decisions have to be made qualitatively. Hence a more robust model, dependant on the physics of the vehicle will be more useful and have a broader scope.

This work is a step towards developing an indigenous analytical tool for preliminary helicopter design.

## 1.3 Literature Survey

Several design methods for helicopter have been developed in academic institutes, industries as well as research organisations. These models have been coded with varying degrees of sophistication of helicopter flight dynamics. Some of them are confined to the respective organisations whereas some are made public. The following methods were studied for this work:

- Tishchenko's method for preliminary design of transport helicopters [1].
- Prouty's method as described in the book Helicopter Performance, Stability, and Control, Chapter 10[2]

- Kee' method for conceptual design which utilizes closed form formulae and approximations from historical data[3]
- Davis' design methodology for developing concept independent Rotorcraft [4]
- Selvi's probabalistic conceptual design and sizing approach [5]
- Xin-lai's approach, which uses genetic algorithm and neural network for Helicopter Sizing[6]

In this work, the design methods by Prouty has been modelled. The method is emperical in nature, with equations based on historical data of existing helicopters. It is also dependant on the weight category of the helicopter to be designed. In order to make the method independant of weight class, the emperical calculations need to be replaced by physics based calculations. The emperical formula for calculation of power have been replaced by blade element momentum theory analysis. The book by Leishman[7] and lecture notes by Prof. Venkatesan[8] on Helicopter Technologyprovides a comprehensive treatment of the theoretical background of Blade Element Momentum Theory. For manual design a graphical method to for visualising affect on the final design due to changes in various parameter is helpful. Carpet plots are used often to get an estimate of the design, or to get a starting point for more complex design codes. An Analysis of Three approaches to the Helicopter Preliminary Design Problem [9] describes how carpet plots can be used as a design tool. Since small changes in every parameter may affect the final design drastically, an optimization method is used to obtain the best design for a particular mission. Genetic algorithm has been used in this work to obtain an optimal design solution. Goldberg's book[10] describes genetic algorithm provides a theoretical background for the topic. K. Deb's book on evolutionary algorithms[11] describes the implementation of genetic algorithm as well as various forms of the algorithm that can be used to solve a problem.

## 1.4 Approach

The methods currently available for carrying out the design process are emperical in nature. We have selected one such method as starting point for the design tool. The design method by Prouty [2] is selected. Validation of the design code is carried out for a sample helicopter. Next the emperical equation for calculation of power is replaced by a Blade Element Momentum Theory based calculation for power required during hover. A demonstration of carpet plot technique used earlier for design is done. Finally it is attempted to find an optimum design of a helicopter for three different flight missions, given design constraints using Genetic Algorithm.

## 1.5 Organization

The thesis is divided into 4 chapters the outline of which is as follows:

**Chapter 1** introduces the reader to the general idea, motivation and approach followed in the thesis. It also discusses the existing methods for solving the design problem.

**Chapter 2** describes the emperical method used for this study, the calculation of hover power required using Blade element momentum theory and gives the details of the genetic algorithm used for optimisation.

**Chapter 3** presents the results of the study including the carpet plots for sample helicopter followed by the optimised designs obtained from the genetic algorithm code.

**Chapter 4** summarizes the thesis and suggests future research directions on this topic.

Apart from this there is one appendices in the thesis

**Appendix A** Includes all the Matlab codes developed for this work.

# Chapter 2

# Design Methodology

An emperical design method by Prouty is studied in this section. It is meant for design of light and medium weight helicopters. To make this model independent of the weight class of the helicopter the emperical formulae can be replaced by analytical formulae. The emperical formula for calculation of Power is replaced by a blade element momentum theory based calculation, in this work. With the framework established in this work, various other sizing calculations may be selectively replaced with physics based calculations in future.

## 2.1 Prouty's Method

The following section provides an overview of the design method by Prouty[2].

The method is designed to work for medium and light weight helicopters and depends on emperical formulae based on historical data. Assumptions of gross take-off weight, main rotor tip velocity, main rotor radius, aspect ratio and number of main rotor blades are made by studying existing helicopters of similar type. Performance parameters like payload weight, flight altitude range etc. are specified based on mission requirements.

Weight of main rotor blades, $W_b$, is given by

$$W_b = 0.026 * z_{MRBL}^{0.66} * c * R^{1.3} * v_{tip}^{0.67} \tag{2.1}$$

where $z_{MRBL}$ is the number of main rotor blades, c is the blade chord, R is the main rotor radius, and $v_{tip}$ is the tip speed of main rotor blades.

Moment of Inertia of blades, $J$, is given by

$$J = \frac{W_b * R^2}{3} \tag{2.2}$$

Hub weight, $W_{hub}$, is given by

$$W_{hub} = 0.0037 * z_{MRBL}^{0.28} * R^{1.5} * v_{tip}^{0.43} * (0.67 * W_b + \frac{g * J}{R^2})^{0.55} \tag{2.3}$$

The size and aspect ratios of Horizontal stabilizer, $W_{hs}$, and Vertical Stabilizer, $W_{vs}$, are selected based on existing helicopters. Their weights can be calculated as follows:

$$W_{hs} = 0.72 * A_h^{1.2} * AR_h^{0.32} \tag{2.4}$$

where $A_h$ is the area of the horizontal stabilizer, and $AR_h$ is the aspect ratio of the horizontal stabilizer.

$$W_{vs} = 1.05 * A_v^{0.94} * AR_v^{0.53} * n_{TG}^{0.71} \tag{2.5}$$

where $A_v$ is the area of the vertical stabilizer, $AR_v$ is the aspect ratio of the vertical stabilizer, and $n_{TG}$ is the number of tail rotor gearboxes

Tail rotor weight, $W_{tr}$, is given by

$$W_{tr} = \frac{1.4 * R_t^{0.09} * P_{trans}}{v_{tip}} \tag{2.6}$$

where $R_t$ is the tail rotor radius and $P_{trans}$ is the transmission horse power rating.

Weight of nacelles, $W_n$, is given by

$$W_n = 0.041 * (n_{eng} * W_{eng})^{1.1} * n_{eng}^{0.24} + 0.33 * S_{wetn}^{1.3} \tag{2.7}$$

where $W_{eng}$ is the weight of the selected Engine and $n_{eng}$ is the number of engines. Design of the nacelles is selected depending on the engine. $S_{wetn}$ is the wetted surface area of the nacelles.

Propulsion system Weight, $W_{pss}$, is given by

$$W_{pss} = 2 * W_{eng}^{0.59} * n_{eng}^{0.79} \tag{2.8}$$

Fuel System Weight, $W_{fs}$, is given by

$$W_{fs} = 0.43 * V_{tot}^{0.77} \tag{2.9}$$

where $V_{tot}$ is the volume of the fuel tank.

Drive System Weight, $W_{ds}$, is given by

$$W_{ds} = 13.6 * P_{trans}^{0.82} * (\frac{rpm_{eng}}{1000})^{0.037} * (\frac{P_{trans_t}}{P_{trans}} * \frac{v_{tip}}{v_{tip_t}})^{0.068} * \frac{n_{gb}^{0.66}}{v_{tip}^{0.64}} \tag{2.10}$$

where $rpm_{eng}$ is the rpm of the selected engine, $v_{tip_t}$ is the tip speed of tail rotor, $n_{gb}$ is the number of gear boxes.

Control Systems weight, $W_{sc}$, is given by

$$W_{sc} = 36 * z_{MRBL} * c^{2.2} * (\frac{v_{tip}}{1000})^{3.2} \tag{2.11}$$

Hydraulics weight, $W_{hyd}$, is given by

$$W_{hyd} = 37 * z_{MRBL}^{0.63} * c^{1.3} * (\frac{v_{tip}}{1000})^{2.1} \tag{2.12}$$

The following formulae are use non dimensional weight $W_{nd}$ which is equal to $W_{TO}/1000$, where 1000 lbs is the reference weight Fuselage Weight, $W_f$, is given by

$$W_f = 6.9 * W_{nd}^{0.49} * L_f^{0.61} * S_{wetf}^{0.25} \tag{2.13}$$

where $L_f$ is the length of the fuselage ,$S_{wetf}$ is the wetted area of the fuselage.

Cockpit Controls weight, $W_{cc}$, is given by

$$W_{cc} = 11.5 * W_{nd}^{0.40} \tag{2.14}$$

Instrument weight, $W_{inst}$, is given by

$$W_{inst} = 3.5 * W_{nd}^{1.3} \tag{2.15}$$

Electrical Systems weight, $W_{el}$, is given by

$$W_{el} = 9.6 * \frac{P_{trans}^{0.65}}{W_{nd}^{0.4}} - W_{hyd} \tag{2.16}$$

Weight of Furnishings and equipment, $W_{fe}$, is given by

$$W_{fe} = 6 * W_{nd}^{1.3} \tag{2.17}$$

Landing gear weight, $W_{lg}$, is given by

$$W_{lg} = 40 * W_{nd}^{0.67} * n_{leg}^{0.54} \tag{2.18}$$

where $n_{leg}$ is the number of landing gear legs.

Air conditioning and anti-ice weight, $W_{acai}$, is given by

$$W_{acai} = 8 * W_{nd} \tag{2.19}$$

Weight due to variations in manufacturings, $W_{mv}$, is given by

$$W_{mv} = 4 * W_{nd} \tag{2.20}$$

Fuel weight depends on the power, $hp_{installed}$, required, which can be calculated as follows

$$hp_{installed} = \frac{W_{to}^{1.5}}{21 * 0.72 * 0.94 * 20} \tag{2.21}$$

Fuel weight, $W_{fuel}$, is given by

$$W_{fuel} = 0.4 * hp_{installed} * t_{mission} \tag{2.22}$$

where $t_{mission}$ is the tie of flight for the mission.

Adding all the weights above we get the gross take-off weight. The above steps are iterated till the value of take-off weight converges.

After converged design is obtained, performance calculation of Lift to Drag Ratio is done:

$$\frac{L}{D} = \frac{W_{TO} * V_{CR}}{hp_{installed}} \tag{2.23}$$

## 2.2 Blade Element Momentum Theory

After the emperical analysis has been completed once and values of rotor radius, tip speed and lift required based on total weight, selection of airfoil is carried out. The power characteristics of a single rotor helicopter in hovering flight are calculated based on the Blade Element Momentum theory as described by Leishman[7]. This is done by calculating the inflow, thrust and power for each blade segment and adding them along the length of the blade.

The inputs to the Blade Element Momentum code are Lift coefficient $C_{L_\alpha}$, Drag coefficient $C_d$ , density of air $\rho$, number of blades $z_{MRBL}$, blade chord c, blade twist $\theta_{tip}$ in degrees, blade tip velocity $v_{tip}$, rotor radius R, root cut-off e and number of divisions to be considered $N_r$.

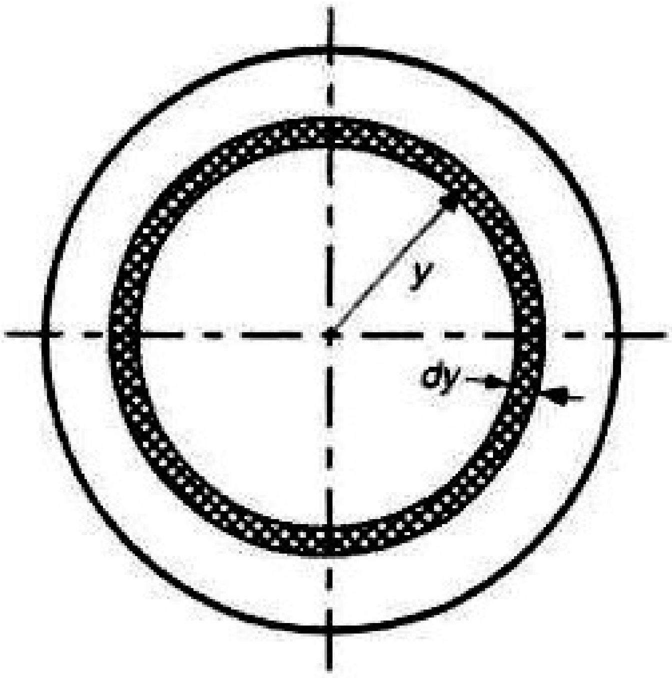


FIGURE 2.1: Annulus of rotor disk used for BEMT analysis of hovering rotor(top view)

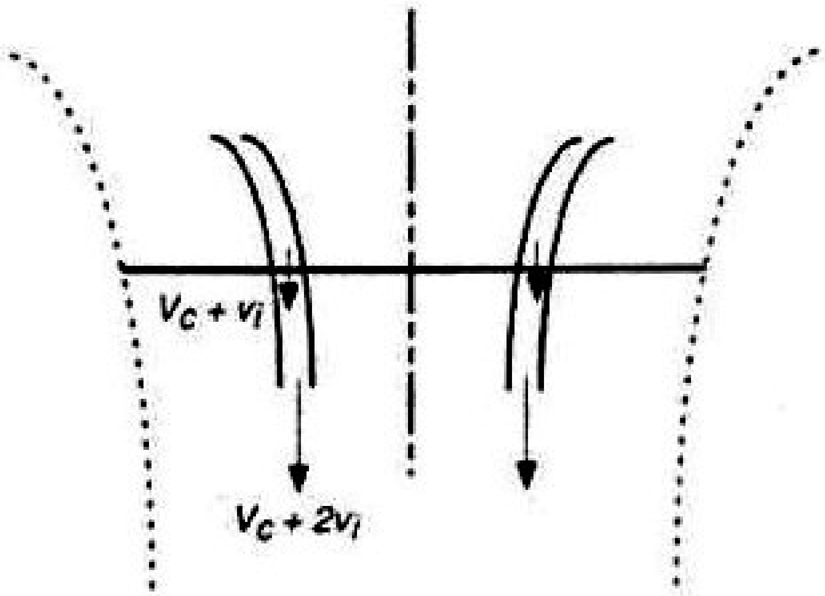


FIGURE 2.2: Annulus of rotor disk used for BEMT analysis of hovering rotor(Cross-sectional view)

To solve the equations of BEMT numerically, the blade is discretized into a series of small elements of span dr. The inflow at the $n^{th}$ station ($\lambda_n$) is obtained using the discretized equation

$$\lambda_n = \frac{\sigma * C_{L_\alpha}}{16} * [\sqrt{1 + \frac{32}{\sigma * C_{L_\alpha}} * r * \theta_n} - 1] \tag{2.24}$$

where $\sigma$ is blade solidity and $\theta_n$ is the local pitch angle.

The incremental thrust at the $n^{th}$ segment can be found using

$$(\frac{\Delta C_T}{\Delta r}) = \frac{\sigma * C_{L_\alpha}}{2} * (\theta_{tip} * r_n^2 - \lambda_n * r_n) \tag{2.25}$$

The incremental profile power consumed by the $n^{th}$ annulus is

$$(\frac{\Delta C_{p_o}}{\Delta r}) = \frac{\sigma * C_d}{2} * r_n^3 \tag{2.26}$$

The incremental induced power consumed by the annulus is

$$\frac{\Delta C_{p_i}}{\Delta r} = \frac{\Delta C_t}{\Delta_r} * \lambda_n \tag{2.27}$$

The net power coefficient is obtained by integrating over the blade. The inflow is considered constant at each segment. Thus

$$C_P = \sum_{n=1}^{N_r} (\frac{\Delta C_{p_i}}{\Delta r} + \frac{\Delta C_{p_o}}{\Delta r}) \Delta r \tag{2.28}$$

## 2.3 Genetic Algorithm

Genetic Algorithms are adaptive heuristic search algorithm based on the evolutionary principles of natural selection and genetics. They belong to the larger class of evolutionary algorithms (EA). As such they represent an intelligent exploitation of a random search used to solve optimization problems. GAs utilize historical information to direct the search into the region of better performance within the search space. The basic techniques of the GAs are designed to simulate processes in natural systems necessary for evolution, specially they follow the principles of "survival of the fittest" by Charles Darwin.

### 2.3.1 Overview

GAs simulate the survival of the fittest among individuals over consecutive generation for solving a problem. Each generation consists of a population of character strings that are analogous to the chromosome that are seen in DNA. Each individual represents a point in a search space and a possible solution. The individuals in the population are then made to go through a process of evolution.

GAs are based on an analogy with the genetic structure and behaviour of chromosomes within a population of individuals. Individuals in a population compete for resources and mates. Those individuals most successful in each 'competition' will produce more offspring than those individuals that perform poorly. Genes from 'fitter' individuals propagate throughout the population so that two good parents will sometimes produce offspring that are better than either parent. Thus each successive generation will become more suited to their environment.

### 2.3.2 Search Space

A population of individuals is maintained within search space for a GA, each representing a possible solution to a given problem. Each individual is coded as a finite length vector of components, or variables, in terms of some alphabet, usually the binary alphabet 0,1. To continue the genetic analogy these individuals are likened to chromosomes and the variables are analogous to genes. Thus a chromosome (solution) is composed of several genes (variables). A fitness score is assigned to each solution representing the abilities of an individual to 'compete'. The individual with the optimal (or generally near optimal) fitness score is sought. The GA aims to use selective 'breeding' of the solutions to produce 'offspring' better than the parents by combining information from the chromosomes. The GA maintains a population of n chromosomes (solutions) with associated fitness values. Parents are selected to mate, on the basis of their fitness, producing offspring via a reproductive plan. Consequently highly fit solutions are given more opportunities to reproduce, so that offspring inherit characteristics from each parent. As parents mate and produce offspring the population is kept at a constant size. Individuals in the population are removed and replaced by the new solutions, eventually creating a new generation of the same size. Over successive generations better solutions thrive while the least fit solutions die out. New generations of solutions are produced containing, on average, more good genes than a typical solution in a previous generation. Each successive generation will contain more good 'partial solutions' than previous generations. Eventually, once the population has converged and is not producing offspring noticeably different from those in previous generations, the algorithm itself is said to have converged to a set of solutions to the problem at hand.

### 2.3.3 Implementation of GA

After an initial population is randomly generated, the algorithm evolves the through three operators:

1. **Selection** : This equates to survival of the fittest. While selecting the individuals from the population for mating preference is given to fitter individuals, allowing them to pass on their genes to the next generation. The result is that each new generation is, on an average, fitter than the older generation.

2. **Crossover**: This action represents the mating between selected individuals. Once two individuals have been selected for mating, crossover sites are randomly selected in the bit strings representing the individuals. the values of the bits at these points are exchanged and the two new offsprings are placed in the next generation. By recombining portions of good individuals, this process is likely to create even better individuals.

3. **Mutation** This action introduces random modifications into the individuals. The purpose of this acion is to maintain diversity within the population and to avoid premature convergence. With some low probability, a portion of the new individuals will have their bits flipped.

### 2.3.4 Termination

The process is repeated until a termination condition has been reached. Common terminating conditions are:

- A solution that satisfies minimum criteria is found

- A maximum number of generations is reached, or an allocated time is reached
- The highest ranking solution's fitness is reaching or has reached a plateau such that successive iterations no longer produce better results

### 2.3.5 Details of Genetic Algorithm

The following section describes the details of the genetic algorithm used for the design optimisation:

1. Number of Variables: There are 7 variables in each case namely Main rotor radius($R_{MR}$), Main rotor blade Aspect Ratio(AR), Tail rotor radius($R_t$), main rotor tip speed($v_{tip}$), cruise velocity($V_{CR}$), blade twist($\theta_{tip}$) and number of main rotor blades($z_{MRBL}$). FPS units are used for all variables.
2. Precision: Each variable is has a precision of 32 bits except $z_{MRBL}$ (Number of main rotor blades), which takes only integral values within the specified range. The lower and upper limits for every variable are specified beforehand. A bitstring of 32 bits represents the variable for the genetic operations. The equivalent decimal value can be obtained by dividing the variable range into $2^{32}$ divisions, with 0 representing the lower limit and $2^{32} - 1$ the upper limit.
3. Population Size: A population size of 100 individuals is selected.
4. Selection: Tournament selection is used to select the individuals for mating. In tournament selection a number of variables are randomly selected and a tournament is performed to find the fittest. at every stage two individuals compete and the one with the higher fitness progresses. This allows fitter individuals more opportunities for mating. The tournament size is 16.

5. Crossover: Uniform Crossover technique has been used to mimic mating of the two individuals. A random bitstring of the same size as the individuals is generated. The new individual has bits from the first parent where ever there is a 0 bit and from the second parent where ever there is a 1bit.

6. Mutation: After forming the new individual, random bits in it will be flipped with a probability of the mutation rate. The mutation rate selected is 0.02.

7. Termination: The algorithm is run for 5000 steps.

# Chapter 3

# Results and Discussions

The validation of the code has been performed on a reference helicopter provided in reference [2] Appendix A. Trade studies are then performed using carpet plot method to find out how a change in each variable affects the final design parameters. All results are presented in $feet/s$ units.

Finally results of two case studies for optimization of helicopter design for specific mission requirements, using Genetic Algorithms on Prouty method are presented. The values of parameters obtained are then compared with the baseline helicopter for the design.

## 3.1 Validation

The validation of the code has been performed on a reference helicopter provided in reference [2] Appendix A. The characteristics of the example helicopter are given in table 3.1

| Variable | Value | units |
|---|---|---|
| $R$ | 30 | feet |
| $AR$ | 15 | |
| $v_{tip}$ | 650 | feet/s |
| $z_{MRBL}$ | 4 | |
| $\theta_{tip}$ | 10 | deg |
| $R_t$ | 6.5 | feet |
| $AR_t$ | 6.5 | |
| $A_H$ | 18 | $ft^2$ |
| $AR_H$ | 4.5 | |
| $A_V$ | 33 | $ft^2$ |
| $AR_V$ | 1.8 | |
| $L_f$ | 57 | feet |
| $S_{wetf}$ | 680 | $ft^2$ |
| $S_{wetn}$ | 94 | $ft^2$ |

TABLE 3.1: Characteristics of Example Helicopter

The results of the validation are presented in table 3.2

| Variable | Prouty | Original | units |
|---|---|---|---|
| $GrossTakeoffWeight$ | 23015.63 | 20000 | lbs |
| $DiskLoading$ | 7.0112 | 7.074 | $lbs/ft^2$ |
| $BladeLoading$ | 0.042 | 0.044 | |
| $HoverPower$ | 5114.78 | 4000 | hp |

TABLE 3.2: Validation Results for Prouty's Method

## 3.2 Trade Studies using Carpet Plots

In the following section results for trade-off studies for inter-dependence of various vehicle properties are shown Three trade studies are done:

1. This trade study investigates the relationship between Take-off Weight and Disk Loading for different aspect ratios and number of main rotor blades. It can be seen that the weight increases with increasing aspect ratio and increases with increasing the number of blades.

   For a given aspect ratio, an increase in number of blades correspond to an increase in blade solidity. In turn, the disk loading decreases, leading to a decrease in hover power required. The results are shown in Fig. 3.1. In general increase in number of blades increases total blade weight and hub weight, resulting in increased gross take-off weight

2. Figures 3.2 shows the relationship between Empty Weight and Blade Loading for different aspect ratios and number of main rotor blades. Empty weight increases with increasing Aspect ratio and increases with increasing number of blades.

   For a given Aspect ratio, an increase in number of bladed corresponds to a decrease in Blade Loading, reducing the maneuvering capability of the vehicle.

3. This trade study investigates the relationship between Hover Power Required and Blade Loading for different aspect ratios and number of main rotor blades. It can be seen that the weight increases with increasing Aspect ratio and decreases with increasing number of blades.

   The results are shown in Fig. 3.3

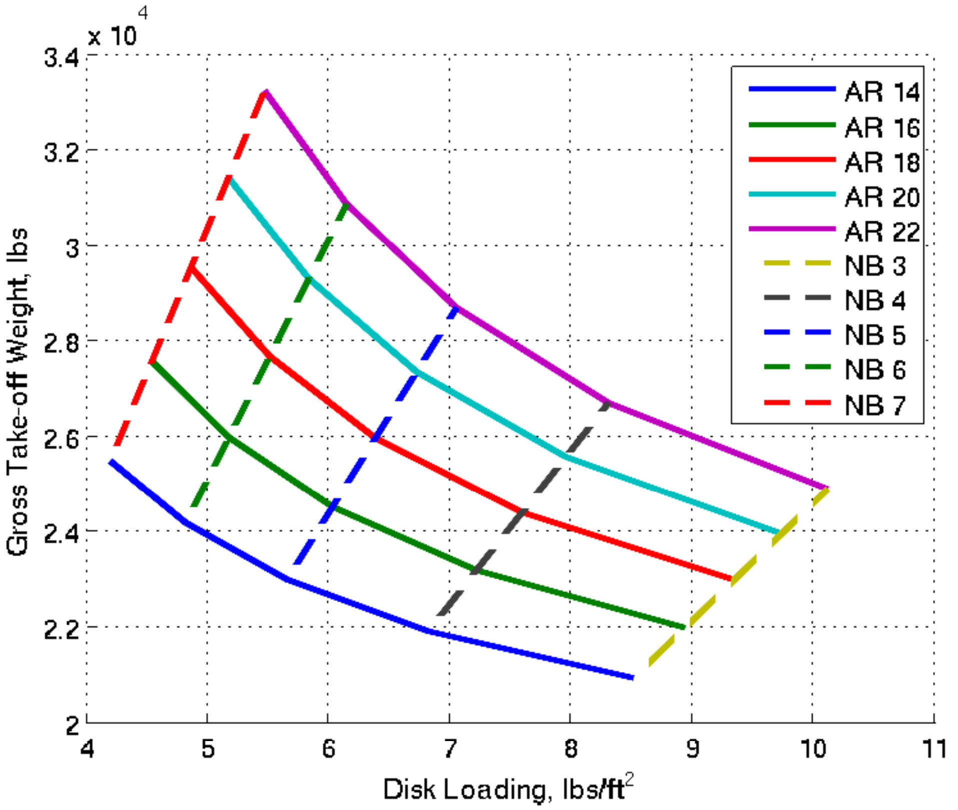


FIGURE 3.1: Gross Takeoff Weight as a function of Disk Loading(Prouty)

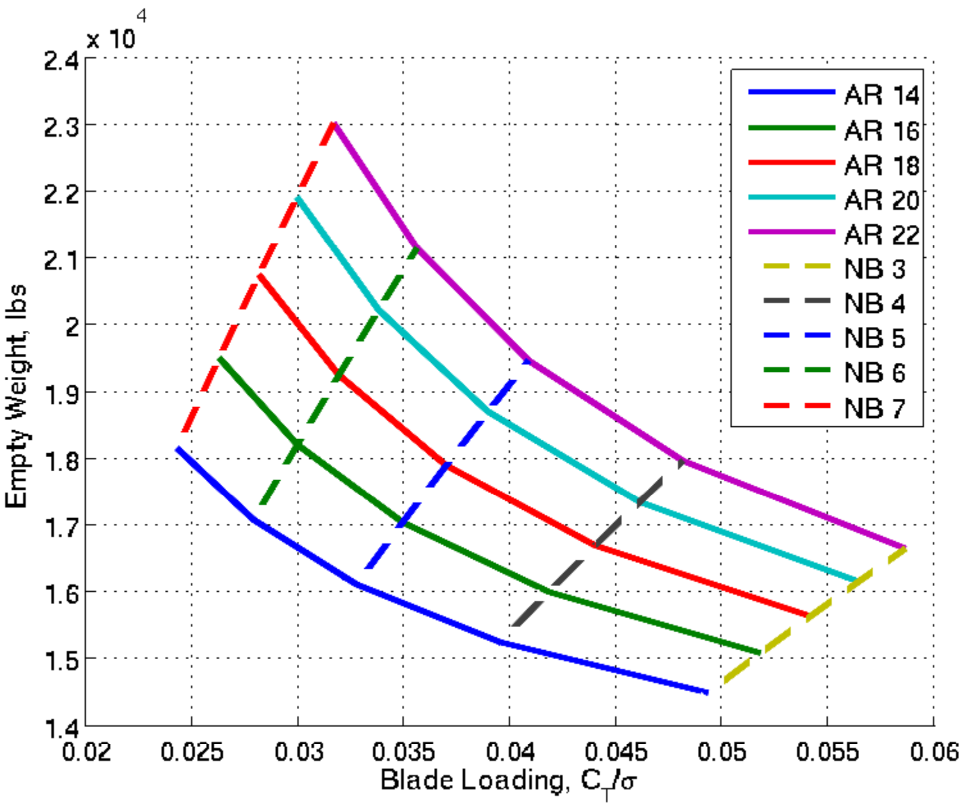


FIGURE 3.2: Empty Weight as a function of Blade Loading(Prouty)

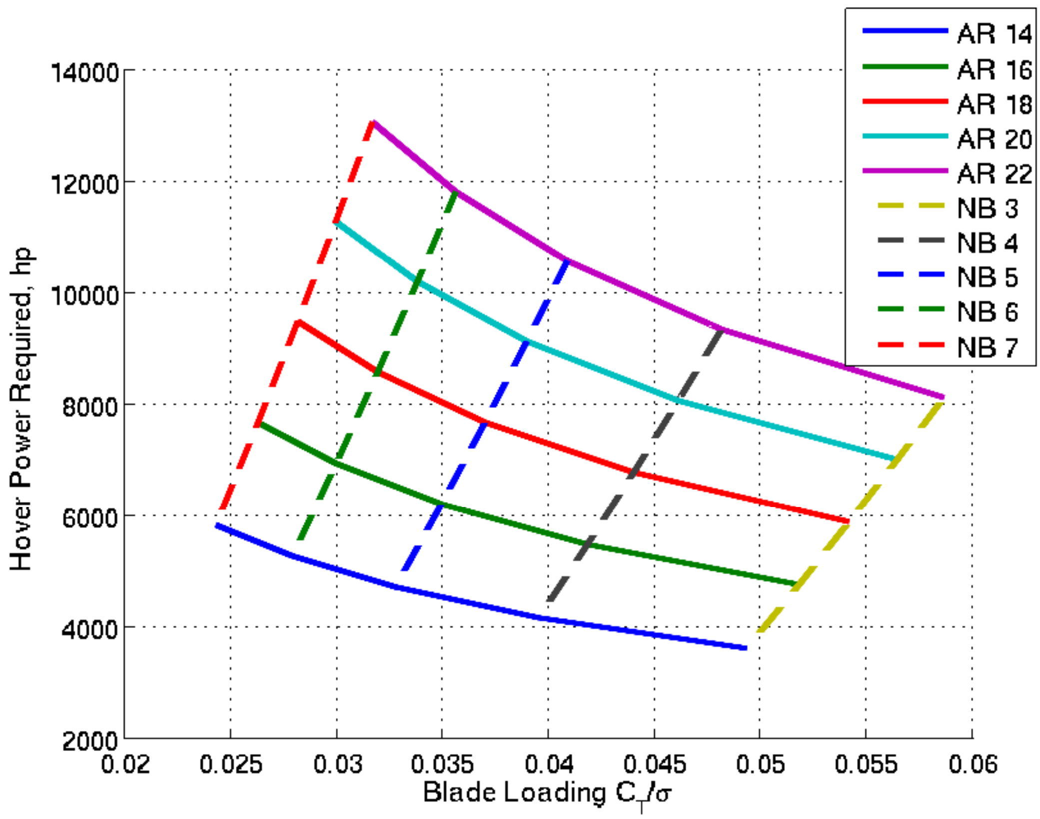


Figure 3.3: Hover Power Required as a function of Blade Loading(Prouty)

From figures 3.1 to 3.3 it can be noted that the selection of key design parameters can significantly change the design. For example, in Fig. 3.1, changing the number of blades from 4 to 5 keeping aspect ratio constant at 18 leads to an 8% change in Gross take-off weight and 15% change in disk loading.

Hence performing manual selection of data for optimum design is very difficult. Hence an optimization technique can be used for appropriate selection of design parameters. Genetic Algorithm has been used in this work to obtain an optimum design for a helicopter for two cases.

## 3.3 Design Case Studies Using Genetic Algorithm

The three mission requirements for which the design is optimized are:

- Minimum Disk Loading: Lower Disk Loading has many advantages. The first being low power requirement in hovering conditions. In missions where larger hovering time is required, low disk loading is beneficial. Another advantage of low disk loading is lower induced velocities. In missions where the helicopter has to hover close to a sand or gravel surface low disk loading is crucial. Helicopters with high disk loading may experience brownout in this situation. Another advantage of low disk loading is low autoroative rate of descent. It is easier for the pilot to ensure safe landing in case of lower rate of descent.

- Minimum Weight: Weight Efficiency is defined as the ratio of useful weight to total weight of the vehicle. In this example it is attempted to find the helicopter with maximum weight efficiency by minimizing the total weight of the helicopter.

- Maximum Range: In this example it is attempted to optimize the helicopter for maximum range while carrying the same payload. In a certain kind of mission if the payload weight is fixed and maximum range is desired from a vehicle irrespective of cost then this method can be used.

### 3.3.1 Case Study 1: Heavy Lift Helicopter

A heavy lift helicopter is designed for various mission requirements. The Mil Mi-26 is taken as reference Design for this Case Study. The Payload weight for each case is kept fixed at 40000 lbs, and all results are presented in fps units.

Table 3.3 shows the calculation of performance parameters using Prouty's method for Mi-26 with the actual helicopters cahracteristics. These results are compared with the optimised designs obtained in each case.

| Variable | Prouty | Mi26 | units |
|---|---|---|---|
| $GrossTakeoffWeight$ | 85545 | 109350 | lbs |
| $DiskLoading$ | 9.8734 | 12.1608 | $lbs/ft^2$ |
| $BladeLoading$ | 0.0609 | 0.07501 | |
| $HoverPower$ | 16166.8 | 22798 | hp |

Table 3.3: Initial Calculation for Mil Mi26 using Prouty's Method

#### 3.3.1.1 Minimum Disk Loading

The reults of optimization for minimum disk loading are presented in table 3.4

| Variable | Prouty | Mi-26 | units |
|---|---|---|---|
| $R$ | 61.2651 | 53.5 | feet |
| $AR$ | 21.8388 | 19.16 | |
| $R_t$ | 14.9879 | 13.123 | feet |
| $v_{tip}$ | 607.6904 | 630 | feet/s |
| $V_{CR}$ | 212.343 | 232.393 | feet/s |
| $\theta_{tip}$ | 2.4934 | 5 | degrees |
| $z_{MRBL}$ | 2 | 8 | |

| Final Values | | | |
|---|---|---|---|
| $W$ | 80793 | 109350 | lbs |
| $DL$ | 6.58 | 12.1608 | $lbs/ft^2$ |
| $range$ | 2378.126 | 1036 | miles |
| $Power$ | 17400.485 | 22798 | hp |
| $\frac{L}{D}$ | 35.5242 | | |

Table 3.4: Results for minimum disk loading for Case Study 1

The Disk Loading is reduced from 9.8734 $lbs/ft^2$ in the original design to 6.58 $lbs/ft^2$ in the optimised design. using Prouty's method, a decrease of 33.4%.

Using Prouty's method the net weight of the vehicle goes down from 85545 lbs to 80793 lbs and the radius increases from 53.5 feet to 61.2651 feet. Range is increased from 1036 miles to 2378 miles.

#### 3.3.1.2 Minimum Weight

The reults of optimization for minimum weight are presented in table 3.5

| Variable | Prouty | Mi-26 | units |
|---|---|---|---|
| $R$ | 40.3906 | 53.5 | feet |
| $AR$ | 21.9842 | 19.16 | |
| $R_t$ | 13.5913 | 13.123 | feet |
| $v_{tip}$ | 687.5 | 630 | feet/s |
| $V_{CR}$ | 225.575 | 232.393 | feet/s |
| $\theta_{tip}$ | 4.956 | 5 | degrees |
| $z_{MRBL}$ | 2 | 8 | |

| Final Values | | | |
|---|---|---|---|
| $W$ | 68004 | 109350 | lbs |
| $DL$ | 13.31 | 12.1608 | $lbs/ft^2$ |
| $range$ | 2471.692 | 1036 | miles |
| $Power$ | 15967.0357 | 22798 | hp |
| $\frac{L}{D}$ | 32.4923 | | |

Table 3.5: Results for minimum weight for Case Study 1

The Gross Take-off weight is reduced from 85545 $lbs$ in the original design to 68004 $lbs$ in the optimised design using Prouty's method, a decrease of 20.50%.

Using Prouty's method the main rotor radius is reduced from 53.5 feet to 40.3906 feet and the disk loading increases from 9.8734 $lbs/ft^2$ to 13.3 $lbs/ft^2$. The number of blades is also reduced from 8 to 2 to keep the weight to a minimal. Range is increased, from 1036 miles to 2471 miles.

#### 3.3.1.3 Maximum Range

The reults of optimization for maximum range are presented in table 3.6

| Variable | Prouty | Mi-26 | units |
|---|---|---|---|
| $R$ | 54.419 | 53.5 | feet |
| $AR$ | 21.8113 | 19.16 | |
| $R_t$ | 14.6442 | 13.123 | feet |
| $v_{tip}$ | 658.341 | 630 | feet/s |
| $V_{CR}$ | 237.864 | 232.393 | feet/s |
| $\theta_{tip}$ | 3.3251 | 5 | degrees |
| $z_{MRBL}$ | 10 | 8 | |

| Final Values | | | |
|---|---|---|---|
| $W$ | 111495.2634 | 109350 | lbs |
| $DL$ | 12.161 | 12.1608 | $lbs/ft^2$ |
| $range$ | 2610.3383 | 1036 | miles |
| $Power$ | 11750.93 | 22798 | hp |
| $\frac{L}{D}$ | 38.9929 | | |

Table 3.6: Results for maximum range for Case Study 1

Range increases from 1036 miles in the original design to 2610.3383 miles in the optimised design using Prouty's method, an increae of 152%.

Using Prouty's method the net weight of the vehicle increases from 85545 lbs to 111495.26 lbs. The number of blades is increased to 10.

### 3.3.2 Case Study 2: Light Trainer Helicopter

A Light Trainer helicopter is designed for various mission requirements. The Robinson R-22 is taken as reference Design for this Case Study. The Payload weight for each case is kept fixed at 400 lbs, and all results are presented in fps units.

Table 3.7 shows the calculation of performance parameters for Robinson R-22 with the actual helicopters characteristics. These results are compared with the optimised designs obtained in each case.

| Variable | Prouty | R22 | units |
|---|---|---|---|
| $GrossTakeoffWeight$ | 1290 | 1370 | lbs |
| $DiskLoading$ | 2.6003 | 2.7542 | $lbs/ft^2$ |
| $BladeLoading$ | 0.0151 | 0.01599 | |
| $HoverPower$ | 105.2543 | 124 | hp |

Table 3.7: Initial Calculation for Robinson R22 using Prouty's Method

#### 3.3.2.1 Minimum Disk Loading

The reults of optimization for minimum disk loading for case study 2 are presented in table 3.8

| Variable | Prouty | Mi-26 | units |
|---|---|---|---|
| $R$ | 13.9879 | 12.583 | feet |
| $AR$ | 21.75 | 21 | |
| $R_t$ | 2.4814 | 1.75 | feet |
| $v_{tip}$ | 649.8761 | 650 | feet/s |
| $V_{CR}$ | 143.6094 | 161.308 | feet/s |
| $\theta_{tip}$ | 2.4998 | 4 | degrees |
| $z_{MRBL}$ | 2 | 2 | |

| Final Values | | | |
|---|---|---|---|
| $W$ | 1562 | 1370 | lbs |
| $DL$ | 2.158 | 2.7542 | $lbs/ft^2$ |
| $range$ | 218.707 | 240 | miles |
| $Power$ | 113.41 | 124 | hp |
| $\frac{L}{D}$ | 4.3806 | | |

Table 3.8: Results for minimum disk loading for Case Study 2

The Disk Loading is reduced from 2.6003 $lbs/ft^2$ in the original design to 2.158 $lbs/ft^2$ in the optimised design using Prouty's method, a decrease of 17%.

Using Prouty's method the net weight increases from 1290 lbs to 1560 lbs, while main rotor radius increases from 12.583 feet to 13.9879 feet. The range is reduced from 240 miles to 218.71 miles

#### 3.3.2.2 Minimum Weight

The reults of optimization for minimum Weight for case study 2 are presented in table 3.9

| Variable | Prouty | Mi-26 | units |
|---|---|---|---|
| $R$ | 11.609 | 12.583 | feet |
| $AR$ | 21.9801 | 21 | |
| $R_t$ | 2.4999 | 1.75 | feet |
| $v_{tip}$ | 649.4995 | 650 | feet/s |
| $V_{CR}$ | 157.679 | 161.308 | feet/s |
| $\theta_{tip}$ | 2.4606 | 4 | degrees |
| $z_{MRBL}$ | 2 | 2 | |

| Final Values | | | |
|---|---|---|---|
| $W$ | 1233 | 1370 | lbs |
| $DL$ | 2.9155 | 2.7542 | $lbs/ft^2$ |
| $range$ | 313.9606 | 240 | miles |
| $Power$ | 77.0035 | 124 | hp |
| $\frac{L}{D}$ | 5.1352 | | |

TABLE 3.9: Results for minimum weight for Case Study 2

The net weight is reduced from 1290 lbs in the original design to 1231 lbs in the optimised design using Prouty's method, a decrease of 4.57%.

Using Prouty's method the main rotor radius decreases from 12.583 feet to 11.609 feet and the number of blades remains the same at 2 which is the lowest allowable value for number of blades. The range is increased from 240 miles to 313.9606 miles.

#### 3.3.2.3 Maximum Range

The reults of optimization for maximum range for case study 2 are presented in table 3.10

| Variable | Prouty | Mi-26 | units |
|---|---|---|---|
| $R$ | 13.7249 | 12.583 | feet |
| $AR$ | 21.7461 | 21 | |
| $R_t$ | 2.4916 | 1.75 | feet |
| $v_{tip}$ | 648.8378 | 650 | feet/s |
| $V_{CR}$ | 148.4933 | 161.308 | feet/s |
| $\theta_{tip}$ | 2.4197 | 4 | degrees |
| $z_{MRBL}$ | 10 | 2 | |
| Final Values | | | |
| $W$ | 1621 | 1370 | lbs |
| $DL$ | 2.735 | 2.7542 | $lbs/ft^2$ |
| $range$ | 371.4166 | 240 | miles |
| $Power$ | 46.9579 | 124 | hp |
| $\frac{L}{D}$ | 7.4394 | | |

Table 3.10: Results for maximum range for Case Study 2

The Range is increased from 240 miles in the original design to 371.4166 miles in the optimised design using Prouty's method, an increase of 54.8%.

Using Prouty's method the net weight increases from 1290 lbs to 1620 lbs.

# Chapter 4

# Conclusion

## 4.1 Summary

A preliminary design methodology for a conventional helicopter with single main rotor and a tail rotor has been developed. The design code was coupled to a Genetic Algorithm based optimization. For the optimisation problem, two cases were explored. A light trainer helicopter and a heavy lift transport helicopter. The results of the design code were compared with the original helicopters and the following improvements were achieved:

- Case Study 1: Heavy Lift Transport Helicopter
  - Disk loading optimization led to a reduction of 33.4% in disk loading from original design.
  - Gross takeoff weight optimization led to a reduction of 20.5% in weight from original design.
  - Range optimization led to an increase of 152% in range from original design.

- Case Study 2: Light Trainer Helicopter
  - Disk loading optimization led to a reduction of 17% in disk loading from original design
  - Gross takeoff weight optimization led to a reduction of 4.57% in weight from original design.
  - Range optimization led to an increase of 54.8% in range from original design

## 4.2 Contributions of present work

Following are the contributions of the work presented in this thesis:

- Design methodology based utilizing historical data for preliminary helicopter sizing was explored.
- The emperical equation for calculation of required power in Prouty's method was replaced by Blade Element Momentum Theory Calculation.
- Validation of the two design methods was done for two helicopters of different weight classes.
- Carpet Plots analysis was explored. Development of a graphical solution matrix using this method provides a visual interpretation of changes occurring in final design when key parameters are varied.
- Optimisation was carried out for two cases,a light trainer helicopter and a heavy lift transport helicopter. For both these cases optimum designs for minimum weight, minimum disk loading and maximum range, have been found.

## 4.3 Future Work

The code developed here is the first step for developing an analytical design method. With the framework established in this work, various other sizing calculations can be selectively replaced with physics based calculations in future. For example, The calculation of hub loads can be done and can be used to calculate the weight of rotor hub and swashplate. Eventually a tool like this could be coupled to comprehensive analysis code with capability of blade loads prediction during severe maneuvers, to facilitate detailed rotor design.

# Appendix A

# Matlab Code

Main Code

```
clc
clear all
close all

global popl Psize nvar n_prec var_range mutationRate ...
tournamentSize elitism W_to z_MRBL R AR R_t v_tip ...
v_tip_t g L_f S_wetf S_wetn n_leg P_trans P_trans_t ...
A_h AR_h V_tot A_v AR_v n_TG n_eng n_gb rpm_eng rho ...
W_pl W_eng  t_mission theta_tip Cla Cd e

header();
max = 5000;
initialize();
[itemp,fittest] = getfittest(popl);
counter = 0;
ftn = zeros(1,max);
while counter <max
    evolve();
    [itemp,fittest] = getfittest(popl);
    counter = counter + 1
    ftn(counter)=fittest;
if mod(counter,100) == 0
        save data.mat
```

```
    end
end

indv = itemp;
var = zeros(nvar,1);
for i = 1:nvar
    var(i) = bin_decode(indv((i-1)*n_prec+1:i*n_prec), ...
var_range(i,1),var_range(i,2));
end

figure();plot(1:max,ftn);

% for Prouty
R1 = var(1);
AR1 = var(2);
R_t1 = var(3);
v_tip1 = var(4);
t_mission1 = var(5);
theta_tip1 = var(6);
z_MRBL1 = ceil((var(7)));


save data.mat
```

Header Prouty: contains the Helicopter model, search space and coefficients for Prouty Model

```
function [] = header()
global popl Psize nvar n_prec var_range mutationRate ...
tournamentSize elitism W_to z_MRBL R AR R_t v_tip ...
v_tip_t g L_f S_wetf S_wetn n_leg P_trans P_trans_t ...
A_h AR_h V_tot A_v AR_v n_TG n_eng n_gb rpm_eng rho ...
W_pl W_eng  t_mission theta_tip Cla Cd e

nvar = 7;
Psize = 100;
```

```
n_prec = 32;
var_range = [11,14;18,22;1.5,2.5;600,700;0.5,1.5;0,5;1,10];

% variables
% R = var(1);
% AR = var(2);
% R_t = var(3);
% v_tip = var(4);
% t_mission = var(5);
% theta_tip = var(6);
% z_MRBL = ceil((var(7)));

%algorithm properties
mutationRate = 0.02;
tournamentSize = 16;
elitism = 1;



W_to = 1000;       %W_to = G.T.O.W, lbs. initial guess
%z_MRBL = 2;       %z_MRBL = no. of blades
%R = 12.58;        %R = M.R radius,ft.
%AR = 21;
%R_t = 1.75;       %Tail rotor radius, feet
%v_tip = 650;      %v_tip = omega*R, ft./s
%v_tip_t = v_tip; %v_tip = omega*R, ft./s
g = 32.174;
L_f = 5;           %L_f = length of the fuselage
S_wetf = 100;      %S_wetf = wetted area of the fuselage
S_wetn = 5;        %S_wetn = wetted area of nacelles
n_leg = 2;         %n_leg = no. of landing gear legs
P_trans = 100;     %P_trans, hp
P_trans_t = 0;     %P_trans, hp
A_h = 2;           %A_h = area of horizontal stabilizer, sq. ft.
AR_h = 2;          %AR_h = aspect ratio of horizontal stabilizer
V_tot = 1000;      %V_tot = fuel tank capacity,gallons
A_v = 4;           %area of vertical stabilizer, sq. ft.
AR_v = 4;          %aspect ratio of vertical stabilizer
```

```
n_TG = 1;          %number of tail rotor gearboxes
n_eng = 1;         %number of engines
n_gb = 1;
rpm_eng = 2652;
rho = 1.225;

%INITIALIZATION AND ASSUMPTION
W_pl = 200;
W_eng = 100;      %Weight of engine
%t_mission=1;

Cla = 0.11;
Cd = 0.04;
%theta_tip = 4;  %negative tip deflection in deg
e = 0.01;

end
```

Helicopter Model: Prouty

```
function [ftval] = fitness(indv)

global Psize nvar n_prec var_range mutationRate ...
tournamentSize elitism W_to z_MRBL R AR R_t v_tip ...
v_tip_t g L_f S_wetf S_wetn n_leg P_trans P_trans_t ...
A_h AR_h V_tot A_v AR_v n_TG n_eng n_gb rpm_eng rho ...
W_pl W_eng t_mission theta_tip Cla Cd e

var = zeros(nvar,1);
for ft_i = 1:nvar
    var(ft_i) = ...
bin_decode(indv((ft_i-1)*n_prec+1:ft_i*n_prec),...
var_range(ft_i,1),var_range(ft_i,2));
end
%variables[R,AR,R_t,v_tip,t_mission,theta_tip]
R = var(1);
```

```
AR = var(2);
R_t = var(3);
v_tip = var(4);
t_mission = var(5);
theta_tip = var(6);
z_MRBL = ceil((var(7)));

v_tip_t = v_tip;
c = R/AR;
W_b = 0.026*z_MRBL^0.66*c*R^1.3*v_tip^0.67;
J = W_b*R^2/3;
W_hub=0.0037*(z_MRBL^0.28)*(R^1.5)*(v_tip^0.43)...
*(0.67*W_b+g*J/R^2)^.55;
%horizontal stabilizer
W_hs = 0.72*(A_h^1.2)*(AR_h^.32);
%vertical stabilizer
W_vs = 1.05*(A_v^0.94)*(AR_v^0.53)*(n_TG^0.71);
%tail rotor
W_tr = 1.4*(R_t^0.09)*(P_trans/v_tip);
%Weight of nacelles
W_n = 0.041*((n_eng*W_eng)^1.1)*(n_eng^0.24)+0.33*S_wetn^1.3;
%Propulsion system
W_pss = 2*(W_eng^0.59)*(n_eng^0.79);
W_fs = 0.43*V_tot^0.77;
W_ds = 13.6*(P_trans^0.82)*((rpm_eng/1000)^0.037)*...
(((P_trans_t/P_trans)*(v_tip/v_tip_t))^0.068)*...
(n_gb^0.66/v_tip^0.64);
W_sc = 36 * z_MRBL * c^2.2*(v_tip/1000)^3.2;
W_app = 150;
W_hyd = 37 * z_MRBL^.63*c^1.3*(v_tip/1000)^2.1;
W_av = 150; %average avionics

W_fixed = W_pl + W_b + W_hub +  W_hs + W_vs + W_tr ...
+ n_eng* W_eng + W_n + W_pss + W_fs + W_ds + W_sc ...
+ W_app + W_hyd + W_av;

W_nd = W_to/1000;
```

```
%ITERATIVE WEIGHTS
i=1;j=0;
while(i == 1)
    j=j+1;
    W_f = 6.9 * W_nd^.49*L_f^.61*S_wetf^.25;
    W_cc = 11.5*W_nd^.40;
    W_inst = 3.5*W_nd^1.3;
    W_el = 9.6*(P_trans^.65)/(W_nd^.4) - W_hyd;
    W_fe = 6*W_nd^1.3;
    W_lg = 40*(W_nd^0.67)*(n_leg^0.54); %landing gear
    W_acai = 8*W_nd;
    W_mv = 4*W_nd;
    %hp_installed = (W_to^1.5)/(21*0.72*0.94*20);
    hp_installed = BEMT(Cla,Cd,rho,z_MRBL,c/3.3,...
theta_tip,v_tip/3.3,R/3.3,e,100)/745;
    W_fuel = 0.4 * hp_installed *t_mission;

    W_TO = W_fixed + W_fuel + W_f + W_cc + W_inst ...
+ W_el + W_fe + W_lg + W_acai + W_mv;

    W_useful = W_fuel + W_pl;
    if (abs((W_TO - W_to)/(W_TO)) < 0.001)
        i = 0;
    else
        i = 1;
        W_to = W_TO;
        W_nd = W_to/1000;

    end
end

ftval = W_TO/(pi*R^2);
end
```

Blade Element Momentum Theory Code for Power Calculation

```
function Power = BEMT(Cla,Cd,rho,Nb,c,theta_tip,vtip,R,e,Nr)

Rmax = R;       %Maximum Rotor Radius
Rmin = R*e;    %Root Cut out
%CALCULATED VALUES

theta_tip = theta_tip*pi/180;   %Converting deg to rad
TipDeflection = R*theta_tip;
NormalR = sqrt((Rmax-Rmin)^2-TipDeflection^2);
sigma = (Nb*c)/(pi*(Rmax));     %Solidity per rotor
dr = 1/Nr;                      %Radial incriment percentage
r = (dr:dr:1);                  %preallocating the r-range
Cla = Cla*180/pi;               %Converting 1/deg to 1/rad
vz = 0;
Ad = pi*R^2;                    %Disc Area

laminf = vz*(ones(1,length(r)));

i = 1;
lam = zeros(1,length(r));
while i <= 10
    f = (Nb/2)*((1-r)./lam);
    F = (2/pi)*acos(exp(-f));
    F(length(F)) = F(length(F)-1)/2;

    A = (sigma*Cla/16)./(F) - laminf/2;
    B = (sigma*Cla*theta_tip/8)*(r./F);

    lam = sqrt(A.^2 + B) - A;
    i = i + 1;
end

%Calculation of the Coefficients
dCt_on_dr = (sigma*Cla/2)*(theta_tip*(r.^2) - lam.*r);
Ct = sum(dr*dCt_on_dr);
dCpo = (sigma*Cd*dr/2)*(r.^3);
```

```
dCpi = dr*(dCt_on_dr.*lam);
Cp = sum(dCpo + dCpi);

Power = (NormalR/(Rmax-Rmin))*Cp*rho*Ad*((vtip)^3);
end
```

Genetic Algorithm Initialize Population

```
function [] = initialize()
global popl Psize nvar n_prec

popl = zeros(Psize,nvar*n_prec);
for init_i = 1:Psize
    popl(init_i,:) = rndm(nvar*n_prec,0.5);
end

end
```

Genetic Algorithm Tournament Selection

```
function [indv] = tselect()
global popl Psize nvar n_prec tournamentSize

trn_popl = zeros(tournamentSize,nvar*n_prec);
for t_i =1:tournamentSize
    r = int8(random('unif',0.5,Psize+0.49));
    trn_popl(t_i) = popl(r);
end
[indv,temp] = getfittest(trn_popl);
end
```

Genetic Algorithm Uniform Crossover

```
function [indv] = Ucrossover(indv1,indv2)
global nvar n_prec

uc_l = nvar*n_prec;
indv = indv2;
urate = fitness(indv1)/(fitness(indv1)+fitness(indv2));
crsvr = rndm(uc_l,urate);
for uc_i = 1:uc_l
    if crsvr(uc_i) == 1
        indv(uc_i) = indv1(uc_i);
    end
end
end
```

Genetic Algorithm Get Fittest Individual

```
function [ind,ft] = getfittest(Popl)

s = size(Popl);
gf_i = 1;
ft = fitness(Popl(1,:));
for ctr = 2:s(1)
    ft1 = fitness(Popl(ctr,:));
    if ft1<ft
        gf_i = ctr;
        ft = ft1;
    end
end
ind = Popl(gf_i,:);
end
```

Genetic Algorithm Evolve Population

```
function [] = evolve()
global popl Psize nvar n_prec elitism

new_popl = zeros(Psize,nvar*n_prec);
if elitism == 1
    [new_popl(1,:),temp] = getfittest(popl);
    e_offset = 2;
else
    e_offset = 1;
end

%crossover
for e_i = e_offset:Psize
    indv1 = tselect();
    indv2 = tselect();
    new_popl(e_i,:)=Ucrossover(indv1,indv2);
end

%mutate
for e_i = e_offset:Psize
    new_popl(e_i,:)=mutate(new_popl(e_i,:));
end

popl = new_popl;

clear new_popl;
```

Genetic Algorithm Mutate Individual

```
function [indv] = mutate(indv1)
global nvar n_prec mutationRate

m_l = nvar*n_prec;
indv = indv1;
mu_rate = rndm(m_l,mutationRate);
```

```
for m_i = 1:m_l
    if mu_rate(m_i) == 1 && indv1(m_i) == 0
        indv(m_i) = 1;
    else if mu_rate(m_i) == 1 && indv1(m_i) == 1
            indv(m_i) = 0;
        end
    end
end
end
```

random binary bit generation

```
function [d] = b2d(b)

d = 0;k = 1;
for i = 1:length(b)
    d = d + k*b(i);
    k = k*2;
end
end
```

Binary to Decimal Conversion

```
function [d] = b2d(b)

d = 0;k = 1;
for i = 1:length(b)
    d = d + k*b(i);
    k = k*2;
end
end
```

Binary to Decimal to binary

```
function [num] = bin_decode(P,l_bd,h_bd)

H = 2^length(P)-1;
p = b2d(P)/H;
num = l_bd*p +h_bd*(1-p);
end
```

# Bibliography

[1] Marat Tishchenko, *Preliminary Design of Transport Helicopters.* Journal of the American Helicopter Society, Volume 48, Number 2, 2003.

[2] Raymond W Prouty, *Helicopter Performance, Stability, and Control.* Kreiger Publishing Comapny, Malabar, Florida, 2002.

[3] Stephen Glenn Kee *Guide for Conceptual Helicopter Design.* Naval Postgraduate School, Monterey, California, 1983.

[4] Joseph Davis *Design Methodology for developing Concept Independent Rotorcraft Analysis and Design Software.* Georgia Institute of Technology, 2007.

[5] Selim Selvi *A Probabalistic Conceptual Design and Sizing approach for a Helicopter.* Middle East Technical University, 2010.

[6] Lu Xin-lai *Helicopter Sizing Based on Genetic Algorithm Optimized Neural Network.* Chinese Journal of Aeronautics, Volume 19, No.3, 2006.

[7] J Gordon Leishman, *Principles of Helicopter Aerodynamics.* Cambridge University Press, Cambridge, U.K., 2000.

[8] C. Venkatesan *Short Course on Helicopter Technology.* Department of Aerospace Engineering, IIT Kanpur, 1997.

[9] Allen C. Hansen *An Analysis of Three approaches to the Helicopter Preliminary Design Problem.* Naval Postgraduate School, Monterey, California, 1984.

[10] David E. Goldberg, *Genetic Algorithms for Search, Optimization, and Machine Learning.* Addison-Wesley, 1989.

[11] Kalyanmoy Deb, *Multi-Objective Optimization using Evolutionary Algorithms.* John Wiley and Sons, Chichester, UK, 2001.