MISSILE SYSTEM DESIGN AND OPTIMIZATION INTEGRATED WITH SYSTEM ENGINEERING METHODOLOGIES

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submitted by **DENIZ KARATABAN** in partial fulfillment of the requirements for the degree of **Master of Science in Aerospace Engineering Department, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** _______________

Prof. Dr. İsmail Hakkı Tuncer
Head of Department, **Aerospace Engineering** _______________

Assist. Prof. Dr. Ali Türker Kutay
Supervisor, **Aerospace Engineering Dept., METU** _______________

Examining Committee Members:

Prof. Dr. Ozan Tekinalp
Aerospace Engineering Dept., METU _______________

Assist. Prof. Dr. Ali Türker Kutay
Aerospace Engineering Dept., METU _______________

Prof. Dr. Coşku Kasnakoğlu
Electrical and Electronical Engineering Dept., TOBB ETU _______________

Assoc. Prof. Dr. Nilay Sezer Uzol
Aerospace Engineering Dept., METU _______________

Assoc. Prof. Dr. İlkay Yavrucuk
Aerospace Engineering Dept., METU _______________

Date:

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Surname: Deniz Karataban

Signature :

ABSTRACT

MISSILE SYSTEM DESIGN AND OPTIMIZATION INTEGRATED WITH SYSTEM ENGINEERING METHODOLOGIES

Karataban, Deniz
M.S., Department of Aerospace Engineering
Supervisor: Assist. Prof. Dr. Ali Türker Kutay

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In the missile system design process, customer's requirements and system design are entirely interrelated. From the beginning of the design process, customer requirements should be taken into consideration carefully to avoid an inappropriate design. Moreover, in order to handle the changes in the requirements efficiently, both the requirement's implementation into the design and design processes should be accelerated. Within the scope of this thesis, a design optimization tool that provides solutions to these engineering problems has been studied.

This thesis covers an agile and efficient conceptual design optimization tool that ensures the optimal design to fulfill the requirements of the customer.

Various system-engineering methods can be used to convert the customer's requirements into technical parameters. Analytical Hierarchy Process (AHP) and Quality Function Deployment (QFD) methodologies are the most effective ones. With Analytical Hierarchy Process, requirements of the customer are prioritized, then they are linked to the technical parameters with Quality Function Deployment. In detail, QFD shows what the customer wants and how the designer can provide it. By this way, the order of importance of design parameters is revealed. In the meantime, weights of parts of the cost function which is used for optimization are also determined directly with the results of QFD analysis.

For the missile design, external geometry properties are the most ascendant technical parameters. For this reason, in this thesis, the critical technical parameters, which are the geometric properties of the missile, are also studied. By optimizing the critical design parameters, the optimal missile configuration is achieved. In order to obtain the optimal missile configuration, Neural Network and Genetic Algorithm are used together.

As a whole, this tool, which is the consideration point of this thesis, accelerates the conceptual design process, creates alternative configurations, optimizes them according to prioritized technical parameters, assesses them and selects the optimum alternative by incorporating the voice of the customer into the design loop.

Keywords: Missile System, Optimization, MDO, Analytical Hierarchy Process, AHP, Quality Function Deployment, QFD

ÖZ

SİSTEM MÜHENDİSLİĞİ METODOLOJİLERİ İLE BÜTÜNLEŞİK FÜZE SİSTEM TASARIMI VE OPTİMİZASYONU

Karataban, Deniz
Yüksek Lisans, Havacılık ve Uzay Mühendisliği Bölümü
Tez Yöneticisi: Dr. Öğr. Üyesi. Ali Türker Kutay

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Füze sistemi tasarım sürecinde, müşterinin gereksinimleri ve sistem tasarımı her adımda birbiriyle ilişkilidir. Tasarım sürecinin başlangıcından itibaren, uygunsuz bir tasarımdan kaçınmak için müşteri gereksinimleri dikkatli bir şekilde göz önünde bulundurulmalıdır. Ayrıca, gereksinimlerdeki değişikliklerin verimli bir şekilde ele alınması için, değişen gereksinimlerin tasarıma aktarılması ve güncel gereksinimlerle yeniden tasarım süreci hızlandırılmalıdır. Yapılan bu tez kapsamında, bu mühendislik problemlerine çözüm sağlayacak bir tasarım optimizasyon aracı çalışılmıştır.

Bu tez, müşterinin tüm gereksinimlerini karşılamak için en uygun tasarımın yapılmasını sağlayan çevik ve etkili bir kavramsal tasarım optimizasyon aracını kapsamaktadır.

Müşterinin gereksinimlerini teknik parametrelere dönüştürmek için çeşitli sistem mühendisliği yöntemleri kullanılabilir. Analitik Hiyerarşi Süreci (AHS) ve Kalite İşlev Yayılımı (KİY) en etkili olanlardandır. Analitik Hiyerarşi Süreci ile müşterinin gereksinimlerine önceliklendirilir ve Kalite İşlev Yayılımı ile bu gereksinimler teknik pa-

rametrelere bağlanırlar. KİY müşterinin ne istediğini ve tasarımcının bunu nasıl sağlayabileceğini gösterir. Bu sayede, tasarım parametrelerinin önem sırası ortaya konur. Aynı zamanda, optimizasyon parametreleri olarak değerlendirilen teknik parametreler için kısıtlamalar da, KİY analizi ile, gereksinimler göz önünde bulundurularak belirlenebilmektedir.

Füze tasarımı için, dış geometri özellikleri büyük önem taşıyan teknik parametrelerdir. Bu nedenle, bu tezde füze tasarımında kiritk teknik parametrelerden olan, füzenin dış geometri özellikleri de incelenmektedir. Kritik tasarım parametrelerini optimize ederek, optimum füze konfigürasyonuna ulaşılması amaçlanmaktadır. Optimum füze konfigürasyonunu elde etmek için, optimizasyon çalışmalarında, Yapay Sinir Ağı ve Genetik Algoritma birlikte kullanılmaktadır.

Özetle, tez kapsamında geliştirilen araç, kavramsal tasarım sürecini hızlandırmakta, alternatif konfigürasyonlar sunmakta, önceliklendirilen teknik parametrelere göre konfigürasyonlar arasında eniyileme yaparak konfigürasyonları değerlendirmekte ve müşterinin sesini tasarım döngüsüne dahil ederek en uygun alternatifi seçmektedir.

Anahtar Kelimeler: Füze Sistemi, Optimizasyon, Analitik Hiyerarşi Süreci, AHS, Kalite İşlev Yayılımı, KİY

To my lovely parents Serpil-Tulon Karataban

and

To my beloved love Onur Bahçeci

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TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
QFD	Quality Function Deployment
DOF	Degree of freedom
TPM	Technical performance measure
ANN	Artificial Neural Network
GA	Genetic Algorithm
MCDM	Multi-criteria decision making
p	Preference vector
HoQ	House of Quality
CR	Customer’s Requirement
DR	Design Requirement
AI	Absolute Importance
RI	Relative Importance
X, Y, Z	Axes of body reference frame
M	Mach number
α	Angle of attack
δ	Aerodynamic control surface deflections
C_X	Force coefficient in body frame X axis
C_Y	Force coefficient in body frame Y axis
C_Z	Force coefficient in body frame Z axis
C_L	Moment coefficient in body frame X axis
C_M	Moment coefficient in body frame Y axis
C_N	Moment coefficient in body frame Z axis

SSE	Sum of Squared Error
LHS	Latin Hypercube Sampling
BM	Ballistic Missile
MDO	Multi Disciplinary Optimization

CHAPTER 1

INTRODUCTION

1.1 Objective of the Study

Design is a long process. Moreover, design of the complex systems requires consensus of different aspect of views. Initial point in the design process of complex missile system is defining the requirements. Requirements are defined by customers. In terms of expectation from a ballistic missile system, there may be lots of requirements which are competing against or contradicting each other. For these circumstances, there should be prioritization of these requirements. Moreover, the prioritization should be objective and judicious. System engineering methodology which is The Analytical Hierarchy Process (AHP) [31], [32], [33] is used to define and prioritize the requirements.

Even when the requirements are well defined, the relation between the requirements and technical measures are crucial to design at system which satisfies all of the defined requirements. For each requirement, a different technical parameter is more related and more effective. System engineering methodology which is Quality Function Deployment is used to relate requirements with the defined technical measures.

System development lifecycle contains conceptual design, preliminary design and detailed design phases. System concept is determined at the end of the conceptual design phase. Conceptual design is also a multifocal phase. Conceptual design of a ballistic missile contains respectively the design iteration of the aerodynamics, propulsion, mechanical properties flight performance of a ballistic missile at the conceptual design phase, mostly depends on the aerodynamic characteristics of the missile. So, the design of external geometry of the missile can enhance the aerodynamic characteristics, hence the flight performance.

Time limitation is one of the critical parameters for design of ballistic missile systems. The more mature results of conceptual design make the preliminary and detailed design phases shorter. In order to mature the conceptual design results, the optimization should be done. Moreover, during the optimization, the requirements should be taken to the consideration.

The optimization of external geometry of a ballistic missile is a challenging issue. Many different optimization algorithms have been used so far in this area. Furthermore, because of the complexity of the missile system, the optimization takes long time. In this thesis, in order to find an optimum external geometry of a ballistic missile, Genetic Algorithm is used. Also, the large design space and the complexity of the missile system are regarded and Neural Network is used as a part of the optimization process.

The main purpose of this thesis is to propose a ballistic missile external shape optimization tool which is integrated with system engineering methodologies. For this purpose, this thesis contains four main keystones. They are AHP, QFD, conceptual design of a missile system and optimization of the design. By partsgoing through these stages, requirement analysis is directly included to the design, thus the optimal design satisfying the requirements can be found.

1.2 Literature Review

AHP and QFD are used for defining the requirements, prioritization of requirements and determining the relation between the requirements and technical measures. Moreover, conceptual design of the missile, especially the design of the external geometry of the missile is a commonly studied topic. Optimization is a widely used to enhance better solutions for any problem. Also, there are different methods and algorithms used for optimization.

In ballistic missile conceptual design, the purpose is to satisfy requirements as much as possible. In other words, the main aim is to provide a mature design for preliminary phase. Prioritization of the requirements and relating them with technical measures, paves the way for a more mature conceptual design. Moreover, there may be more than one missile configuration which satisfies the requirements. For such cases, the optimal solution in terms of the determined technical performance measures should be chosen as the concept design.

There are different tools which are used to design and optimize missile systems. In 2009, EXCON tool is developed by Tanil [36]. EXCON is used for conceptual design and optimization of external geometry of subsonic cruise missiles which are surface to surface and air to air missiles. Genetic algorithm is used as an optimization method. Moreover, two degree of freedom simulation is used for analysis of the obtained missile.

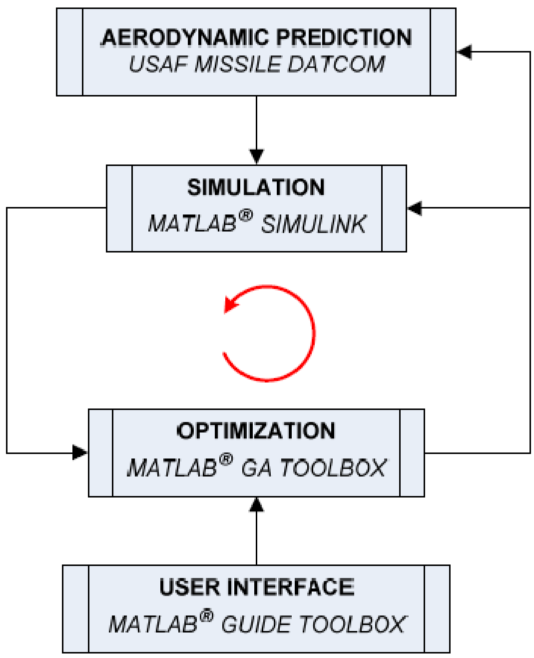


Figure 1.1: Flowchart of EXCON (Tanil, 2009) [36]

In 2009, Riddle, Hartfield, Burkhalter and Jenkins [29] carried out a study "Genetic-Algorithm Optimization of Liquid-Propellant Missile Systems" which whole parts of the conceptual design is considered for a liquid-propellant missile system. Aerodsn and Missile Datcom are used for aerodynamic analysis and they are compared. Moreover, genetic algorithm is used for optimization of propulsion and aerodynamic characteristics of the missile. The results are compared with 6 DOF missile simulations.

In 2012, Yang, Jung, Cho and Myong [43] conducted a study named "Aerodynamic Shape Optimization System of a Canard- Controlled Missile Using Trajectory-Dependent Aerodynamic Coefficient". In this study, shape optimization of a guided missile is analysed. The main aim is to maximize the range of the guided missile by performing aerodynamic shape optimization. Moreover, genetic algorithm is used as the optimization method. Trajectory is considered by 3 DOF missile simulation.

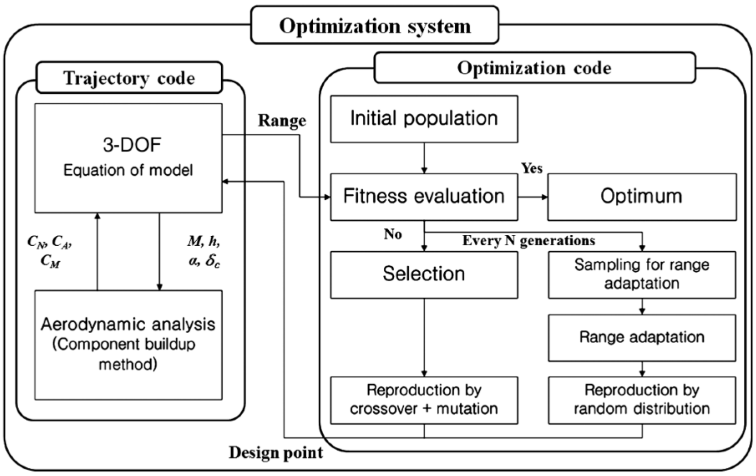


Figure 1.2: Flowchart of Range Maximization System for a Guided Missile by Yang [43]

Ahmed and Qin 2 performed a study in 2009 named "Surrogate-Based Aerodynamic Design Optimization: Use of Surrogates in Aerodynamic Design Optimization". In this study, metamodels are tried to be constructed to decrease the effort for aerodynamic design optimization. Artificial Neural Network and Genetic Algorithm are used together for aerodynamic design optimization.

There are also different studies about the usage of Analytical Hierarchy Process and Quality Deployment Function.

In 2011, Garrett, Laveck and Rhodes [18] carried out a study "Using Technical Performance Measures". Technical performance measures (TPM) are defined for a rocket programme. Also, different decisions regarding the design are studied. The effects of different decisions, by comparing the TPMs, are studied. Utility Analysis, which is used at Pratt & Whitney Rocketdyne J-2X rocket engine programme, is described.

Büyüközkan, Ertay, Kahraman and Ruan [9] performed a study in 2004 named "Determining the Importance Weights for the Design Requirements in the House of Quality Using the Fuzzy Analytic Network Approach". In this study, more general form of the Analytical Hierachy Process, Analytic Network Process is used in House of Quality matrix. By this way, customer needs (CNs) and design requirements (DRs) are related by regarding the priority of needs. Moreover, ANP provides to prioritize the DRs by taking the interdependence between the CNs and DRs and the inner dependence among them into account.

In 2002, a study is conducted by Kumpel, Barros and Mavris [22] named "A Quality Engineering Approach to the Determination of the Space Launch Capability of the Peacekeeper ICBM Utilizing Probabilistic Methods". In this study, alternative concepts of Peacekeeper ICBM which can be used as an expendable launch vehicle are evaluated by integrated product and process development approach. Customer needs are directly added to the decision making step.

In 2017, a study is carried out by Tsegaw, Blasundaran and Kumar [39] about the usage of QFD in conceptual product design process. In this study, general design and production method is stated by integrating the QFD. Also, the QFD analysis effect on decreasing of design and manufacturing problems is stated in this study.

As an example of usage of Neural Network and Genetic Algorithm together for the optimization, "Airframe Performance Optimization of Guided Projectiles Using Design of Experiment" study can be given. It is performed by Fowler and Rogers [15] in 2015. The design problem is range extension by optimizing the projectile configuration. At the same time, impact velocity is aimed to increase and value of maximum angle of attack value is tried to minimize. For each case, different projectile configuration is created by using GA and Neural Networks. When this optimization method is used, the range extension of projectile is succeeded.

Genetic algorithm is not only used for system design problems for missiles, but also optimization of subcomponents. In 2018, Rasuo, Vidanovic and Kastratovic [28] performed a study named “Multi-Disciplinary Design Optimization of Missile Fin Configuration”. In this paper, aerodynamic and structural optimization is considered for a short range ballistic missile. Genetic algorithm is used for the shape optimization of missile fin configuration. As a result of the study, the optimal configuration for fin presents more reliable and improved performance. With optimized finset, structure response to critical stress is reduced. Also, range extension is succeeded.

For design and optimization of very light aircraft, “Process of Establishing Design Requirements and Selecting Alternative Configurations for Conceptual Design of a VLA” is performed by Bae, Kim, Lee, Nguyen and Chung [21] in 2017. In this study, system engineering based requirement analysis method AHP is used. Then QFD is used to reflect the voice of customer. Then, results of these analyses are taken into consideration and different configurations are created. TOPSIS which is one of the system engineering methods to choose the most appropriate configuration is used and the optimal VLA configuration is chosen.

In 2018, Rajaram, Cai, Chakraborty and Mavris [27] are carried out a study “Integrated Sizing and Optimization of Aircraft and Subsystem Architectures in Early Design”. In this study, multi objective optimization of specific two types of aircraft is considered. Genetic algorithm is used for optimization. Difference of this study is that subsystem architecture is also a design and optimization parameter.

In 2009, Öztürk [26] performed a study named "Multiobjective Design Optimization of Rockets and Missiles". In this study, basic performace parameters which are range, angle of hit and time of flight are considered. Multiple Coolign Multiobjective Simulated Anneling algorithm is reworked. The modifes algorithm is applied to different optimization problems for missile design. For the flight simulation of a missile, 2 DOF simulation algorithm is used.

Tekinalp and Bingol [37] carried out a study named "Simulated Annealing for Missile Optimization: Developing Method and Formulation Techniques" in 2004. In this study, optimization of trajectory of missile and combined optimization of design and control variables and a new points of views to hide-and-seek optimization method are regarded.

In 2011, Dede [13] studied "External Geometry and Flight Performance Optimization Of Turbojet Propelled Air To Ground Missiles". In this thesis, multi objective optimization for air to ground missiles is considered. Non Dominated Sorting Genetic Algorithm and Multiple Cooling Multi Objective Simulated Annealing Algorithm are used as heuristic optimization methods. Moreover, a surrogate model which contains Simulated Annealing and Genetic Algorithm is focused. These three methods are compared as solutions of for the missile external optimization problem.

For the optimization of the trajectory of nano satellite launcher, "Conceptual Design Optimization of a Nano-Satellite Launcher" is carried out by Arslantaş [4] in 2012. Multi-Criteria Multi-Objective Simulated Annealing is used for this study. As parameters of the optimization problem, specific aerodynamics and propulsion system parameters are chosen.

For the usage of QFD and Genetic Algorithm in optimization problems, study in different areas can be found. Jianmin, Jun and Hui [20] carried out a study in 2016 named as “Optimization Design Method of PSS Based on GA and QFD”. In this study, product service system design is optimized by using genetic algorithm and Quality Function Deployment. As a case study, sewage treatment system is optimized by using GA and QFD. As a result of this study, it is seen that optimized system meets the customer needs more satiably. Also, the optimized configuration reduces the cost and the process capability for decontamination of water increases.

1.3 Contributions

The contributions of this thesis provide can be listed as follows:

- Results of Analytical Hierarchy Process (AHP) will be implemented into Quality Deployment Function (QFD),
- AHP and QFD are directly used in conceptual design of a ballistic missile,
- QFD will be used as a determinative proves for cost function and constraints of an optimization problem,

- Artificial neural network will be used together with genetic algorithm for an optimization problem of a ballistic missile system,
- Compared to other studies in the literature, system engineering methodologies which are AHP and QFD will be implemented to conceptual design of a ballistic missile. Moreover, optimization of this missile will be done in same study.
- A tool will be improved which serve both the customer and technical team.

1.4 The Scope of the Thesis

In the following sections, the missile optimization and design integrated with system engineering methodologies and the developed tool are described. Firstly, the general information about the parts of the tool is detailed. Chapter 2 contains information about the Analytical Hierachy Process. Chapter 3 includes the information and analysing techniques of Quality Function Deployment. Brief information about conceptual design of a missile system is given in Chapter 4. Genetic algorithm which is used as optimization method in this thesis and neural network are explicated in Chapter 5. In Chapter 6, the implementation of the previous chapters into the tool is described. The developed tool is introduced completely. Chapter 7 containes two different case studies for optimization of external geometry of surface to surface, tail controlled, ballistic missiles which have same requirements with different priorities. Chapter 8 is the final chapter of the thesis. Here, the conclusions of the thesis are stated. Moreover, some suggestions for future works are given as well.

CHAPTER 2

ANALYTICAL HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) is developed by Thomas L. Saaty in the late 1970s to organize and analyse complex decisions. The AHP is a multi-criteria decision making (MCDM) method which commonly used in defence, transportation and healthcare areas. AHP is an effective tool to cope with complex decisions and it helps to prioritize and make the most appropriate decision. In other words, AHP is a decision support tool. Pairwise comparisons and synthesis of the results with the AHP provide to apprehend both the subjective and objective aspects of the decision. Furthermore, AHP shows the consistency of the decision maker and it makes the priority of the decision clear. AHP has been applied in a variety of decision-making scenarios as follows:

- Selection of one alternative from a set of alternatives.
- Prioritization of a set of alternatives.
- Making best combination of alternatives subject to a variety of constraints.
- Benchmarking – of processes or systems with other, known processes or systems.
- Quality management.

The advantages of AHP are addressed by Saaty (1990,22-26) as in Figure 2.1.

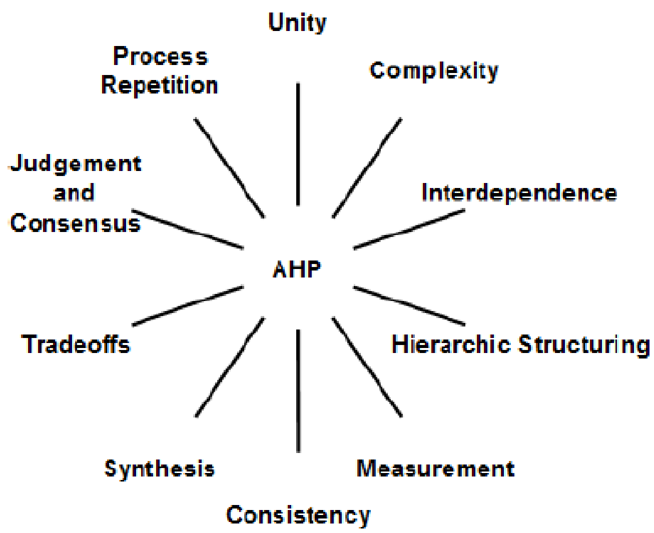


Figure 2.1: Advantages of AHP [32]

2.1 How The AHP Works

The AHP contains a set of alternative options and evaluation criteria in order to make the best decision. During the analytical hierarchy process, a weight for each evaluation criteria is generated by pairwise comparisons. The criterion which has higher weight is more important at the pairwise comparison.

2.2 Features of the AHP

The computations, which are made by the AHP, are always guided by the decision maker's experience, so AHP can be considered as a tool that is able to translate the evaluations (both qualitative and quantitative) made by the decision maker into a multi criteria ranking. [31]

For the problems which have many criteria and options, the AHP may entail a large number of evaluations. Although, evaluations include just comparison of the criteria, the number of pairwise comparisons grows quadratically with the number of criteria. Hence, the comparison may be getting unreasonable for decision maker. From this side, the matrix of AHP should be tried to be downsized.

The most distinctive feature of AHP into all other decision-making methods is the use of pairwise comparisons to input quantitative information. This feature provides to compare each option head-to-head (one-on-one) with each of the other options. For requirement definition problem, this feature provides to sort the requirements according to priority.

2.3 Principles of the AHP

There are three main principles of AHP. They are decomposition, comparative judgement and hierarchic composition or synthesis of priorities.

2.3.1 Decomposition

The decomposition is applied to understand and construct the hierarchy of decision problem. The construction of the hierarchy can be schematized as in Figure 2.2.

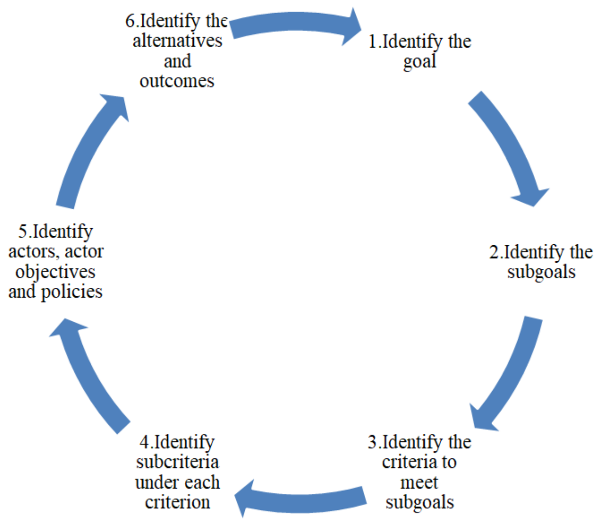


Figure 2.2: Construct of Hierarchy [32]

The first step of the construction is stating the overall objective. The second step is to get the main objective details by identifying the subgoals. The most important part is the third step. At that step the major factors and parameters which affect the decision are determined by brainstorming. These factors are called as criteria. At the fourth step, the criteria are broken to the subcriteria. For example, safety (criterion) for a missile system depends on reliability, maintenance defects, failure modes and design defects (subcriteria). At the fifth step, the decision maker can determine the actors and their objectives. This step may not be used for the initial analysis steps. At the final step, the decision is made. The general visualisation of the constructed hierarchy as in Figure 2.3.

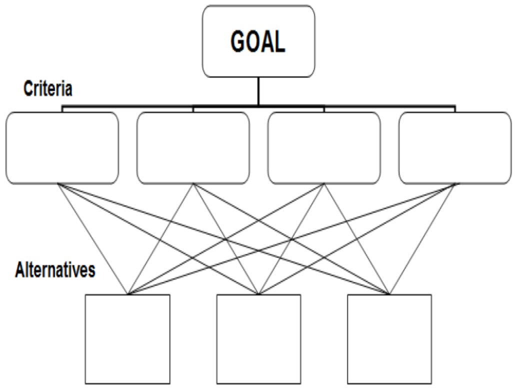


Figure 2.3: The Constructed Hierarchy [33]

2.3.2 The Comparative Judgement

The comparative judgements are applied to make pairwise comparisons of all combinations of elements of hierarchy. The comparative judgement part makes the analytical hierarchy process a quantitative tool. The criteria are graded according to the scale which is given at Table 2.1.

Intensity of Importance	Definition	Explanation
1	**Equal Importance**	**Two activities contribute equally to the objective**
2	Weak	
3	**Moderate Importance**	**Experience and judgement slightly favor one activity over another**
4	Moderate Plus	
5	**Strong Importance**	**Experience and judgement strongly favor one activity over another**
6	Strong Plus	
7	**Very Strong or Demonstrated Importance**	**An activity is favored very strongly over another; its dominance demonstrated in practice**
8	Very, very Strong	
9	**Extreme Importance**	**The evidence favoring one activity over another is of the highest possible order of affirmation**

Table 2.1: The Comparative Judgement Scale [38]

2.3.3 Hierarchic Composition or Synthesis of Priorities

The hierarchic composition or synthesis of priorities is applied to make the local priorities of each element global priorities in the problem. All of the criteria are aligned at the hierarchic composition.

2.4 Mathematical Theory of AHP

As mentioned before, the main aim of the AHP is making decisions by comparing criteria. Preferences in the AHP are determined on the basis of pairwise comparison. Preference process includes the evaluation of each element with all the other elements

at a given hierarchical level. Element is a criterion for the decision.
For the pairwise comparison, a matrix, which can be called as preference matrix, must be constructed.

$$[a_{ij}], \quad \text{where} \quad i,j = 1,2,...,n \tag{2.1}$$

$$a_{ij} = 1 \quad \text{for} \quad i = j, \tag{2.2}$$

$$a_{ij} = \frac{1}{a_{ji}} \quad \text{for} \quad i \neq j. \tag{2.3}$$

Equation 2.1, equation 2.2. and equation 2.3 explain the basis of matrix. Equation 2.1 means that there is a matrix with dimensions n×n and n is the number of criteria. Equation 2.2 is an expression of the principle of identity of the matrix. If there are two identical criteria compared with each other, decision does not differentiate with them. Hence, all the element values along the diagonal of the matrix are 1.
For the comparisons between criteria at a given hierarchical level, a criterion in row i is compared with a criterion in column j. Also, a_{ij} shows that how much (or less) important the i-th criterion is than the j-th criterion. In that sense, if the i-th criterion is x times more important than j-th criterion, then j-th criterion is 1/x as important as the i-th element. The equation 2.3 states that principle. Hence the pairwise comparison matrix becomes as in the equation 2.4 ;

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \tag{2.4}$$
$$\text{where} \quad a_{ij} = \frac{1}{a_{ji}} \quad \forall i,j.$$

During the construction of the matrix which has n criteria, it is sufficient to give the values just the above of the diagonal in matrix A. Therefore, the total number of comparison is in the equation 2.5 ;

$$\frac{n(n-1)}{2} \tag{2.5}$$

In the AHP analysis, preference vector gives the order of precedence for requirements. This vector is calculated by using Saaty's method. This method is detailed in [8] and [10].
Saaty's method bases on normalised arithmetic averages. The results of the pairwise comparison matrix (A) are normalised. The normalized matrix can be called as matrix B. The components of the B matrix are calculated as in equation 2.6.

$$\begin{gathered} \mathbf{B} = [b_{ij}] \\ b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \end{gathered} \tag{2.6}$$

The evaluation of results for prioritization of criteria is achieved by calculating the arithmetic averages from the row of the normalized comparison matrix. The components of this vector are calculated as in equation 2.7.

$$p_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \tag{2.7}$$

The preference vector p gives the order of precedence for the requirements. This vector is also called as normalized principal Eigenvector. An example for the calculation of preference vector can be found in Appendix A.

2.5 Usage of the AHP in Requirement Analysis

The most common usage area of AHP in system engineering, in other words the most common problem in system engineering which AHP is applied, is helping customer understand and prioritize their own requirements. The three main parts of AHP are schematized for this problem as in figure 2.4.

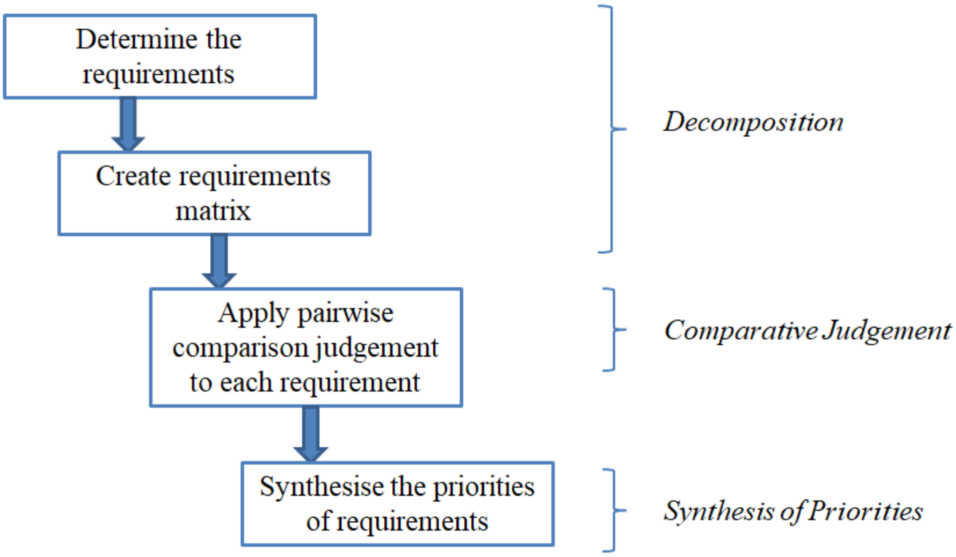


Figure 2.4: AHP Steps for Requirement Definition

Determination of the requirements is completely related with the definition of the problem. Customers tell what they want as a product in different aspects.They explain the performance, environmental, safety etc. requirements. These requirements are criteria for the customers. This is the first step of decomposition part. As mentioned before, at the decomposition part, the AHP matrix is created. This matrix is constructed as in figure 2.5.

Criteria (Requirements)	Criterion 1 (Requirement 1)	Criterion 2 (Requirement 2)	Criterion 3 (Requirement 3)
Criterion 1 (Requirement 1)	1	X	Y
Criterion 2 (Requirement 2)	1/X	1	Z
Criterion 3 (Requirement 3)	1/Y	1/Z	1

Figure 2.5: AHP Matrix

This matrix is used to conduct pairwise comparison. Each criterion is compared with each other. The scale ranges from one to nine. Scale table is called as Saaty Scale. One implies that compared elements have equal importance. On the other hand, nine implies that the criterion which is on column is extremely more important than the criterion on the row. The pairwise scale is shown in table 2.2.

Table 2.2: Saaty's Scale [34]

Scale	Verbal Expression	Explanation
1	Equal Importance	Two activities contribute equally to objective
3	Moderate Importance	Experience and judgement slightly favour one activity over another
5	Strong Importance	Experience and judgement strongly favour one activity over another
7	Very Strong Importance	An activity is favoured very strongly over another
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation

After the pairwise comparison, the synthesis of the priorities of the requirements is performed. At this step, preference vector which is the prioritization of the requirements is appeared. Abovementioned methods are used for this step. In this study, Saaty's Method is used for the the synthesis of the priorities of the requirements. The preference vector which is obtained at the end of the the synthesis of the priorities of the requirements step is used as an input for the QFD. Recently AHP has been proposed for application to QFD to generate the relative importance of the voice of customer.

CHAPTER 3

QUALITY FUNCTION DEPLOYMENT

Quality function deployment (QFD) is “an overall concept that provides a means of translating customer requirements into the appropriate technical requirements for each stage of product development and production (i.e., marketing strategies, planning, product design and engineering, prototype evaluation, production process development, production, sales)” (Sullivan, 1986b). Quality Function Deployment was developed by Yoji Akao in Japan in 1966. By 1972 the power of the approach had been well demonstrated at the Mitsubishi Heavy Industries Kobe Shipyard (Sullivan, 1986) and in 1978 the first book on the subject was published in Japanese and then later translated into English in 1994 (Mizuno and Akao, 1994) [39].

QFD has four phases in whole design and production process. These phases are product planning, product design, process planning and process control.

- Phase 1- Product Planning:

  Product planning is building the House of Quality. Product planning phase documents customer requirement, technical measures and technical ability of the design team to satisfy each customer requirement. This phase is the basis of the QFD. Most of the companies, which are related with design of complex systems, use only this phase of QFD process. In this study, conceptual design of a missile system will be detailed, in that sense only the product planning phase will be used for QFD analysis.

- Phase 2- Product Design:

  This phase requires creativity and innovative engineering ideas. At this phase concept of the product is created and some of the specifications are documented.

- Phase 3-Process Planning:

  Process planning phase is directed by manufacturing team. During this phase, manufacturing processes are schematized and target values of process parameters are documented.

- Phase 4-Process Control:

  Process control phase is the final phase of the QFD. The main aim of this phase is quality assurance by using the quality check points.

These four phases can be summarized as in figure 3.1;

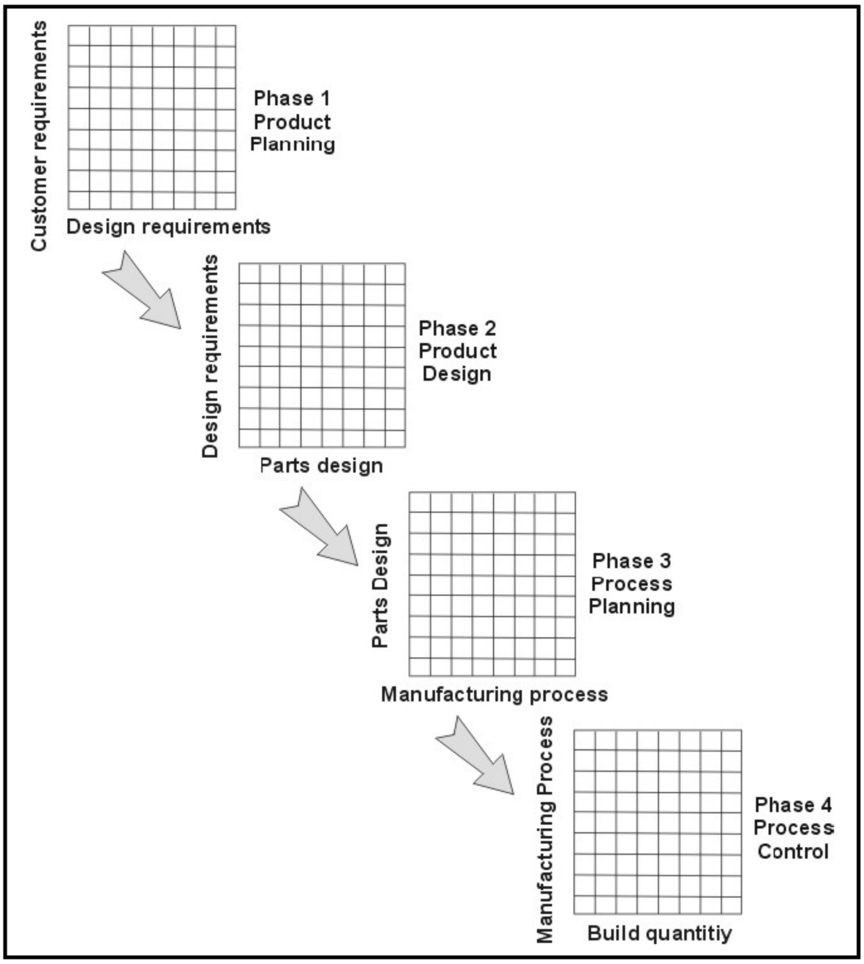


Figure 3.1: Phases of QFD [19]

As mentioned before, QFD has been used from 1966. According to the Reference

[41], organizations, which are applying the QFD, realized,

- %30 to %50 reduction in engineering charges and
- %30 to %50 reduction in design cycle time.

There are some statistical studies for determination of decrease in number of design changes when the QFD is used. The results are concluded as in figure 3.2. The figure 3.2 shows that when the QFD method is used, design changes decreases during the design cycle.

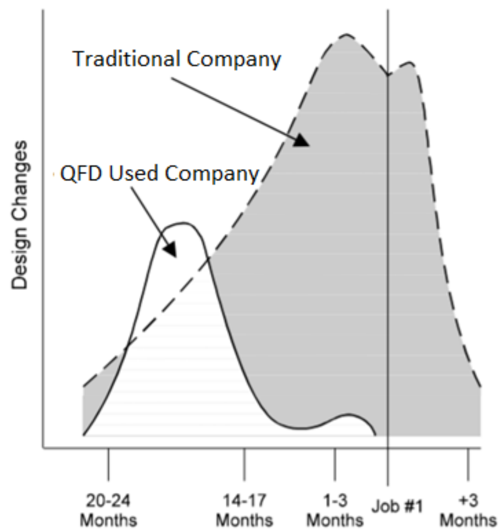


Figure 3.2: Comparison of Design Changes Necessary with and without QFD

Although there are different phases of QFD, it is mainly used as a systematic design and analysis tool to translate customer requirements into engineering characteristics which are technical performance measures via the House of Quality Matrix. This tool enables to have a technically feasible design concept via customer driven product. By using the QFD analysis three main goals are aimed. They are summarized in foolowing as in Reference [19]:

- Prioritize spoken and unspoken customer wants and needs.
- Translate these needs into technical characteristics and specifications.

- Build and deliver a quality product or service by focusing everybody toward customer needs' satisfaction.

3.1 House of Quality Matrix

For three main purposes which are listed at the end of the previous section, the House of Quality Matrix is used in QFD analysis. The house of quality matrix is composed by numerous rooms, in other words steps. Figure 3.3 shows the complex QFD analysis matrix.

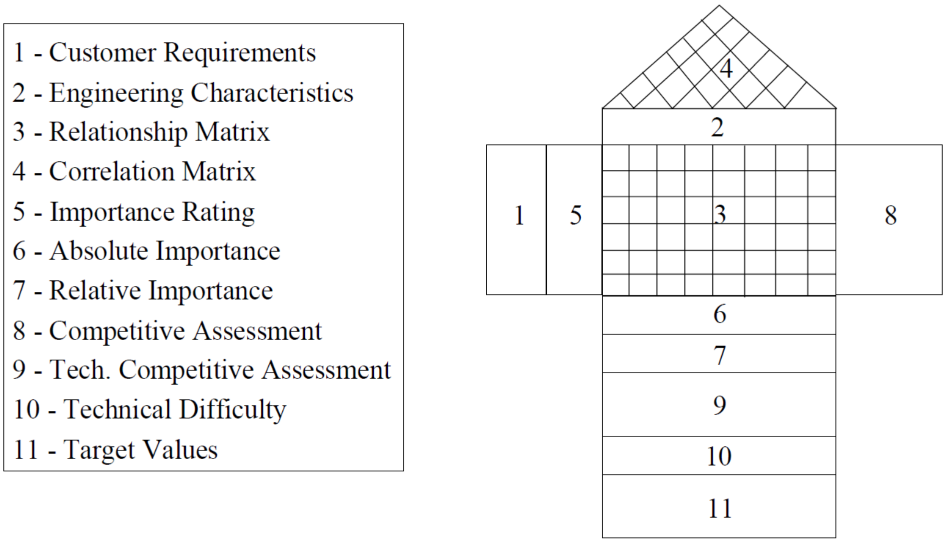


Figure 3.3: Rooms of House of Quality Matrix [22]

As seen in the figure 3.3, there are eleven rooms in a complex QFD matrix. Each room represents different steps of QFD analysis. According to usage case, different combinations of the rooms can be used for analysis.

The first and the second rooms which are Customer Requirements and Engineering Characteristics are the main stone of the QFD. Customer requirements room is referred as "Whats" which mainly are the needs of customer. Ingredients of this room are the initial requirements of the designed system. The second room is Engineering Characteristics. This room is referred as "How" which contains design / technical attributes. According to system which will be designed, technical parameters are changed.

The third room, Relationship Matrix is the main body of the QFD diagram. It reflects the relationship between customer needs and design attributes, in other words it shows the correlation between the first room and the second room. Mainly there are three possibilities for relation of “Whats” and “Hows”. They can be classified as weak, medium or strong. Each classified group is allied to a quantitative value. By using this room, all of the requirements are allocated to engineering parameters.

The fourth room, which is the roof of the House of Quality, is called as the Correlation Matrix. This room is used to correlate engineering characteristics to each other. This room is very essential in the trade-off studies. There are four different relationship used in roof section. They are positive, strong positive, negative and strong negative.

The fifth room is the Importance Rating Room. This room sorts the customer requirement based to importance. Importance is coefficient of the requirements. Coefficients are determined by using Analytical Hierarchy Process. The Analytical Hierarchy Process is detailed in Chapter 2.

The sixth room which is the Absolute Importance is obtained by multiplying the numerical value in each of the cells of the Relationship Matrix by the importance rating. These resulting values are then summed for each column in the Relationship Matrix to obtain the absolute importance. Actually, the final result of the QFD analysis is the Absolute Importance coefficients.

The seventh room, Relative importance is the normalized scale from 1 to 100 of the absolute importance. Value of this room, provide the rapid identification of the engineering characteristic for the design problem in terms of importance.

The eighth and ninth rooms are The Competitive Assessment and Technical Competitive Assessments rooms. These rooms are useful if there are a lot of competitive products. These rooms show the relationship between customer’s requirements and competitive products’ features.

The tenth room is The Technical Difficulty room. This room shows the easiness level of achieving to the each engineering characteristics by a numerical scale. Numerical values are estimated by design team based on the probability of achieving the target values.

The final room is the eleventh one which is The Target Values room. This room contains the goals of the engineering characteristic by considering the requirements. These target values are the basis of design process.

As described in previous parts, all of the important points of design could be considered in a QFD analysis with different rooms. According to the case, some of the rooms could be excluded from the House of Quality Matrix.

3.1.1 Construction of Matrix

According to the described rooms, the House of Quality Matrix is constructed. Initially, the customer's needs are clarified and specified. The specified requirements are implemented to the related room in the matrix. After that, the technical team examines the requirements and related technical parameters are designated. As mentioned before, these parameters reflect formation of the characteristics of the customer matrix ("What?") in the technical characteristics ("How?"). These parameters are implemented to the related room which is the Engineering Characteristic Room. Then, the mapping for the relationship between the customer's requirements and engineering characteristics is done by technical team and is written into the Relationship Room. For different user of QFD, this relationship can be shown in different ways. In detail, some of the QFD operators use symbols to show the strength of the relevance, behind, some of them use the numerical values. Usage of numerical values makes the metric more understandable and more objective. These steps of QFD analysis can be schematized as in figure 3.4.

In addition to these steps, there is a step for prioritization of the requirements. The determination of the values in this room is a work other than QFD. As mentioned before, the prioritization of the requirements is done with the Analytical Hierarchy Process. The requirements' importance values are obtained in the AHP and implemented into the Importance Rating Room of the House of Quality (HoQ).

After the construction of matrix and the relationships between the requirements and

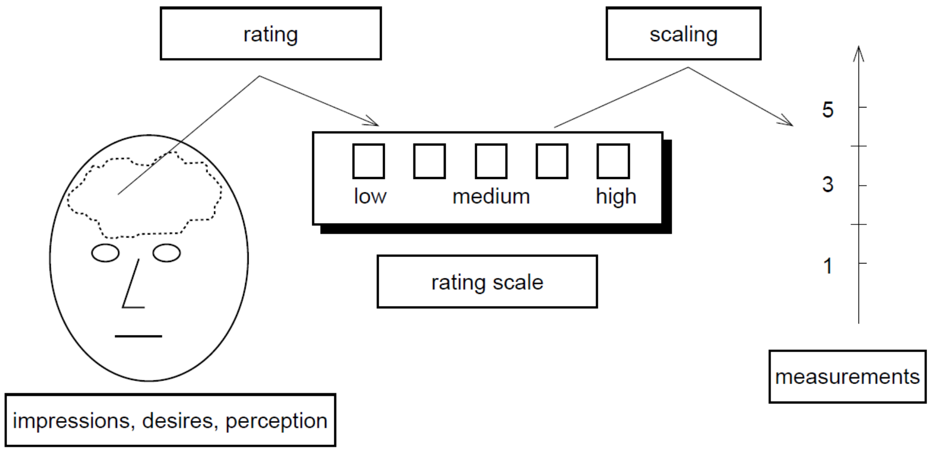


Figure 3.4: Scheme for QFD Analysis [16]

technical measures are determined, absolute importance and relative importance for each technical measure are calculated.

3.1.2 Mathematical Theory of QFD

As abovementioned, after the matrix construction, absolute importance and relative importance for each technical measure are calculated. Moreover, the results, which are the coefficients for the priority of the requirements, from AHP are implemented and included to the calculation to prioritize the requirements and technical measures. Firstly, in order to explain the mathematical theory of the QFD, we can summarize the HoQ matrix as in figure 3.5. In figure 3.5, CR represents customer's requirements, DR represents design requirements which are technical requirements, R indicates the relation between the corresponding CR and DR and d indicates the priority of the CR. d directly comes from the results of the AHP.

For the R_{ik}, it shows the relationship between CR_i and DR_k. This coefficient is a scale based on 4 points scale. This scale can be configured according to the user of the QFD. Basically, the relationship intensity between customer requirements and the technical measures are graded as 0 for unrelated pair, 1 for weak relationship, 3 for moderate relationship and 9 for strong relationship. These values are varied according to the analyser. The main consideration point during the determination of the scale

Design Requirement (DR) / Customer Requirements (CR)	**DR1**	**DR2**	**DR3**	**..**	**DRk**	**Importance (AHP Results)**
CR1	R_{11}	..	..	..	..	d_1
CR2	..	..	..	..	..	d_2
CR3	..	..	..	..	..	d_3
..	..	..	..	..	..	
CRi	..	..	..		R_{ik}	d_i
Absolute Importance	AI_1	..	..	..	AI_k	
Relative Importance	RI_1	..	..	..	RI_k	

Figure 3.5: HoQ

is making difference more visible. In other words, by increasing the difference at the numerical values, the effectiveness rates of the technical measures are made more understandable.

Scale	**Relationship Intensity**
0	Unrelated
1	Weak
3	Moderate
9	Strong

Figure 3.6: Scale of Relationship in HoQ

In order to evaluate the relative importance of a technical parameter, firstly the absolute importance is calculated. Absolute importance (AI) is calculated as in equation 3.1 by sum of multiplication of the priority coefficient with the corresponding coefficient of relation intensity for each customer requirement.

$$AI_k = \sum_{i=1}^{n} d_i R_{ik} \tag{3.1}$$

Although the absolute importance shows the importance level for each technical parameter, there is a more understandable parameter which is relative importance (RI). Relative importance indicates the importance of the technical parameters in all of the technical parameters in the range of 0-100. In that sense, the used formulation for relative importance (RI) can be written as in equation 3.2:

$$RI_k = \frac{\sum_{i=1}^{n} d_i R_{ik}}{\sum_{k=1}^{k}(\sum_{i=1}^{n} d_i R_{ik})} * 100 \tag{3.2}$$

The obtained importance coefficients show the ranking of the technical measure. This ranking provides both customer and technical team to understand the critical design parameters. Generally these critical design parameters are both the cost and constraint function during the optimization problems. Moreover, the House of Quality matrix is a simple method to show linkage between technical parameters and requirements. In that sense, at the end of the QFD process, requirements are clearly defined by customer and clearly understand by technical team.

CHAPTER 4

CONCEPTUAL DESIGN

Design is a long and iterative process. It is divided to phases in order to organize this complex process. Mainly, there are three design phases which are conceptual design, preliminary design and detailed design. System development lifecycle, in other words design of a system, can be schematized as in figure 4.1.

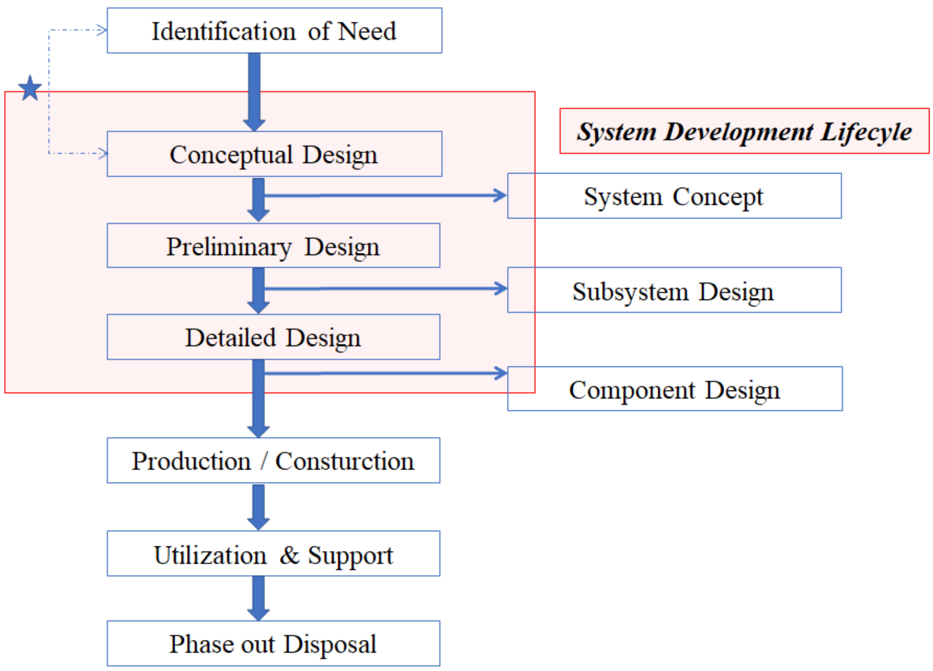


Figure 4.1: System Development Lifecycle

In this study, conceptual design phase is emphasized. The conceptual design is aimed at investigating and developing of good understanding of the required system, and defining the very general type of solution that will be pursued, for the system and the subsystems [5]. This phase of design is an explicit construction of ideas or concepts that a user needs to learn about what a product is, what it can do, and how it is intended to be used.

Conceptual design is an iterative process for both designer and customer. Designer tries to achieve a balance between inputs and outputs. Also, customer tries to tailor the requirements according to own priorities and initial design solutions. By iterative process, the requirements are clearly stated and the methods for satisfying the design objectives are expressed during the conceptual design.

At the conceptual design, the main aim of the designer is finding the best configuration, which will be input for the preliminary design, as rapid and correct as possible. But, especially for the design of very large and complex systems, like missile systems, requirements and design are too much intricate to solve rapidly. Moreover, there are some constraints due to project schedule, small number of team members and uncertainties on the system requirements. Under these circumstances, the main difficulty of the conceptual design rises that the relationship among the design objectives, which are the requirements, and the design parameters are generally not modelled or understood. In order to overcome this problem, a multidisciplinary design should be applied.

As explained in the previous sections, there are some system engineering methods to link requirements and technical parameters. These methods play a leading role in conceptual design. Moreover, in order to obtain optimal multidisciplinary design, analysis and synthesis in several disciplines concurrently is a keystone of conceptual design. Since a set of complex interrelations exist between mission requirements and constraints such as trajectory shaping, propulsion, weights and aerodynamics, an appropriate optimization strategy should be applied in order to match conflicting goals [23].

4.1 Conceptual Design of Missile Systems

The mission requirement synthesis in the conceptual design of missiles is an iterative process that requires the evaluation of alternative external geometry configurations and resizing the missile. Initial steps of the conceptual design stage are the mission definition and weapon requirements [14]. Iteration of the conceptual design of a missile can be schematized as in figure 4.2.

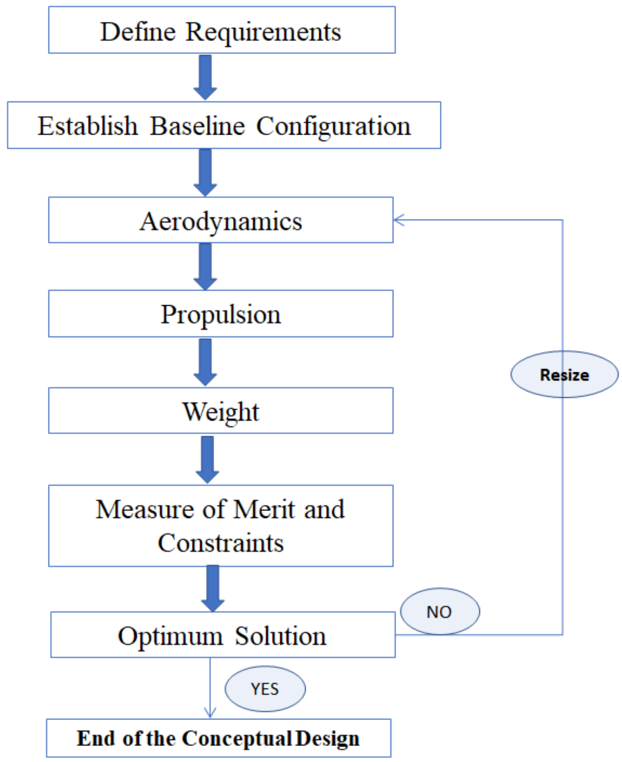


Figure 4.2: Iteration of Conceptual Design of Missile

Initial baseline from competitor study for desired missile with similar propulsion is recognized. It is used as a starting point for the design iteration. Then according to detailed customer's requirements, baseline of missile aerodynamics, propulsion, weight and flight trajectory are improved. Performance requirements which are mostly driven by the relationship of technical parameters and customer's requirements are evaluated. Aerodynamic design part of the conceptual design process is an investigation of alternatives in configuration geometry. Then, the results of conceptual aerodynamic design are inputted to the propulsion system and structural design for weight estimation.

During the conceptual design of the missile systems, there is always time limitation. Because of that, investigation of the configuration in depth is not very possible. Number of input variables, which can be listed as missile length, diameter, nose shape, nose length, body properties, number of fin sets, fin set location etc., are excessive. Moreover, there are some limitations which come from the launch platform, cost and production time. Although all of these limitations, the conceptual design results should be improved. Requirements implementation for appropriate design and optimization should be gathered to overcome difficulties. In order to make that, conceptual design iteration of missile can be reformed by integration of system engineering tools into the design loop directly. Design loop can be seen in figure 4.3.

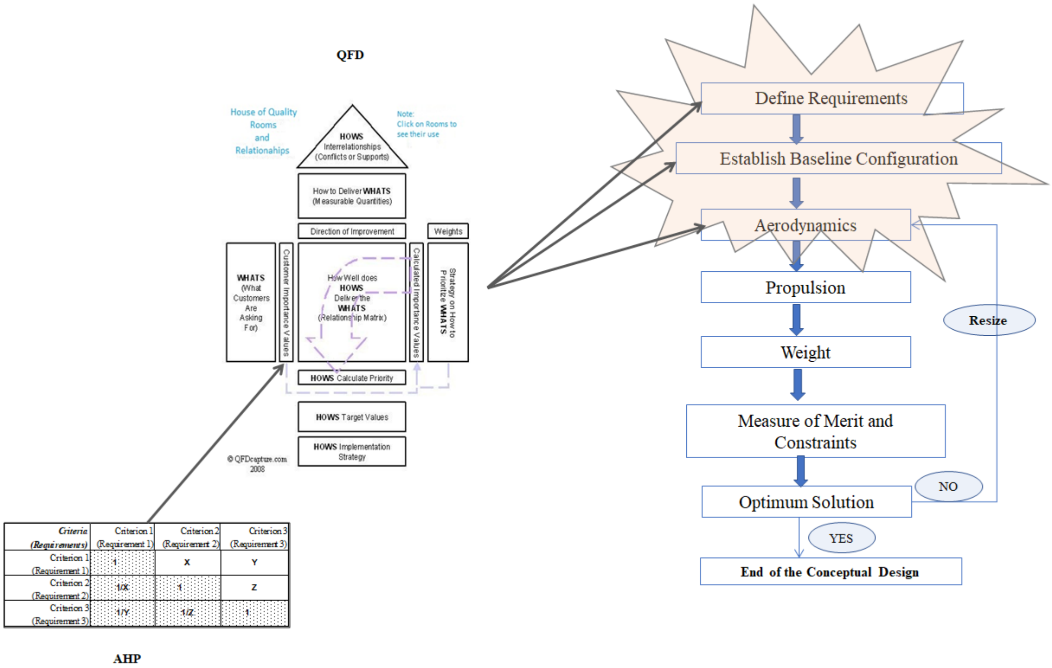


Figure 4.3: Implementation of System Engineering Methods into Design Loop

In this study, conceptual design is reformed by implementing analytical hierarchy process (AHP) and quality function deployment (QFD) into the first three steps of the conceptual design. In other words, requirements and technical parameters are made related directly. Then, they determine the key technical parameters for the initial external configuration of the missile.

4.2 External Configuration

One of the crucial aims in conceptual design phase is to find the optimum external configuration of missile which satisfies the customer's requirements. This external configuration baseline is used as origin of the preliminary and detailed design phases. External configuration of the missile is very effective on the missile aerodynamics. So, if the external configuration parameters are optimized, aerodynamics of the system can be optimized in the conceptual design phase. Moreover, aerodynamic characteristic of the missile directly affects the flight performance. So, in order to satisfy the flight performance requirements, aerodynamic characteristics should be base of the object and constraints of the optimization. Because of the time limitation in design projects, numerous external geometry candidates are rapidly eliminated according to the objectives and constraints specified by designer. In this elimination, the external geometry candidates are evaluated according to flight performance of each configuration in order to find the optimum solution. There is very elaborate relation between configuration parameters and possible flight performance requirements. One example for a missile's aerodynamic configuration sizing parameters and their impacts are shown in figure 4.4.

	Impact on Weapon Requirement									
	Aero Measures of Merit			Other Measures of Merit						Constraint
Aero Configuration Sizing Parameter	Weight	Range / Maneuver	Time to Target	Robust-ness	Lethality	Miss Distance	Observ-ables	Survivability	Cost	Launch Platform
Nose Fineness	●	●	●	○	●	●	●	●	◒	○
Diameter	●	●	●	○	●	◒	○	○	●	●
Length	●	●	◒	○	◒	◒	○	○	●	●
Wing Geometry / Size	●	●	◒	○	●	●	◒	◒	◒	●
Stabilizer Geometry / Size	●	●	○	○	●	●	◒	◒	◒	●
Flight Control Geometry / Size	●	●	○	○	●	●	◒	◒	◒	●
Propellant / Fuel	●	●	●	○	◒	◒	◒	●	◒	◒
Thrust Profile	●	●	●	○	◒	◒	●	●	◒	–
Flight Conditions (α, M, h)	●	●	●	●	●	●	●	●	●	○

● Very Strong ◒ Strong ○ Moderate – Relatively Low

Figure 4.4: Aerodynamic Configuration Sizing Parameters and Their Impacts [14]

As an example, figure 4.4 shows that the nose fineness, diameter, length, wing geometry/size, stabilizer geometry/size, flight control geometry/size, propellant/fuel, thrust profile and flight conditions are the aerodynamic configuration sizing parameters. These parameters are very effective on some of the missile characteristics which are weight, range and maneuverability. Moreover, they are also effective on the areas of lethality, miss distance and cost of the missile [14]. Although, this figure can be considered as the base of the aerodynamic configuration characteristic of missile, impacts of the parameters can change according to the system requirements and types of missile.

As mentioned before, external shape of the missile is the main optimization part of the conceptual design in terms of flight performance requirements. The most effective parameters on flight performance of the missile are the moments and forces acting on it. So, aerodynamic configuration sizing parameters should be taken as the optimization parameters.

External configuration parameters can be selected according to the type of missile. Tail controlled, surface to surface, ballistic missile is the consideration point of this thesis. Because of that, the configuration parameters to be focused are the nose shape and the control surfaces geometries. These parameters are directly related with flight performance parameters.

4.2.1 Geometrical Parameters

The nose shape includes the nose bluntness of the missile and the length of the nose. In detail, the length of the nose means that the length of the conic section of the body. Nose shape is an effective factor for the aerodynamic forces. As the sharpness of the nose increases, drag force is getting smaller. But, the avionic units, which are located closer to the nose like seeker, need area to fit into. At the same time, length of the nose is also important for such reasons. Cylindrical sections of the missile create more drag force. When the length of the nose increases, the drag force decreases. On the other hand, the packaging of the avionic units is getting harder, when the length of conic section increases.

In this thesis, Missile DATCOM is used for aerodynamic analysis. As abovementioned, nose shape is one of the input parameters. Basically, there are five types of nose shapes in DATCOM. They are Conical, Power, Tangent Ogive, Haack and Von Karman. Formulas of them can be tabulated as in table 4.1.

Furthermore, control surface geometries are also configuration parameters. As the Missile DATCOM inputs, they can be classified under three groups. They are fin set,

Table 4.1: Nose Shape Formulas in DATCOM [7]

Nose Shape	Equation(s)	
Conical	$y = \frac{xR}{L_N}$	-
Power	$y = R\left(\frac{x}{L_N}\right)^n$	$0 \leqslant n \leqslant 1$
Tangent Ogive	$y = \sqrt{\rho^2 - (L_N - x)^2} + \frac{R}{\rho}$	$\rho = \frac{R^2+L^2}{2R}$
Haack	$y = R\sqrt{\frac{1}{\pi}\left(\theta - \frac{sin(2\theta)}{2} + \frac{1}{3}sin^3\theta\right)}$	$\theta = arccos\left(1 - \frac{2x}{L}\right)$
Von Karman	$y = R\sqrt{\frac{1}{\pi}\left(\theta - \frac{sin(2\theta)}{2}\right)}$	$\theta = arccos\left(1 - \frac{2x}{L}\right)$

axial body and nose parts. These parts are defined with numerous elements. The following figures show the required elements for explanation of the corresponding parts in Missile DATCOM.

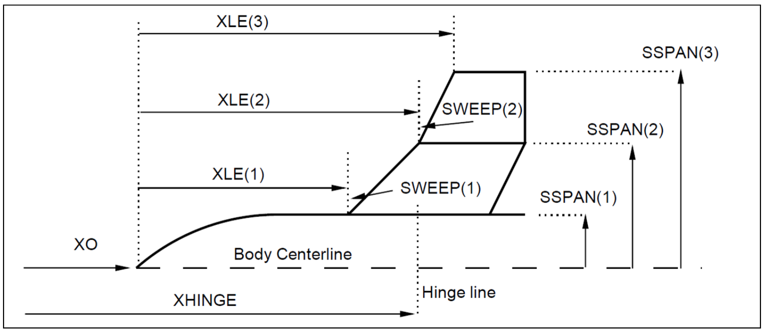


Figure 4.5: Definition of Required Parameters of Explanation of Finset [7]

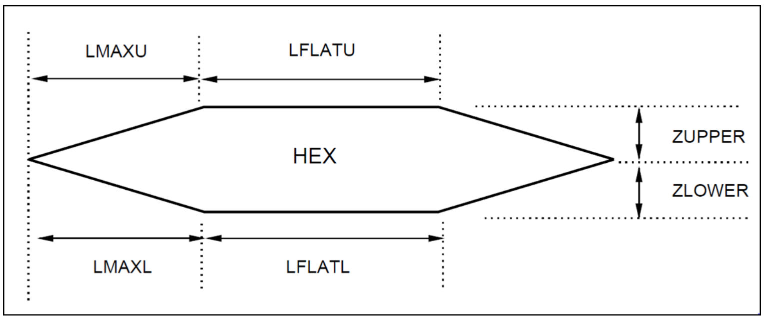


Figure 4.6: Definition of Required Parameters of Explanation of Fin set Cross-section [7]

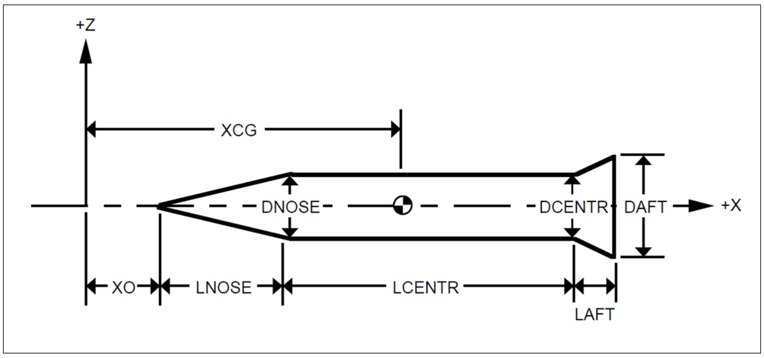


Figure 4.7: Definition of Required Parameters of Explanation of Axial Body [7]

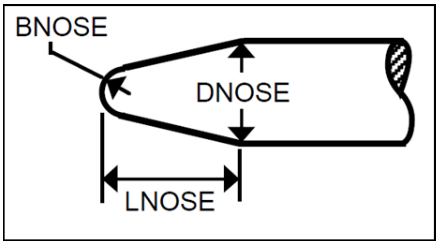


Figure 4.8: Definition of Required Parameters of Explanation of Nose [7]

In this study, the surface to surface ballistic missile system is taken into consideration. Moreover, only tail controlled systems are focused. For such a case, eleven parameters are used to describe the missile to the DATCOM. The external geometry design parameters and input file parameters for DATCOM are detailed in the tool section.

4.2.2 Performance Parameters

In the conceptual design phase, the most important technical measurement parameters in terms of performance objectives related to the external geometry of the missile are, control effectiveness and stability. Moreover, as the most important and general consideration point in the requirements is range of the missile. The parameters which affect that point are also performance parameters. In that sense, drag coefficient can also be considered as performance parameters.

4.2.2.1 Aerodynamic Forces and Moments Acting on a Missile

Missile aerodynamic analysis can be done by using three forces and three moments in body fixed coordinate frame. Generally, moment coefficients and force coefficients are used for missile aerodynamics. In order to obtain moment coefficient, value of moment in related direction is divided by free stream dynamic pressure, reference area and reference length. Also, in order to obtain force coefficient, value of force in related direction is divided by free stream dynamic pressure and reference area. There are two examples for moment coefficient and force coefficient formulation in equation 4.1.

$$
\begin{aligned}
C_N &= \frac{N}{qS_{ref}}\epsilon \\
C_m &= \frac{M}{qS_{ref}L_{ref}}
\end{aligned}
\tag{4.1}
$$

The coefficients of forces and moments on a missile can be shown as in figure 4.9.

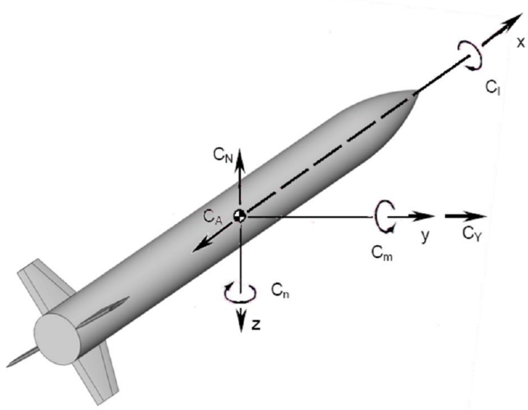


Figure 4.9: Forces and Moments Acting on a Missile [3]

4.2.2.2 Control Effectiveness

Stability and control have impacts on the aerodynamic configuration design, particularly in tail sizing; and they should be considered early in the conceptual design [14]. The aerodynamic control effectiveness can be defined as the effect of the control surfaces on each axes of the missile. In the conceptual design phase, the roll and yaw rotations are not the main focus points. The control effectiveness in pitch axes is more critical at this phase.

Hence, the control effectiveness of missile can be defined as the pitch due to angle of attack.

$$\frac{C_{m_\delta}}{C_{m_\alpha}} = \frac{\Delta\alpha}{\Delta C_m} = \frac{\Delta\alpha}{\Delta\delta} \tag{4.2}$$

During the conceptual design phase, safety margin is very important in order to overcome the disturbances which may appear in following phases. So, for the conceptual design of tail and control surfaces of a missile, the ratio for control effectiveness should be greater than one. The limitation of this ratio is directly related with the maximum turn capacity of the fin actuator motor that creates hinge moment. In that sense, the main aim is to create more angle of attack change with the minimum change in control surface angle.

$$\frac{\Delta\alpha}{\Delta\delta} \geq 1 \tag{4.3}$$

On the other hand, the optimized value of this ratio is not as much as possible. There are also some limitations which come from the control surface actuators. The motor precision of the fin actuator system is defined as the minimum deflection angle that motor can give to the control surfaces. If it is less than the maximum angle of attack and the control effectiveness ratio is less than one, there would be no way to give a full angle of attack to the missile [36]. Furthermore, if this ratio is very high, backlash effect on control surfaces causes unintentionally change in angle of attack. This may cause instability of missile and fail the flight.

$$1 \leq \left(\frac{\Delta\alpha}{\Delta\delta}\right)^l \leq \frac{\Delta\alpha}{\Delta\delta} \leq \left(\frac{\Delta\alpha}{\Delta\delta}\right)^u \tag{4.4}$$

4.2.2.3 Stability

Stability of a missile is distinguished to two groups which are static and dynamic stability. In this thesis, static stability is studied as a critical performance parameter for missile.

The static stability of a missile is a measure of its tendency to return to its equilibrium attitude after being disturbed [11]. There are mainly three types of static stability. They are positive, neutral and negative types.

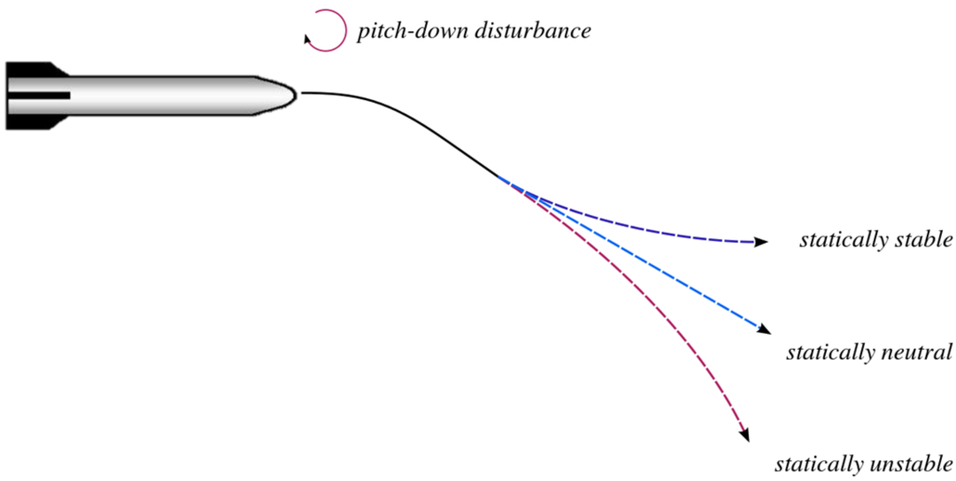


Figure 4.10: Types of Statically Stability

Positive static stable (statically stable) systems tend to return to its original position when they are disturbed. Neutral static stable (statically neutral) systems tend to stay in new attitude when it is disturbed. Negative static stable (statically unstable) systems tend to continue moving away from its original attitude when it is disturbed.

Specifically, statically stable missile produces pitching moment with increasing angle of attack in opposing manner [14]. Statically stability of a missile depends on the location of center of gravity where the total inertial forces of missile act and center of pressure where the total aerodynamic forces act. A statically stable missile has the center of pressure aft of its center of gravity as shown in Figure 4.11.

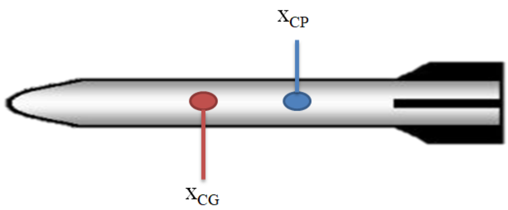


Figure 4.11: Statically Stable Missile Configuration

The static stability in pitch is analysed by the slope of the pitching moment versus the angle of attack. For the statically stable pitch flight, the slope of the pitching moment coefficient vs the angle of attack must be negative.The relates curves are given in Figure 4.12.

$$C_{m_\alpha} = \frac{\Delta C_m}{\Delta \alpha} \leq 0 \tag{4.5}$$

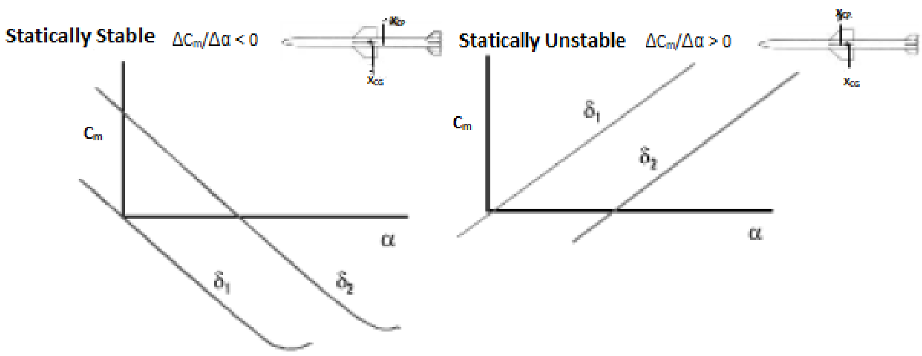


Figure 4.12: Static Stability Curve [14]

When the angle of attack increases, the pitching moment decreases and the angle of attack tends to decrease. Moreover, the shift in the curve in figure is provided by the control surface deflection.

Capability of missile to change direction, attitude and speed in a limited time is called as maneuverability. Maneuverability of a missile is crucial to follow the desired trajectory and overcome disturbances, so, to satisfy flight performance. For highly maneuverable missiles, they can give agile reactions to little change of angle of attack. In that sense, very stable missiles have less maneuver capability. Hence, static stability could be restrictive for the maneuver capability of missile. For the optimization of a missile, maneuver capability should be considered during the stability analysis.

For the aerodynamic conceptual design of a missile, these parameters are very crucial. But, if the priority of the requirements are different then expected (maximize range, minimize drag coefficient and get a controllable missile); these parameters may not be the most effective parameters in optimization problem of missile external shape.

CHAPTER 5

OPTIMIZATION AND NEURAL NETWORK

5.1 Optimization

Optimization can be simply defined as a process to find the optimal solution by minimizing/maximizing cost function and satisfying the constraints. In other words, optimization is performed iteratively by comparing each solution until the satisfactory solution is found. This operation is done by optimization algorithms.

For the simple problems, optimal design can be achieved by comparing only a few solutions by alternating values of the variables. At each iteration, feasibility and variables should be checked and the objective should be satisfied. But, for complex engineering problems, this method is nonapplicable. In order to handle these problems, mathematical model of optimal design problem is created and then they can be solved using an optimization algorithm. Outline of the steps usually involved in an optimal design problem is shown in figure 5.1.

The first step of the optimal design process is choosing the design variables. Engineering design process involves many design parameters but all of them are not the parameters for optimization. Generally, the most effective parameters on the design are chosen as optimization parameters. One of the most crucial points of the optimization is minimizing the number of optimization design variables to simplify the problem.

There are two main stones in optimization algorithms. They are constraints and objective function.

Constraints are the functional relationships which are important to satisfy required

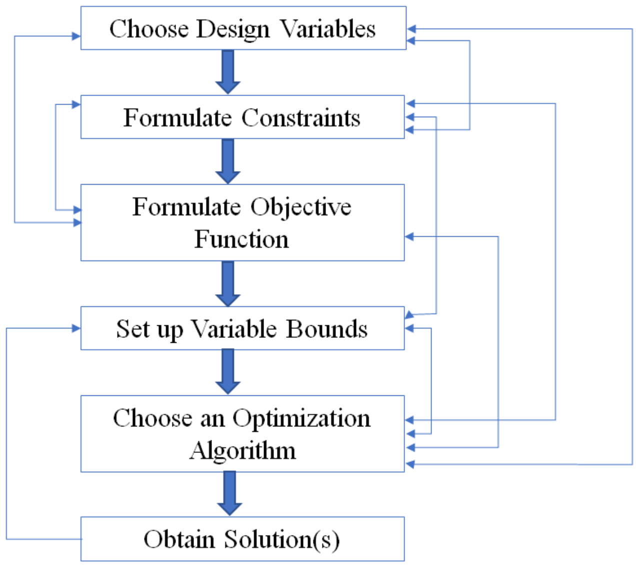


Figure 5.1: Flowchart of the Optimal Design Procedure

physical phenomenon and certain resource limitations [30]. There are two types of constraints which are inequality type constraints and equality type constraints. Inequality constraints are used to state the functional relationships which are either greater than, smaller than or equal to, a resource value. Equality constraints are used to state functional relationships which are exactly same to a resource value.

Objective functions, which are called as cost functions, are the main aim of the optimization. In detailed, it is aimed that minimization or maximization of the object of the design problem by changing the optimization design parameters.

Variable bounds are the maximum and minimum values of each design variables. The variable bounds can be eliminated if the constraints completely surround the feasible region. But this way is not generally preferred. Determination of the variable bounds is very important to shorten the optimization process. If the maximum and minimum values of the bound can be chosen closer to the optimal solution, the optimization algorithm can provide the result in shorter time.

The previous parts are the components of an optimization algorithm. Although, the optimization problem cannot be constructed without these components, there is also a main body of an optimization algorithm. The formulation of the engineering design problems differs according to related case. There are lots of optimization techniques which are the base of the optimization algorithms. Optimization techniques can be divided two main groups which are derivative based optimization (gradient based optimization) techniques and derivative free optimization (non-gradient based optimization) techniques. Derivative based optimization techniques are used in local optimization algorithms and derivative-free optimization techniques are used in global optimization algorithms. The components of optimization algorithm which are described in previous paragraphs and schematized in the figure 5.1, can be summarized in equation set 5.1 [35]. The equation set 5.1 defines weighted multiobjective, single cost function non-linear, constrained optimization problem which is studied in this thesis.

$$\begin{aligned} minimize \quad F(x) &= \sum_{m=1}^{M} w_m f_m(x) \\ subject \quad to \quad g_j(x) &\geqslant 0, \quad j = 1, 2, ..., J \\ h_k(x) &= 0, \quad k = 1, 2, ..., K \\ x_i^{(L)} \leq x_i &\leq x_i^{(U)}, \quad i = 1, 2, ..., n \end{aligned} \tag{5.1}$$

In the equation 5.1; F(x) represents objective function, $g_j(x)$ represents inequality constraints and $h_k(x)$ represents equality constraints. The x is a vector and represents n optimization parameters to obtain the optimum design solution. The upper and lower bounds are expressed as $x_i^{(L)}$ and $x_i^{(U)}$. The main aim of the all optimization techniques is finding the solution to the optimization problem. This solution is based on finding the combination of optimization variables which results in the finnest objective function value and satisfies all the equality and in equality constraint functions.

There are lots of derivative based and derivative free optimization techniques. In the following parts, derivative based and derivative free optimization techniques is going to be expressed and detail information about the most commonly used techniques is going to be given.

5.1.1 Derivative Based Optimization Techniques

Derivative based optimization is generally called as gradient based optimization. As signposted by the name, derivative based optimization techniques use the derivative information to find optima. For the local optimization problems, derivative based optimization techniques are commonly used.

Besides, derivative based optimization techniques have different disadvantages. They are competent only for finding local optimum solutions. For complex engineering design problems, these techniques are not adequate and they are hard to implement. Also, they are more sensitive for numerical noise.

The derivative based optimization can be summarized mathematically as in equation 5.2 This equation can be directly used for unconstrained derivative based optimization problems. In this equation, x represents the state, q represents the iteration number, S represents the search direction and α^* represents the stepsize.

$$x^q = x^{q-1} + \alpha^* S^q \tag{5.2}$$

There are two subproblems in derivative based optimization for each iteration. First one is finding the search direction S and second one is finding the step size α^*. Depending on the types of optimization problem which are unconstrained or constrained optimization problems, effect of search direction on the solution changes. For unconstrained optimization problems, any direction which decreases objective function is usable. For constrained optimization problems, search direction is usable if both objective function and constraint functions tend to be oriented to the desired value. The difference between the types of derivative based optimization methods is used method for choosing the search direction. Furthermore, after the determination of the search direction, the step size is tuned by observing the values of the cost and constraint functions.

Derivative based optimization algorithms exploit the derivatives of the functions in optimization. For the optimization, line search is used to reach a better solution for the optimization problem. For the line search, search direction and step size are chosen. In that sense, derivative based optimization methods are considered, for the nonlinear optimization problems, these methods can be unusable. Moreover, for the large design space, global optimum point cannot be found only by using the derivative based optimization methods.

5.1.2 Derivative Free Optimization Techniques

For the engineering optimization problems where the cost function and constraints require complex simulations, derivative free optimization methods are robust and easy to implement methods.

Derivative free optimization methods have gained a lot of attention recently, because these methods are easy to implement and program, they are the most effective ways to find the global optima and they do not require any gradient information. The most important feature of these methods is their ability to solve the problems which includes highly discontinuity and discrete search spaces. Besides, these methods have some weaknesses like high computational costs and tuning requirement for each problem [40].

Many of the derivative free optimization methods are based on the mathematical modelling of the problem. These methods are evolutionary and heuristic algorithms. Derivative free algorithms have the following properties;

- They provide stochastic approximations to the global optimum
- They are robust to changes in the problem characteristics,
- They are not too sensitive with consider tuning the parameters,
- They are easily implemented to many problems.

Evolutionary optimization algorithms are commonly used in engineering industry, nowadays. Unlike derivative based optimization techniques in which gradient information are used for each iteration, these algorithms do not use any gradient information. They use populations to find optimum design. These algorithms are originated from the nature phenomena.

The most popular evolutionary optimization algorithms are Genetic Algorithm (GA) which is originated from the Darwin's principle of survival of the fittest and the Particle Swarm Optimization (PSO) which is based on simplified social model. In this thesis, genetic algorithm method is used. Genetic Algorithm will be detailed in the following section.

5.1.2.1 Genetic Algorithm

Genetic algorithm for optimization is inspired by the process of natural evolution of creatures. GA is developed by John Holland in the 1960's and published in 1975 [12]. Holland was aimed to consider the evolution of life by simulating in a computer program and use this process in solution of optimization problems.

Genetic algorithms are based on three crucial components which are selection, crossover and mutation. Moreover, elitism is another component of the genetic algorithm to converge to optimum solution quickly.

- Selection

At the selection part of the GA, parents are selected to create new generation. Natural selection is the origin of this process. As in the natural selection, the most powerful genes are transferred to new population. In the selection process, chromosomes are ranked based on the fitness values. The chromosomes which have better fitness values have higher chance to keep to the next generation to provide better fitness values in the new generations.

For the selection process, there are different methods which are Roulette Wheel Selection, Stochastic Universal Sampling, Tournament Selection, Rank Selection, Random Selection etc.

- Crossover

The crossover process is based on the reproduction in the nature. In other word, it is the exchange of the genes between chromosomes. The cross-over process is one of the most important points of the genetic algorithm. Some part of the chromosomes is taken from one of the parent and the other part is taken from another parent. The schematized description of the crossover is given in the figure 5.2. There are also multi point crossover, uniform crossover etc. methods for the crossover process.

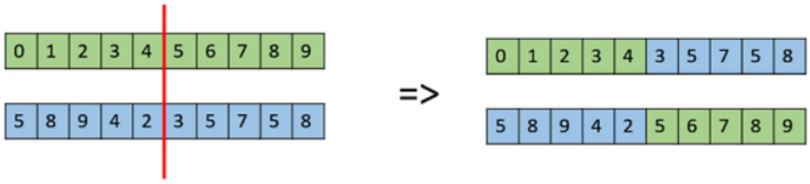


Figure 5.2: One Point Crossover

- Mutation

Mutation comes after the selection and crossover processes. It can be defined as small random changes in chromosomes. These random changes occur according to mutation probability. Mutation is used to maintain the diversity in new generated populations. If the probability of the mutation is too low, there may be more optimal solution which cannot be reached.

- Elitism

At the end of the selection, crossover and mutation processes, new population is created to find the optimal solution. But, when the design space and bounds are too extensive, the genes which provide the optimal solution can be overlooked. For that purpose, elitism can be used.

Although elitism is not one of the essential processes of the genetic algorithm, it is highly recommended to use this process. By using elitism, the best genes from the initial and the current generation are carried on to the next generation. This strategy warranties that the solution superiority gained by the GA will note diminish from one generation to the next.

The general flowchart of a GA is schematized in figure 5.3. The first step is creating an initial random population. The population is a combination of genes. Genes include chromosomes. Chromosomes are the possible solutions for the optimization problem. The population size does not change during the optimization. The population is analysed based on the object function and constraint function values. If this population is the solution of the optimization problem, then the iteration is finished. But generally iteration does not converge at the initial population and the genes which have the better fitness value according to the results of the analyse, have higher probability of being select for the next generation.

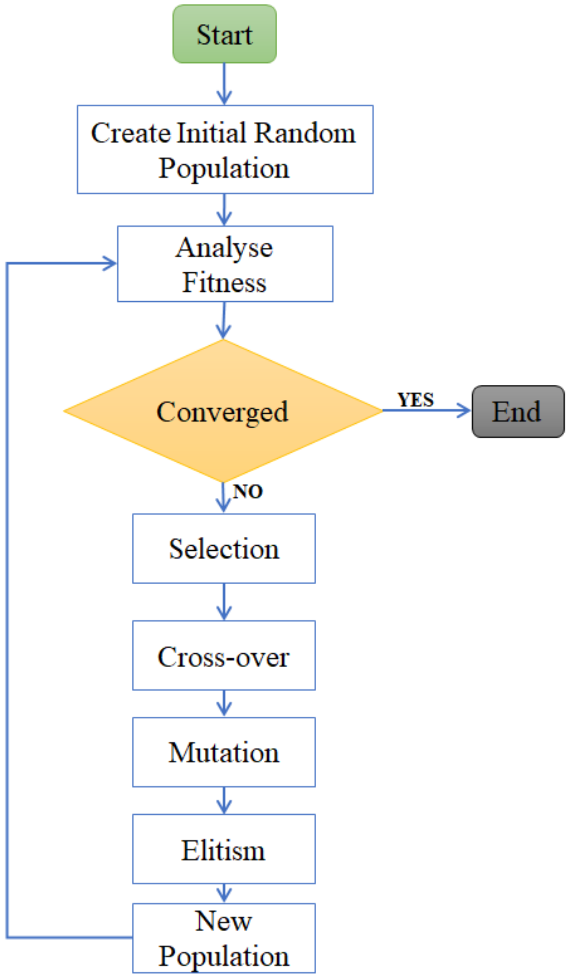


Figure 5.3: Genetic Algorithm Flowchart

5.2 Neural Network

Neural Network is a process which based on the biological nervous system. The human brain learning process is different from the computers' working methodology.

This is the motivation point for the artificial neural network. The basic structural component and the module for learning of the brain is the neuron. Human brain contains huge numbers of the neurons which are organized in extremely complex, nonlinear and parallel structure. Moreover, the neurons are interconnected by synapses to map input signals to output signals and familiarize to particular tasks throughout training phase. By the help of this structure, the human brain is very efficient for learning and reasoning. In that sense, an artificial neural network is a structure which is constructed to solve complex problems by endeavouring to imitate the approach of the human brain would solve the problem. The neural network is generally used to cover high-dimensional, nonlinear data, so, it can be said that it is a "black box" model. Neural networks are not generally used to build a model of a system; they are usually used to solve prediction problems for systems.

As mentioned, the neural network is inspired by neurology. In that sense, the first simulations are created by McCulloch and Pitts at 1943 based on their understanding of neurology. These models made assumptions about how the neurons work. These works are the base of the neural networks. Nowadays, neural network technology is still developing to solve more complex problems in a better way.

An artificial neuron can have many inputs and only one output. It can be defined as a tool which connects the inputs and output. There are two modes which are training and use modes. In teach (training) mode, the neuron can be trained for particular input patterns. After the teach mode is completed, the map between input and output is created. In use mode, inputs is given to the specified neuron and the output is obtained. In engineering problems, neural network is used as an alternative to response surface methodology.

For the architecture of neural network, there are several methods for training algorithms like feedforward neural networks, recurrent neural networks etc. The most commonly used method in engineering applications is feedforward neural networks architecture method. Architecture of a neural network contains two main elements which are the neurons and synapses. Synapse is used to transform the signal flow between two neurons. For feedforward networks the transformation of the information between the neurons is only one directional which is from input to output [6].

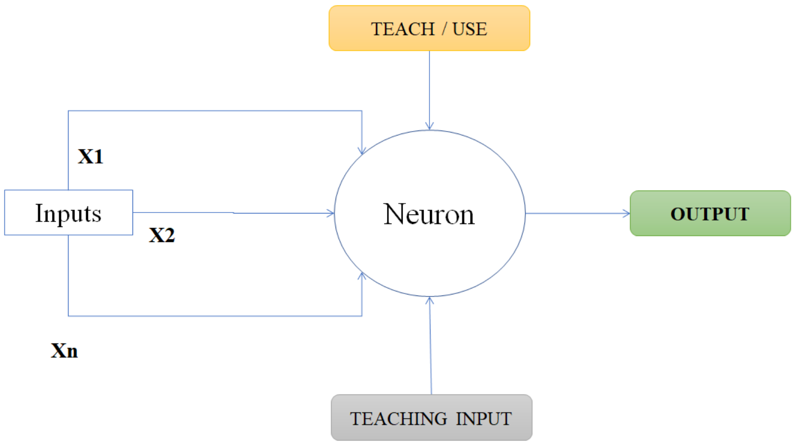


Figure 5.4: Simple Neuron

Multilayer feedforward artificial neural network model has several layers. The most commonly used structure contains three layers which are the inputs, the hidden layer and the output layer.

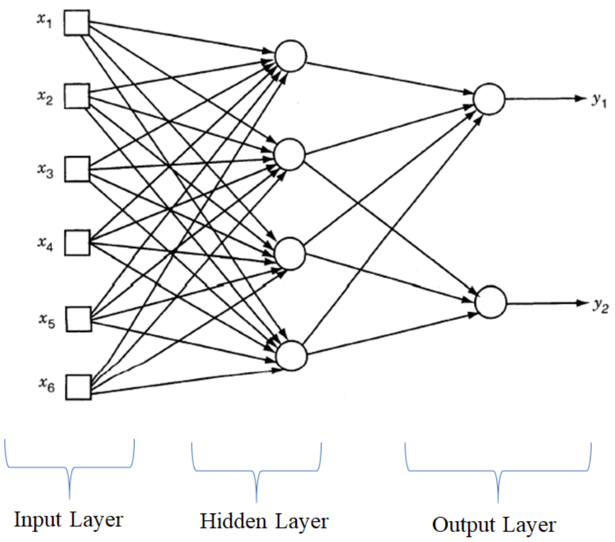


Figure 5.5: Three Layers Artificial Neural Network

When the construction of a neural network model of a system, the following three steps are followed.

- Network architecture is selected. In detail, the number of neurons in each layer is determined. Number of hidden layer is decided. The type of transfer functions of neurons and the method for training are settled.

- Training of the network to minimize the Sum of Squared Error (SSE) in equation 5.3 where k is the number of training samples, y_i and $\hat{y}_i$ are the target values and the network output for the i_{th} training sample

$$SSE = \sum_{i=1}^{k} \|y_i - \hat{y}_i\|^2 \tag{5.3}$$

- By using different inputs, the networks are tested and SSE is checked again.

For these three steps of construction of an artificial neural network model, the number of neurons is very important. For complex nonlinear problems, if there are so many neurons, overfitting can be appeared. Overfitting means, neural network provides almost perfect fit for the inputs. But, for the new data, fitness is not as good as expected. It can be defined as memorization of the human brain. In order to handle this problem, number of neuron should be optimized and the inputs set should be divided as training and test data.

CHAPTER 6

DEVELOPED TOOL

During the conceptual design of the missiles, time is the most critical parameter. One of the most important issues at this stage is to minimize the time spent.

Recognizing the customer's requirements and order of precedence of these requirements and obtaining the best possible system design under given requirements and constraints in a limited time are the components of engineering design optimization problem.

A conceptual design and optimization tool which integrated with system engineering methodologies is developed as a product of the thesis. As abovementioned, the main purpose of this tool is to handle with the time limitation during the conceptual design phase of missile systems, in military projects. Moreover, this tool offers an automation of the procedure which declines the intervention of human in missile design interval. By using the tool, the undesirable and unfeasible configurations are eliminated at the conceptual design phase. Hence, the preliminary and detailed design phases start with a more mature design in a shorter time.

In the previous chapters, the main components of the tool are explained in general form. In this chapter, usage of them in the tool and interconnection of them with each other will be detailed.

6.1 Skills of Conceptual Design and Optimization Tool

The tool has two main actors. They are optimization and DATCOM Processor. Furthermore, AHP matrix and QFD matrix are the co-actors which make the tool integrated with system engineering methodologies. In general design process, requirements definition and prioritization are not included to the design process. They are thought as a starting point for the projects. But, by using this tool, requirements are directly comprised to the design process.

For the explanation of the tool skills, the tool can be divided into three parts which can be called as AHP, QFD and Design and Optimization parts. In that classification, optimization and DATCOM Processors are unified under the heading of Design and Optimization part.

The general skeleton of the tool is given with figure 6.1. Detailed expressions of the parts are given in the following sections.

6.2 The AHP Part

The AHP part of the tool is the requirement part. Before this part, the concept and the mission of the missile system are determined by the customer. According to the concept and mission of the missile, the requirements are defined and listed by customer. In that sense, brainstorming is an action in this step. At the end of the brainstorming, there are lots of requirements without regarding the order of precedence. As mentioned in the AHP section of thesis, the main aim of the AHP is making decision by pairwise comparison method. The decision for missile system design problem is prioritization of the requirements in this thesis.

According to the defined mission and concept, requirements and their importance among themselves can change. In detailed, missile requirements can be classified into some groups like performance, functional, environmental, safety and reliability and maintenance requirements. For most cases, performance requirements are the most crucial class of the requirements. Ballistic missiles are generally strategically used systems and the main consideration point of the requirement definition is obtaining the most effective missile system in terms of performance characteristics.

At the AHP part of the tool, firstly, the requirements are placed to the AHP matrix to pairwise comparison by manually from the matrix at the Excel. The requirements are placed to the column and the row of the matrix, and then they are compared with each other. Criterion in row is compared with the criterion in the column. They are graded by manually according to the Saaty's scale.

In order to find the order of precedence of the requirements, preference vector of this matrix is found by the tool automatically. As mentioned in the AHP section, Saaty's Method is used to find it. This method is the most commonly used and consistent method. Related equations are implemented into matrix in Excel. The results of the pairwise comparison are inputted to these equations and the preference vector of the matrix is found. This becomes an input for the QFD analysis. It gives the order of priority of requirements.

6.3 The QFD Part

In the QFD part, technical parameters' effectiveness rate on the requirements is determined. In that sense, it can be said that the system design and optimization parameters are determined at that part.

As explained in the Chapter 3, there are eleven rooms in the House of Quality matrix. Each of the rooms is used for different aim. The type of the designed system, usage area, customer profile and company policy etc. determine which rooms to use. Usage of the all rooms is not an essential point for every QFD analysis. According to the case, usage of different rooms together can be meaningful. In this tool which is used for surface to surface ballistic missile systems, the following rooms are used;

- Customer Requirements,
- Engineering Characteristics,
- Relationship Matrix,
- Importance Rating,
- Absolute Importance.

At the beginning of the QFD part, design team reviews the requirements and determines the technical measures which are related to the requirements. In other words, each requirement is linked to technical parameters. Requirements are located to the rows and technical measures are located to the columns of the HoQ matrix in Excel

manually.
Each requirement is evaluated in terms of the effect of the technical parameter on the requirement. If this effect is strong, the corresponding grade in the relation matrix is greater. As mentioned at the Chapter 3, the numerical values for the scale of the relationship can be varied. In this tool, “0-1-3-9” scale is used. This evaluation is made for each requirement and each technical parameter and the grades are inputted to the relationship matrix by manually. Thus, each technical parameter is considered for each requirement. In that sense, technical parameters are both the design variables and the base of cost function and constraints of optimization. When QFD analysis is applied more consciously, requirements can be more accurately integrated into the design.
After the construction of relationship matrix, the order of precedence of requirements is taken into consideration. The preference vector of the AHP matrix is implemented automatically by the tool to the importance rating room of the QFD analysis and added to calculations for the relative importance.
All of the numerical values are implemented into the matrix, absolute importance is calculated by multiplication of AHP results and value of the corresponding relationship matrix’s cell for each requirement according to the equation 3.1. This parameter shows the importance level for each technical parameter. But, the relative importance is more understandable parameter. The relative importance shows the effectiveness of the technical parameters for system requirements in the range of 0-100. The higher percentage value shows the higher effectiveness.
The absolute importance and relative importance are calculated automatically in the tool. The tool ranks the technical measures by using the calculated relative importance values. Also, there is a visualization row which is Technical Performance Measures (TPM’S) Weight Chart to show the importance weight with different length of bars. For the TPM’S Weight Chart, the relative importance values are used and the bars are created automatically.
For the optimization problems, determination of the cost and constraint parameters is generally determined by experience and intuition of the engineer. Moreover, there are iterations for the cost function and constraints parameters in order to obtain more optimum solution. By using the QFD analysis, the cost and constraint functions’ parameters can be determined based on the effectiveness of the TPM. In other words,

if the TPM is more effective, minimizing or maximizing of the according parameter during the design optimization provides optimum solution in a shorter time. The same consideration point is valid for constraints also. When the parameters in the constraints are more effective, the design can be optimized in a shorter time.
Moreover, obtained relative importance weight values are directly implemented to the object function of optimization as weight of the components of the function.

6.4 Design and Optimization Part

Design and optimization part is about construction of missile system. These two parts involve design, analysis and optimization of the conceptual design.

6.4.1 Design Part

Design of a missile system is a multidisciplinary design problem. Moreover, design is a long process. In this thesis, only conceptual design part of the missile system is studied. In detail, aerodynamic design and external geometry optimization of the missile are the main design topics of the study.
Type of the missile is the base of the design. According to the type of the missile; its requirements, order of precedence of requirements, design parameters and the optimization types can change. For example, for the tactical missiles, cost efficiency is one of the most crucial requirements. On the other hand, for the ballistic missiles, range and hit accuracy are more important than the cost efficiency.
After requirement definition, prioritization and conversion of the requirements to technical measures parts finish; design and optimization part starts. During the QFD process, the type and mission concept of the missile are determined and comprehended. Although, at the beginning of the QFD, technical measures are determined by regarding the requirements,through design parameters are determined after the QFD analysis. At the end of the QFD analysis, mission concept becomes more clear. So, design parameters are chosen according to the type and the mission of missile. For instance, for tactical missiles, fin type is generally chosen as both canard and tail controlled. Besides, for ballistic missiles, tail controlled fin type is generally more commonly used and effective design. These kinds of differences between types of missiles affect the design variables.

At the Chapter 4, general design principles and parameters for the tail controlled surface to surface ballistic missile are described. This tool, which is developed for such kind of a missile, requires 11 parameters to describe the external geometry properties of the tailed controlled missile.
Eleven parameters are the main design parameters. Design space is created by using these parameters. They are the base of the DATCOM inputs in terms of the definition of the external geometry of the missile. Design parameters are shown in figure 6.2 and defined in table 6.1.

Table 6.1: Definitions of Design Parameters

Input Name	Definition	Unit
Lnose	Nose length	mm
Rn	Nose bluntness radius	mm
Sspan2	Span length of the tail	mm
Lmaxu_base	Length of the part of the chord at the base of the tail.	mm
Lflatu_base	Length of the flat part of the chord at the base of the tail.	mm
a_base	Length of the part of the chord at the base of the tail.	mm
Zupper_base	Thickness of the tail at the base of the tail.	mm
Lmaxu_tip	Length of the part of the chord at the tip of the tail.	mm
Lflatu_tip	Length of the flat part of the chord at the tip of the tail.	mm
a_tip	Length of the part of the chord at the tip of the tail.	mm
Zupper_tip	Thickness of the tail at the tip of the tail.	mm

Generally competitor study is done before the QFD analysis. But detailed technical competitor study should be repeated after the determination of the technical parameters. For the design parameters in in table 6.1, upper and lower limit values are determined and inputted to the tool with the reference of the competitor study. These limits determine the design space. The optimum solution for the missile external geometry is found in this space.

Not only competitor study results and design space but also the establishment of the dataset are crucial for the design. According to the chosen number of sampling (n), between the upper and lower limits of the inputs, n numbers of dataset are created. Latin Hypercube Sampling is used when dataset is created. Latin Hypercube Sampling (LHS) is a statistical method which is used to create a near-random sample of the parameters from a multidimensional distribution. In LHS, the number of samples and the location of the samples in the space are remembered. In that sense, the same location for the samples is not chosen again. So, randomness is satisfied by LHS. Also, LHS reduces the number of runs. Besides, lower and upper limits for inputs are not always so clear. Although, the competitor study is done, because of the confidentiality for ballistic missile systems, exact values for required inputs cannot be found easily. Especially, aerodynamic surface dimensions are generally the most critical information about external geometry design. Thus, interval of some of the inputs could be wide during the design and optimization. So, the number of the sampling should be considered carefully. Because, when the number of the sampling is increased, the space design is denser and the process is longer. On the other hand, if the number of sampling is not enough, design cannot converge to optimal design. As mentioned above, LHS provides random dataset profile, so the number of sampling can be decreased when LHS is used. At this part of the tool, upper and lower limits for each inputs and the number of sampling are given to the tool.

Created dataset contains the missile configurations in the given interval of the inputs. These configurations are the parts of the design space. For each design configuration, aerodynamic analysis is done by using DATCOM Missile. In order to analyse aerodynamic characteristic of the missile, input file is prepared to use in DATCOM. Both inputs from external geometry of the missile and some flight mission parameters are required. So, for the aerodynamic analysis of the tail controlled surface to surface missile by DATCOM, the needs for the input file can be defined as in the table 6.2. Furthermore, the parameters can be enhanced in order to describe the missile and flight mission profile in more detail. But, for the conceptual design phase, information about the flight mission profile and external geometry of the missile are limited. So, minimizing the needs for aerodynamic analysis is another important point for the conceptual design of the missile system. When the number of the parameters is minimized, parameters should be chosen to define the missile external geometry and flight mission profile adequately and accurately. The parameters which are described in the table 6.2 are the minimum needs of the tool. Names of inputs, their definitions and the units which are used in the tool are specified in table 6.2.

Table 6.2: DATCOM Input File Parameters [7]

Flight Condition Definition		
Input Name	**Definition**	**Unit**
NALPHA	Number of analysed angles of attack	-
ALPHA	Angle of attack values	deg
NMACH	Number of analysed Mach number	-
MACH	Mach numbers	-
BETA	Sideslip angle values	deg
ALT	Altitudes	m
Reference Lengths		
Input Name	**Definition**	**Unit**
LREF	Longitudinal reference length	mm
SREF	Reference area	mm2
XCG	Longitudinal position of center of gravity	mm
Body Geometry Definition		
Input Name	**Definition**	**Unit**
X0	Longitudinal coordinate of tip of nose	mm
TNOSE	Type of nose shape	-
LNOSE	Length of nose	mm
DNOSE	Diameter of nose at base	mm
BNOSE	Radius of nose bluntness	mm
LCENTR	Lenth of centerbody	mm
DCENTR	Diameter of centerbody at base	mm
DEXIT	Diameter of nozzle	m

Tail Geometry Definition		
Input Name	**Definition**	**Unit**
SSPAN	Semi-span locations	m
XLE	Distance from missile nose to chord leading edge at each span location.	-
NPANEL	Number of control surfaces	-
PHIF	Roll angle of each control surface measured clockwise from top vertical center looking forward	deg
CHORD	Chord of the panel at each semi-span location	mm
LMAXU	Fraction of chord from section leading edge to maximum thickness of upper surface	-
LFLATU	Fraction of chord of constant thickness section of upper surface	-
ZUPPER	Thickness to chord ratio of upper surface	-
DELTA1	Deflection angles for each control surfaces	deg

By using the parameters in table 6.2, DATCOM input file is constituted. This input file is used for aerodynamic analysis of the missile. Results of this analysis are aerodynamic coefficients and their derivatives. Aerodynamic coefficients and their derivatives can be found in all axes with appropriate input files by DATCOM. In this study, during the conceptual design of the missile, the parameters in the table 6.3 are considered and are taken from the DATCOM as results of the aerodynamic coefficients.

These parameters are obtained for all missile configurations in dataset. In detail, these parameters are examined for specific flight conditions. In other words, the aerodynamic analysis is done for specific Mach number and angle of attack values. These values are completely dependent with the flight mission profile. Approximate values of Mach number and angle of attack which are reasonable for the flight profile should be used in the aerodynamic analysis. Mach number and angle of attack values are the inputs for design tool. These values are decided by user and inputted to the tool from the Matlab code.

Table 6.3: Aerodynamic Coefficients [7]

Variable	**Definition**
C_A	Axial force coefficient
C_m	Pitching moment coefficient
C_n	Normal force coefficient
C_{m_α}	Pitching moment coefficient derivative with angle of attack
C_{m_δ}	Pitching moment coefficient derivative with control surface angle
C_{n_α}	Normal force coefficient derivative with angle of attack

At the end of the analysis, design part finishes. To conclude, in the design part, design space for the external geometry of the missile is constricted by following the steps in the figure 6.3.

6.4.2 Optimization Part

Design optimization can be described as a progress wherein design variables are updated to obtain a better design output [17]. In detail, the main aim of optimization in the conceptual design phase of a missile is to find the optimal external missile geometry to maximize flight performance in terms of specified criteria.

At the design part of the tool, design space is created. But, finding the optimal solution from this space is handled by optimization part of the tool. General information about optimization is given in the chapter 5. As mentioned in that section, object function, constraints and type of optimization algorithm are the main components of the optimization.

For the optimization of the missile system, object function and constraints change depending on the type of the missile system. So, before optimization, object function and constraints should be determined. The results of the QFD are guide to determine the object function and constraints.

One of the most crucial part of this thesis is that results of the QFD are used in the cost function of the optimization. As mentioned before, technical parameters and requirements are graded. Hence, coefficients for the technical parameters are obtained at the end of the QFD analysis. Also, the technical parameters in QFD analysis are used in cost function of the optimization. Results of the QFD analysis are directly used in cost function. As mentioned before, weighted multiobjective single cost function is used for optimization. They are used as weights of weighted parts of the cost function. This situation can be shown as in equation 6.1.

$$
\begin{aligned}
minimize \quad F(x) &= \sum_{m=1}^{M} C_{QFD_m}.w_m.f_m(x) \\
where \quad C_{QFD_m} &= m^{th} \text{ Relative Importance Weight} \\
w_m &= m^{th} \text{ Part of Cost Function Weight} \\
f_m &= m^{th} \text{ Part of Cost Function}
\end{aligned}
\tag{6.1}
$$

Although, constraints can also be determined according to the results of QFD, in this tool, all of the components of the optimization are implemented to the cost function because of usage of weighted MDO.

For the optimization, type of the optimization and related algorithm are the most critical parts. In this thesis, genetic algorithm is used to optimize the external geometry of the missile. Genetic algorithm is one of the way to find the global optimum solution of the optimization problem. It has lots of elements like selection, mutation etc. They provide to create new populations to reach the global optima. Missile external shape optimization is a complex design problem; so, gradient based optimization methods cause to stick around the local optima of the problem. Gradient-based methods are also tried at the beginning of this thesis in order to obtain a very agile tool, but it is seen that the solution is not the global optimum. When the genetic algorithm is used, vales of cost function for optimum missile configurations are lower.

Furthermore, for such a complex design optimization problem, usage of genetic algorithm alone is not effective especially in term of the time. In detail, it makes the conceptual design phase longer. Thus, usage of neural network makes the optimization shorter and easier. At the beginning of the thesis, genetic algorithm is tried to use alone for optimization. But, time consumed to obtain the optimum solution with only genetic algorithm is ten times longer than the time consumed to obtain the optimum solution with neural network and genetic algorithm. Because, when only genetic algorithm is used DATCOM is called by the tool at population. This makes the process so long. But, when neural network is added before the genetic algorithm, networks are used instead of DATCOM during the optimization. The calculations are done on a computer having a processor Intel Core i7-7700HQ CPU @2.80 GHz with 16,00 GB of RAM.

Created dataset in design part and the results of aerodynamic analysis are used to create required inputs for the neural networks and optimization. The needs of optimization part of the tool are the design parameters and the results of aerodynamics analysis for missile configurations dataset. Objective function and constraints are determined before this step, thus, only values of related coefficients for the optimization are inputted to this part of the tool.

Geometrical parameters are called as inputs for the neural network, and the cost function and constraints are called as targets in the tool. In order to establish effective neural networks between inputs and targets, number of neurons is very important. These values are configurable in the tool. The number of the neurons is chosen by regarding R^2 value. The R^2 value of the fitness is tried to make close to 1. When the number of neurons increases, the R^2 value is getting closer to the 1. But increase in the number of neurons causes the longer process time for neural networks. Moreover, the neurons should be grouped for training, validation and test. The user gives percentage for these sets. Training set of neuron is used to make regression between inputs and output. Validation and test neuron sets are used to check this regression. When the all of the neurons are used to train, the neural network does not learn the relation between inputs and output; it just memorizes the pattern between them [24]. In order to avoid such a case, percentage of validation and test neuron sets should be carefully considered. These values should be determined by iteration. During this iteration, R^2 values for training neuron set and testing neuron set should be regarded. Both values are expected to be close to 1 as much as possible. After that, neural networks are created between inputs and target.

The created neural networks are used in optimization with the genetic algorithm. For complex optimization problems, finding the global maxima or minima is a challenging point for optimization algorithms. Especially, derivative-based optimization algorithms can find just the local maxima or minima. In that sense, for complex optimization problem which has lots of nonlinear terms, genetic algorithm is the most appropriate algorithm type.

For the optimization with genetic algorithm, Matlab toolbox is used. Although, default values of most of the parameters are applicable for this optimization case, each choices is scrutinised and the options for this Matlab tool are decided. These choices are determined according to the dataset, optimization parameters and constraints.

Genetic algorithm creates genes which contain all of the external geometry parameters. These genes are checked with networks which are used in cost function and constraints in terms of the achievement of constraints and minimization of cost function. Until all of the constraints are satisfied and cost function is minimized, the tool continues to create new genes. Finally, it gives the optimized missile external geometry parameters and sketch of the missile.

After that point, the missile geometry is completely obtained. The optimization is finished and the conceptual design of the missile is completed. The general path which is followed in the optimization part can be schematized as in figure 6.4.

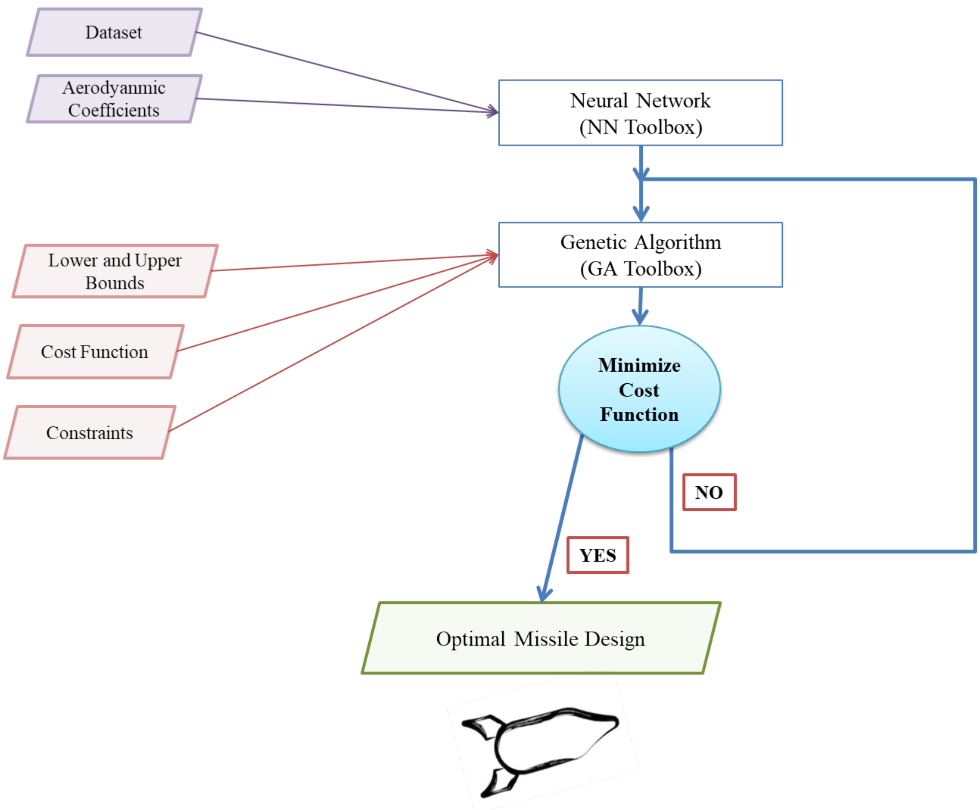


Figure 6.4: Optimization Part Chart

6.5 Environment and Subpackages of Tool

The tool is developed in the MATLAB. It includes MATLAB toolboxes and other supporting packages. Mainly, the tool has four parts which are;

- AHP Part,
- QFD Part,
- Design Part and
- Optimization Part.

For the AHP part and QFD part of the tool, usage of the customer is expected and assumed. Thus, Microsoft Excel is used at these parts to provide more simple and user-friendly interface for customer. For the design and optimization parts, Matlab scripts and toolboxes are used. These codes and toolboxes are expected to be used by technical team. Furthermore, the use of Matlab scripts ensures that both parts are configurable according to different cases. Also, these four parts interconnect to each other by Matlab scripts.

6.5.1 Used MATLAB Toolboxes

In design and optimization parts of the tool, MATLAB and its toolboxes are used. The main toolboxes which are used for optimization are neural network and genetic algorithm toolboxes.
Neural network toolbox provides a structure for designing and implementing deep neural networks with algorithms, pretrained models, and applications [1]. Also, training progress can be observed easily.
Genetic algorithm toolbox is used for optimization. The core purpose of the toolbox which is built with "ga" function in MATLAB is finding the input set which minimizes the objective function by satisfying the constraints. Though, some of the operator in the genetic algorithm like mutation, crossover and creation are particular according to the problem; they can be coded according to the needs of external configuration optimization problem.

6.5.2 DATCOM

Missile DATCOM is used for estimation of aerodynamic coefficients of a given geometry. It is capable of dealing with a wide variety of conventional missile designs. There are several versions of DATCOM. The most available and verified version of the DATCOM is Missile DATCOM97. In this tool, the executable version of DATCOM 5/97 produced by USAF (United States Air Force) is used.

In this tool, there is an operator code which is developed in MATLAB to prepare appropriate input sets for DATCOM and read and organize the output file generated by DATCOM. Moreover, the operator code organizes the output file to create aerodynamic coefficients which depend on Mach number and angle of attack. Furthermore, DATCOM provides geometrical data for the optimized missile external geometry. This data does not make sense without any operation. The operator code makes this data understandable and creates the model of the missile.

There are additional functions to handle the interconnection between four parts. Also, there is a main code which acts as a user interface.

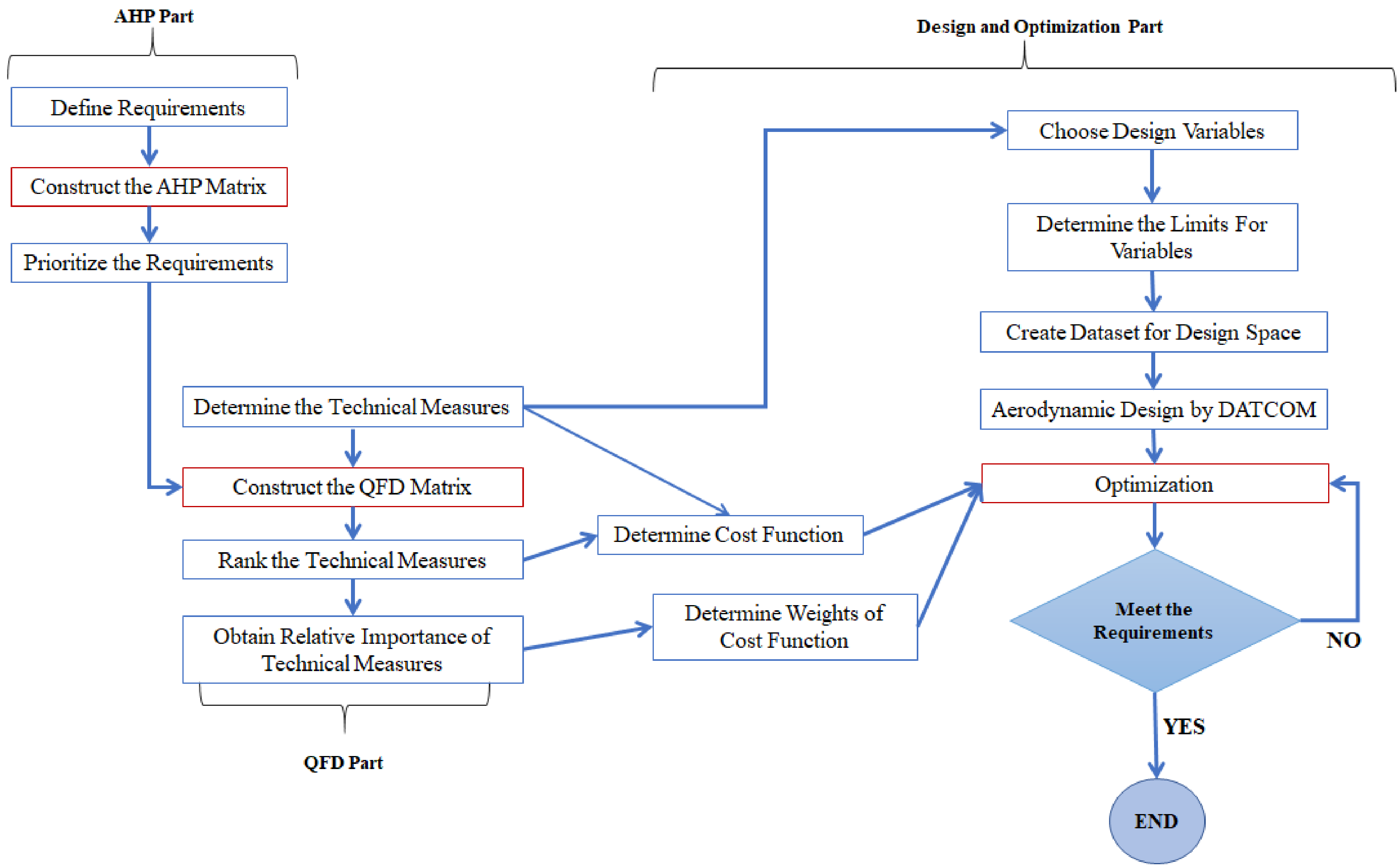


Figure 6.1: Scheme of the Tool

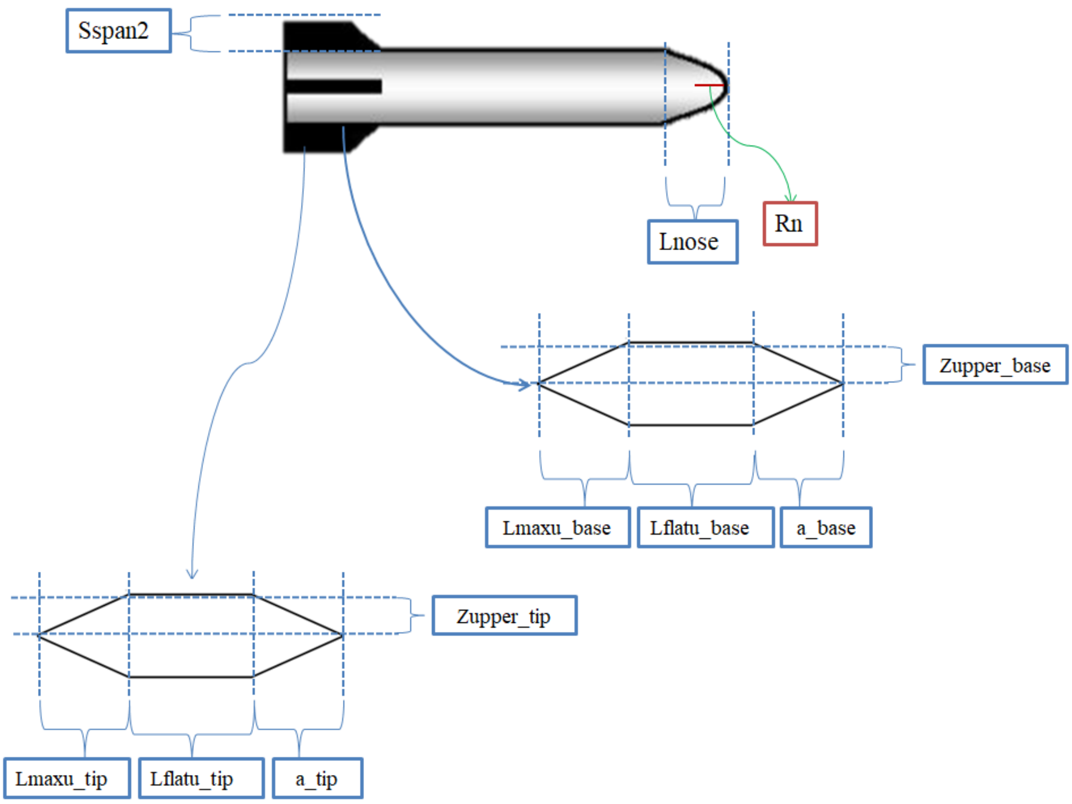


Figure 6.2: Design Parameters

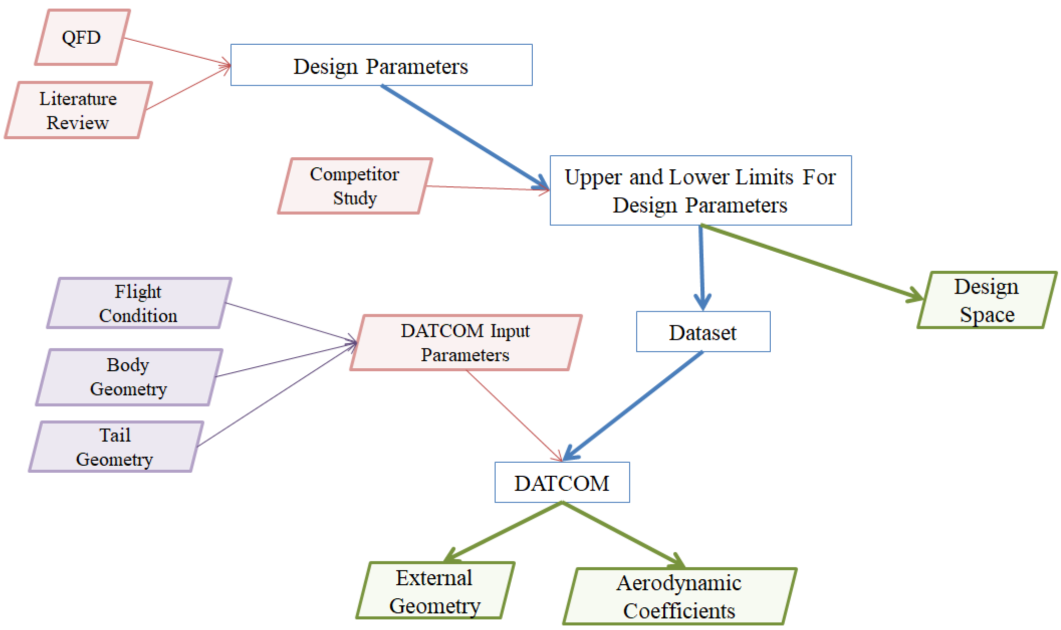


Figure 6.3: Design Part Chart

CHAPTER 7

CASE STUDIES

As case studies and the main aim of this thesis, conceptual design and optimization integrated with system engineering methodologies of surface to surface, tail controlled, ballistic missiles are struggled at this part of the thesis by using developed tool.

There is not a specific ballistic missile which is pointed in this study. Designed ballistic missiles are created according to the requirements which are given in the following parts. Values of required parameters are assumed from the average values theatre ballistic missiles. The ballistic missiles which will be designed in this study will be called as BM-1 and BM-2 in the thesis.

For the case studies, as aimed in the tool, firstly, AHP will be conducted and the results of the AHP will be inputted to QFD analysis, then, the results of the QFD will be inputted to the cost function of the optimization. Cost function is chosen as a complex function which will be used for different studies with different weigths from results of AHP and QFD analysis. According to design variables, external geometry design process will be initialized. By using neural network and genetic algorithm, the optimal missile configuration will be found.

In this chapter, two different case studies are considered. In detail, design and optimization of two different missile systems are handled. As mentioned before, requirements' set is same for both case but the priority of the requirements differs because of usage scenario. Also, cost functions for the optimization problem are same for both cases but the weights of components of the functions are different. The developed tool is used for both cases in exactly the same way as shown in figure 7.1.

Descriptions about AHP, QFD, external geometry design and optimization parts are detailed under the heading of Case Study 1. Also, results of the Case Study 1 are described. At the Case Study 2 part, only brief information is given about the steps, because the steps are same with Case Study 1. Result of these cases are the main topic of this part.

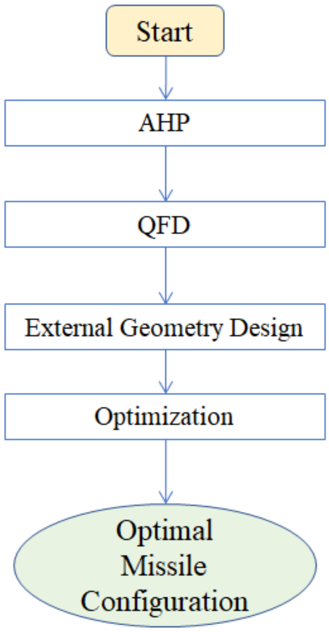


Figure 7.1: Case Study Flowchart

7.1 CASE STUDY 1

In the Case Study 1, each step of developed tool is applied for the optimization of BM-1 missile external shape optimization. AHP, QFD, initial external geometry design and optimization parts are performed respectively.

7.1.1 The AHP for BM-1

The AHP part is performed in three steps which are decomposition, comparative judgement and synthesis of priorities.

First, decomposition step is practiced in two parts. At the first part of this step, the requirements are determined. For the determination of the requirements, generic ballistic missile requirements are considered constitutively. Because there is not an addressed ballistic missile system, general requirements for ballistic missiles are revised. In that sense, the requirements for BMs can be listed as follows.

- The range of the missile should be greater than [A] km.
- The missile should be able to maneuver at least [B]g.
- The flight time should be less than [C] sec.
- The maximum altitude should be greater than [D] km.
- The launch platform should be [E]x[F]x[G] m.
- The R&D cost and manufacturing cost should be less than [H] $.
- The missile should have seeker.
- The missile should not damage the launch platform after the launch.
- The missile should escape from the anti-ballistic missiles.
- The CEP value should be less than [J] m.
- Offset distance should be less than [K] m.
- When the humidity is % [L] and the temperature is between [M] – [N] °C, the missile should operate.
- The missile should have at least [P] years.

The given requirements are the base for the design of the BM-1 and BM-2. In general, the usage scenario and the priority of the requirements are determined by the customer. But, customer is not involved into this study. So, the pairwise comparison of the requirements is assumed based on the general information about the ballistic missiles. In detail, as mentioned before, two different usage scenarios are created. According to these scenarios, open sources and some articles for the ballistic missiles' requirements are researched to compare the requirements. So, the comparison is performed in the light of such information. As a second part of the decomposition step, the AHP matrix which is called as comparison matrix is constituted based on the edited scenario. Each requirement is assigned as a criterion to compare.

Secondly, the comparative judgement step is practiced. At this step, the matrix is used to compare the pair of requirements. For the pairwise comparison of the requirements Saaty's Scale is used. The used scale is shown at table 7.1.

Table 7.1: Scale Used For AHP Matrix

	Relative Comparison Coefficients		
Extreme Importance	**9,0**	1/9	0,111
	8,0	1/8	0,125
Very Strong or Demonstrated Importance	**7,0**	1/7	0,143
	6,0	1/6	0,167
Strong Importance	**5,0**	1/5	0,200
	4,0	1/4	0,250
Moderate Importance	**3,0**	1/3	0,333
	2,0	1/2	0,500
Equal Importance	**1,0**	1/1	1,000

As explained in the AHP section, only the upper – diagonal part of the AHP matrix is graded. The importance order of the criterion at the row with respect to the criterion at the column is graded and the corresponding matrix is filled. Finally, synthesis of the priority of the requirements is done. In order to ensure simplicity and consistency in the matrix, the Saaty's Method is used to analyse the order of precedence.

AHP matrix, analysis and the results of the AHP analysis for BM-1 can be seem from the table 7.2. Prioritization of the requirements is shown at the column which is labelled as "Order of Precedence" of the table 7.2. According to these values, usage scenario of the ballistic missile and the importance rating for the requirements can be summarized as follows. For BM-1 range maximization is one of the crucial requirements. Also, in order to have high capable missile to hit the targets, maneuverability is another crucial requirement. Another important point is that, for the strategical ballistic missile systems; time to target should be as less as possible for the achievement of the operation, hence, it makes the requirement which is "time to target" an important factor. Also, higher altitute for the flight trajectory is a significant requirement for the BM-1.

The results of AHP analysis for BM-1 are inputs for the QFD analysis as weight of priority for the corresponding requirement.

7.1.2 The QFD for BM-1

Quality Function Deployment (QFD) is used to link customer requirements and technical measures. House of Quality Matrix is constructed for that purpose.

In this tool, six rooms are used in house of quality matrix. So, for Case Study 1 and Case Study 2, same rooms are used. The rooms are shown in the figure 7.2. They are;

1. Customer Requirements,
2. Engineering Characteristics (Technical Performance Measures),
3. Relationship Matrix,
4. Importance Rating (AHP Results),
5. Absolute Importance and
6. Relative Importance.

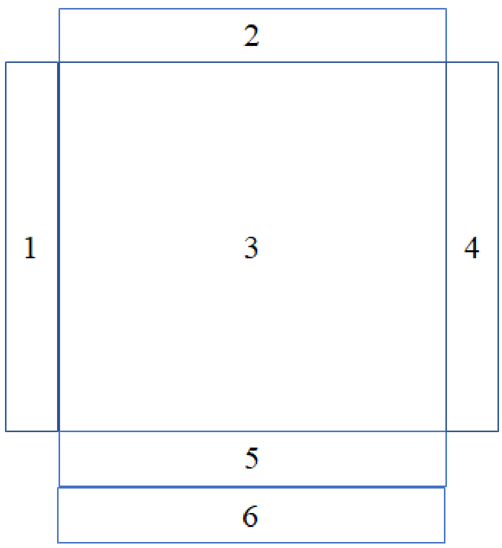


Figure 7.2: HoQ Matrix Rooms in Tool

Customer requirements for BM-1 are determined at the beginning of the AHP part. These requirements are placed into the HoQ matrix. Meanwhile, the technical performance measures, i.e. engineering characteristics are determined. For the conceptual external geometry design, technical performance measures can be written as in table 7.3. These performance measures are general characteristics for design of ballistic missiles. The requirements, technical performance measures and their relations are mentioned in [42], [14] and [24]. These references are used to determine technical performance measures and relationship intensity between the commensurate requirement and TPM.

In the relationship matrix, “0-1-3-9” scale is used to show the relationship intensity between the requirements and the technical measures. Moreover, the order of precedence which is obtained from the AHP matrix is embedded into the HoQ matrix. By using the equations which are given in the Chapter 3, absolute importance and relative importance of each technical measure are calculated. According to the obtained values, the technical measures are ranked and the importance scale is shown in the TPM's Weight Chart.

As explained in the Chapter 4, drag coefficient, control effectiveness and stability are the most important technical measure parameters in the conceptual design phase. So, they should be the parts of the cost function which is used for optimization. Also, as explained in the the Chapter 4, nose bluntness, length of nose ,which is the conical part of the missile, are the critical parameters for the missile systems. Especially, need of usage of seeker makes these parameters much more significant. In detail, by considering the both cases, one generic, complex and weighted cost function is created for multiobjective optimization. Although, one cost function is determined, the tool permits user to configure cost and constraints functions.

Results of the QFD analysis show the most critical parameters to satisfy the requirements. So, these results can be used to determine the parts of the cost function and weights of these parts for the optimization problem of BM-1.

Hose of Quality matrix for BM-1 is given in Table 7.3. Requirements are described in previous parts. They are implemented to the "Customer Requirements" room. Technical parameters which could be effective to satisfy these requirements are implemented to the "Engineering Characteristics" room. Then, each requirement - technical parameters are graded in terms of the effectiveness. For example, for "maximum range - drag force" pair, grade is 9, because, drag coefficient is directly related with maximum range. In other words, in order to maximize the range, drag coefficient should be minimized.

7.1.3 External Geometry Design of BM-1

At the design part, values of eleven parameters to describe the external geometry properties of the missile should be determined and inputted to the tool. These eleven parameters are defined at the Section 6.4.

As mentioned at the beginning of this section, theatre ballistic missile is designing conceptually at this part. For that purpose, the upper and lower limits for design parameters must be determined. These parameters are determined by literature review. In the [25], surface-to-surface missiles which have different ranges are investigated. The results are listed related with range. By using the values which are obtained for theatre missiles, the upper and lower limits are determined for design parameters of BM-1 and BM-2.

During the external geometry design process, choosing the number of sampling is one of crucial points. When the number of sampling is not enough to represent the whole design space, optimization may not converge to optimum configuration. On the other hand, if the number sampling is too much, consumed time to find optimum solution becomes too long, needlessly. By considering both cases, different number of sampling are tried during this study. Firstly, number of sampling was chosen as 100 and design and optimization process were detailed over these samples. But, as mentioned before, that number of sampling was not enough to represent the whole design space. Obtained missile configuration was not the best solution. After that, number of sampling was increased to 250. This value was not also enough to find the best optimum solution. When the dataset was changed to another 250 samples, optimum configuration and corresponding results for aerodynamic coefficients changed significantly. In order to see the results, the number of sampling was raised to 5000. When 5000 sapmles were used, the same optimum solution can be found at each trial.

But, the consumed time may be reduced by decreasing the number of sampling. In other words, the optimum value of the number of sampling should be found to develop a time efficient tool. Hence, the number of sampling (n) is chosen as 1000 and it is seen that 1000 is enough to represent the design space. Also, the optimum missile configuration is almost same with the missile configuration which had been found by using 5000 samples. The optimum configuration does not change considerably when different 1000 samples are used for design and optimization.

Dataset is created with the LHS method. LHS provides the randomly distributed dataset between given limits. When the sampling number increases, the coverage of the space between bounds is getting better. As an example, Figure 7.3 shows the distribution of the dataset for span length and nose radius.

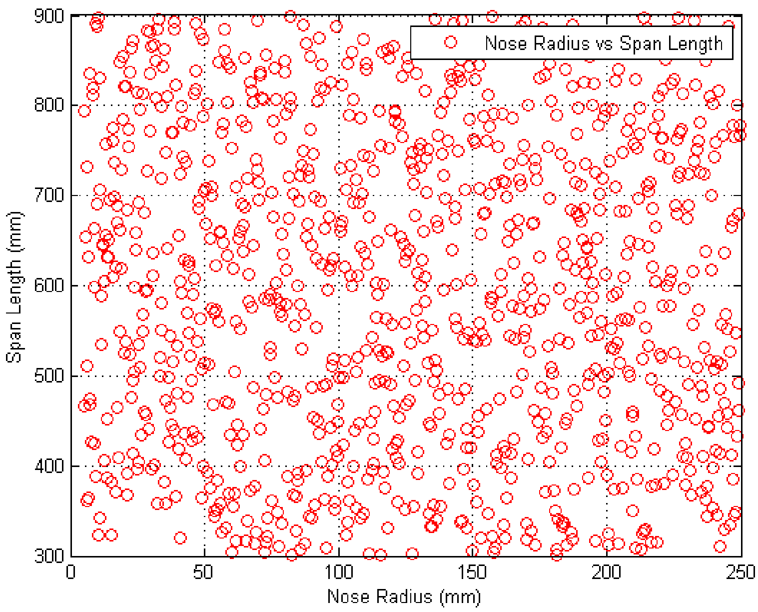


Figure 7.3: LHS Dataset for Nose Radius vs Span Length

Dataset contains 1000 sampling for eleven design parameters. That means, 1000 different configurations are constituted by this dataset.

Moreover, flight condition parameters are also inputted for the DATCOM analysis. Flight conditions are also decided according to competitor study and initial basic flight simulations. In order to determine different aerodynamic coefficients, different pairs of angle of attack values and Mach numbers are used. Table 7.4 shows the flight condition parameters used for BM-1 and BM-2 conceptual design.

Table 7.4: Flight Conditions

Flight Condition Definition		
Input Name	**Value**	**Unit**
NALPHA	2	-
ALPHA	0,1 - 5,6	deg
NMACH	1	-
MACH	3 – 5 – 7	-
BETA	0	deg
ALT	0	m

The required aerodynamic coefficients for the cost function and constraints are obtained by running the DATCOM for each configuration. C_d, C_m, C_{m_α} and C_{m_δ} values are obtained for each configuration. At the end of this part, design space is created. These values are used in the artificial neural network and genetic algorithm parts.

7.1.4 Optimization of BM-1

At the beginning of the optimization part, cost function and its parts should be clarified in order to use equation 6.1 in Chapter 6. The technical parameters which are pointed in the QFD section should be inclоded by the cost function. At the same time, the cost function should be more generic to cover the other possibile results of the AHP and QFD. In other words, by using a generic cost function, two different case studies, which are carried out in this thesis, should be covered. So, drag coefficient, C_{m_α} for static stability, $\frac{C_{m_\delta}}{C_{m_\alpha}}$ for control effectiveness, nose bluntness and nose legth become the parts of the cost function. So, the cost function can be written as in equations 7.1, 7.2 and 7.3.

$$
\begin{aligned}
f_1 &= C_{d_{M=3,\alpha=0}} + C_{d_{M=5,\alpha=0}} + C_{d_{M=7,\alpha=0}} \\
f_2 &= C_{m_{\alpha_{M=3,\alpha=5}}} + C_{m_{\alpha_{M=5,\alpha=5}}} + C_{m_{\alpha_{M=7,\alpha=5}}} \\
f_3 &= \frac{C_{m_{\delta_{M=3,\alpha=5}}}}{C_{m_{\alpha_{M=3,\alpha=5}}}} + \frac{C_{m_{\delta_{M=5,\alpha=5}}}}{C_{m_{\alpha_{M=5,\alpha=5}}}} + \frac{C_{m_{\delta_{M=7,\alpha=5}}}}{C_{m_{\alpha_{M=7,\alpha=5}}}} \\
f_4 &= R_n \\
f_5 &= L_{nose}
\end{aligned}
\tag{7.1}
$$

$$
\begin{aligned}
where \quad w_1 &= 1 \\
w_2 &= 1 \\
w_3 &= -0.1 \\
w_4 &= -10 \\
w_5 &= 0.1
\end{aligned}
\tag{7.2}
$$

$$
\begin{aligned}
minimize \quad F(x) = C_{QFD_1}.w_1.f_1(x) + \\
C_{QFD_2}.w_2.f_2(x) + C_{QFD_3}.w_3.f_3(x) + \\
C_{QFD_4}.w_4.f_4(x) + C_{QFD_5}.w_5.f_5(x)
\end{aligned}
\tag{7.3}
$$

The weights of the cost function which are w_m are determined as normalization coefficients of the parts of the cost function. After normalization, only QFD coefficients become the dioristic factor for the weight of each component.

QFD coefficients for the cost function are obtained from the "Relative Importance" room of the HoQ matrix. For the BM-1 these values are shown in table 7.5.

Table 7.5: QFD Coefficients for Case Study 1 / BM-1

C_{QFD_1}	C_{QFD_2}	C_{QFD_3}	C_{QFD_4}	C_{QFD_5}
18.05	17.24	14.71	2.93	5.66

Optimization part of the tool is the combination of neural network and optimization with genetic algorithm tool.

The design parameters are also inputs for neural networks. Neural network aims to form nonlinear regression between the inputs which are design parameters and the targets which are the cost and constraints. For the artificial neural network, neuron number is chosen as 1000. %60 of them are for training the neurons, %20 of them are for validation and %20 of them are for test the neural networks.The default options of the Neural Network toolbox are used.

The most important criterion for the analysis of the neural network is fitness value between actual value and predicted value. For the BM-1, neural network is established between design parameters and each cost function and constraint. Statistics shows the fineness of the network by the value of R^2. Neural networks are used to find the predicted values of three different parts of the cost function. So, the values of R^2 for f_1, f_2 and f_3 are checked seperately. Also, figure 7.4, figure 7.5 and figure 7.6 show the fineness of the regression for each of them.

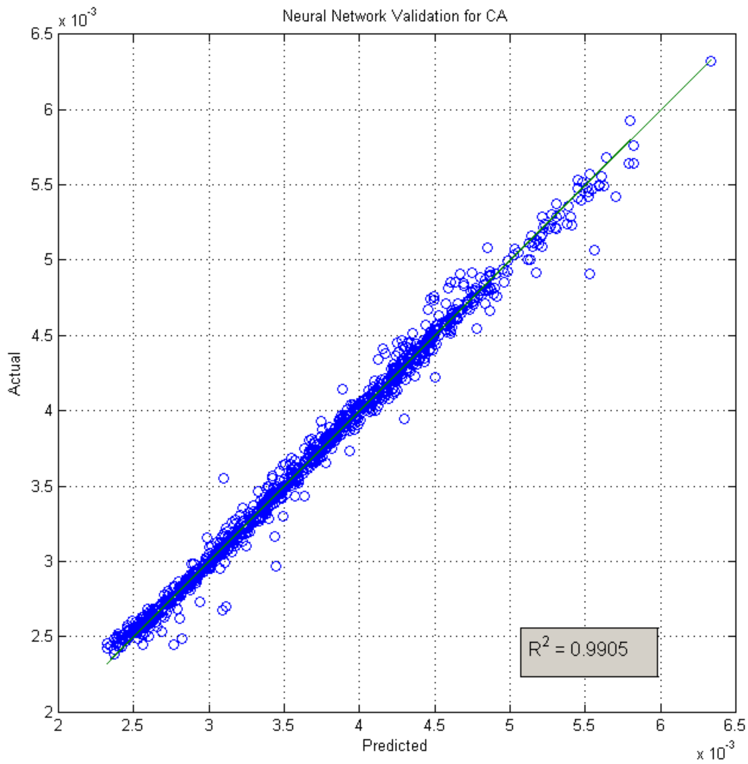


Figure 7.4: Fineness of Neural Network Results for C_d of BM-1

The created neural networks are used to optimize the external geometry of the BM-1.

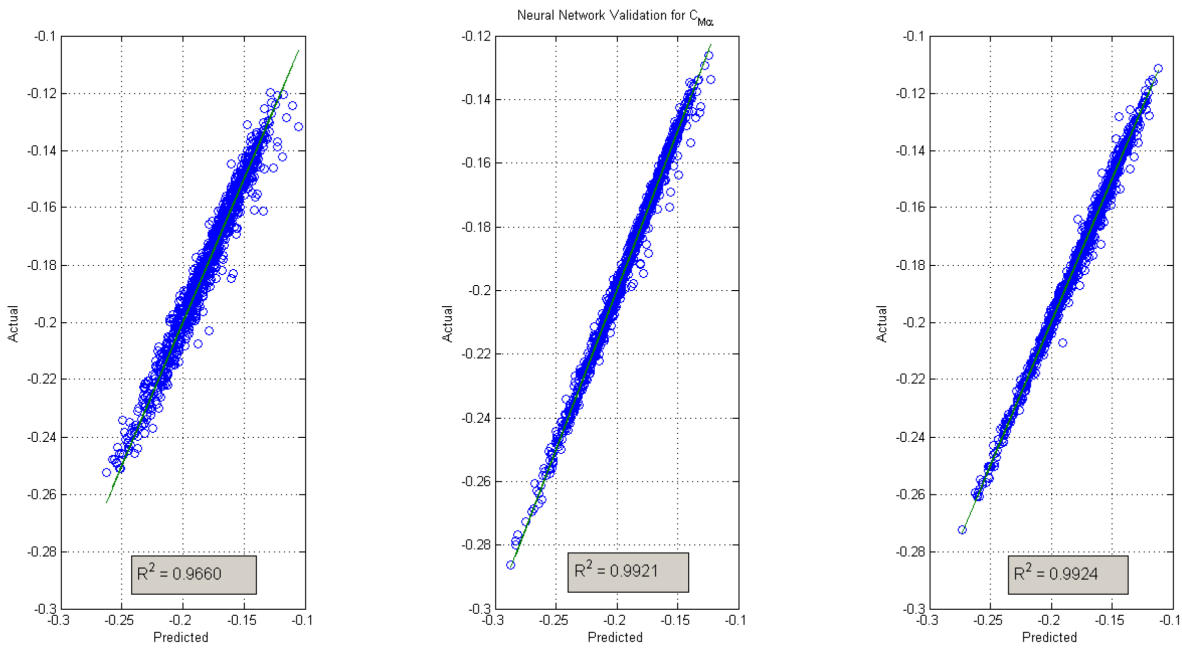


Figure 7.5: Fineness of Neural Network Results for $C_{m\alpha}$ of BM-1

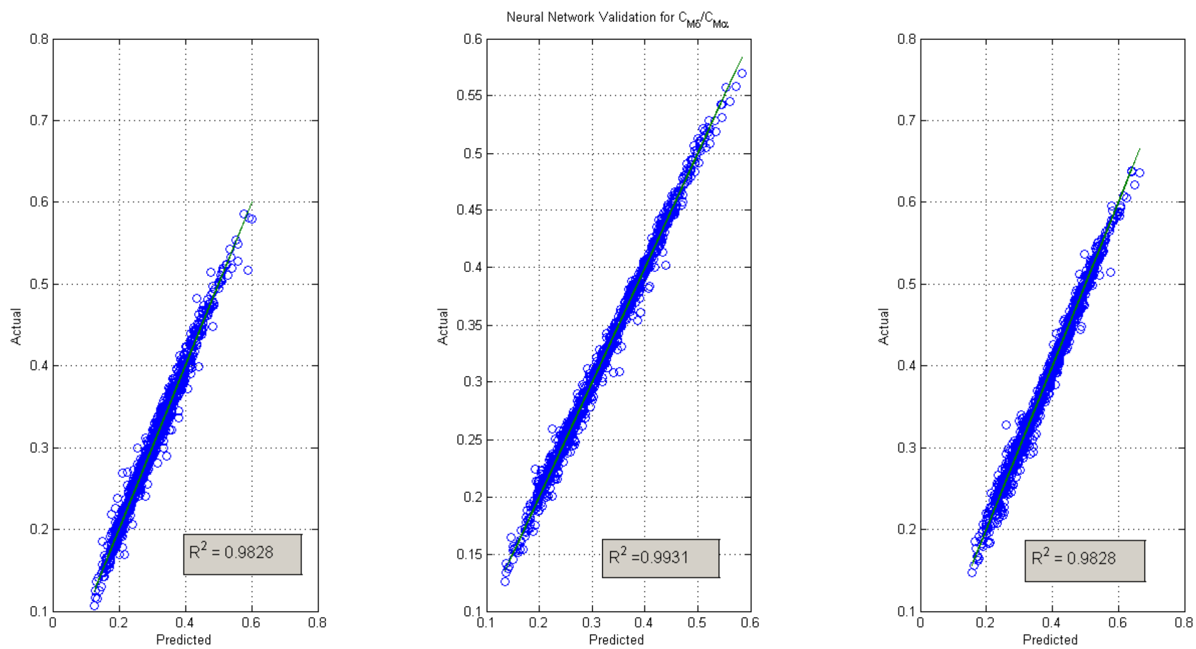


Figure 7.6: Fineness of Neural Network Results for $C_{m_\delta}/C_{m_\alpha}$ of BM-1

Lower and upper bounds for the design parameters are determined at the beginning of optimization part. Moreover, parts of the cost function and their weights are determined at the QFD part. In order to use genetic algorithm toolbox, some of the options are decided. Their default values are used generally. They can be specified as in table 7.6.

Table 7.6: Default for GA Toolbox

Option	Value
CreationFcn	@gacreationuniform
CrossoverFcn	@crossoversinglepoint
Display	iter
EliteCount	%10
SelectionFcn	@selectionroulette

According to given options, genetic algorithm toolbox is used. The lower and upper bounds for eleven design parameters are determined at the external shape design part. These bounds are limit for the maximum and minimum values of each gene. These genes contain eleven design parameters. As mentioned before, genetic algorithm toolbox of Matlab is used for optimization. The used options are detailed in table 7.6. First of all initial population is created as a random initial population as a uniform distribution in given lower and upper bounds for each design parameter. Also, population size is 200, that means 200 new dataset are created at each generation. After the creation of initial population, optimization with genetic algorithm begins. Value of cost function is calculated using the networks. At the selection part, parents are chosen for the next generation. As specified in table 7.6, “Roulette Selection” is used. This option for selection provides higher possibility for selection of lower cost function chromosomes. While the selection of parents finishes, the crossover process initiates. Single point crossover method is used. When the single point crossover is used, crossover point is decided randomly and the child is created with respect to this point. After crossover, mutation starts. At the mutation, small random changes in chromosomes occur. Adaptive feasible mutation method is used to determine automatically directions of small changes with respect to the last successful or unsuccessful generation. In order to create new generation, elitism is applied. %1 of the population which have the best fineness value are directly carried to the next population. At the end of the elitism, new generation is created. This loop continues until the value of the cost function is minimized or the iteration number is attained to upper limit. After that point, the optimal genes are obtained and the best population which makes the cost function minimum is created.

At the end of the described optimization process, the BM-1 external missile geometry is obtained as in figure 7.7 .

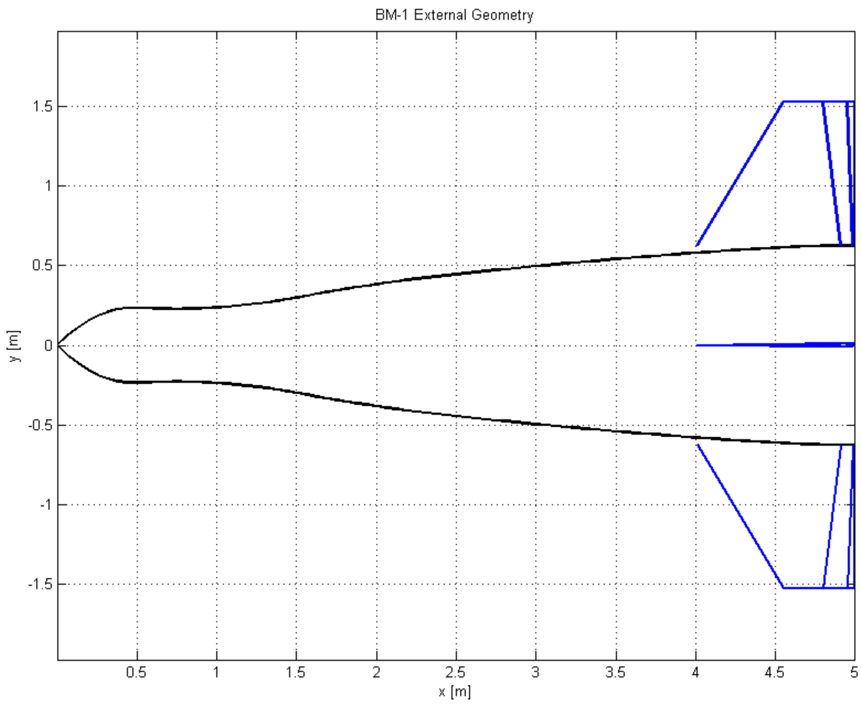


Figure 7.7: Optimal Missile External Shape Configuration for BM-1

For BM-1, weight of the drag coefficient part in cost function is the highest. That means, drag minimization is the most significant aim of the optimization. So, the optimization algorithm tries to make bluntness of the nose minimum. Also, nose length is long and most of the missile external geometry is conical to minimize drag. For the same purpose, length of the cylindrical part is less. Weights of static stability and control effectiveness parts are the second and third ones. Thus, to provide statically stable and controllable missile, the length of the span and the length of the chord are higher. Although, bluntness of nose and length of nose are parts of the cost function and they are tried to maximize in order to satisfy other requirements, weight of the drag coefficient makes C_d more dominant Hence, BM-1 missile external shape which is more pointed nose and longer nose part, is obtained.

The aerodynamic coefficient values, which are considered in the parts of the cost function, for BM-1 are given in table 7.7.

Table 7.7: Aerodynamic Coefficients of BM-1

Aerodynamic Coefficient	**Values**
$C_{d_{M=3,\alpha=0}}$	0.11
$C_{d_{M=5,\alpha=0}}$	0.14
$C_{d_{M=7,\alpha=0}}$	0.1
$C_{m_{\alpha_{M=3,\alpha=5}}}$	-0.28
$C_{m_{\alpha_{M=5,\alpha=5}}}$	-0.32
$C_{m_{\alpha_{M=7,\alpha=5}}}$	-0.29
$\frac{C_{m_{\delta_{M=3,\alpha=5}}}}{C_{m_{\alpha_{M=3,\alpha=5}}}}$	7.9
$\frac{C_{m_{\delta_{M=5,\alpha=5}}}}{C_{m_{\alpha_{M=5,\alpha=5}}}}$	8.2
$\frac{C_{m_{\delta_{M=7,\alpha=5}}}}{C_{m_{\alpha_{M=7,\alpha=5}}}}$	7.4

7.2 CASE STUDY 2

In the Case Study 2, each step of developed tool is applied for the optimization of BM-2 missile external shape optimization. AHP, QFD, initial external geometry design and optimization parts are performed respectively.

7.2.1 The AHP for BM-2

At that part, steps of AHP are performed same as in BM-1 AHP analysis. Requirements are determined for BMs which are taken into consideration in this thesis as in section 7.1.1. But the most important distinctiveness is that, the usage scenario of BM-2 is different. So, this difference makes the order of precedence of requirements disparate. The AHP matrix is constructed based on the usage scenario of BM-2.

Saaty's scale is used for pairwise comparison. AHP matrix for BM-2 can be seen in figure 7.8

According to the results of AHP analysis for BM-2, it can be said that seeker usage is a must for this scenario. Also, easiness of subsystem integration which are seeker and other avionic units is another crucial point. Furthermore, range and maneuverability of the missile are not as significant as seeker usage and easiness of subsytem integration. But, they should still be considered.

The results of AHP analysis for BM-2 are inputted to the QFD analysis as weight of priority for the corresponding requirement.

7.2.2 The QFD for BM-2

QFD analysis for BM-2, HoQ matrix is constructed. Values of "Importance Rating" room is different from the corresponding values for BM-1. Because, these values show the priority of the requirements.Importance rating of requirements directly effects the results of QFD analysis. House of quality matrix for the QFD analysis of BM-2 is given in figure 7.9.

As a result of QFD analysis for BM-2, to satisfy the prioritized requirements, nose bluntness and nose length are the crucial technical parameters. Also, drag force, static stability and control effectiveness are sequent factors to appease the customer's needs. Values of weights, which are QFD coefficients, of each part of the cost function are obtained from the "Relative Importance" room of HoQ matrix. These values are used for optimization of external geometry of BM-2 directly.

7.2.3 External Geometry Design of BM-2

For design and optimization, eleven parameters are determined to define the external geometry. These parameters are same for BM-2, too. Moreover, in order to obtain a controlled results, the upper and lower bound of these parameters are kept same. During the literature review, missiles with seeker and easy subsystem implemented missiles are also considered. The same dataset and flight conditions which are given in table 7.4, which are used for BM-1, are used for BM-2. Aerodynamic analysis are done with these conditions. C_d, C_m, C_{m_α} and C_{m_δ} values are obtained for each configuration. These values are used in the artificial neural network and genetic algorithm parts.

7.2.4 Optimization of BM-2

The main purpose of this case study is optimizing BM-2 missile external shape by using the same cost function with BM-1 but with different weights for parts of this function. In other words, systematical solution capability of the developed tool for optimization problems is intended to show by this way. In that way, equation 7.1, equation 7.2 and equation 7.3 are used as cost function. QFD coefficients, which are shown as C_{QFD_m} in equation 7.3, are obtained from the "Relative Importance" room of HoQ matrix which is given in table 7.9. For the BM-2 optimization problem, these coefficients are shown in table 7.10

Table 7.10: QFD Coefficients for Case Study 2 / BM-2

C_{QFD_1}	C_{QFD_2}	C_{QFD_3}	C_{QFD_4}	C_{QFD_5}
8.21	10.94	12.40	15.85	15.74

The used neuron number is chosen as 1000. %60 of them are for training the neurons, %20 of them are for validation and %20 of them are for test the neural networks. Fineness of networks are checked by considering values of R^2. The values of R^2 for f_1, f_2 and f_3 are checked seperately. Also, figure 7.8, figure 7.9 and figure 7.10 show the fineness of the regression for each of them.

The created neural networks are used to optimize external geometry of BM-2 by cooperating with genetic algorithm. The described steps in section 7.1.4 are applied in the same way to the BM-2 optimization process.In detail, options of genetic algorithm toolbox, which are specified in table 7.6, are used. Selection, crossover, mutation and elitism are performed according to these options and the BM-2 external missile geometry is obtained as in figure 7.11.

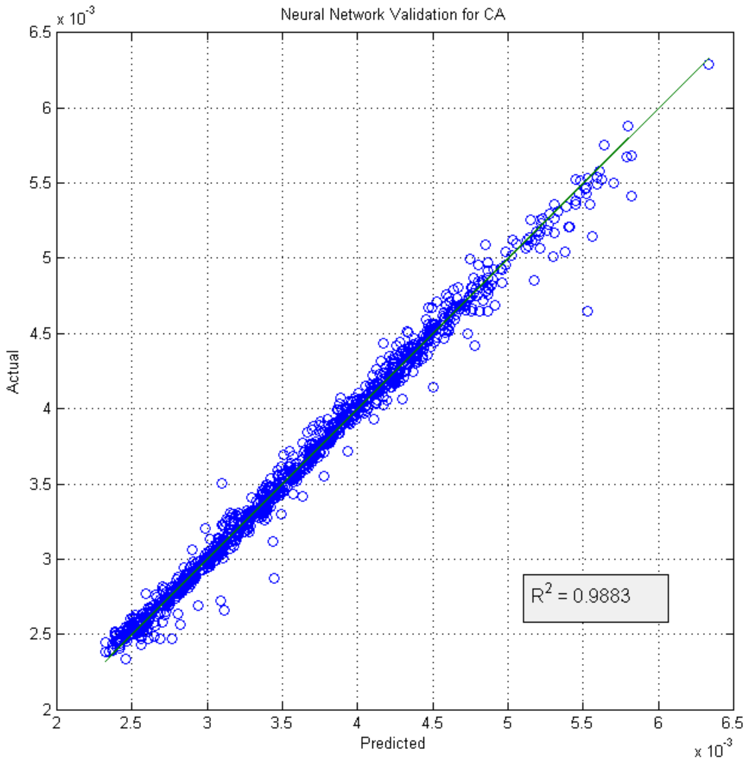


Figure 7.8: Fineness of Neural Network Results for C_d of BM-2

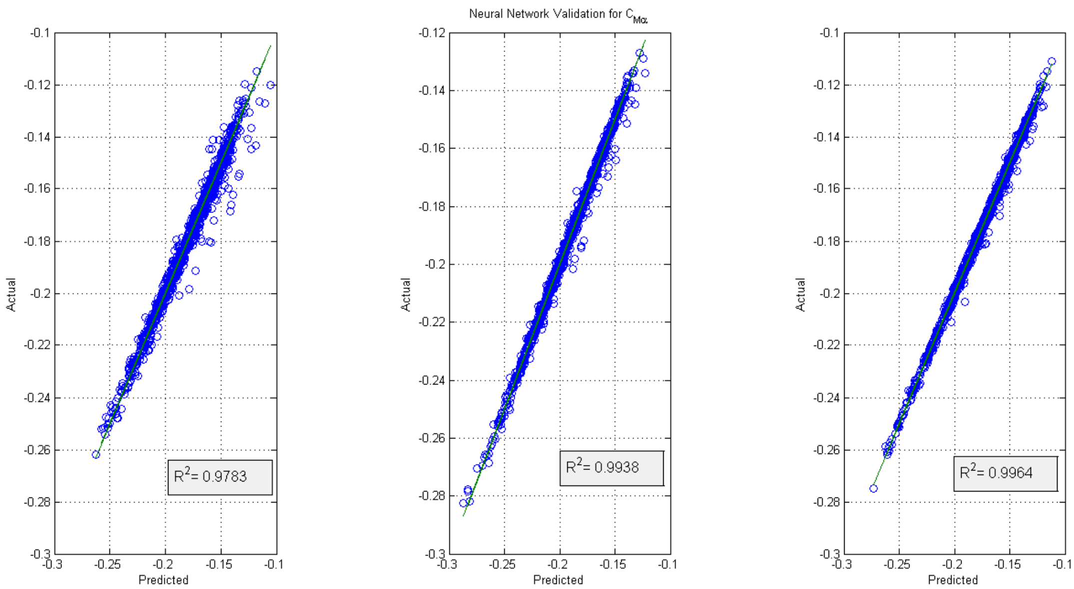


Figure 7.9: Fineness of Neural Network Results for $C_{m\alpha}$ of BM-2

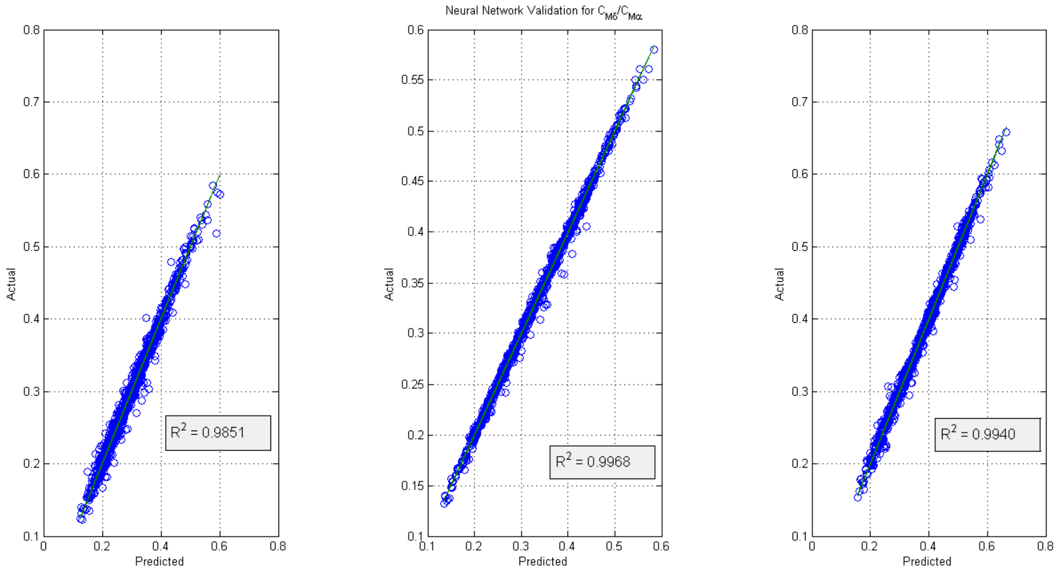


Figure 7.10: Fineness of Neural Network Results for $C_{m_\delta}/C_{m_\alpha}$ of BM-2

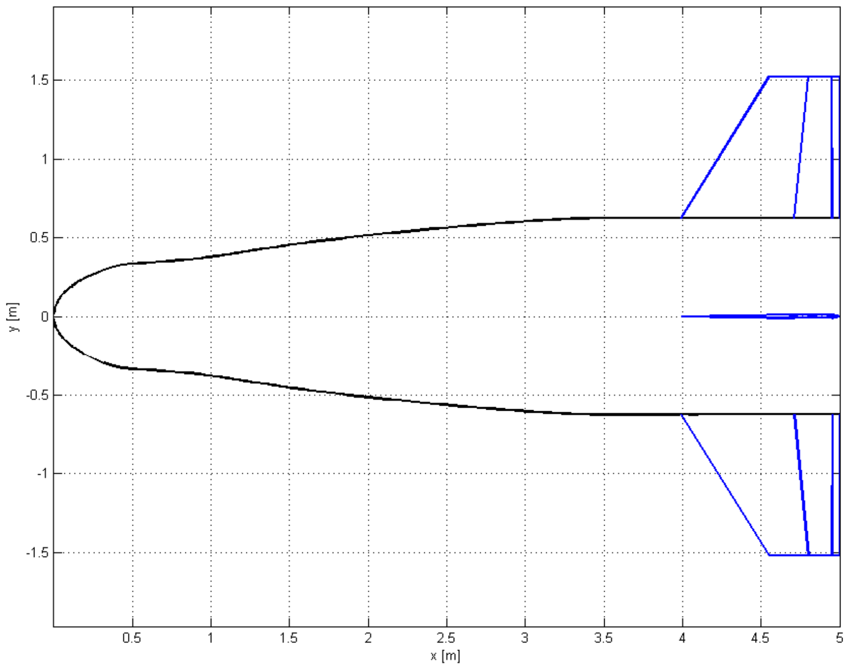


Figure 7.11: Optimal Missile External Shape Configuration for BM-2

For BM-2, seeker usage and subsystem integration are the primary requirements. This scenario makes the weight of bluntness of nose and weight length of nose parts in cost function higher. That means, more blunt nose is needed. Also, the cylindrical part of the nose is also expected to be longer according to conical part of the nose. On the other hand, controllability of missile is still a desired parameter for BM-2. This implies that BM-2 should have long span and chord. Moreover, the drag coefficient and static stability are in the loop of the optimization as parts of the cost function. Thus, the bluntness of the nose and the length of the nose should not be at the limit value for them. The configuration should be optimized by considering their coefficients. As seen from the figure 7.11, the missile external shape is as expected.

The aerodynamic coefficient values, which are considered in the parts of the cost function, for BM-2 are given in table 7.11.

Table 7.11: Aerodynamic Coefficients of BM-2

Aerodynamic Coefficient	**Values**
$C_{d_{M=3,\alpha=0}}$	0.25
$C_{d_{M=5,\alpha=0}}$	0.22
$C_{d_{M=7,\alpha=0}}$	0.14
$C_{m_{\alpha_{M=3,\alpha=5}}}$	-0.27
$C_{m_{\alpha_{M=5,\alpha=5}}}$	-0.26
$C_{m_{\alpha_{M=7,\alpha=5}}}$	-0.23
$\frac{C_{m_{\delta_{M=3,\alpha=5}}}}{C_{m_{\alpha_{M=3,\alpha=5}}}}$	8.4
$\frac{C_{m_{\delta_{M=5,\alpha=5}}}}{C_{m_{\alpha_{M=5,\alpha=5}}}}$	6.62
$\frac{C_{m_{\delta_{M=7,\alpha=5}}}}{C_{m_{\alpha_{M=7,\alpha=5}}}}$	6.21

Table 7.2: The AHP Matrix for Case Study 1 / BM-1

Requirements	Maximum Range	Maneuverability	Time to target	Altitude	Launch Platform Size Limitation	Minimum R&D cost	Minimum Manufacturing Cost	Seeker usage	Launch platform compatibility	Escape from anti-ballistic missiles	Subsystem Integration	CEP	Minimum offset distance	Resistance to environmental conditions	Long shelf life	Reusable launch platform	Simple design	Order of Precedence
Maximum Range	1	1	9	5	9	9	9	9	9	9	9	9	9	9	9	9	9	0,248
Maneuverability	1	1	9	5	9	3	5	7	3	5	7	7	3	7	5	3	7	0,216
Time to target	0,111	0,111	1	9	9	9	9	9	9	9	9	9	9	9	9	9	9	0,160
Altitude	0,200	0,200	0,111	1	9	9	9	9	9	9	9	9	9	9	9	9	9	0,107
Launch Platform Size Limitation	0,111	0,111	0,111	0,111	1	3	5	9	1	1	7	1	5	1	1	1	7	0,037
Minimum R&D cost	0,111	0,333	0,111	0,111	0,333	1	3	9	1	1	5	1	1	1	3	1	3	0,028
Minimum Manufacturing Cost	0,111	0,200	0,111	0,111	0,200	0,333	1	9	1	1/3	1	1	3	5	3	1	1	0,016
Seeker usage	0,111	0,143	0,111	0,111	0,111	0,111	0,111	1	1	1/5	1	1	1	5	7	1	1	0,011
Launch platform compatibility	0,111	0,333	0,111	0,111	1	1	1	1	1	1	3	1	1	1	1	1	3	0,025
Escape from anti-ballistic missiles	0,111	0,200	0,111	0,111	1	1	3	5	1	1	9	9	9	9	9	9	9	0,027
Subsystem Integration	0,111	0,143	0,111	0,111	0,143	0,200	1	1	0,333	0,111	1	1	1	1	1	1	5	0,014
CEP	0,111	0,143	0,111	0,111	1	1	1	1	1	0,111	1	1	1	1	5	1	7	0,019
Minimum offset distance	0,111	0,333	0,111	0,111	0,200	1	0,333	1	1	0,111	1	1	1	1	1	3	3	0,020
Resistance to environmental conditions	0,111	0,143	0,111	0,111	1	1	0,200	0,200	1	0,111	1	1	1	1	1	5	5	0,017
Long shelf life	0,111	0,200	0,111	0,111	1	0,333	0,333	0,143	1	0,111	1	0,200	1	1	1	1	9	0,017
Reusable launch platform	0,111	0,333	0,111	0,111	1	1	1	1	1	0,111	1	1	0,333	0,200	1	1	3	0,025
Simple design	0,111	0,143	0,111	0,111	0,143	0,333	1	1	0,333	0,111	0,200	0,143	0,333	0,200	0,111	0,333	1	0,014

Table 7.3: HoQ Matrix for Case Study 1 / BM-1

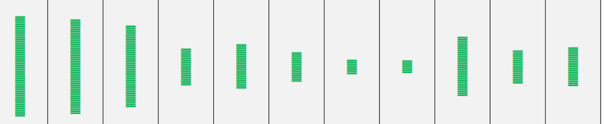
Requirements \ Technical Performance Measures	Drag Force	Static Stability	Control Effectiveness	Length of Span	Aerodynamic Heating	Nose Length	Nose Bluntness	l/d Ratio	Maximum Speed	Mechanical Strength	Battery Lifetime Duration	AHP Results	Percentage of Requirement (%)
Maximum Range	9	9	3	3	3	3	9	1	1	1	1	0,248	24,806
Maneuverability	1	9	9	1	0	1	3	0	0	5	0	0,216	21,587
Time to target	9	0	1	1	0	1	1	0	9	0	9	0,160	16,025
Altitude	9	3	3	0	9	1	5	0	9	0	1	0,107	10,666
Launch Platform Size Limitation	0	0	0	9	0	0	0	0	0	0	0	0,037	3,677
Minimum R&D cost	1	1	9	3	9	1	1	1	1	1	1	0,028	2,824
Minimum Manufacturing Cost	0	1	9	3	9	9	9	1	3	9	1	0,016	1,603
Seeker usage	1	0	0	0	9	1	9	0	3	1	1	0,011	1,083
Smaller Launch Platform	0	0	0	9	0	3	1	9	0	0	0	0,025	2,469
Escape from anti-ballistic missiles	9	9	9	1	1	1	1	1	9	3	1	0,027	2,664
Subsystem Integration	0	0	0	3	1	9	9	3	0	3	0	0,014	1,378
CEP	3	3	9	1	0	0	3	0	0	0	0	0,019	1,932
Minimum offset distance	3	3	9	1	1	0	3	0	9	0	0	0,020	2,019
Resistance to Environmental Conditions	0	0	0	0	0	0	0	0	0	0	0	0,017	1,703
Long shelf life	0	0	0	0	0	0	0	0	0	0	9	0,017	1,672
Reusable launch platform	0	0	0	1	0	0	0	0	0	0	0	0,025	2,469
Simple design	1	9	9	3	9	1	9	9	1	9	1	0,014	1,424
Absolute Importance (Tehcnical Importance Rating)	526,218	502,611	428,928	198,113	238,879	164,925	85,313	71,062	319,478	176,020	204,337		
Relative Importance Weigth (%)	18,05	17,24	14,71	6,79	8,19	5,66	2,93	2,44	10,96	6,04	7,01		
Over 1	0,18	0,17	0,15	0,07	0,08	0,06	0,03	0,02	0,11	0,06	0,07		
Ranking	1	2	3	7	5	9	10	11	4	8	6		
TPM's Weight Chart													

Table 7.8: The AHP Matrix for Case Study 2 / BM-2

Requirements	Maximum Range	Maneuverability	Time to target	Altitude	Launch Platform Size Limitation	Minimum R&D cost	Minimum Manufacturing Cost	Seeker usage	Launch platform compatibility	Escape from anti-ballistic missiles	Subsystem Integration	CEP	Minimum offset distance	Resistance to environmental conditions	Long shelf life	Reusable launch platform	Simple design	Order of Precedence
Maximum Range	1	1	5	7	7	3	3	3	5	3	3	1	1	3	7	5	3	0,104
Maneuverability	1	1	5	7	7	3	3	1/7	5	3	1/7	1	1	3	7	5	3	0,104
Time to target	1/5	1/5	1	3	3	1/3	1/3	1/3	1	1/3	1/3	1/5	1/5	1/3	3	1	1/3	0,024
Altitude	1/7	1/7	0,333	1	1	1/5	1/5	1/5	1/3	1/5	1/5	1/7	1/7	1/5	1	1/3	1/5	0,011
Launch Platform Size Limitation	1/7	1/7	1/3	1	1	1/5	1/5	1/5	1/3	1/5	1/5	1/7	1/7	1/5	1	1/3	1/5	0,011
Minimum R&D cost	0,333	0,333	3	5	5	1	1	1/3	3	1	1/3	1/3	1/3	1	5	3	1	0,049
Minimum Manufacturing Cost	0,333	0,333	3	5	5	1	1	1/3	3	1	1/3	1/3	1/3	1	5	3	1	0,049
Seeker usage	0,333	7	3	5	5	3	3	1	9	9	9	9	9	9	9	9	9	0,118
Launch platform compatibility	0,2	0,2	1	3	3	0,333	0,333	0,111	1	1/3	1	1/5	1/5	1/3	3	3	1	0,024
Escape from anti-ballistic missiles	0,333	0,333	3	5	5	1	1	0,111	3	1	1/9	1	1	3	7	7	3	0,049
Subsystem Integration	0,333	7	3	5	5	3	3	0,111	1	9	1	9	9	9	9	9	9	0,118
CEP	1	1	5	7	7	3	3	0,111	5	1	0,111	1	1	3	7	5	3	0,104
Minimum offset distance	1	1	5	7	7	3	3	0,111	5	1	0,111	1	1	3	7	5	3	0,104
Resistance to environmental conditions	0,333	0,333	3	5	5	1	1	0,111	3	0,333	0,111	0,333	0,333	1	5	3	1	0,049
Long shelf life	0,143	0,143	0,333	1	1	0,2	0,2	0,111	0,333	0,143	0,111	0,143	0,143	0,2	1	1/3	1/5	0,011
Reusable launch platform	0,2	0,2	1	3	3	0,333	0,333	0,111	0,333	0,143	0,111	0,2	0,2	0,333	3	1	1/3	0,024
Simple design	0,333	0,333	3	5	5	1	1	0,111	1	0,333	0,111	0,333	0,333	1	5	3	1	0,049

Table 7.9: HoQ Matrix for Case Study 2 / BM-2

Requirements \ Technical Performance Measures	Drag Force	Static Stability	Control Effectiveness	Length of Span	Aerodynamic Heating	Nose Length	Nose Bluntness	l/d Ratio	Maximum Speed	Mechanical Strength	Battery Lifetime Duration	AHP Results	Percentage of Requirement (%)
Maximum Range	9	9	3	3	3	3	9	1	1	1	1	0,104	10,369
Maneuverability	1	9	9	1	0	1	3	0	0	5	0	0,104	10,369
Time to target	9	0	1	1	0	1	1	0	9	0	9	0,024	2,374
Altitude	9	3	3	0	9	1	5	0	9	0	1	0,011	1,095
Launch Platform Size Limitation	0	0	0	9	0	0	0	0	0	0	0	0,011	1,095
Minimum R&D cost	1	1	9	3	9	1	1	1	1	1	1	0,049	4,896
Minimum Manufacturing Cost	0	1	9	3	9	9	9	1	3	9	1	0,049	4,896
Seeker usage	1	0	0	0	9	1	9	0	3	1	1	0,118	11,820
Smaller Launch Platform	0	0	0	9	0	3	1	9	0	0	0	0,024	2,374
Escape from anti-ballistic missiles	9	9	9	1	1	1	1	1	9	3	1	0,049	4,896
Subsystem Integration	0	0	0	3	1	9	9	3	0	3	0	0,118	11,820
CEP	3	3	9	1	0	0	3	0	0	0	0	0,104	10,369
Minimum offset distance	3	3	9	1	1	0	3	0	9	0	0	0,104	10,369
Resistance to Environmental Conditions (for storage)	0	0	0	0	0	0	0	0	0	0	0	0,049	4,896
Long shelf life	0	0	0	0	0	0	0	0	0	0	9	0,011	1,095
Reusable launch platform	0	0	0	1	0	0	0	0	0	0	0	0,024	2,374
Simple design	1	9	9	3	9	1	9	9	1	9	1	0,049	4,896
Absolute Importance (Tehcnical Importance Rating)	262,793	350,053	492,969	182,594	245,286	503,833	507,541	125,939	238,905	217,197	74,083		
Relative Importance Weigth (%)	8,21	10,94	12,40	5,70	7,66	15,74	15,85	3,93	7,46	6,78	2,31		
Over 1	0,08	0,11	0,12	0,06	0,08	0,16	0,16	0,04	0,07	0,07	0,02		
Ranking	5	4	3	9	6	2	1	10	7	8	11		
TPM's Weight Chart													

CHAPTER 8

CONCLUSION

In this thesis, external geometry optimization of a ballistic missile is investigated. System engineering methodologies which are AHP and QFD are integrated to this optimization process. A surrogate model which contains neural networks and genetic algorithm is used as an optimization method. All of them are compounded into an optimization tool. At the end of this study, a conceptual design and optimization tool is gained.

Customer's requirements are directly included into the conceptual design loop. For that purpose, the order of precedence of the requirements is determined by the AHP. Saaty's Grade is used for that purpose.

The results of the AHP, which are the values of the prioritization of the requirements, are used in the QFD analysis. In this QFD analysis, House of Quality (HoQ) matrix is used. HoQ is used as a bridge between requirements and the technical performance measures. Requirements, related technical measure parameters and their relationship intensity are base of the analysis. By using all of these elements, the effectiveness ratio of the technical parameters on the requirements is analysed. The results which are called in this thesis as QFD coefficients are used as weights of parts of cost function of the optimization problem.

For the conceptual aerodynamic design of the surface to surface ballistic missile external geometry, eleven design parameters are determined. These parameters are also inputs for the DATCOM Missile. By using these parameters, aerodynamic characteristic of the missile is analysed. Aerodynamic coefficients, which are used for cost function and the constraints, are obtained at the end of this analysis.

From the insights which are gained from literature survey, there are various optimization algorithms to be used in conceptual external shape optimization problems. In the beginning of the study, derivative based optimization method was tried to use for this optimization problem. But, because of the complexity of the optimization problem; optimal solution can not be found in much of trial or only local optimal solutions can be found.As a second idea, genetic algorithm was thought to be used for optimization. But for such a complex optimization problem, usage of the algorithm is very time consuming. So, neural network is decided to insert into the optimization process which is done with genetic algorithm. Between design parameters and targets which are the parts of cost function, artificial neural networks are established. The R^2 values of the trained and tested networks are considered. When the R^2 values are closer to 1, the networks are established well. After that point, these networks are used for optimization with genetic algorithm. All of the establishment of the artificial neural networks are done by using Matlab Neural Network Toolbox.

Optimization with genetic algorithm is also done by using Matlab Genetic Algorithm Toolbox. Selection, crossover, mutation and elitism are performed to the created population in order to reach optimal solution. There are different types of selection, crossover, mutation and elitism. Types which are described in previous chapter are chosen by trial error. During optimization, cost function is calculated by using created networks. That makes the optimization process shorter. At the end of the genetic algorithm process, optimized missile configuration is obtained and they are perused in term of the expectations by considering the results of AHP and QFD. The sketch of the missile is obtained as a result of the optimization.

As mentioned before, two different case studies are carried out in chapter 7. Comparison of the obtained missile configuration can be seen from figure 8.1. As explained in chapter 7 section 7.1.4 for BM-1 configuration; in order to minimize drag, at the end of the optimization bluntness of nose becomes minimum and length of the cylindirical part of the body is less than conical part of the body as expected. Moreover, in order to obtain a static stable and control effective missile configuration, length of the span and length of the chord become higher. Meanwhile, configuration of BM-2 is explained in chapter 7 section 7.2.4. In order to provide easiness of integration of subsystems and usage of seeker, nose of BM-2 becomes more blunt. Also, cylindrical part of the body is longer than the conical part of the nody as expected.

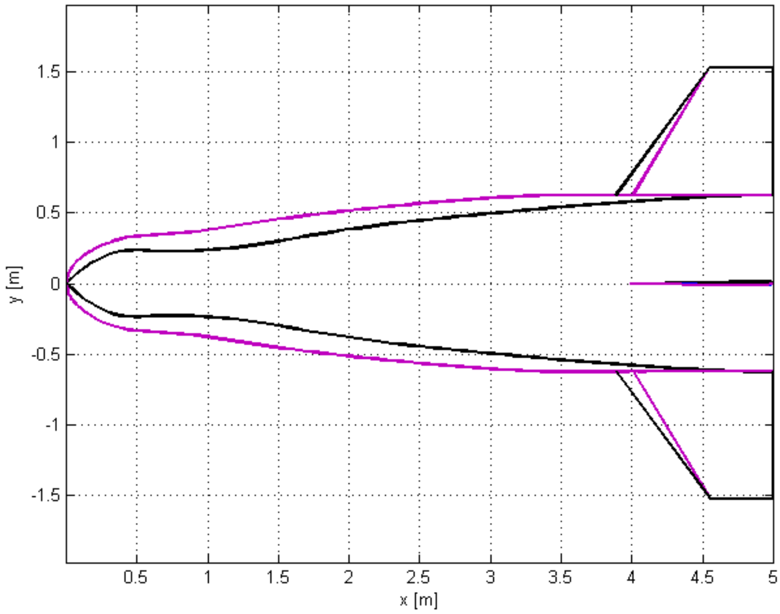


Figure 8.1: Comparison of Optimal Missile External Shape Configurations for BMs

8.0.1 Future Works

- In the future studies, other system engineering methodologies can be integrated to the tool (TOPSIS etc.).
- Optimization of different types of missiles (canard controlled missiles etc) can be integrated to the tool.
- Instead of DATCOM Missile, more accurate aerodynamic analysis methods can be integrated (CFD etc.).
- Comparison of optimization results which are obtained by using DATCOM and CFD can be done after implementation of CFD.
- 6 DOF analysis for the flight performance can be integrated to the tool.
- Conceptual design optimization for other disciplines like propulsion, avionics can be directly included into the optimization loop.

- Gradient based methods can be included to end of the optimization with genetic algorithm for fine tuning.

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APPENDIX A

PREFERENCE VECTOR

Comparison matrix is constructed in AHP analysis. Preference vector is calculated by using this matrix. In this chapter, an example is given for the calculation method of precedence matrix in AHP analysis.

Suppose the comparison matrix is constructed by pairwise comparison of three criteria. Thus, the comparison matrix is 3x3.

$$A = \begin{bmatrix} 1 & 1/3 & 5 \\ 3 & 1 & 7 \\ 1/5 & 1/7 & 1 \end{bmatrix} \tag{A.1}$$

According to the Saaty's Method, matrix A is normalized.So, by using the equation 2.6 each column of the matrix is summed.

$$\begin{gathered} \sum_{i=1}^{n} a_{i1} = 21/5 \\ \sum_{i=1}^{n} a_{i2} = 31/21 \\ \sum_{i=1}^{n} a_{i3} = 13 \end{gathered} \tag{A.2}$$

Then, by continuing to the equation 2.6, each element of the matrix A is divided to with sum of the column to obtain the normalized matrix B.

$$B = \begin{bmatrix} 5/21 & 7/31 & 5/13 \\ 15/21 & 21/31 & 7/13 \\ 1/21 & 3/31 & 1/13 \end{bmatrix} \tag{A.3}$$

After that point, the preference vector is calculated according to equation 2.7.

$$p = 1/3 * \begin{bmatrix} 5/21 + 7/31 + 5/13 \\ 15/21 + 21/31 + 7/13 \\ 1/21 + 3/31 + 1/13 \end{bmatrix} \tag{A.4}$$

Hence, the preference vector for matrix A;

$$p = \begin{bmatrix} 0.282 \\ 0.643 \\ 0.074 \end{bmatrix} \tag{A.5}$$