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Missile System Design Integrated with System Engineering Methodology

Deniz Bahceci and Asst.Prof.Dr.Ali Turker Kutay***
**Roketsan Inc.*
Roketsan Inc, Ankara, 06780, Turkey
denizkarataban@hotmail.com
*** Middle East Technical University*
Aerospace Engineering Department, Middle East Technical University, Ankara, 06800, Turkey
kutay@metu.edu.tr

Abstract

In the missile 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. This study covers an agile and efficient conceptual design optimization tool that ensures the optimized design to fulfil all requirements of the customer.

1. Introduction

Design is a long process. Moreover, design of the complex systems requires consensus of different aspect of views and teams. Origin of design of complex missile system is being defined the requirement by customers. Moreover, prioritization and conversion of them into technical parameters are done by system engineering methodologies which are Analytical Hierarchy Process (AHP) and Quality Function Deployment (QFD). With the Analytical Hierarchy Process, the requirements of the customers are prioritized and linked to the technical parameters with the Quality Function Deployment. In detail, AHP shows the order of precedence of the requirements; QFD shows what the customers want and how the designer can provide it. The most important part of the design is obtaining the optimal configuration which satisfies all the requirements. For the design of a missile system, system development lifecycle contains conceptual design, preliminary design and detailed design phases. System concept is determined at the end of the conceptual design phase. Especially for the conceptual phase of the missile system design, external geometry properties are the most ascendant technical parameters. For this reason, in this study, the critical technical parameters, which are the geometric properties of the missile, are also studied. 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.

In the literature survey, there are different studies which carried out system engineering methodologies and system design tools separately. For examples of the studies about the system design tools, they can be summarized as follows. Low Observables Design Synthesis Tool (LODST), developed by Bennett [1], creates arbitrary body shaped missile configurations. Mechanical properties, aerodynamic properties and propulsion properties of the missile are determined by analytical and semi-empirical methods, in this tool. The properties of the subsystems are inputs for the tool. Also, the missile aerodynamic is analysed according to the properties of different specific sections of the missile. Force and moment values are considered for each section and the total missile aerodynamic characteristic is extracted by taking all of the components. In 2009, EXCON tool is developed by Tanil [2]. 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. Ahmed and Qin [3] performed a study in 2009. 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 to aerodynamic design optimization. In 2017, a study is carried out by Tsegaw, Blasundaran and Kumar [4] 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.

The main purpose of this study is to propose a ballistic missile external shape optimization tool which is integrated with system engineering methodologies. For this purpose, this study contains four main keystones. They are AHP,

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QFD, conceptual design of a missile system and optimization of the design. By using these parts, the requirements definition parts are directly included to the design and the optimal design which satisfies the requirements can be found.

2. Methodology

In the conceptual design phase of the missile system, time is a crucial parameter. Minimizing the spending time in this phase makes the project more time efficient. Comprehending the customer requirements, prioritizing them, accordingly finding the most suitable and efficient system design solution within the bounds of given requirements and constraints in a restricted time indicates an engineering design optimization problem which occurs in the conceptual design phase. In this sense, this tool aims to manage time more efficiently during the conceptual design phase of missile systems. More than this, an automation of the design procedure is introduced by the tool, which refuses human interference during the missile design phase. By means of this tool, undesirable and unfeasible configurations are screened out of the design configuration pool at conceptual design phase.
Ballistic missile design and optimization tool flowchart is given in Figure 1. The tool has two main actors, which are optimization and DATCOM Processor. Furthermore, AHP matrix and QFD matrix are the co-actors which make the tool integrated with system engineering methodologies.

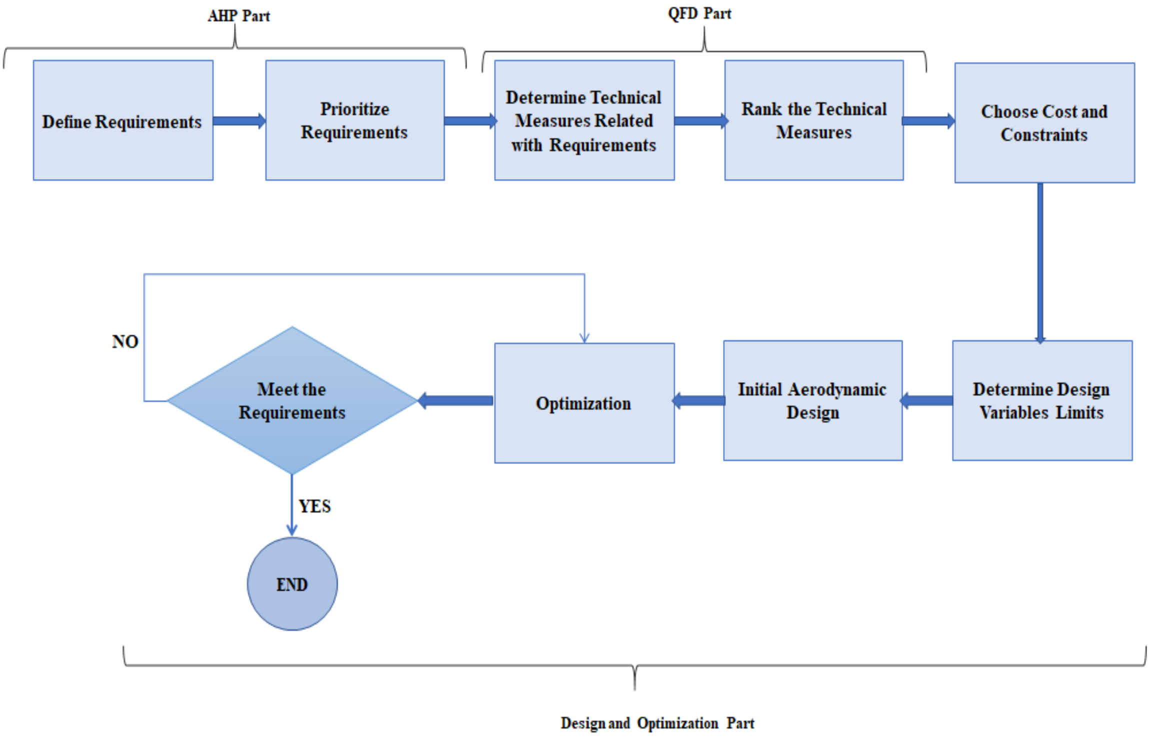

Figure 1: Ballistic Missile Design Tool Flowchart

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. Moreover, Missile DATCOM97 is used for aerodynamic analysis.

2.1 The Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) has a wide usage in defence, transportation and healthcare industries as a multi-criteria decision making (MCDM) method. AHP is significantly helpful when dealing with complex decisions, as it concretely prioritizes design criterias and facilitates the optimal decision. Pairwise comparisons and synthesis of the results with the AHP provides to perceive both the subjective and objective aspects of the decision. Moreover, AHP also verifies the coherence of the decisions made during the pairwise comparison process, therefore consolidates the overall decision

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 gets higher score at pairwise comparison is considered more important than its pair. AHP is generally employed when dealing with the system engineering problem of guiding the customer through understanding and prioritizing their own requirements. The three main parts of AHP are schematized for this problem as in Figure 2.

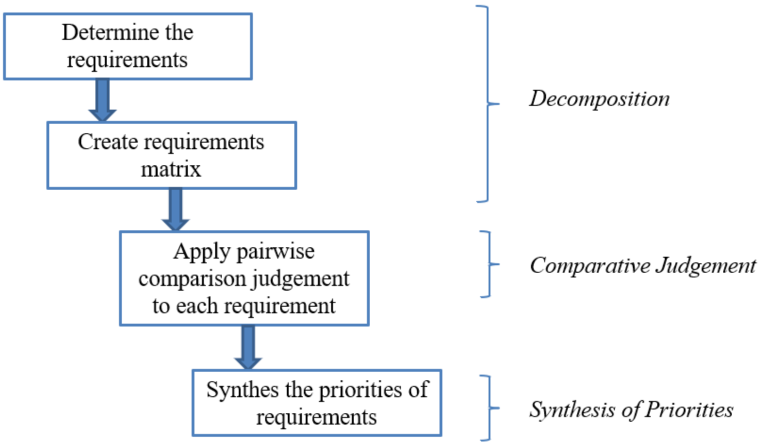

Figure 2: AHP Steps for Requirement Prioritization

Determination of the requirements is completely related with the definition of the problem. Customer says what they want as a product in different aspects. In details, they explain the performance, environmental, safety etc. requirements. These requirements are criteria for the customers. This is the first step of decomposition part.

At the decomposition part, the AHP matrix is created. This matrix is constructed as in Figure 3.

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 3: AHP Matrix

AHP matrix is used to conduct pairwise comparison. Each criterion is compared with each other. The scale, which is called Saaty Scale, ranges from one to nine. Conversely, nine infers that the criterion on the row is severely more important than the criterion on the corresponding column. The evaluation scale used in pairwise comparison is given by Table 1.

Table 1: Saaty's Scale

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

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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 synthesis of the priorities of the requirements.

The preference vector which is obtained at the end of 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. The eigenvector of the AHP matrix shows the order of precedence of the requirements.

2.2 Quality Deployment Function (QFD)

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). For the QFD analysis, House of Quality Matrix is used. The house of quality matrix is composed by numerous rooms, in other words steps. Figure 4 shows the complex QFD analysis matrix.

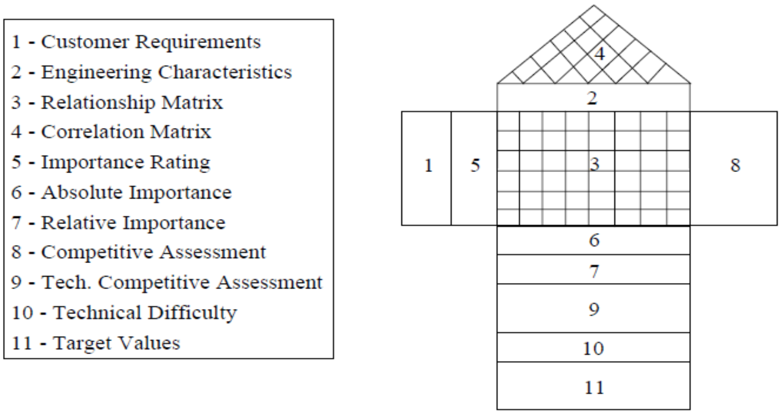

Figure 4: House of Quality Rooms [5]

Each of the rooms is used for different aims. The type of the designed system, used 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, different rooms 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.

The House of Quality Matrix which is used in the tool can be shown as in Figure 5. Figure 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 vector is the eigenvector of the AHP matrix. It directly comes from the results of the AHP.

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Design Requirement (DR) / Customer Requirements (CR)	**DR_1**	**DR_2**	**DR_3**	**..**	**DR_k**	**Importance (AHP Results)**
CR_1	R_{11}	..	..	..	..	d_1
CR_2	..	..	..	..	..	d_2
CR_3	..	..	..	..	..	d_3
..	..	..	..	..	..	
CR_i	..	..	..		R_{ik}	d_i
Absolute Importance	AI_1	..	..	..	AI_k	
Relative Importance	RI_1	..	..	..	RI_k	

Figure 5: House of Quality Matrix (HoQ)

Firstly, requirements are reviewed by the design team. Related engineering characteristics are determined. 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.

After the construction of relationship matrix, the order of precedence of requirements is taken into consideration. The eigenvalue 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. Absolute importance is calculated by multiplication of AHP Results and value of the corresponding relationship matrix’s cell for each requirement. The relative importance shows the effectiveness of the technical parameters for system requirements in the range of 0-100.

In order to evaluate the relative importance of a technical parameter, firstly the absolute importance is calculated.

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

Then, relative importance can be calculated.

$$RI_k = \frac{\sum_{i=1}^{n} d_i R_{ik}}{\sum_{k=1}^{k} \left(\sum_{i=1}^{n} d_i R_{ik} \right)} * 100 \tag{2}$$

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.

2.3 Conceptual Design of Ballistic Missile

The conceptual design is aimed at investigating and developing o good understanding of the required system, and defining the very general type of solution that will be pursued, for the system and the subsystems. [6] 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 of a missile is a multidisciplinary and iterative process. It contains aerodynamic, propulsion and mechanical design. Eugene L. Fleeman states that there are different major disciplines which are the parts of conceptual design. As it can be seen as Figure 6 the first step of any conceptual design starts with mission requirements definition, it continues establishing a baseline, aerodynamic design, propulsion design, and mechanical design. Then their total effect on the flight performance of the missile is considered and the result is regarded in terms of the measure of merits [7].

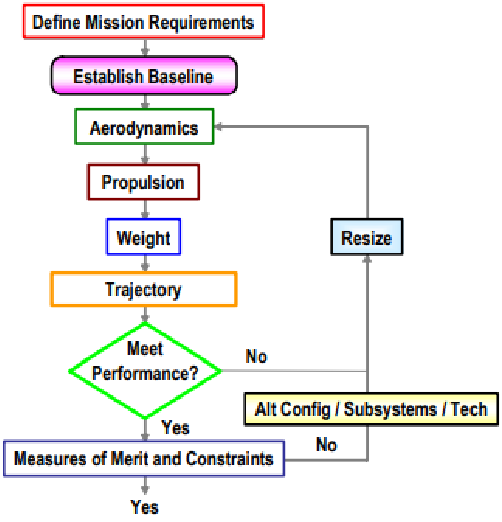

Figure 6: Process for Conceptual Design of Missile

External geometry of the missile is the most important factor for the aerodynamic characteristic of a missile. As a first step of the conceptual design, external geometry of the missile can be designed. There are number of design variables which can be listed as missile length, diameter, nose shape, nose length, body properties, number of fin sets, fin set location etc. Increase in number of these variables makes the design more complex.

In order to design and optimize the external geometry of the missile, the design parameters should be determined. In this study, surface to surface, tail controlled ballistic missile systems are taken into consideration. Therefore, 11 design parameters are inputted to the tool. These parameters are the inputs for aerodynamic analysis which is done with DATCOM Missile. These parameters are shown in the Figure 7.

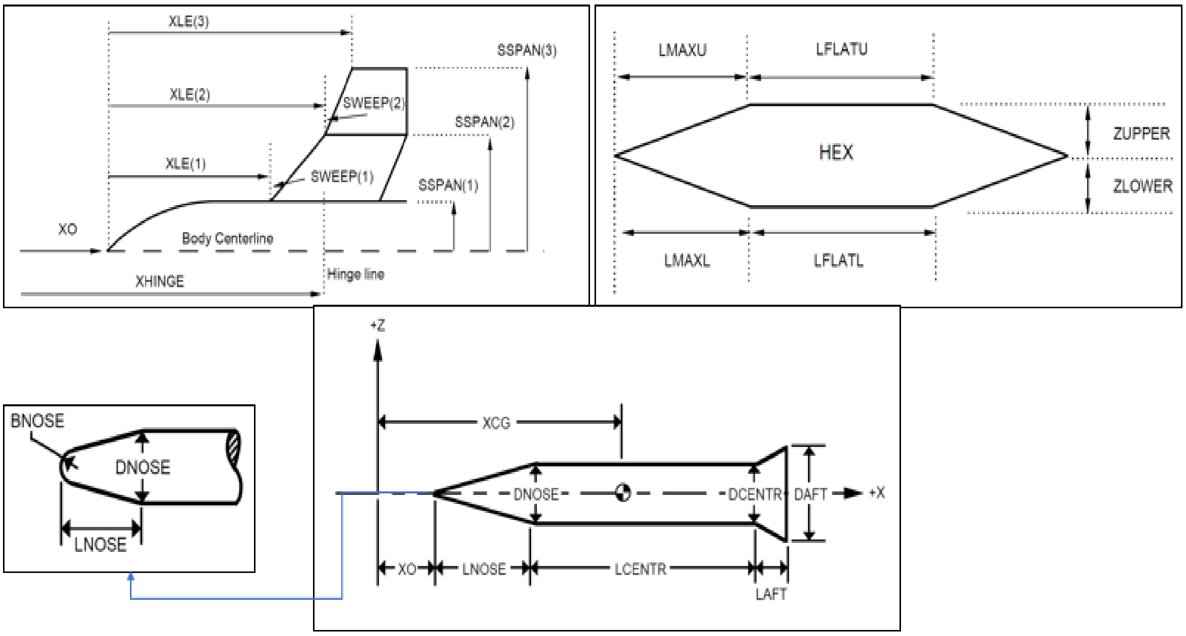

Figure 7: Definition of Required Design Parameters [8]

Lower and upper bounds of the design parameters are determined according to the requirements of the system. These values are also the bounds of the design space. Dataset in this design space is created by Latin Hypercube Sampling method which a near-random sample of the parameters from a multidimensional distribution. The created dataset which are different missile configurations is analysed by DATCOM Missile. In this analysis, important coefficients

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for constraints and cost function are obtained as results. Although, the constraints and cost function can be configured according to the results of QFD; for a tail controlled, surface to surface ballistic missile, range is the most important performance criterion. This criterion is directly affected by drag coefficient. Moreover, control effectiveness and static stability are the key parameters to obtain the desired trajectory. As mentioned before, according to the requirements of the system, the QFD results can change these parameters.
The effect of the control surfaces on each axes of the missile is called as control effectiveness. It can be formulized as in the following equation.

$$\frac{C_{m\delta}}{C_{m\alpha}} = \frac{\Delta C_{m\delta}}{\Delta\delta} * \frac{\Delta\alpha}{\Delta C_m} = \frac{\Delta\alpha}{\Delta\delta} \tag{3}$$

In order to obtain control effective missile, pitch due to angle of attack should be greater than 1.

$$\frac{\Delta\alpha}{\Delta\delta} \geq 1 \tag{4}$$

Other constraint is static stability. The static stability of a missile is a measure of its tendency to return to its equilibrium attitude after being disturbed. It can be defined as the slope of the pitching moment versus angle of attack. For the static stability in the pitch axis, $C_{m\alpha}$ should be less than zero. This provides, the nose of the missile go down when the angle of attack increases.

$$C_{m_\alpha} = \frac{\Delta C_m}{\Delta\alpha} \leq 0 \tag{5}$$

For the dataset, DATCOM Missile runs and the related aerodynamic coefficients are taken as output of the aerodynamic analysis. At the conceptual design part of the tool, the aerodynamic analysis is done for the created dataset. By using these results, in the optimization part of the tool, external geometry of the missile is aimed to optimize to satisfy the customers' requirements.

2.4 Optimization

An optimization problem can be defined as a problem to find the optimal solution which satisfies the constraints and minimize the cost function. These kinds of problems can be solved with different types of optimization algorithms. For complex optimization problems like optimization of missile system etc., derivative free optimization methods are more robust and easier to implement methods. These kinds of algorithms are better to find the global optimum point of the problem. Genetic algorithm (GA) is one of the derivative free optimization methods. It based on the evolutionary computation. The biological process of natural selection and reproduction is imitated to obtain the optimal solution. Randomness is one of the important properties of the genetic algorithm. In this study, there are four crucial operation is considered to solve the optimization problem with genetic algorithm. They are selection, crossover, mutation and elitism.

- Selection: As in natural selection in biology, more powerful genes are transferred to new population. In order to determine the more powerful genes, the fitness value is the criterion. The genes which have better fitness values have a better chance to select for new population. For the selection process, there are different methods which are Roulette Wheel Selection, Tournament Selection, Rank Selection, Random Selection etc.
- Cross-over: As in reproduction in nature, the genes exchanges between chromosomes. This process is the most important part 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 8. There are also multi point crossover, uniform crossover etc. methods for the crossover process.

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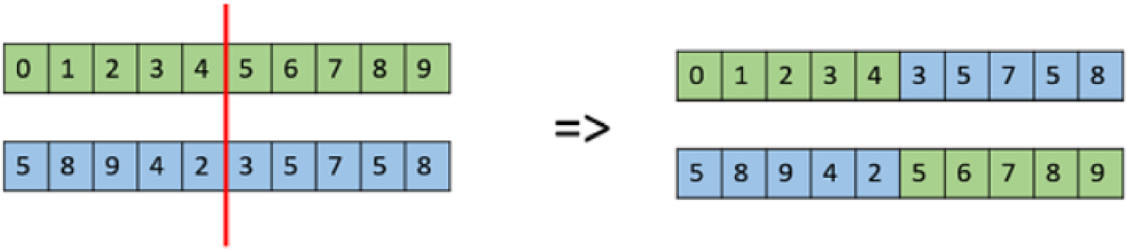

Figure 8: One Point Crossover

- Mutation: Mutation comes after the selection and crossover processes. The small random changes in chromosomes are supplied by mutation process in the range of mutation probability. Diversity in new generated populations is maintained by mutations. Mutation can be considered as fine tuning to reach the optimal solution.
- Elitism: Though elitism is not an essential process for genetic algorithm, it supports to generate more fit generations. 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.

For complex optimization problems which have many parameters, finding the optimal solution just using the GA could be a long process. Also, because of the large design space, created genes may not converge to the optimal solution. Besides, the developed tool aims to make the conceptual design more rapid. For that purpose, Neural Network is used.

Neural Network is based on the biological nervous system. Neuron which is the basic structural component of the brain for learning is the keystone of the artificial neural network. In engineering problems, neural networks are not generally used to build a model of a system; they are usually used to solve prediction problems for systems.

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, as used in this study. Multilayer feedforward artificial neural network models comprise of several layers. Input layer, hidden layer and output layer are the basic layers.

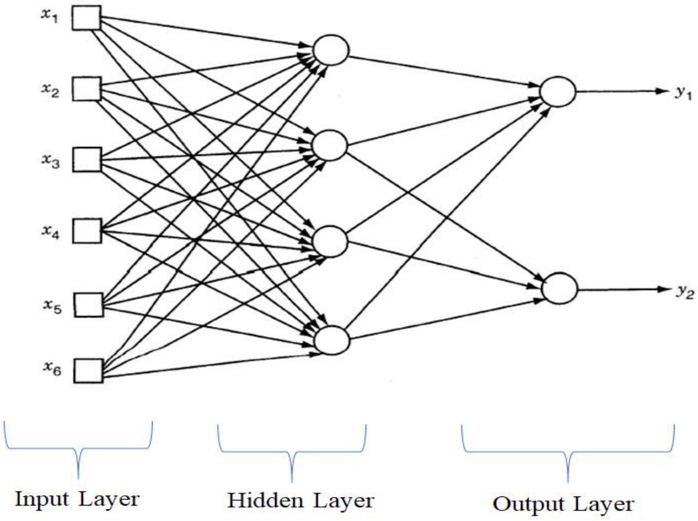

Figure 9: Three Layers Artificial Neural Network

In this tool, design parameters are inputs for neural network architecture. Also, the cost function and the constraints constitute the output layer and they are called as targets in the tool. Number of neuron which is the most important parameter to obtain an efficient response surface is determined according to the R^2 value of the neural network. R^2 value is aimed to as much as closer to 1. Generally, the number of the neuron increases, R^2 value is getting closer to 1. But, increase in the number of neuron makes time of the creation of networks longer. Hence, the number of the neurons is specified according to the case by trial. Moreover, other important consideration point is the percentage of the number of neurons for training, validation and test. These percentages are also configurable in the tool according

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to the case. At that point, it should be regarded that 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.

The consideration points in the tool when the neural network architecture is done are specified. Some of the values are determined according to the optimization problem. Networks are created and genetic algorithm uses the networks to find global optimum.

3. Case Study

The main aim of this study is conceptual design and optimization integrated with system engineering methodologies of a surface to surface, tail controlled, ballistic missile. As a case study, a generic surface to surface, tail controlled ballistic missile which will be called as BM is considered. For the case study, as aimed in the tool, firstly, AHP is conducted and the results of the AHP are inputted to QFD analysis, then, the results of the QFD are determiner for cost function and constraints. Moreover, some of the technical measures of the QFD are considered in terms of the design variables. According to these design variables, external geometry design process is initialized. Aerodynamic analyses are done by using DATCOM Missile. By using neural network and genetic algorithm, the optimal missile configuration is found.

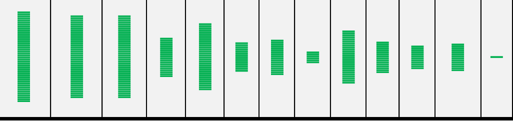
The AHP part is carried out in three steps that are decomposition, comparative judgement and synthesis of priorities. Firstly, in decomposition part, requirements are determined and AHP matrix is constituted. Each requirement is assigned as a criterion to compare. Secondly, the comparative judgement 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. **Table 2** which is the AHP matrix for the BM is filled by regarding the importance order of the criterion at the row with respect to the criterion at the column. Thirdly, the synthesis of the priority of the requirement is done. The eigenvalue vector of the matrix is found. This vector gives the order of precedence of the requirements.

Table 2: AHP Matrix for BM

	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	**Sum of Row**	**Mean of Row**
1	Maximum Range	1	1	5	7	7	1	3	1	5	3	1	5	9	7	1	5	9	1,367	**0,195**
2	Maneuverability	1	1	3	1	3	9	5	1	7	7	9	3	3	3	3	3	3	1,157	**0,165**
3	Time to target	1/5	1/3	1	5	1	7	1	5	1	1	9	7	3	1	5	5	1	0,706	**0,101**
4	Altitude	1/7	1	0,2	1	9	5	1	1	9	7	5	1	5	3	3	5	9	0,740	**0,106**
5	Launch Platform Size Limitation	1/7	1/3	1	1/9	1	3	1	1	1	1	3	1	1	1	3	7	7	0,314	**0,045**
6	Minimum R&D cost	1	0,1111	0,143	0,2	0,333	1	1	1	1	7	5	3	3	7	1	7	9	0,256	**0,037**
7	Minimum Manufacturing Cost	0,33	0,2	1	1	1	1	1	5	3	9	9	1	1	1	9	1	3	0,302	**0,043**
8	Seeker usage	1	1	0,2	1	1	1	0,2	1	5	7	3	9	5	3	5	9	5	0,401	**0,057**
9	Launch platform compatibility	0,2	0,1429	1	0,111	1	1	0,333	0,2	1	9	5	7	1	3	7	7	9	0,195	**0,028**
10	Escape from anti-ballistic missiles	0,33	0,1429	1	0,143	1	0,143	0,111	0,1429	0,111	1	3	3	5	9	1	7	3	0,173	**0,025**
11	Subsystem Integration	1	0,1111	0,111	0,2	0,333	0,2	0,111	0,3333	0,2	0,333	1	1	3	3	3	7	7	0,179	**0,026**
12	CEP	0,2	0,3333	0,143	1	1	0,333	1	0,1111	0,143	0,333	1	1	3	3	5	7	5	0,231	**0,033**
13	Minimum offset distance	1/9	0,3333	0,333	0,2	1	0,333	1	0,2	1	0,2	0,333	0,333	1	3	3	5	5	0,189	**0,027**
14	Resistance to environmental conditions	0,14	0,3333	1	0,333	1	0,143	1	0,3333	0,333	0,111	0,333	0,333	0,333	1	9	5	3	0,235	**0,034**
15	Long shelf life	1	0,3333	0,2	0,333	0,333	1	0,111	0,2	0,143	1	0,333	0,2	0,333	0,111	1	3	7	0,247	**0,035**
16	Reusable launch platform	0,2	0,3333	0,2	0,2	0,143	0,143	1	0,1111	0,143	0,143	0,143	0,143	0,2	0,2	0,333	1	3	0,157	**0,022**
17	Simple design	0,11	0,3333	1	0,111	0,143	0,111	0,333	0,2	0,111	0,333	0,143	0,2	0,2	0,333	0,143	0,333	1	0,152	**0,022**

After the AHP part, QFD part is the next step. In order to relate customers’ requirements with technical measures, House of Quality Matrix (HoQ) is constructed and QFD analysis is done. In tool, six rooms of HoQ which are, Customer Requirements, Engineering Characteristics, Relationship Matrix, Importance Rating, Absolute Importance and Relative Importance are defined and used. 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. 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.

Table 3: HOQ Matrix for BM

Technical Performance Measures Requirements	Drag Force	Static Stability	Control Effectiveness	Length of Span	Aerodynamic Heating	Nose Length	Nose Bluntness	l/d Ratio	Maximum Speed	Length of Conic Nose	Mechanical Strength	Battery Lifetime Duration	Moment of Inertia		AHP Results	Percentage of Requirement (%)
Maximum Range	9	9	3	3	3	3	1	0	0	1	0	1	1		0,1952	19,521
Maneuverability	3	9	9	1	0	1						0	0		0,1653	16,526
Time to target	9				0	1						9	0			
Altitude	9				9	1						1	0			
Launch Platform Size Limitation	0				0	0						0	0			
Minimum R&D cost	1	1	9	3	9	1						1	0			
Minimum Manufacturing Cost	0	1	9	3	9	3						1	0			
Seeker usage	1	0	0	0	9	1						1	0			
Smaller Launch Platform	0						1	9	0	3	0	0	0			
Escape from anti-ballistic missiles	9						1	1	9	1	3	1	0			
Subsystem Integration	0						9	3	0	9	0	0	0			
CEP	3						0	0	0	0	0	0	0			
Minimum offset distance	3						0	0				0	0			
Resistance to Environmental Conditions	0						0	0				0	0			
Long shelf life	0						0	0	0	0	0	0	0		0,0353	3,535
Reusable launch platform	0	0	0	1	0	0	0	0	0	0	0	0	0		0,0224	2,241
Simple design	1	9	9							3	9	1	0		0,0217	2,171
,																
Absolute Importance (Tehcnical Importance Rating)	463												19,52			
Relative Importance Weigth (%)	15,56												0,66			
Over 1	0,16												0,01			
Ranking	1	2	3	6	4	9	7	12	5	8	11	10	13			
TPM's Weight Chart																

At the design part, values of eleven parameters to describe the external geometry properties of the missile are determined and inputted to the tool. In order to define the external geometry and analyse aerodynamically the tail controlled ballistic missile, eleven design parameters are input. The design parameters are listed and explained at Table 4.

Table 4: Design Parameters

Input Name	**Definition**	**Unit**
Lnose	Nose length	mm
Rn	Nose bluntness radius	mm

Input Name	**Definition**	**Unit**
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

In order to determine design space upper and lower bound is determined for each parameter. After that, sampling is done. The number of sampling (n) is chosen as 1000. Dataset is created with the LHS method. By this way, 1000 different missile configuration is obtained. Aerodynamic analysis is done by DATCOM Missile for each parameter. CA, CM, CM_α and CM_δ values are obtained for each configuration. At the end of this part, design space is created. These values will be used in the artificial neural network and genetic algorithm parts.

At the beginning of the optimization part, cost and constraint functions should be clarified. Considering the results of the QFD and general design approach for ballistic missiles, cost and constraints are determined as follows.

$$\text{Minimize: } f = C_{d_{M=3,\alpha=0}} + C_{d_{M=5,\alpha=0}} + C_{d_{M=7,\alpha=0}}$$

$$\text{Constraints: } C_1 = C_{m_{\alpha_{M=3,\alpha=5}}} \leq 0$$

$$C_2 = C_{m_{\alpha_{M=5,\alpha=5}}} \leq 0$$

$$C_3 = C_{m_{\alpha_{M=7,\alpha=5}}} \leq 0$$

$$C_4 = \frac{C_{m_{\delta_{M=3,\alpha=5,}}}}{C_{m_{\alpha_{M=3,\alpha=5}}}} \geq 1$$

$$C_5 = \frac{C_{m_{\delta_{M=5,\alpha=5,}}}}{C_{m_{\alpha_{M=5,\alpha=5}}}} \geq 1$$

$$C_6 = \frac{C_{m_{\delta_{M=7,\alpha=5,}}}}{C_{m_{\alpha_{M=7,\alpha=5}}}} \geq 1$$

Design parameters are inputted to neural network process. Neural network aims to form response surface 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 chosen for training the neurons, %20 of them are chosen for validation and %20 of them are chosen for test the neural networks. When the fineness results of the neural networks are examined, R^2 value for both training and test are almost 1.

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The created neural networks are used to optimize the external geometry of the BM. Lower and upper bounds for the design parameters are determined at the beginning of optimization part. Moreover, cost and constraint are determined at the QFD part. By using the genetic algorithm toolbox of the Matlab, optimal configuration is obtained as in Figure 10.

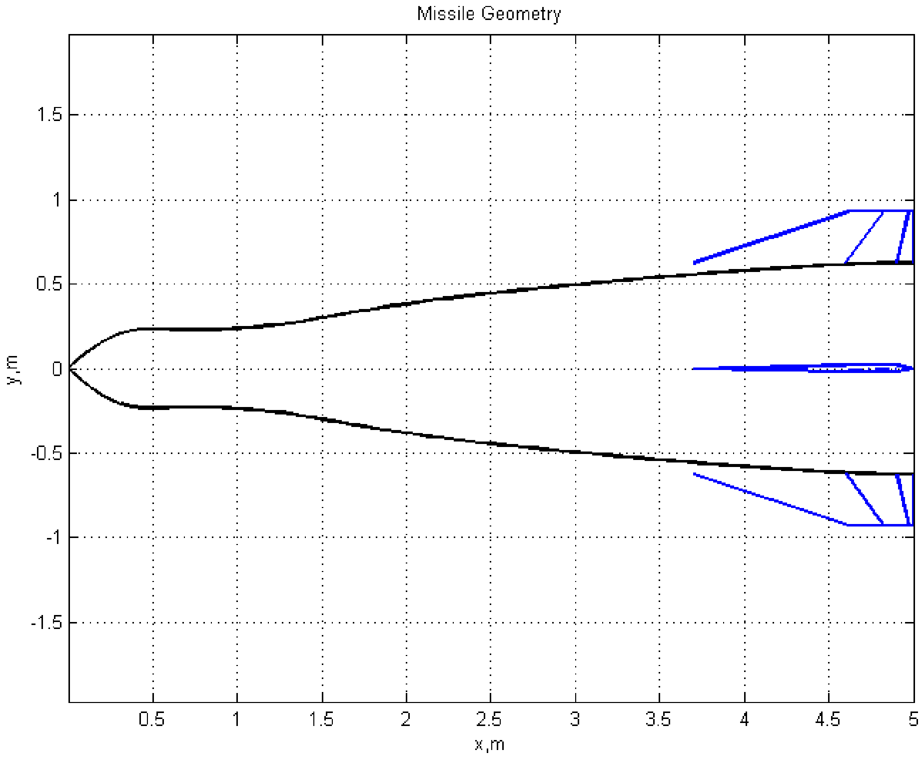

Figure 10: Optimized Missile External Geometry with Tool

Furthermore, the cost and constraints functions values for the optimized missile geometry are checked.

Table 5: Cost and Constraint Values for Optimized Missile

Cost / Constraint	Value
f	0,18
C1	-0,175
C2	-0,19
C3	-0,17
C4	3,14
C5	3,23
C6	2,83

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4. Conclusion

In conclusion, this paper present the methodology to design and optimize the external geometry integrated with system engineering methodologies of a surface to surface ballistic missile. The developed tool contains AHP, QFD, external geometry design and analysis, neural network and optimization with genetic algorithm parts. So, the tool provides to design, analyse and optimization by considering the requirements for ballistic missiles. It makes the conceptual design part quicker. Designer and customer can obviously see the optimal design by using this tool. Moreover, according to the changing requirements the new design can be created. A case study for a tail controlled surface to surface ballistic missile is conducted as a verification of the tool. The cost function and constraints are satisfied with the created missile.

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