FUZZY FORECASTING OF WORKLOAD FOR AIRCRAFT DESIGN PROJECTS

HAVA ARACI TASARIM PROJELERİ İŞ YÜKÜNÜN BULANIK MANTIK İLE TAHMİN EDİLMESİ

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I dedicate this thesis to

my wonderful wife Elif, little daughter Selin and parents

for their endless support,

encouragement and love.

ETHICS

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- All cited studies have been fully referenced
- I did not do any distortion in the data set
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VEYSEL CENK KARAKUZ

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Veysel Cenk KARAKUZ

ABSTRACT

FUZZY FORECEASTING OF WORKLOAD FOR AIRCRAFT DESIGN PROJECTS

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Master of Science, Department of Industrial Engineering

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The aim of this thesis is to constitute a valid, accurate and simply applicable model for predicting aircraft design workload in system environment that have lack of data set or uncertainty. Design cycle of an aircraft is described with three concepts. These are concept design, preliminary design and detail or critical design. In concept design phase, rough sketchs are determined. Also, characteristics about aircraft such as performance, size and systems architecture are settled on. Preliminary design phase is interested in more detailed design requirements. Some technical calculations, aerodynamics, propulsion and other system design features are extended. Detail design is the final phase that notified all product characteristics meet desired necessities in terms of aircraft components. During this stage, aircraft parts are tried to be fabricated and prototype of a real aircraft is manufactured and tested. As it is seen, product development, especially for aircraft design loop, has troublesome and complicated progression. In all phases, it requires continues iterations to reach exact match. There can be numerous activities from the beginning to the end of the design cycle and each activity can contain uncertainty by nature of design. Therefore, it is probable that prediction of any activity is also uncertain. In previous studies, there are lots of methods for forecasting and generally titled as cost estimation methods. These methods are splitted into two categories as qualitative and quantitative cost estimation techniques. While qualitative cost estimation methods are often used prior to design in product development, providing an inference based on the intuitive similarities of the past product or project, quantitative cost estimation techniques are applied using a detailed mathematical analysis, mostly due to the existence of an adequate set of data in a more mature project or product phase.

In this study, fuzzy logic, which is a qualitative estimation method, is used because it is easy to respond to the uncertain system environment in the proposed model. The data set has been analyzed for different types of aircraft obtained from the literature, and some performance and size characteristics of the aircraft have been determined as input variables. It has been observed that the prediction of the workload estimation of the future aircraft design projects with the model formed by the triangular fuzzy membership function, which is frequently used in the fuzzy logic methodology, can give the appropriate results according to the similarity variables.

Keywords: Aircraft, Design, Workload, Cost estimation, Fuzzy logic, Forecasting

ÖZET

HAVA ARACI TASARIM PROJELERİ İŞ YÜKÜNÜN BULANIK MANTIK İLE TAHMİN EDİLMESİ

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Bu tezin amacı, yetersiz veri kümesi veya belirsizliği olan sistem ortamında uçak tasarımı iş yükünü tahmin etmek için geçerli, doğru ve basit bir şekilde uygulanabilir bir model oluşturmaktır. Bir uçağın tasarım döngüsü üç kavramla tanımlanmaktadır. Bunlar, konsept tasarımı, ön tasarım ve detay veya kritik tasarımlardır. Konsept tasarım aşamasında kaba çizimler belirlenir. Ayrıca, performans, boyut ve sistem mimarisi gibi hava taşıtlarının karakteristik özelliklerine karar verilir. Ön tasarım aşaması, daha detaylı tasarım gereklilikleri ile ilgilenmektedir. Bazı teknik hesaplamalar, aerodinamik, itki gücü ve diğer sistem tasarımı özellikleri genişletilerek ele alınır. Detay tasarımı, onaylanan ürün özelliklerinin hava taşıtı bileşenleri için istenen gereksinimleri karşıladığı tasarımın son aşamasıdır. Bu aşamada, uçak parçaları imal edilmeye çalışılır ve gerçek bir uçağın prototipi üretilir ve test edilir. Görüldüğü gibi, ürün geliştirme, özellikle uçak tasarım döngüsü için, zahmetli ve karmaşık bir ilerlemeye sahiptir. Tüm aşamalarda, tam eşleşmeye ulaşmak için sürekli yineleme gerekir. Tasarım döngüsünün başından sonuna kadar sayısız aktivite olabilmekte ve her aktivite de tasarımın doğası gereği belirsizlik barındırabilmektedir. Bu nedenle, herhangi bir aktivitenin tahmininin de belirsiz olması muhtemeldir. Literatürde, tahmin için çok sayıda yöntem vardır ve bunlar genellikle maliyet tahmini yöntemleri olarak adlandırılır. Bu yöntemler, nitel ve nicel maliyet tahmini yöntemleri olarak iki kategoriye ayrılır. Nitel maliyet tahmin yöntemleri,

geçmişteki ürün veya projenin sezgisel olarak benzerliklerine dayalı bir çıkarım sağlayarak, genellikle ürün gelişiminde tasarım öncesinde sıklıkla kullanılıyorken, nicel maliyet tahmin yöntemleri daha olgun proje veya ürün evresinde kullanılarak çoğunlukla yeterli veri setinin varlığından dolayı detaylı matematiksel analiz ile uygulanır.

Bu çalışmada önerilen modelde belirsiz sistem ortamına cevap vermesi ve aynı zamanda uygulaması kolay olduğu için nitel bir tahmin yöntemi olan bulanık mantık kullanılmıştır. Literatürden elde edilen değişik hava aracı tipleri için veri seti analiz edilmiş olup, hava araçlarının bazı performans ve boyut özellikleri de giriş değişkenleri olarak belirlenmiştir. Bulanık mantık metodolojisi içerisinde yer alan ve sıklıkla kullanılan üçgensel bulanık sayılar ile oluşturulan model ile gelecekteki hava aracı tasarım projeleri iş yükü tahmininin belirlenen giriş değişkenleri benzerliklerine göre uygun sonuçlar verebildiği gözlemlenmiştir.

Anahtar Kelimeler: Hava aracı, Tasarım, İş yükü, Maliyet Tahmini, Bulanık Mantık, Tahminleme

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CONTENTS

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SYMBOLS AND ABBREVIATIONS

Symbols

A	Universal Set
X_A	Traditional membership function of *A*
$\mu_A(x)$	Membership function of *x* in the fuzzy set *A*
(a, b, c)	Triangular fuzzy numbers with lower, mean and upper values
∪	Union Operator
∩	Intersection Operator
$\_$	Complement Operator
+	Addition Operator
-	Substraction Operator

Abbreviations

FIS	Fuzzy Inference System
CBR	Case Based Reasoning
RB	Rule Based
FL	Fuzzy Logic
ES	Expert Systems
RA	Regression Analysis
BPNN	Back-Propagation Neural-Network
PCE	Parametric Cost Estimation
CER	Cost Estimation Relationships
RAND	Research and Development
CPM	Critical Path Method
FBW	Fly-By-Wire
COG	Center of Gravity

COA	Center of Area
MOM	Mean of Maximums
SOM	Smallest of Maximum
LOM	Largest of Maximum
EL	Extremely Low
VL	Very Low
L	Low
ML	Moderate Low
SL	Slightly Low
M	Moderate
SH	Slightly High
MH	Moderate High
H	High
VH	Very High
EH	Extremely High

1. INTRODUCTION

An aircraft is a flying machine by the help of airflow. Since invention of aircraft, it was used for various purposes. Considering the types of aircraft, air platforms differ in terms of their usage. Firstly, the aircraft may be diversified by lighter than air such as balloon (unpowered) and airship (powered); heavier than air such as fixed-wing and rotary-wing; type of propulsion such as powered and unpowered; usage area such as military, civil, commercial, experimental and model; manned/unmanned, size and speed [1].

Aircrafts are the vehicles that have complex structures, systems and subsystems. In general, the aircraft design process is composed of three phases which are conceptual design phase, preliminary design phase and detail design phase (also detoned as critical design phase) [2]. Conceptual design phase is the starting point of the design process. According to the requirements of the customer, main framework of the design is determined. Sketchy draft drawings are also created. The team consisting of different disciplines which are generally from mechanical, electric/electronic, aerospace engineerings seek to get desired design elements with regard to aircraft's characteristics. Performance, size, construction and general program overview about aircraft such as aerodynamics, propulsion, structure and systems are also choosen in this stage [3] [4].

After determination of critical characteristics, the next phase is preliminary design phase. At this stage, conceptual design is improved to adapt to necessities in detail. Design team may do some technical calculations. Moreover, structural analyses are implemented during this phase. According to outcomes of analyses about structural test design team take corrective actions [5]. Final stage of the aircraft design is the critical or detail design phase. In this phase, determined structural elements begin fabricating, also systems and sub-systems begin to form. If necessary, all these processes may be transferred to sub-contractors in terms of cost reduction. All elements of aircraft design are achieved and fully optimized in comparison to preliminary design phase. At the end of the detail design and aircraft comes into existence, the process continues with flight-test, roll-out, first flight and certification [6] [7].

In competitive aviation industry, the fundamental thing is to bring together accurate products on time to customer within accurate budget. Hence, getting into the market quicker and less cost at the proper time is becoming more of an issue [8]. That's why aviation companies give importance to estimate the cost of both designing and manufacturing in order to analyze and test suitability of product in the market. Especially in the design phase of an aircraft, it is not easy to predict because of its complexity to measure. Since, an aircraft come into existence from many system and subsystems [9]. It is more than probable that schedule shifting and cost overruns as leading an aircraft design project. Hamdi A. Bashir and Vince Thomson [10] stated that schedule slippage and cost overruns occur nearly a hundered percent in many design projects. For this reason some big aerospace authorities have already used some computer-based cost estimation tools to optimize cost for pre-design phase in addition to manufacturing [8], [11], [12], [13].

Cost estimation is so important issue for financial control in any project life cycle. It also provides motivation for project release. Thanks to the cost estimation, companies can maintain cost management activities, can simulate budgeting scenarios and can use as decision-making for risks about the project [8]. There are various type of estimation techniques according to literature mentioned in ongoing sections in depth. They are generally composed under the titles; qualitative and quantitative cost estimation techniques. Qualitative methods generally depend on heuristic principles like complexity, quality, etc. and works with similarities or comparable things of a product previously manufactured whereas quantitative models depend on statistical analysis, deep research about a product, its features or processes [14].

Fuzzy logic is a method that was initially introduced by Lotfi Asker Zadeh in 1965 to bring an optional perspective to traditional set theory. On the contrary of classic set theory that is interested in an element is a member of a set or not, fuzzy logic provides gradually some degrees of membership of an element. Thus, it provides to users model mathematicaly with uncertainty and vagueness linguistic variables in any system caused by human reasoning [15].

In this thesis, fuzzy logic which is an qualitative cost estimation technique will be used. The proposed model is implemented on a problem from real life in order to predict aircraft design workload for performance and size variables using fuzzy logic which is an qualitative cost estimation technique. The database including some aircrafts whose types are fighter, transportation, bomber and training will be used from literature [16]. Some crisp variables about performance and size such as aircraft unit weight, aircraft empty weight, speed and climb rate will be modeled using with fuzzy logic and will be converted linguistic fuzzy variables. After that, using MATLAB software's fuzzy logic toolbox FIS (Fuzzy Inference System) will be generated and a comparison of current outcomes and fuzzy outcomes will be evaluated.

The following chapters include literature review, methodology, proposed model and finally presents and analyzes the results and the model. In Chapter 2, definitions are given for the concepts such as design, cost estimation and fuzzy logic. Literature review on these concepts are also included. In Chapter 3, methodology section, aircraft, aircraft design, aircraft components, workload and fuzzy inference system are investigated. Chapter 4 includes the proposed model for fuzzy forecasting of design workload for aircraft projects based on model that will be used in general concept and results will be compared in terms of current and fuzzy outcomes. In Chapter 5 results will be evaluated. Finally, in Chapter 6 the model is analyzed and potential improvement possibilities is presented.

2. LITERATURE REVIEW

Evolution of technology has brought in many inventions that resulted in significant changes in various areas, from people's daily lives to countries' political situations and affairs. Some of these inventions even changed the flow of history. One of the most valuable and crucial invention that has affected the flow of history is the invention of aircraft.

The first successfully flying aircraft was designed by Wright Brothers, Wilbur and Orville Wright, in 1903 even if there were some trials for flying in anywhere on earth until that time. This aircraft was experimental, fixed-wing and powered. From that first prototype the Wright Brothers has developed a second aircraft, an improved version in two years and by 1905, it was upgraded from experimental to "practical flying machine" [17]. This first designed, powered and controllable aircraft has inspired to many people and countries and it has started a development or improvement phase for aircraft until today.

2.1. Design and Cost Estimation

Design is a process that mainly customer needs trigger. The way of performance can differ in terms of methods that are used or the design scope can diversify tangible or intangible as product, place, information, and so on [18]. Villecco and Pellegrino [19] stated there is always uncertainty in engineering design because of inadequacy of data and knowledge. Daalhuizen et al. [20] also explained the source of uncertainty as lack of knowledge and proficiency, changes in rules and complexity in assignment. MacCormack [21] asserted that when a new product is designed aggressive conditions can appear unsurprisingly or advance gradually. He also recommended that companies should be flexible in changing conditions for new product implementation. Lawrence and Lorsch [22] claimed external uncertainty in new product design can be brought about amendment by customer or technological progress. Moreover, Bstieler [23] explained that exterior vagueness leads to vagueness in project execution which noone makes sense of why. That's why cost estimation or, in other words, the effort of design process is very important for handling. From individuals to countries which make design process in different areas has already given importance to this issue. Moreover, in order to manage cost estimation or forecasting workload of design, Arditi and Riad [24] evaluated softwares frequently used for estimation in various areas of industry. As mentioned above cost estimation that there are many methods can be evaluated in wide variety of usage areas.

2.1.1. Cost Estimation Methods

Niazi et al. [14] describes classification of cost estimation methods as qualitative and quantitative. According to his view, qualitative cost estimation techniques commonly works on comparison of past and new. Especially, similarities between past and future works are the most important decision makers for estimation. On the other hand, quantitative cost estimation methods needs to make detailed analysis of given project's features. A brief representation of classification of cost estimation methods is shown in Figure 2.1 and comparison of this methods in terms of advantage and disadvantage is shown Figure 2.2.

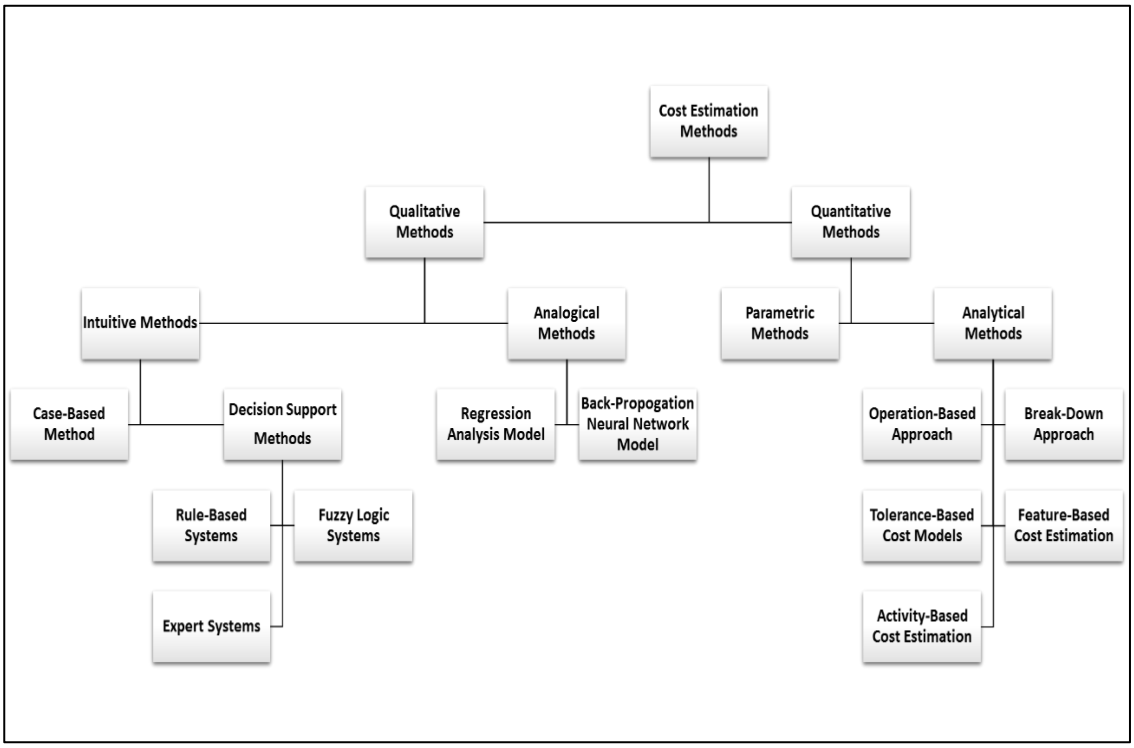


Figure 2.1. Classification of Cost Estimation Methods [14]

Cost Estimation Techniques				Strengths	Drawbacks
Qualitative Cost Estimation Techniques	Intuitive Cost Estimation Techniues	Case-Based Systems		• Quick response • Easy to adapt	• Needs historical data • Similar problems, similar solutions
		Decision Support Systems	Rule Based Methods	• Strong optimized results • Cost effective	• Requires time to implement
			Fuzzy Logic Methods	• Easy to use • Quick response • Precise results • Better reaction to uncertainty	• Experimental • Troublesome for complex multivariable systems
			Expert Systems	• Quick and consistent results	• Subject to expert's knowledge • Suitable for error • Costly
	Analogical Cost Estimation Techniques	Regression Analysis		• Simple method	• Limited only linear problems
		Back Propagation Neural Network Methods		• Deal with complex and non-linear problems	• Fully based on data
Quantitaive Cost Estimation Techniques	Parametric Cost Estimation Methods			• High accurate results • New variables can be adapted easily	• Based on past experience
	Analytical Cost Estimation Techniquess	Operation Based Cost Methods		• Best alternatives can be evaluated	• Time Consuming
		Break Down Cost Methods		• Easiest method to implement	• Detailed information about resources and processes
		Cost Tolerance Methods		• Cost effective design tolerances can be determined	• Detailed design data needed
		Feature Based Cost Methods		• Cost effective features can be determined	• Complex structured product cost is hard to identify
		Activity Based Cost Methods		• Tracibility of cost drivers • Easy way to pursue product unit cost	• Performing poorly in pre-design projects

Figure 2.2 Advantages and Limitations of Estimation Methods [14]

2.1.1.1. Qualitative Cost Estimation Methods

Qualitative cost estimation methods are sorted as intuitive and analogical. Aram et al. [25] emphasized this methods are commonly used in early stage of product design because of deficiency on information. Huang et al. [26] defines *Intuitive Methods* is a technique that experience and knowledge are the performance indicators. Intiutive methods also can be categorised into case-based method and decision support systems that are rule-based systems, fuzzy logic systems and expert systems.

Case-Based Reasoning (CBR) estimation method uses knowledge obtained from past experience [27]. This method requires cases faced before and it works as choosing convenient one for the problem from historical data pool. Briefly, it uses past experience, databases and expert’s knowledge to predict and gives fast result. But the disadvantage of it, to need big data sets and be addicted to human factor. An example can be seen in this method presented by Zima [28]. He examined CBR method to predict unit cost at pre-design phase in sport field construction. To do this, the cases is broken down into pieces related with cost, scope, construction date, location of facility and its solutions (unit cost). As preferring the best cases from database unit cost for every case of new facility is obtained. Another step is modification of unit cost of cases depending on regional variety and indexation and the last step is determination of availability for total costs as comparing past actuals. As a result, he got acceptable result when evaluating estimation error. Stensrud [29] also examined various cost estimation methods including case-based reasoning for ERP projects. Goodall et al. [30] implemented CBR method for remanufacture of wind turbine gearbox for comparing cost for current gearbox remanufacturing or modification. They stated when cost estimation of an acitivity that has uncertainity and limited information occurs, CBR is a good choice. But, the historical data should be used more if available rather than human knowledge, because of transience.

Rule-Based (RB) estimation approach is a technique that based on selection of desired process according to a set of design or manufacture constraints for new product in database where process time and its cost effect are found. It may be time consuming as disadvantageous [31]. Masel et al. [32] used RB approach in order to estimate forging die volume during design period. The rules that they used are such as filling, expanding, plug formation, pulling and filleting, are determined according to the forging process for design constraints of die. They stated that the estimation is done with limited information of part and can be applied pre-design phase of a new product. Elfaki and Alatawi [33] examined RB approach in construction industry for predicting cost in preliminary design phase. Rules that are 11 of 78 estimators from 25 projects that were done before are chose as knowledge based. They claimed if knowledge based estimators are used when estimating cost during design phase it provides ability to see strong and weak points on construction projects.

Fuzzy Logic (FL) method is generally used design and manufacturing for helping uncertainity. A decision table showing the input and output variables of the FL system ensures the set of rules and the relationships among them. It results reliable estimation solution [31]. Seth et al. [34] used FL for deciding components of a software and proposed 5 inputs that are reusability, portability, functionality, security and performance for fuzzy sets. All inputs and outputs are classified as fuzzification. At the end, they evaluated 5 projects and found better solution with the minimum selection effort as using fuzzy approach.

Expert Systems (ES) approach is a knowledge based system that mainly depends on human knowledge or employee expertise for estimation. Vajna [35] stated the main goal of the expert based design is to ensure the accurate information at early stage of design. He also noted that knowledge based systems should follow the necessities for changes along product life cycle. For example, if product design needs new information expert one should learn, update and adapt it to progress.
Another part of qualitative estimation method is *analogical techniques*. This approach utilizes similarities depends on historical data [14]. Analogical cost estimation methods divide into two sub-division as regression analysis and back-propogation neural network model.

Regression Analysis (RA) method is obtaining a linear relationship between the product cost and values of selected variables for previous designs so that this relationship can later be used to forecast the cost of a new product [31]. Mendes [36] implemented RA statistically estimation method as using to forecast effort of web design. Parameters are determined and evaluated together with sub-categories. Every parameter has its own regression model. The results are given in terms of linear and stepwise regression and it is infered that the highest result can change depending on design parameters according to model.

Back-Propagation Neural-Network (BPNN) model is a form of neural network applications to make estimation. BPNN model is composed of 3 elements such as input layer, output layer, and some hidden layers that place between input and output layers. There are neurons that provides designation of connectivity between inputs and outputs in every layer and show an activitiy in the given task or project. All of the neurons give an output according to inputs [37]. Arafa and Alqedra [38] carried out cost estimation using BPNN in construction industry both to specify cost and to make project managers decide how to manage the project from early stage of design. They analyzed 71 construction projects that were typically available and coherent. The model was developed with one hidden layer (neurons), 7 remarkable parameters (input layer) and outer layer (cost of building). The result showed that the BPNN was successful and four of seven parameters were more effective on pre-design cost estimation rather than others.

2.1.1.2. Quantitative Cost Estimation Methods

Parametric cost estimation (PCE) models are quantitative cost estimation techniques. Bashir and Thomson [10] stated that this type of estimation methods are created by using conventional regression analysis based on past data from finished works. The determination of factors is also most important step to predict future tasks. According to their research about estimation of design effort and time they emphasizes the factors that are product complexity, technical adversity, resource structure (knowledge, ability, harmony in team, size), tools used for design and formal process as prominent indicators in workload of design projects.

Jacome and Lapinskii [39] used size, complexity and productivity as factor in model they proposed. Camargo et al. [40] described that PCE is part of Cost Estimation Relationships (CER) that is a mathematical expression of model resulting cost according to cost drivers. It can be used pre-design phase as determination of parameters needed. It also results fast solution not requiring any detail information and it can easily be kept up with changes. They [40] also implemented PCE in textile industry for pre-design phase of the textile products in order to have consistent and rapid information about cost allocation of the product. They practised parametric cost estimation method in a company which has been producing wool fabric because of design variations. They resulted a statistically mathematical model that could answer vagueness of design and lack of data about product to optimize cost. They concluded that to have good parametric model it requires well-defined past data and determination of other factors affecting the model.

Bashir and Thomson [41] implemented PCE model to predict design effort for hydro-electric generator manufacturing. They made use of 15 projects' past data that were completed before and determined the factors would be used in estimation model as technical difficulty, team expertise, type of drawings sent to the customer, involvement of desing associates. Classically, regression analysis was used to analyze historical datas. As a result, they obtained better result with model comparing with the actuals than GE Hydro employees did.

Hess and Ronaoff [16] from RAND (Research and Development) Coorporation which established by under secretary of defence in United States of America to make research and development activities, but now is a non-profit organization to make solutions to help public, worked on PCE method to predict costs needed for whole product life cycle such as engineering, tooling, manufacturing labor, manufacturing material, development support, flight test, and quality. According to the research, a database consisting of 15 fighters aircraft from 1948 to 1972 was analyzed according to its 25 characteristic specialties like airframe unit weight, empth weight, speed, number of flight test aircraft and so on. They formed parametric models with non-linear regression method for all cost units which are dependent variables as using 25 aircraft characteristic factors which are independent variables. They concluded that the best fit model the handled was the factors such as airframe unit weight, empty weight, speed, specific power, climb rate and number of flights.

Analytical cost estimation method is another technique of quantitative approach. These approaches are classified as operation-based, break-down, tolerance-based, feature-based and activity-based. **Operation-based approach** is more effective in last stage of design and early period of manufacturing because of the necessity of information. It allows predicting manufacturing related cost sort of setup cost, idle cost and manufacturing cost [26]. Jung [42] developed a cost model for estimating manufacturing cost. **Break-down approach** is interested in all cost related activities not only manufacturing cost. More information is needed to estimate hence, it is more accurate for final stage of design [14]. **Tolerance-based approach** is a technique that main aim is to consider design tolerances of a product to predict cost. In other words, it is important to determine boundaries while designing to hold in wished cost plan [43]. Ou-Yang and Lin [44] described that f**eature-based approach** focuses on shape and manufacturability features of a product. This method also provides designer prescience while designing a product during early design phase in order to minimize cost. However, Niazi et al. [14] emphasized this type of method could be impractical for complex and small shapes. According to Ben-Arieh and Qian [45] **activity-based approach** is defined as determining cost drivers according to activities performed by resources. This is different from classic view of cost accounting (direct & indirect cost) policy in terms of application method. Özbayrak et al. [46] suggested that this approach is useless without a design tool with uncertain or not well-defined activities.

2.2. Fuzzy Logic

The process of fuzzy logic depends on information which comes forward human cognition and perception and also these information is mainly uncertain or does not have rigid limitations. Moreover, fuzzy logic puts a better solution and inference from complex multicriteria variables. There are various implementation areas that fuzzy logic appears. Because of the ease of use, it is encountered even in daily lifes such as application of washing machines, air conditioners and vacuum cleaners. Moreover, it is used for decision support as control systems in aircraft and control of subway systems; used for prediction as weather forecasting systems, risk assessment, medical diagnosis and treatment plans and so on [47]. In addition to these examples, fuzzy logic applications about aircraft will be also mentioned.

Dobrescu and Balazinski used fuzzy for environmental control on cabin and cockpit. According to the study, the variables that are temperature, pressure and humidity are handled to control in cabin and cockpit. They specified various linguistic input variables and triangular or trapezaidal fuzzy membership functions for every control variables to give reaction systematically desired outputs. For instance, if the temperature is lower or greater than 0.5 ℃ then the air conditioning system steps in and will continue to set available temperature. After all, they compared current and proposed method used by fuzzy logic and they conculeded that fuzzy logic can be an alternative solution method for a new control system to provide inflexibility and endurance [48].

Atlı and Kahraman worked fuzzy logic as decision making system for aircraft maintenance planning. Aircrafts should be maintained as checking both structural and systems for continuity of its economic life. That’s why they took into account several maintenance type about aircraft and took place different type of fuzzy logic, that is fuzzy critical path method (CPM) that interested in activity dependencies. They determined 24 activities, its precedence relationships and activity times. To conclude that fuzzy CPM provided decision support to which activity should be used in terms of its precedence and time relations for both among activities and maintenance types [49].

Lo et al. implemented fuzzy theory as using genetic algorithm for detecting failures in aircraft. They studied to determine failure of different actuators for F-16 type fighter aircraft’s moving surfaces. According to the study, five fuzzy linguistic variables such as NL (negative large), N (negative small), ZE (zero), PS (positive small), and PB (positive big), three residual input variables r_1, r_2, r_3 contains another fuzzy set R and output variables F_1 (normal or no fault), F_2 (elevator failure), F_3 (aileron failure), F_4 (rudder failure) used in order to evaluation. Study results showed that the system they suggested and used fuzzy genetic algorithm is applicable for detecting failures of various type of actuator on aircraft [50].

Liu et al. proposed a model using fuzzy logic about durable flight control system to explore Mars. According to changing environmental conditions on Mars, designed flight control system should be robust to answer the uncertainty. Speed, path angle, altitude, attack angle and pitch angle rate are selected as input variables and elevator and propulsive factor are as output variables. They used triangular fuzzy membership function for inference system and according to rules they gained result for behavior of flight control under determined conditions. It is concluded that the model they proposed insures effective flight control design for Mars airplane [51].

Lin et al. made a work using fuzzy logic about mobile phones to qualify how product image is important for customer’s sense. They analyzed as conducting a survey about product shape and functionality of 100 mobile phones to three group consisted of young males and females. According to the given survey outputs, a fuzzy model composed with linguistic variables for 33 mobile phones from various manufacturers in terms of shape, size, button functionality, screen dimension and frame of the products. They used triangular membership functions while showing fuzzy numbers. Also, in fuzzy inference process 66 if-then rules are determined. After completion of rules based model, they tested as using 5 samples and results about simplicity or complexity of mobile phones recorded. Moreover, they did comparison of the results using neural network model and suggested that the fuzzy logic model is the better alternative for inference from product image using some product features [52].

Hatagar and Halase studied a fuzzy logic controller model for washing machine to show designers how to determine washing time. Working principle of a washing machine generally depends on optical sensors. These sensors provide to initiate for usage of the water size and chemical material for washing process. They determined 3 input variables that are level of dirt of the cloth, type of dirt and type of cloth for reaching washing time. According to their inference model, crisp inputs and output are converted fuzzy linguistic variables for 27 samples. Then, using triangular membership function for fuzzy members they designed the model and rules are composed for every input samples. At the defuzzification phase, they used centroid method to get result. After all, they concluded that results are suitable and satisfactory comparing with crisp washing time [53].

3. METHODOLOGY

In this chapter, brief information is given about aircraft types, aircraft design phases and aircraft components.

3.1. Aircraft

An aircraft is a vehicle that can fly by support of the air. There are many types of air platform that can be classified with regard to propulsion method, lifting force, usage area, manning type and speed.

3.1.1. Propulsion Method

Propulsion is a trigger to drive or push forward to an object. To the propulsion method aircrafts can be assorted by as powered and unpowered. Powered aircraft uses mechanical source of energy, an engine, to move. Helicopters, jets, propeller aircrafts might be examples of a powered aircraft. As for unpowered aircraft, it does not use any mechanical power in contrast of powered aircraft. Unpowered aircrafts such as glider, balloon and kite do not have any onboard power. They use air as source of energy for its motion [1].

3.1.2. Lifting Force

Aircrafts can be classified as aerostats that are lighter than air and aerodynes that are heavier than air in terms of lifting force. Balloons are a good example for aerostats that can be lifted without an external force, whereas airplanes and helicopters are examples of the aerodynes that need an external lifting force such as an engine and some type of wings that are fixed-wing and rotary wing [1].

3.1.3. Usage

There are different types of aircrafts for intended use as military, civil, commercial, experimental, training, model, etc [1].

3.1.4. Manning Type

Aircrafts can be seperated from each other according to the carrier type as manned and unmanned. The term manned and unmanned aircraft has already been used for years. As the term states, whereas manned aircraft needs pilot or some crew to control unmanned aircraft does not. Unmanned aircrafts can fly autonomously or can be controlled by an operator from an external center where is defined as ground control station [54].

3.1.5. Speed

Depending whether higher than the speed of sound or not, there are two types of aircraft that can be defined as subsonic, transonic, supersonic and hypersonic. The term “Mach” is used for comparing the speed of an aircraft. The Mach, a speed number, is a ratio of the speed of aircraft to the speed of sound. The speed of sound is about 768 miles per hour, in conversion of kilometer is 1.236 km/hour, at sea level. According to given definition if an aircraft has the speed below the ratio of Mach 1 is subsonic aircraft and it has the speed of near to Mach 1 is also transonic aircraft. On the other hand an aircraft that has the speed above of the Mach 1 is denoted as supersonic aircrafts. Supersonic aircrafts can reach up to Mach 5, that is five times higher than the speed of sound. As a final category transonic aircraft is the aircraft that has the speed of higher than Mach 5. Scramjet can be given as an example of hypersonic aircraft [55], [56]Aircrafts can be seperated from each other according to the carrier type as manned and unmanned. The term manned and unmanned aircraft has already been used for years. As the term states, whereas manned aircraft needs pilot or some crew to control unmanned aircraft does not. Unmanned aircrafts can fly autonomously or can be controlled by an operator from an external center where is defined as ground control station [54].

3.2. Aircraft Design

It can be more meaningful to start defining what is design before finding answer specifically to the aircraft design. The word “design” has been ascribed to variety of meanings so far. Taura and Nagai defined the design as effort for creation of expected illustration related with the whole [57]. Gudmundsson stated about design that includes subcomponents of various activities to reach desired result and these activities should be structured in advance [3]. As a term, design, has already been used as a key aspect in engineering activities for years. And so, design might be identified with engineering core subject. Some defines it as thing that what engineers do. Engineers' Council for Professional Development comprised design to define engineering as stated that activities for creation of physical things or whatever to form and develop processes. As doing this, it can be handled part by part or as a whole. Moreover, another definition about engineering from National Academy of Engineering is pointed out as design activities under some limitations [58]. After all, design that has basically focused on drawing or drafting is a fundamental approach and analytical process of engineering.

Aircraft design is a complex part of engineering and also a branch of aeronautical engineering. Someone who designes anything or anywhere of an aircraft might be titled as aircraft designer. To be an aircraft designer, the main disciplines that need to have knowledge about are aerospace engineering and mechanical engineering. One who graduated from these engineering disciplines can design system and sub-system of the aircraft. When designing an aircraft, the important thing is that to have knowledge about different disciplines which form the aircraft such as systems and subsystems like aerodynamic, electric, flight controls, material, structure, etc. and to be experienced. The maturity of design depends on whether the aircraft designer's experiences are enough or not. According to Daniel Raymer [6], a skilled aircraft designer not only finds out some geometric drawings but also analytical creation of expectations on the boundary of requirements. That's why a good designer is critical point of a good design.

An aircraft design process mainly comprises two activities. First is more technical and comprises problem solving with engineering and mathematical knowledge. Second is that making choice an optimality in terms of given necessities. The first activity is to design different structures and systems and the second activity is mostly about controlling the feasibility of design development. The most important part of any design is to achieve available requirements for the aircraft. To sum up, the more reachable requirement the more quality design. For this reason, the decision-making process has crucial effect at the beginning of the design [7].

The aircraft design is a process that includes recurring activities. In short, it is a cycle until desired design, means that answering the expectations, has been achieved. The aircraft design process begins with the syntesis of customer wish and market analysis.

Desired design requirements show aircraft designer to a road map to built basic framework of the design. The design process can mainly be explained under three main steps that will be discussed in detail on next step of this thesis through its design lifecycle period. After all of these design phases, manufacturing and test activities accompany the process.

3.2.1. Design Phases

The design process' three phases are: conceptual design phase, preliminary design phase and detail design phase [3], [6], [2] that also shown in Figure 3.1. In each phases different tools and methods can be used to maintain the design progress. The main objective is to meet to customer requirements under constraints of time and cost, and also to decide feasibility of design.

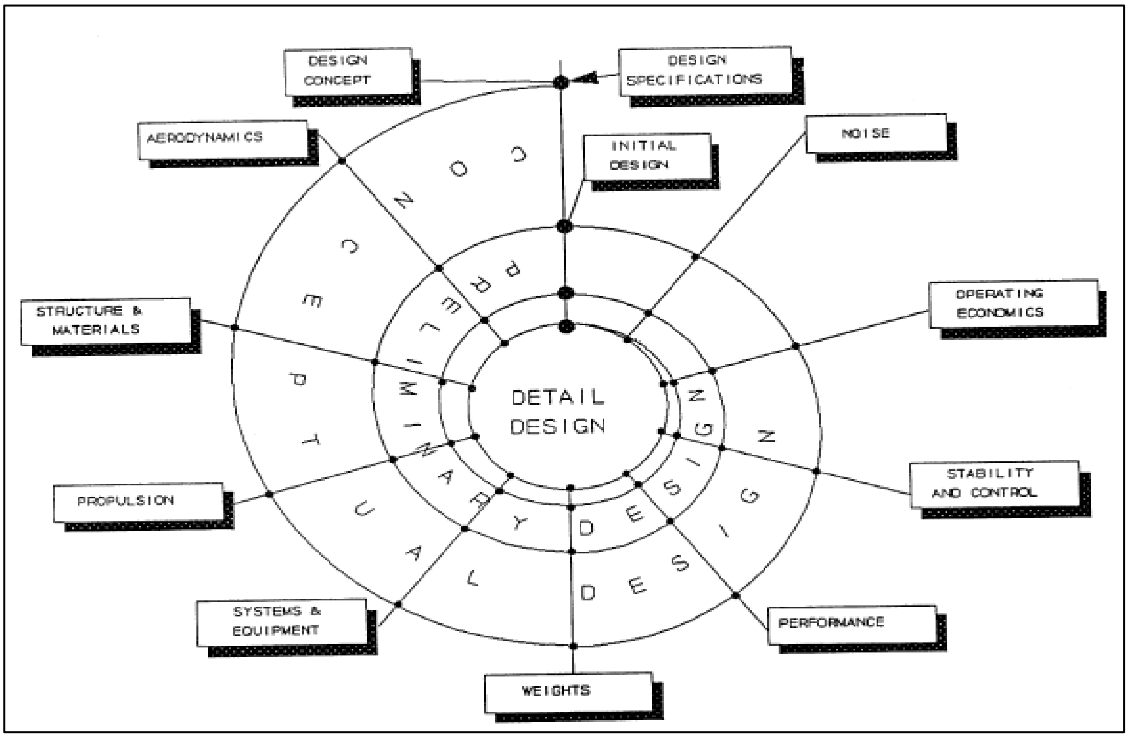


Figure 3.1. The Design Spiral [2]

3.2.1.1. Conceptual Design Phase

Conceptual design is the first attempt but the most important phase of the design progress. The major responsibility of this phase is to determine a road map for the expected design and system configuration in order to answer customer needs. A group of system analysts or aircraft designer team identifies the requirements to be capable of conceptual design. [59] The decisions are given in this phase by the team as follows:

- Manufacturability options (Material type, process types, fastening selection, size of parts, fly by wire choice)
- Determination of structural design policy (weight estimation, strength and power)
- Supportability (supply of equipments, engine match) [60]

During the concept design phase the quantity of data generated on each design alternative will be relatively limited and the allocation of resource is minimal. The output of the alternatives will be an experience and determination of the feasibility of the various concept works. Moreover, it will be an estimate of the draft size of the most likely configurations. It is not possible to work in detail for each concept choice since every concept study will not be as worthy as to be expected. Therefore, it will lead to both time and cost consumption digressively [61].

3.2.1.2. Preliminary Design Phase

Preliminary design phase is the phase that all concept works are evaluated and unnecessary ones are eliminated according to cost based or unfeasibility of design. In this phase resource allocation will gradually increase and common lines of the design geometry will occur. System and sub-system of the aircraft will begin to carry out in this detailed analysis phase. Functional and performance analysis of the sub-systems level will be handled [7]. The fundamental thing is in the preliminary design phase to freeze aircraft's design to be manufactured as defining all requirements in depth. Provided that the concept design phase is definite the only minor changes are made for aircraft in this part of the design [62].

3.2.1.3. Detail Design Phase

The final part of the design stepd is the detail design phase which systems, sub-systems and parts are defined and designed in all details to be fabricated or sub-contracted. Resource allocation is considerably more compare to other phases. During this phase, whole system and design components will be divided into smaller parts that are evaluated and analyzed. Also, manufacturing documentation is released [6]. According to Gudmundsson [3], summary of to-do list in this phase as follows:

- Detail design work (structures, systems, avionics, etc.)
- Study of technologies (vendors, company, cooperation, etc.)
- Subcontractor and vendor negotiations
- Design of limited (one-time use) tooling (fixtures, and jigs)
- Structural detail design
- Mechanical detail design
- Avionics and electronics detail design
- Ergonomics detail design
- Mock-up fabrication
- Maintenance procedures planning
- Material and equipment logistics.

After the detail design phase finishes, recurring and non-recurring trials for the first product such as manufacturing of components and tool begin. Followed by these activities are integration of sub-structures, integration of systems, testing of whole structure and systems, first flight, flight testing, and certification. From beginning of the design to end of delivery to the customer whole process might take place five to eight years [63].

3.3. Aircraft Design Components

Aircrafts generally comprises airframe/structure, engines and systems. The whole components has been analyzing and designing sensitively in all phases by engineers.

3.3.1. Aircraft Structures

Aircrafts are built up from the following basic structure sections; wings, fuselage, tail (horizontal & vertical) which is also denoted by *Empennage*, powerplant and landing gears where shown in Figure 3.2. Sub-details of these sections will be explained in the following chapters.

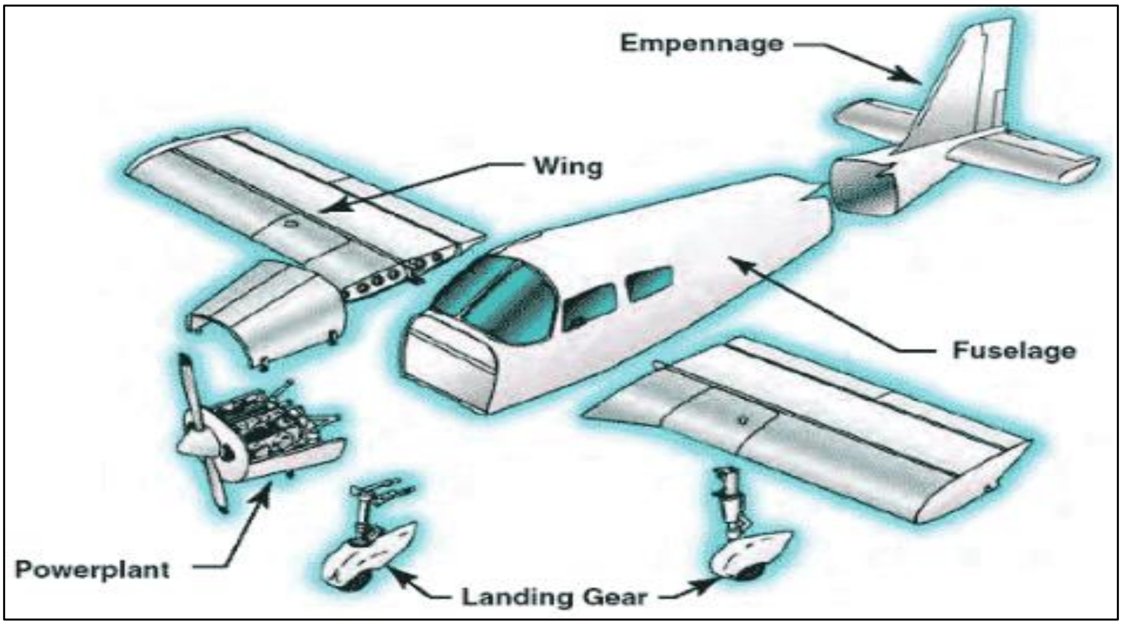


Figure 3.2. Basic Aircraft Structures

3.3.1.1. Fuselage

The fuselage is the main airframe of an aircraft. It can also be said as body of it. The fuselage provides space needed for personnel, cargo, controls, and most of the other accessories. Moreover, wings, stabilizers, moving surfaces, power plant and landing gear are integrated to fuselage [4]. The fuselage structure can vary in terms of type of the aircraft. Whereas some fuselage types can cover engine in its structure like single engine aircraft, engines can be located as inner or outer of the fuselage. Type of the fuselage structure depends on size and adjustment of the different compartments [64].

3.3.1.2. Wings

When considering that a fixed-wing aircraft can not fly without having any wing it can be understood how important of this section of an aircraft's structure. Since both the geometry and its features can affect entirely the whole aircraft components. That's why it will be more logical to begin designing an aircraft with this section [7]. For an aircraft type that is heavier-than-air the important function of the wings is to bring out adequate lift force and briefly to carry the major portion of the lift. Another type of aircraft such as rotary wing that is both heavier than air and powered has no structural wing. Instead of it, there are two rotary wings that are consisted of some rotor blades. One is above the fuselage and the other is at tail section. The design of a wing can vary to the purpose of use. Required variables for designing of an aircraft such as size, weight, speed and rate of climb determines the type of wings [61]. The wing structure is composed of different components shown in Figure 3.3.

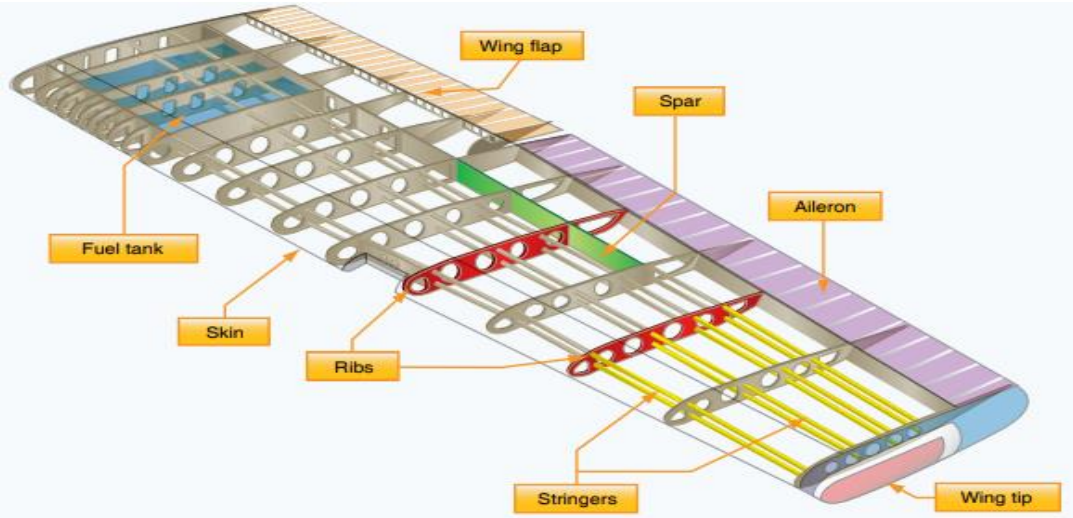


Figure 3.3. Wing Components

3.3.1.3. Empennage

Empennage is rear section, or tail section, of the aircraft. This section includes that is abour movement horizontal tail plane, vertical tail plane, rudder and elevator. Empennage provides the aircraft stability and control. In Figure 3.4 the tail section and the structure of empennage are shown clearly. Horizontal and vertical tail planes are stabilizers of the aircraft. The main objective of them is to provide straight flight. The **horizontal stabilizer** that is also denoted as longitudinal stability ensures stability of the aircraft about its lateral axis whereas the **vertical stabilizer** that is known directional stability works providing the stability of the aircraft as vertical axis. Rudder is attached to vertical stabilizer and elevators are attached to horizontal stabilizer. Both rudder and elevators are movable surfaces of the aircraft. While **rudder** is used to rotate turning or yawing motion the **elevators** are used to move pitching motion [5].

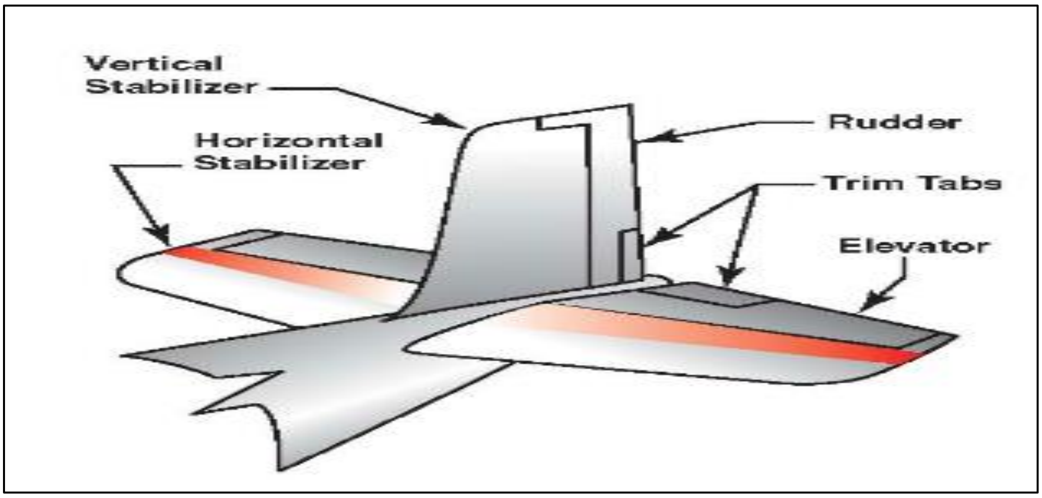


Figure 3.4. Tail Section of the aircraft

Also, the motion types of the aircraft thanks to the parts located in both wings and empennage are shown in Figure 3.5.

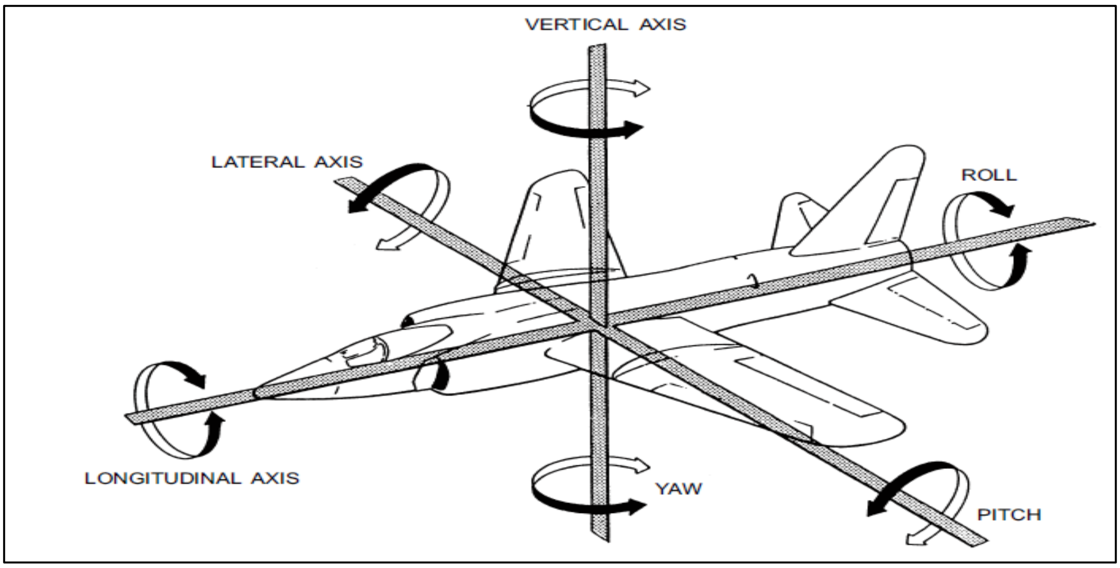


Figure 3.5. Axes and fundamental movements of the aircraft

3.3.1.4. Landing Gear

The landing gears are undercarriage part of the aircraft. It mainly provides support the aircraft on the ground as absorbing the impact of landing. The landing gears generally consist of two part which are straight leg with wheel and trailing link [65].

3.3.1.5. Power Plant

Engines are power plant of the aircrafts. The heavier than aircrafts can have different number of engines which help the aircraft fly. There are many types and models but the working principle is the same and the function is basically to take the air where is in front of the aircraft and then as accelerating and pushing out behind the aircraft [5], [9].

3.3.1.6. Aircraft Systems

The aircraft has systems that are collection of interdependent sub-systems. Sub-systems also have different sub-systems. In all level every dependent sub-system has individual task to perform in aircraft which is also set of systems. The basic aircraft systems such as vehicle, avionic, cabin and mission that all have different missions in the system architecture for the aircraft will be explaining on the next paragraphs.

Vehicle System allows the aircraft to maintain its flight safely. It can be divided into four parts that are fuel, electrical, hydraulic and oxygen systems. *Fuel systems* provide continually fuel to engine in order to support engine power needed. *Electrical system* is designed to support aircraft in terms of electrical power as equipping with a battery. The pilots can activate or deactivate electrical power with a switch control on the aircraft. *Hydraulic system* answer the different and complex needs on the aircraft such as handling the moveable parts of the aircraft or controlling the landing gear section. *Oxygen system* is one of the most important systems. This system supplies the oxygen to the both cabin crews and passenger, it also depends type, in the aircraft when climbing to the altitude that oxygen use needed. In the aircraft the oxygen is usually stored in the portable container that is highly pressured to hold the oxygen [66].

Avionic System is mainly about navigation, communication, display and control equipments. Avionic system also enables to manage vehicle systems with softwares and interfaces. The avionic system architecture is composed of both analog and digital display and control units. This system provides to control *Flight Control Systems* are related with the structure of the aircraft. It means that the system is about controlling the moveable structures on wings, fuselage and undercarriage of it such as ailerons, flaps, rudder, elevator, landing gear. These control systems can be controlled both manually, mechanically as hydraulic and pneumatic, and electronically as fly-by-wire (FBW) that converts the works made to the actuators by the help of electronic signals [67]. *Navigation System* provides worldwide navigation capability for the aircraft. *Communication System* enables communication feature to the aircraft with both other aircrafts and headquarter [68].

Mission System is not included in all types of aircraft. That system is generally required in military aircraft. The fundamental purpose of it to get information about the outside the world with sensors and process this information to find out logical result. According to outcome of the information weapon systems can be released for defensive or offensive actions [68].

3.3.1.7. Engines

Engines are the part of the propulsion system of an aircraft. It provides the aircraft mechanical power to drive or to fly [69].

3.4. Workload

According to nature of the design process, anything that is designed is systematically sliced into small parts, and then joining the full design parts, desired design is reached. In early-design phases designers generally do not work precisely comparing with other phases which are preliminary design and critical design. However, it needs to be done iteratively in every phases. These iterations can be more and more as long as scope of the design becomes deeper and ever process leads to take time. As a result, every effort in design process is a workload for one who works for the specific task. In other words, elapsed time as doing any activity in design can be measured as design workload for the activity [70].

3.5. Fuzzy Inference Process

As mentioned in Chapter 2, fuzzy logic is one of the cost estimation technique that handles uncertainty or vagueness and can make reliable estimates when using it [14]. Basically, fuzzy logic is a certain logic of ambiguity and rough judgement [71], was first introduced by Lotfi Asker Zadeh in 1965 in order to model uncertainty and vagueness in systems that has data imperfections and to provide the flexibility of human reasoning [15]. Fuzzy systems theory can utilize in evaluating some of our more traditional, but less complicated systems. For instance, there is no need to have accurate answers in some problems. An approximate answer, but faster solution can be beneficial in making early design decisions, or as an first prediction in a more certain qualitative technique to save both costs and time in situations where problems are uncertain, ambiguous, or not known at all [72]. Because of lack of knowledge or information, conventional mathematics may not be find enough solution to complex systems. That's why the fuzzy theory is a choice to handle vagueness. Fuzzy logic can be considered as extension of conventional set theory by providing partial memberships of elements to fuzzy sets. In classical set theory, an element either belongs to a set or not, either true or false. Let say x is an element and A is a universal set. If x is an element of set A then membership function, represents an element's membership to a set as assigning a value, takes 1 and if opposite of this occurs then it takes 0. Equation (2.1) shows the characteristic membership function of X_A(x) that defines a certain membership of element x in set A [73].

$$X_A(x) = \begin{cases} 1 & if \;\; x \in A \\ 0 & if \;\; x \notin A \end{cases} \tag{2.1}$$

On the other hand, fuzzy logic provides a way to take membership in some degrees in a fuzzy set where there is no strict boundaries. Degrees of membership of a fuzzy set $\mu_A(x)$ is represented in a closed interval [0,1] shown in equation (2.2) [74].

$$\mu_A(x) \; : X \rightarrow [0,1] \tag{2.2}$$

The end points of this interval [0,1] show total membership and non-membership in a fuzzy set. The closer the value of $\mu_A(x)$ to 1 for an element, the more x belongs to A [75].

3.5.1 Fuzzy Sets, Fuzzy Process and Basic Operations

In a given problem all information is evaluated as *universe of discourse*. All specific events are defined according to that information space. In classical set theory or in other words, crisp set, there is crisp limitations and no vagueness on the context. On the other hand, there is always an uncertainty and fuzzy boundaries or no district limitations in fuzzy set theory. The difference among crisp set and fuzzy set is shown In Figure 3.6. Let *X* be universe of discourse and *A* is shown as a set, Figure 3.6.a denotes crisp set and Figure 3.6.b denotes fuzzy set, respectively. Also, *a*,*b* and *c* are elements of set *A* and shares same universe of discourse. In Figure 3.6.a clearly shows that point *a* is a member of crisp set *A* and point *b* is *not* a member of set *A* as is seen. As mentioned above section, membership state of an element in the set is certain and can be defined binary values, such as 0 and 1, in classical set or crisp set. Figure 3.6.*b* demonstrates the uncertain boundary of a fuzzy set *A*. The gray shaded area shows the boundary region of *A* . In the unshaded region of the fuzzy set, point *a* represents a full member of the set.

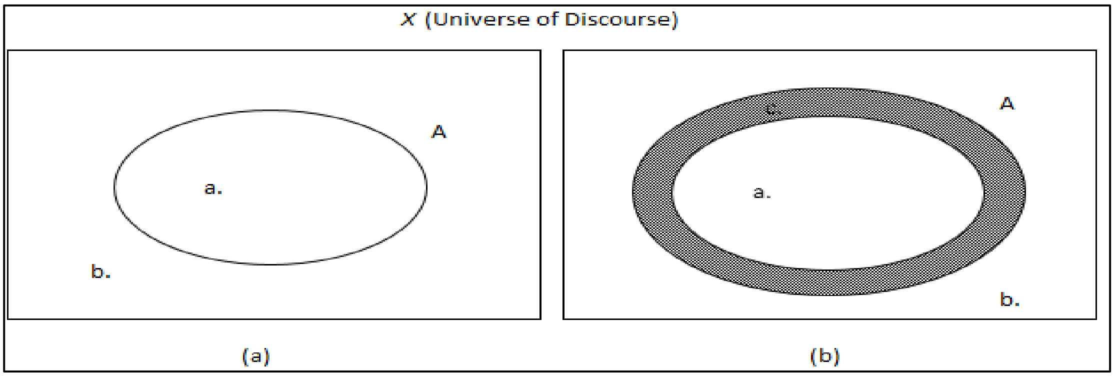


Figure 3.6. Diagrams of Crisp set (a) and Fuzzy Set (b)

Outer area of the boundary in the fuzzy set, point *b* is clearly shown that it is not included in the fuzzy set. However, the membership of point *c*, which is included on the boundary region of the fuzzy set. However, membership of point *c* is ambiguous. Complete membership in a fuzzy set shown in Figure 3.6.*b* is symbolized by the number value 1 (point *a*), and non-membership in a fuzzy set is symbolized by 0 (point *b*). In case point *c* should be located some value between *a* and *b* on the interval [0,1] such as 0.5 as membership of set *A* [72].

Following section will briefly describe the process of a fuzzy system and steps of it are involved in Figure 3.7. The process of fuzzy logic is formed according to three major steps which are fuzzification, fuzzy logic and de-fuzzification. First stage, fuzzification, involves the transformation of crisp input values to fuzzy inputs. Second stage, fuzzy logic, represents the definition of system behavior using fuzzy rules and the final stage, defuzzification, provides values obtained from fuzzy logic [74].

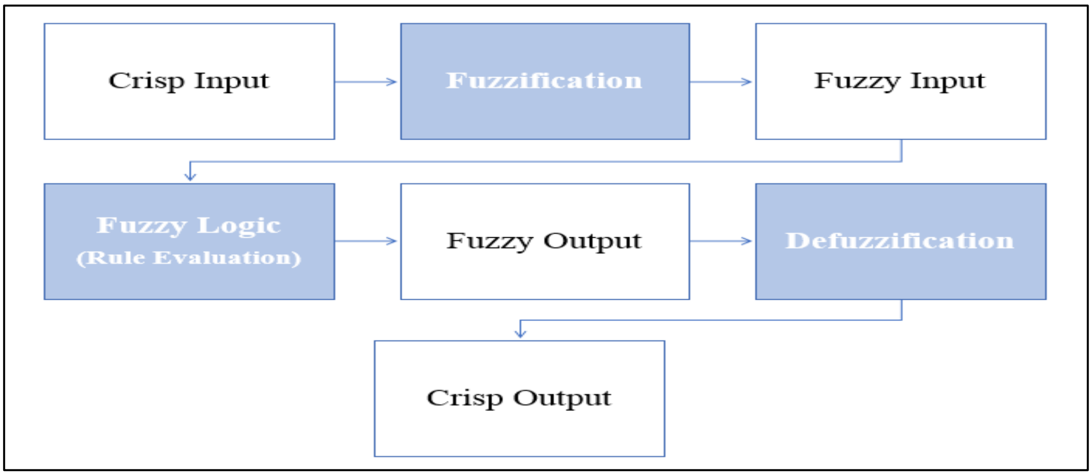


Figure 3.7. Process of Fuzzy Model

Fuzzification is a process that crisp inputs are converted into linguistic variables. Then, linguistic variables are quantified by fuzzy membership function using fuzzy sets. Linguistic variables or linguistic quantifiers are the input or output terms of the system whose values are differ from numeric values, they are denoted as words or sentences from daily language. Every linguistic quantifier refers to a specific fuzzy set [72]. For instance, let be five lectures such as Algorithm & Programming (AP), Computer Network (CN), Mobile Programming (MP), Artificial Intelligence (AI) and Soft Computing (SC) as crisp inputs in a lecturer evaluation program. The skills of the lecturers weighted from the lowest value 0 to highest value 100 shown in Table 3.1.

Table 3.1. Lecturers' Skill [76]

No.	Name	Surname	AP	CN	MP	AI	SC
1	Andie	Siahaan	90	90	90	90	90
2	Michael	Bolton	90	80	80	70	70
3	Van	Damme	80	90	70	60	50
4	Tom	Cruise	90	60	70	80	70
5	Chun	Li	60	60	60	50	40

The decision-maker can select any range of values that reflects his confidence. In this example, three fuzzy sets are described as LOW = (0,20,40), MEDIUM = (20,50,80) and HIGH = (60,80,100) shown in Figure 3.8 [76].

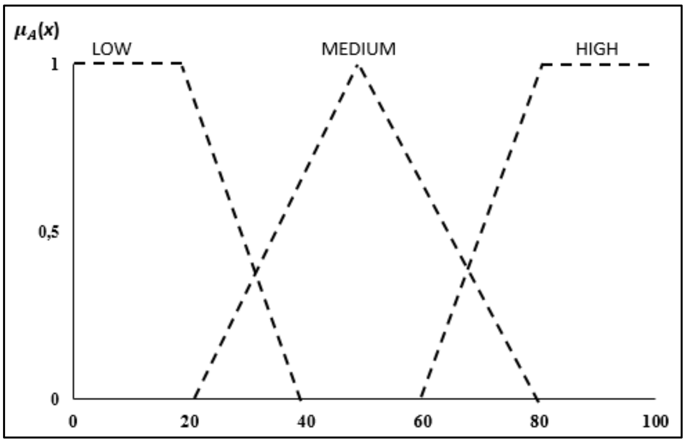


Figure 3.8. Skill Membership Function

There are many types of membership functions that can be different in terms of system design and problem. However, a few types of member functions are mainly used in fuzzification process. These are singleton, gaussian, trapezoidal and triangular membership functions which are shown graphically in Figure 3.9 [75].

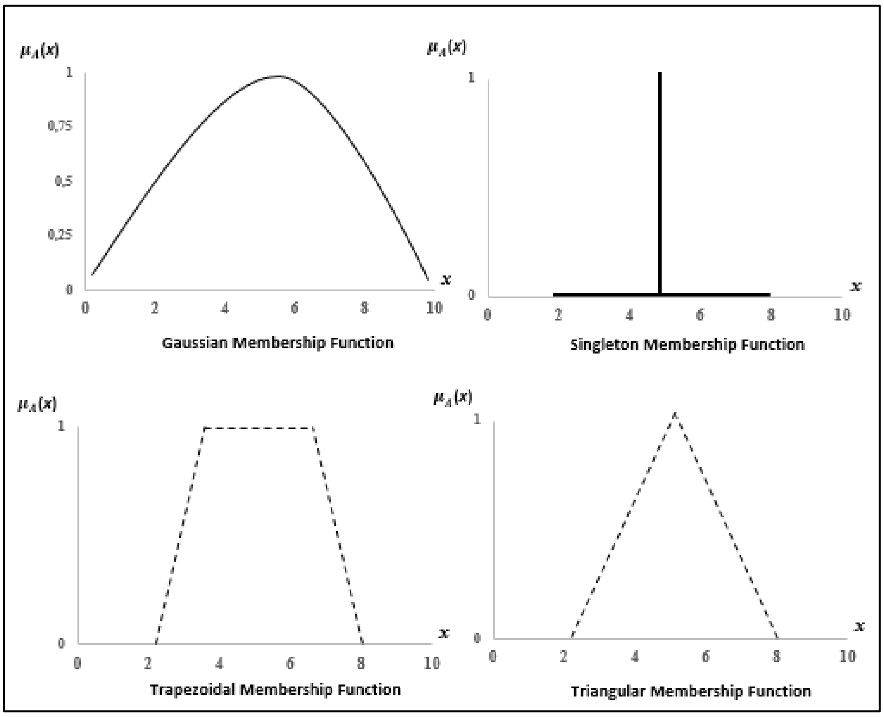


Figure 3.9. Frequently used membership functions

Triangular and trapezoidal fuzzy numbers are also the most preferred types because of their computational simplicity due to their linearity on membership functions. In this thesis, triangular fuzzy numbers will be used in the model and their membership function equation will be presented below. The membership function of symmetric triangular type is illustrated in Figure 3.10 and described as notion in Equation (3.3) as follows:

$$\mu_A(x) = \begin{cases} \frac{(x-a)}{(b-a)}, & a \leq x \leq b \\ \frac{(c-x)}{(c-b)}, & b \leq x \leq c \\ 0 & Otherwise \end{cases} \quad (3.3)$$

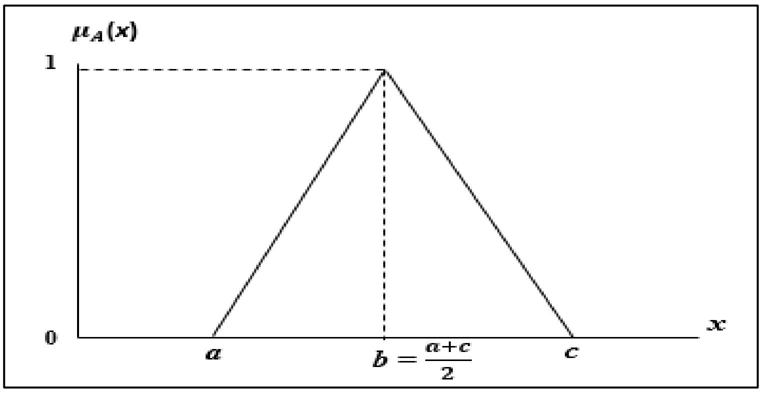


Figure 3.10. Symmetric Triangular fuzzy numbers (a, b, c)

Triangular fuzzy number is defined by three real numbers (*a, b, c*) and they are expressed lower, mean and upper bounds of triangular fuzzy number, respectively [77]. According to above example seen Table 3.1, let *x* be any number between lower and upper boundaries and the membership functions of number three lecturer Van Damme for lecture, Algorithm and Programming (AP) is as follows trough equation 3.4 to 3.6 [76];

$$\mu_{LOW}(x) = \begin{cases} \frac{(x-0)}{(20-0)}, & 0 \leq x \leq 20 \\ \frac{(40-x)}{(40-20)}, & 20 \leq x \leq 40 \\ 0 & Otherwise \end{cases} \quad (3.4)$$

$$\mu_{MEDIUM}(x) = \begin{cases} \frac{(x-20)}{(50-20)}, & 20 \leq x \leq 50 \\ \frac{(80-x)}{(80-50)}, & 50 \leq x \leq 80 \\ 0 & Otherwise \end{cases} \quad (3.5)$$

$$\mu_{HIGH}(x) = \begin{cases} \frac{(x-60)}{(80-60)}, & 60 \leq x \leq 80 \\ \frac{(100-x)}{(100-80)}, & 80 \leq x \leq 100 \\ 0 & Otherwise \end{cases} \quad (3.6)$$

Fuzzification continues with the ***fuzzy inference process*** (fuzzy inference engine) after getting crisp inputs to linguistic fuzzy inputs and *IF -THEN* rules are processed at this stage. *IF-THEN* rules are used to model conditional situations that contain fuzzy theory and to control the outputs [78]. Generally, it is modeled in terms of fuzzy relation with fuzzy inputs for fuzzy output. Let *B*, *C* and *D* be three fuzzy sets in *A* (universe of discourse) between range *X* and *Y* and formal expression for *IF-THEN* rules as follows [79];

- If *x* is *B* then *y* is *C*
  - <u>Given statement</u> "*x* is *B*"
  - <u>Consequence</u> "*y* is *C*"

When more than one condition are necessary, *IF-THEN* connectors are used to point out that are *AND*, *OR* and *NOT*.

- If x_1 is *B* **AND** x_2 is *B* then y_1 is *C*
- If x_1 is *B* **OR** x_1 is *C* then y_1 is *D*
- If x_1 is **NOT** *B* then y_1 is *D*

Final stage of fuzzy logic is ***defuzzification***, is a process coverts fuzzy value infered from fuzzy membership functions in fuzzy sets to crisp value. In brief, producing degree of membership value to the actual or real decision value. To do this, there are various defuzzification methods and mostly used algorithms are center of gravity (COG) or center-of-area (COA), mean of maximums (MOM), smallest of maximum (SOM) and largest of maximum (LOM) [80].

The fuzzy operations that generally performed on fuzzy sets $A = (a_1, a_2, a_3)$ and $B = (b_1, b_2, b_3)$ are listed in equation between (3.7) through (3.11), respectively [15] [81] [49].

Union:

$$\mu_{A\cup B}(x) = \max\,[\mu_A(x), \mu_B(x)] \tag{3.7}$$

Intersection:

$$\mu_{A\cap B}(x) = \min [\mu_A(x), \mu_B(x)] \quad (3.8)$$

Complement:

$$\bar{A} \leftrightarrow \mu_{\bar{A}}(x) = 1- \mu_A(x) \quad (3.9)$$

Addition:

$$\mu_{A+B}(x) = A\,(a_1, a_2, a_3) + B\,(b_1, b_2, b_3) \quad (3.10)$$
$$= (a_1 + b_1, a_2 + b_2 , a_3 + b_3)$$

Subtraction:

$$\mu_{A-B}(x) = A\,(a_1, a_2, a_3) - B\,(b_1, b_2, b_3) \quad (3.11)$$
$$= (a_1 - b_3, a_2 - b_2 , a_3 - b_1)$$

4. PROPOSED MODEL

As stated in earlier chapters, if there is uncertainty conditions and owning lack of desired datas one of the useful methods to predict future is fuzzy theory. Fuzzy theory is a method that is both easy to perform and has better results in vague systems [14].

In this thesis, an aircraft database including 34 military aircraft will be used from literature. These aircrafts' type is examined in 6 categories such as fighter, bomber, transportation, attack and training and bussiness jet. The aircrafts' model and types are listed below [82] in Table 4.1.

Table 4.1. Aircraft Database

Row	Model	Type
1	A-3	Attack
2	A-4	Attack
3	A-5	Attack
4	A-6	Attack
5	A-7	Attack
6	A-10	Attack
7	S-3	Attack
8	B-52	Bomber
9	B-58	Bomber
10	B/RB-66	Bomber
11	C-5	Transportation
12	C-130	Transportation
13	C-133	Transportation
14	KC-135	Transportation
15	C-141	Transportation
16	F3D	Fighter
17	F3H	Fighter

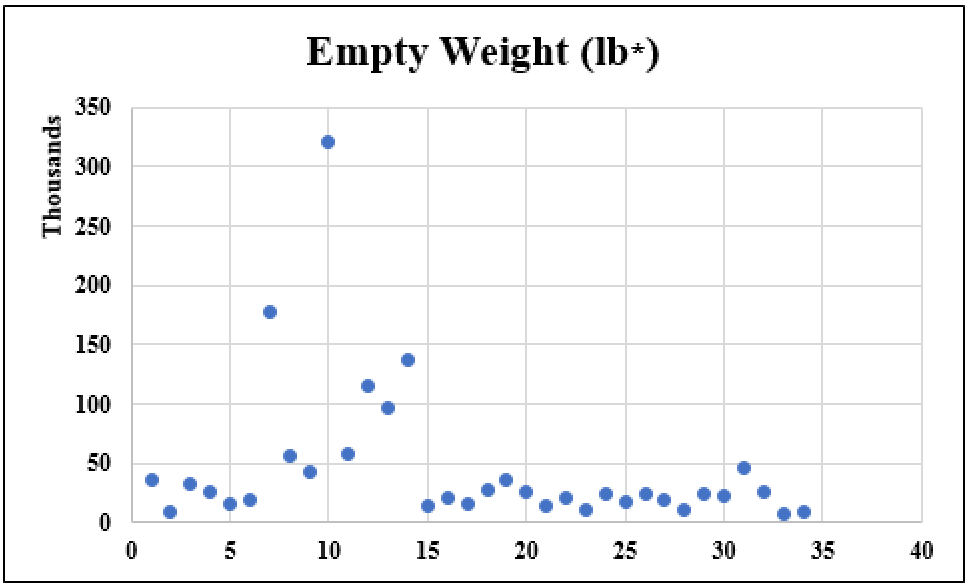
Row	Model	Type
18	F4D	Fighter
19	F-4	Fighter
20	F-14	Fighter
21	F-15	Fighter
22	F-16	Fighter
23	F-18	Fighter
24	F-86	Fighter
25	F-89	Fighter
26	F-100	Fighter
27	F-101	Fighter
28	F-102	Fighter
29	F-104	Fighter
30	F-105	Fighter
31	F-106	Fighter
32	F-111	Fighter
33	T-38	Training Jet
34	T-39	Bussiness Jet

There are several cost factors that affect aircraft manufacturing. Basically, engineering, tooling, staffing, material, development and manufacturing support, flight test operations and quality control are cost levels of an aircraft development process. Especially, the development phase, in other words design phase, is more invisible comparing with others. That's why variable selection is important to make model visible. Aircrafts shown in Table 4.1 are examined according to their characteristics and some dependant variables are determined in terms of size and performance features. The details about selected input variables will be presented next step.

4.1. Crisp Inputs for Aircraft Characteristic

During the modeling phase of this study, many characteristics were considered according to elements of aircraft as possible variables. However, it was important that desired variables had to satisfy the requirements that are related to cost of aircraft. Also, determined variables had to embody all aircraft' design methodology. Variables are analysed in terms of speed and climb rate as performance and aircraft unit weight and empty weight as size metrics of the aircraft.

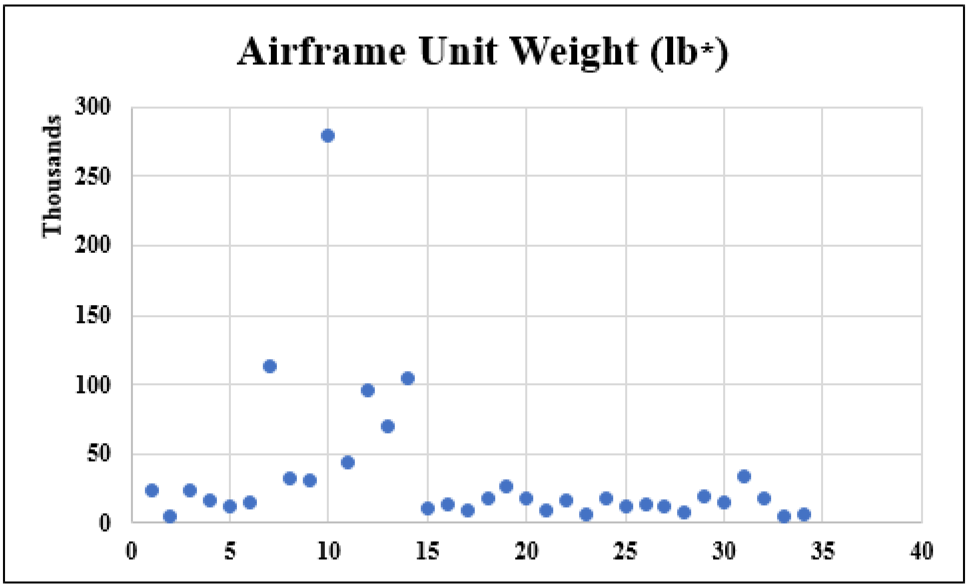
Empty Weight (EW) is defined that weight of the aircraft without fuel, ammunition and crew. Distribution of the aircrafts used according to empty weight shown in Figure 4.1.



*: lb approximately equals 0.45 kg

Figure 4.1. Empty Weight Values of Samples

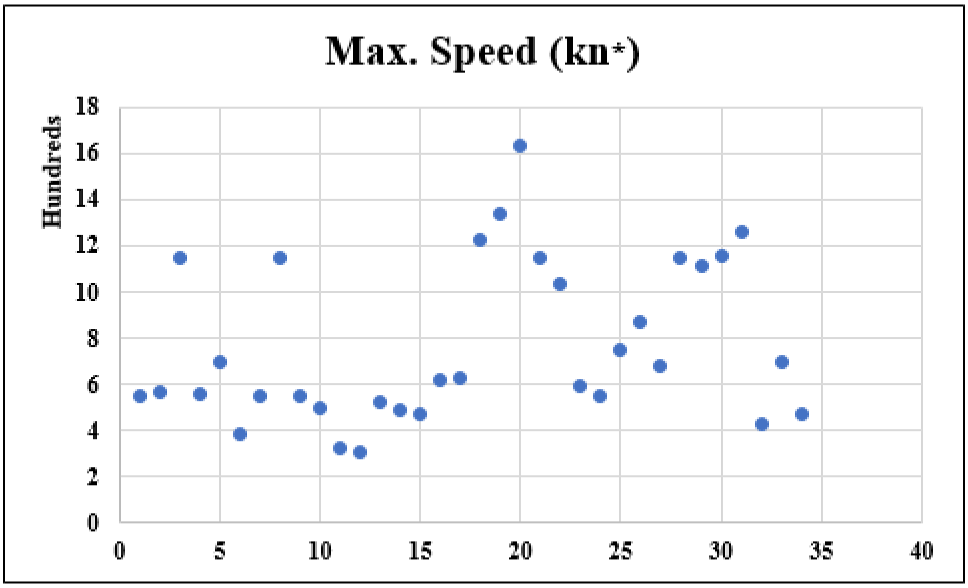
Aircraft Unit Weight (AUW) is calculated as excluding wheels, brakes, tires, engines propellers, avionics and other sysytems and sub-systems. It can also be thought structural weight of the aircraft. Distribution graph also shown in Figure 4.2.



*: lb approximately equals 0.45 kg

Figure 4.2. Aircraft Unit Weight Values of Samples

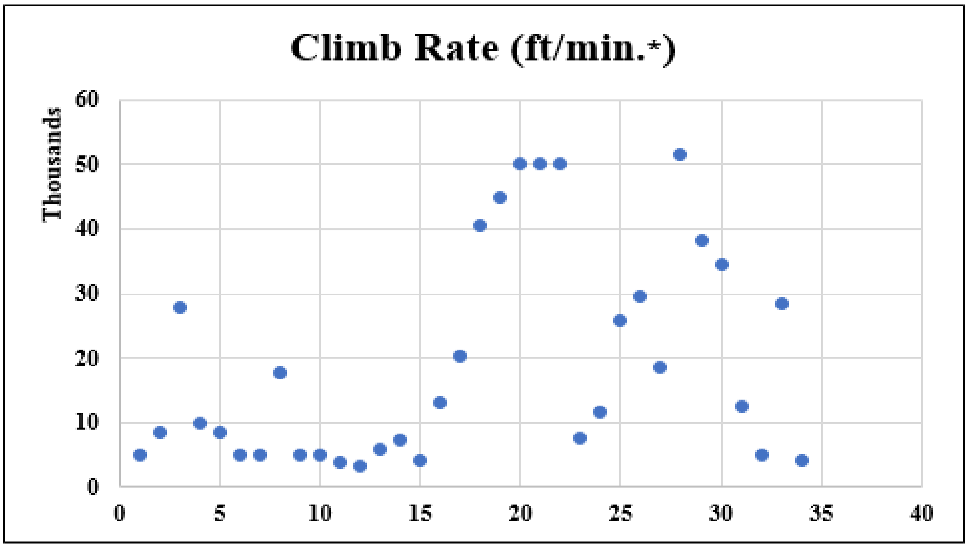
Maximum Speed (MS) is the speed of the aircraft that reaches at any altitude. Distribution graph shown in Figure 4.3.



*: kn is denoted as "*knot*" and approximately equals 1.852 km/hr and 1.151 mph

Figure 4.3. Maximum Speed Values of Samples

Climb Rate (CR) is the vertical maximum climb of the aircraft. Distribution graph also shown in Figure 4.4. Also, all crisp inputs shown in Table 4.2.



*: ft is denoted as "*feet*" and approximately equals 0.3048 meters.

Figure 4.4. Climb Rate Values of Samples

Table 4.2. Crisp Inputs' Values [16]

Model	Airframe Unit Weight (lb)	Empty Weight (lb)	Max. Speed (kn)	Climb Rate (ft/min.)
A-3	23.951	35.999	546	5.050
A-4	5.072	9.146	565	8.400
A-5	23.499	32.714	1.147	27.900
A-6	17.150	25.298	561	10.000
A-7	11.621	15.497	695	8.580
A-10	14.842	19.856	389	5.100
B-52	112.672	177.816	551	5.120
B-58	32.686	55.560	1.147	17.830
B/RB-66	30.496	42.549	548	5.000
C-5	279.145	320.085	495	5.160
C-130	43.446	58.107	326	3.900
C-133	96.312	114.690	304	3.400
KC-135	70.253	97.030	527	5.900
C-141	104.322	136.900	491	7.270
F3D	10.136	14.860	470	4.100
F3H	13.898	21.270	622	13.000
F4D	8.737	16.050	628	20.200
F-4	17.220	27.530	1.222	40.600
F-14	26.500	36.825	1.342	45.000
F-15	17.550	26.795	1.629	50.000
F-16	9.565	14.062	1.145	50.000
F-18	16.300	20.583	1.034	50.000
F-86	6.788	10.040	590	7.660
F-89	18.119	23.870	546	11.800
F-100	12.118	18.260	752	25.700

Table 4.2. Crisp Inputs’ Values [16]

Model	Airframe Unit Weight (lb)	Empty Weight (lb)	Max. Speed (kn)	Climb Rate (ft/min.)
F-101	13.423	24.720	872	29.600
F-102	12.304	19.460	680	18.700
F-104	7.963	11.570	1.150	51.500
F-105	19.301	24.500	1.112	38.300
F-106	14.620	23.180	1.153	34.500
F-111	33.150	46.170	1.262	12.600
S-3	18.536	26.581	429	5.000
T-38	5.376	7.410	699	28.500
T-39	7.027	9.753	468	4.270

4.2. Fuzzification for Proposed Model

In fuzzification process for proposed model crisp inputs which are Aircraft Unit Weight (AUW), Empty Weight (EW), Maximum Speed (MS), Climb Rate (CR) and crisp outputs Engineering Design Hours (EDH) are splitted into 10 equal intervals and converted linguistic variables. The determination of intervals depend on the decision maker’s choice. The reason why 11 fuzzy linguistic variables are used is to have long range data pool. Converted fuzzy linguistic variables are Extremely Low (EL), Very Low (VL), Low (L), Moderate Low (ML), Slightly Low (SL), Moderate (M), Slightly High (SH), Moderate High (MH), High (H), Very High (VH), Extremely High (EH). In Table 4.3 shows the intervals about linguistic variables.

Table 4.3. Fuzzy Interval Values

Linguistic Variable	AUW (lb)	EW (lb)	MS (kn)	CR (ft/min.)	EDH (hr)
EL	[0, 5072, 32479]	[0, 7410, 38677]	[0, 304, 436]	[0, 3400, 8210]	[0, 315934, 784842]
VL	[5072, 32479, 59886]	[7410, 38677, 69945]	[304, 436, 569]	[3400, 8210, 13020]	[315934, 784842, 1253750]
L	[32479, 59886, 87293]	[38677, 69945, 101212]	[436, 569, 701]	[8210, 13020, 17830]	[784842, 1253750, 1722658]
ML	[59886, 87293, 114701]	[69945, 101212, 132480]	[569, 701, 834]	[13020, 17830, 22640]	[1253750, 1722658, 2191567]
SL	[87293, 114701, 142108]	[101212, 132480, 163747]	[701, 834, 966]	[17830, 22640, 27450]	[1722658, 2191567, 2660475]
M	[114701, 142108, 169515]	[132480, 163747, 195015]	[834, 966, 1099]	[22640, 27450, 32260]	[2191567, 2660475, 3129383]
SH	[142108, 169515, 196923]	[163747, 195015, 226282]	[966, 1099, 1231]	[27450, 32260, 37070]	[2660475, 3129383, 3598291]
MH	[169515, 196923, 224330]	[195015, 226282, 257550]	[1099, 1231, 1364]	[32260, 37070, 41880]	[3129383, 3598291, 4067199]
H	[196923, 224330, 251737]	[226282, 257550, 288817]	[1231, 1364, 1496]	[37070, 41880, 46690]	[3598291, 4067199, 4536107]
VH	[224330, 251737, 279145]	[257550, 288817, 320085]	[1364, 1496, 1629]	[41880, 46690, 51500]	[4067199, 4536107, 5005015]
EH	[251737, 279145, 1000000]	[288817, 320085, 1000000]	[1496, 1629, 1000000]	[46690, 51500, 1000000]	[4536107, 5005015, 1000000]

4.3. Rule Evaluation for Proposed Model

Using Matlab software's fuzzy logic toolbox, fuzzy inference process is executed by the help of triangular fuzzy membership function method for fuzzy variables. The FIS process chart for desired model is presented in Figure 4.5. Moreover, as an illustration of triangular membership functions for AUW can be seen below equation through 4.1 to 4.11 and figures of membership function for all variables are shown respectively, in Figure 4.6 – Figure 4.10.

$$\mu_{EL}(x)=\begin{cases} 1, & 0 \leq x \leq 5.072 \\ \frac{(32.479-x)}{(32.479-5.072)}, & 5.072 \leq x \leq 32.479 \end{cases} \tag{4.1}$$

$$\mu_{VL}(x)=\begin{cases} \frac{(x-5.072)}{(32.479-5.072)}, & 5.072 \leq x \leq 32.479 \\ \frac{(59.887-x)}{(59.887-32.479)}, & 32.479 \leq x \leq 59.887 \\ 0 & o.w. \end{cases} \tag{4.2}$$

$$\mu_{L}(x)=\begin{cases} \frac{(x-32.479)}{(59.887-32.479)}, & 32.479 \leq x \leq 59.887 \\ \frac{(87.294-x)}{(87.294-59.887)}, & 59.887 \leq x \leq 87.294 \\ 0 & o.w. \end{cases} \tag{4.3}$$

$$\mu_{ML}(x)=\begin{cases} \frac{(x-59.887)}{(87.294-59.887)}, & 59.887 \leq x \leq 87.294 \\ \frac{(114.701-x)}{(114.701-87.294)}, & 87.294 \leq x \leq 114.701 \\ 0 & o.w. \end{cases} \tag{4.4}$$

$$\mu_{SL}(x)=\begin{cases} \frac{(x-87.294)}{(114.701-87.294)}, & 87.294 \leq x \leq 114.701 \\ \frac{(142.109-x)}{(142.109-114.701)}, & 114.701 \leq x \leq 142.109 \\ 0 & o.w. \end{cases} \tag{4.5}$$

$$\mu_M(x)=\begin{cases}\frac{(x-114.701)}{(142.109-114.701)}, & 114.701 \le x \le 142.109\\ \frac{(169.516-x)}{(169.516-142.109)}, & 142.109 \le x \le 169.516\\ 0 & o.w.\end{cases} \quad (4.6)$$

$$\mu_{SH}(x)=\begin{cases}\frac{(x-142.109)}{(169.516-142.109)}, & 142.109 \le x \le 169.516\\ \frac{(196.923-x)}{(196.923-169.516)}, & 169.516 \le x \le 196.923\\ 0 & o.w.\end{cases} \quad (4.7)$$

$$\mu_{MH}(x)=\begin{cases}\frac{(x-169.516)}{(196.923-169.516)}, & 169.516 \le x \le 196.923\\ \frac{(169.516-x)}{(224.330-196.923)}, & 196.923 \le x \le 224.330\\ 0 & o.w.\end{cases} \quad (4.8)$$

$$\mu_H(x)=\begin{cases}\frac{(x-196.923)}{(224.330-196.923)}, & 196.923 \le x \le 224.330\\ \frac{(251.738-x)}{(251.738-224.330)}, & 224.330 \le x \le 251.738\\ 0 & o.w.\end{cases} \quad (4.9)$$

$$\mu_{VH}(x)=\begin{cases}\frac{(x-224.330)}{(251.738-224.330)}, & 224.330 \le x \le 251.738\\ \frac{(279.145-x)}{(279.145-251.738)}, & 251.738 \le x \le 279.145\\ 0 & o.w.\end{cases} \quad (4.10)$$

$$\mu_{EL}(x)=\begin{cases}\frac{(x-251.738)}{(279.145-251.738)}, & 251.738 \le x \le 279.145\\ 0, & x > 279.145\end{cases} \quad (4.11)$$

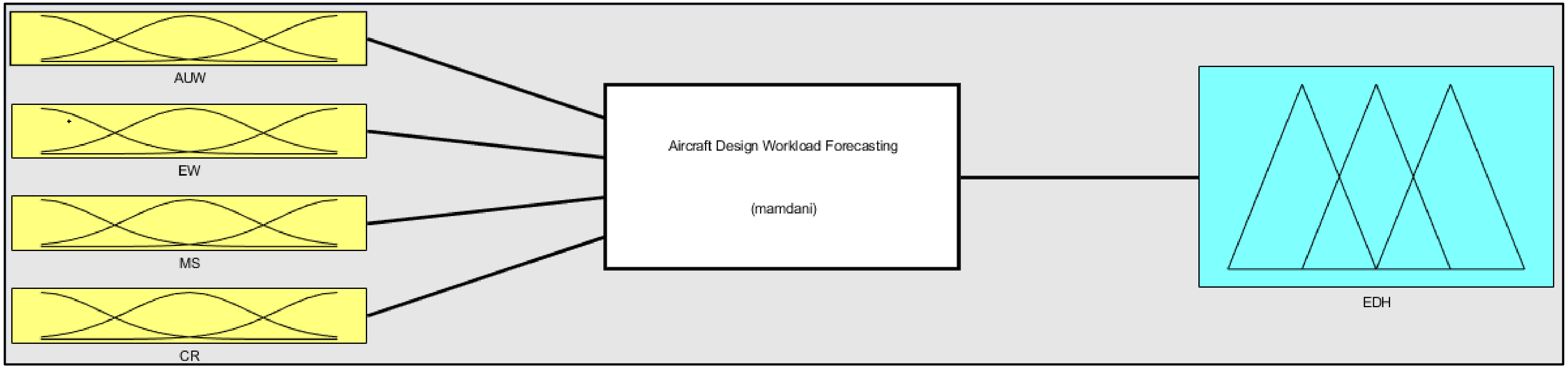


Figure 4.5. FIS (Fuzzy Inference System) Process Chart

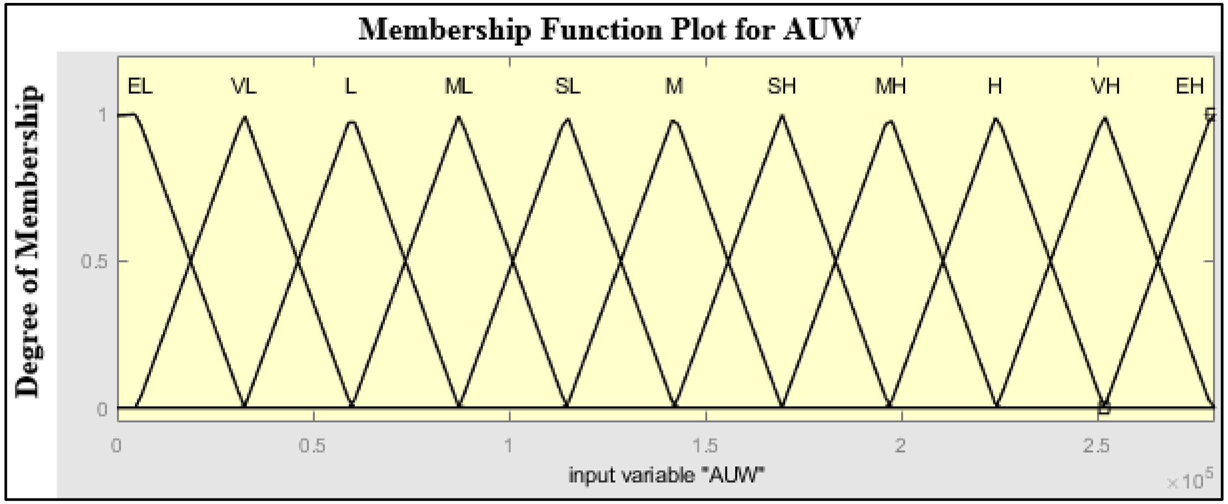


Figure 4.6. Aircraft Unit Weight (AUW) Membership Function

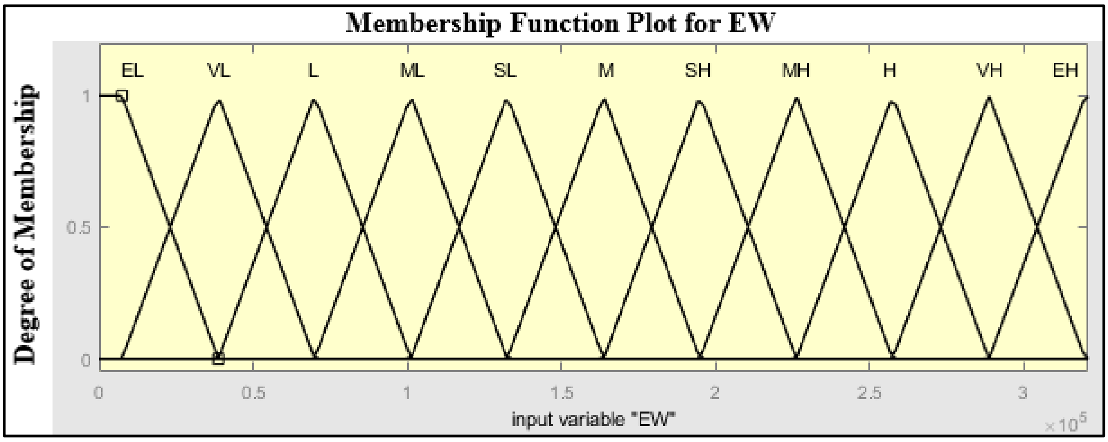


Figure 4.7. Empty Weight (EW) Membership Function

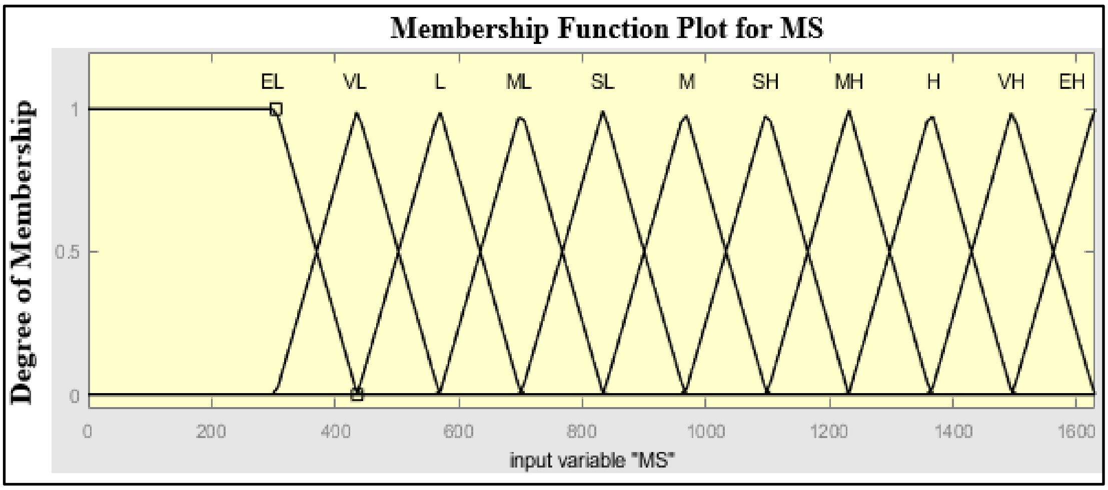


Figure 4.8. Maximum Speed (MS) Membership Function

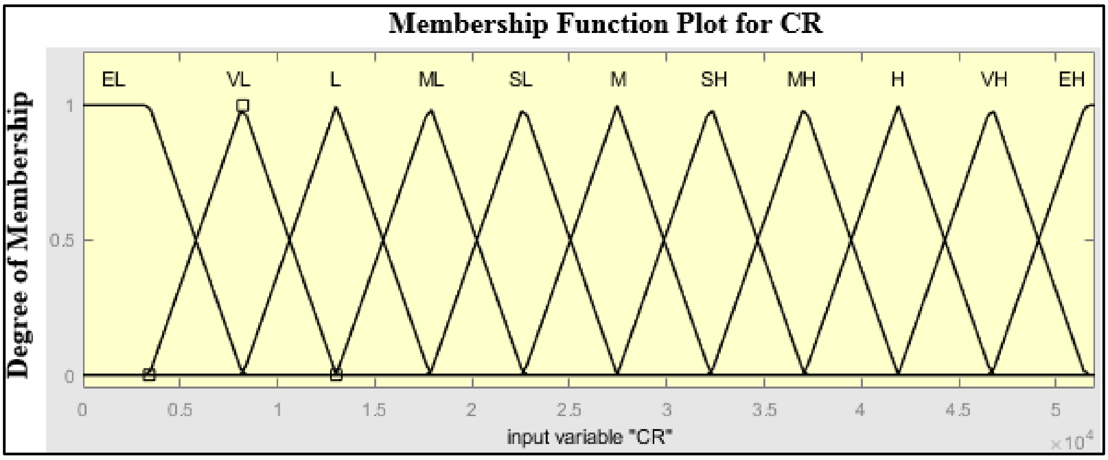


Figure 4.9. Climb Rate (CR) Membership Function

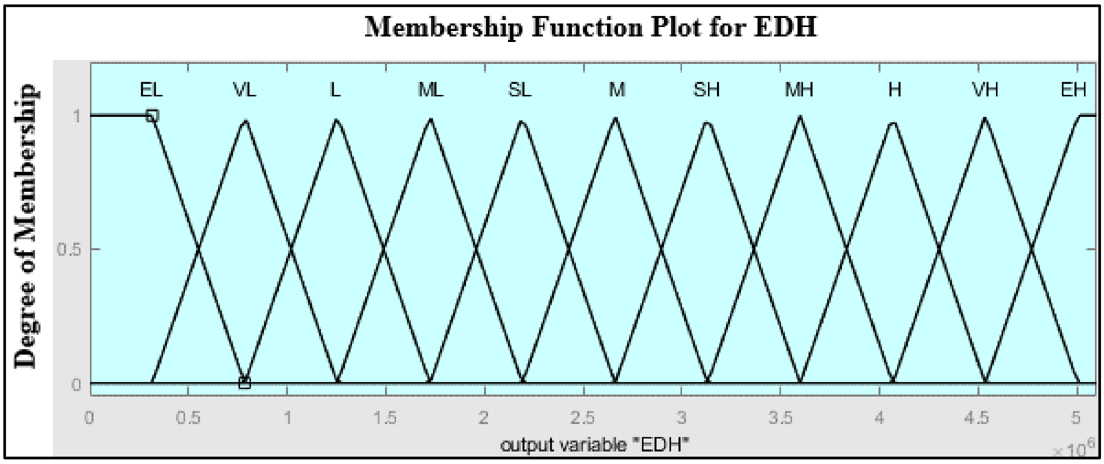


Figure 4.10. Engineering Design Hours (EDH) Membership Function

After formation of the triangular fuzzy membership functions fuzzy rule process is also generated for all fuzzy members. The list of the fuzzy rules shown as follows:

1) If (AUW is VL) and (EW is VL) and (MS is L) and (CR is EL) then (EDH is VL)
2) If (AUW is EL) and (EW is EL) and (MS is L) and (CR is VL) then (EDH is EL)
3) If (AUW is VL) and (EW is VL) and (MS is SH) and (CR is M) then (EDH is ML)
4) If (AUW is EL) and (EW is VL) and (MS is L) and (CR is VL) then (EDH is VL)
5) If (AUW is EL) and (EW is EL) and (MS is ML) and (CR is VL) then (EDH is VL)
6) If (AUW is EL) and (EW is EL) and (MS is VL) and (CR is EL) then (EDH is EL)
7) If (AUW is SL) and (EW is M) and (MS is L) and (CR is EL) then (EDH is MH)
8) If (AUW is VL) and (EW is L) and (MS is SH) and (CR is ML) then (EDH is M)
9) If (AUW is VL) and (EW is VL) and (MS is L) and (CR is EL) then (EDH is L)
10) If (AUW is EH) and (EW is EH) and (MS is VL) and (CR is EL) then (EDH is EH)
11) If (AUW is VL) and (EW is L) and (MS is EL) and (CR is EL) then (EDH is VL)
12) If (AUW is ML) and (EW is ML) and (MS is EL) and (CR is EL) then (EDH is L)
13) If (AUW is L) and (EW is ML) and (MS is L) and (CR is VL) then (EDH is SL)
14) If (AUW is SL) and (EW is SL) and (MS is VL) and (CR is VL) then (EDH is M)
15) If (AUW is EL) and (EW is EL) and (MS is VL) and (CR is EL) then (EDH is EL)
16) If (AUW is EL) and (EW is EL) and (MS is L) and (CR is L) then (EDH is VL)

17) If (AUW is EL) and (EW is EL) and (MS is L) and (CR is ML) then (EDH is VL)

18) If (AUW is EL) and (EW is VL) and (MS is MH) and (CR is H) then (EDH is ML)

19) If (AUW is VL) and (EW is VL) and (MS is H) and (CR is VH) then (EDH is SL)

20) If (AUW is EL) and (EW is VL) and (MS is EH) and (CR is EH) then (EDH is SL)

21) If (AUW is EL) and (EW is EL) and (MS is SH) and (CR is EH) then (EDH is VL)

22) If (AUW is EL) and (EW is EL) and (MS is SH) and (CR is EH) then (EDH is L)

23) If (AUW is EL) and (EW is EL) and (MS is L) and (CR is VL) then (EDH is EL)

24) If (AUW is EL) and (EW is VL) and (MS is L) and (CR is L) then (EDH is VL)

25) If (AUW is EL) and (EW is EL) and (MS is ML) and (CR is M) then (EDH is VL)

26) If (AUW is EL) and (EW is VL) and (MS is SL) and (CR is M) then (EDH is L)

27) If (AUW is EL) and (EW is EL) and (MS is ML) and (CR is ML) then (EDH is VL)

28) If (AUW is EL) and (EW is EL) and (MS is SH) and (CR is EH) then (EDH is VL)

29) If (AUW is VL) and (EW is VL) and (MS is SH) and (CR is MH) then (EDH is L)

30) If (AUW is EL) and (EW is VL) and (MS is SH) and (CR is SH) then (EDH is L)

31) If (AUW is VL) and (EW is VL) and (MS is MH) and (CR is L) then (EDH is M)

32) If (AUW is EL) and (EW is VL) and (MS is VL) and (CR is EL) then (EDH is VL)

33) If (AUW is EL) and (EW is EL) and (MS is ML) and (CR is M) then (EDH is EL)

34) If (AUW is EL) and (EW is EL) and (MS is VL) and (CR is EL) then (EDH is EL)

In defuzzification process, it is a process of converting a crisp value based on the owned fuzzy sets and associated membership degrees. In fuzzy logic tollbox, Center of Gravity (COG) is used as defuzzification method to get the crisp value. It determines the centre of the area of the integrated membership functions. That means it calculates the centroid or COG of integrated output membership functions. Fuzzy rule design is shown in Figure 4.11.

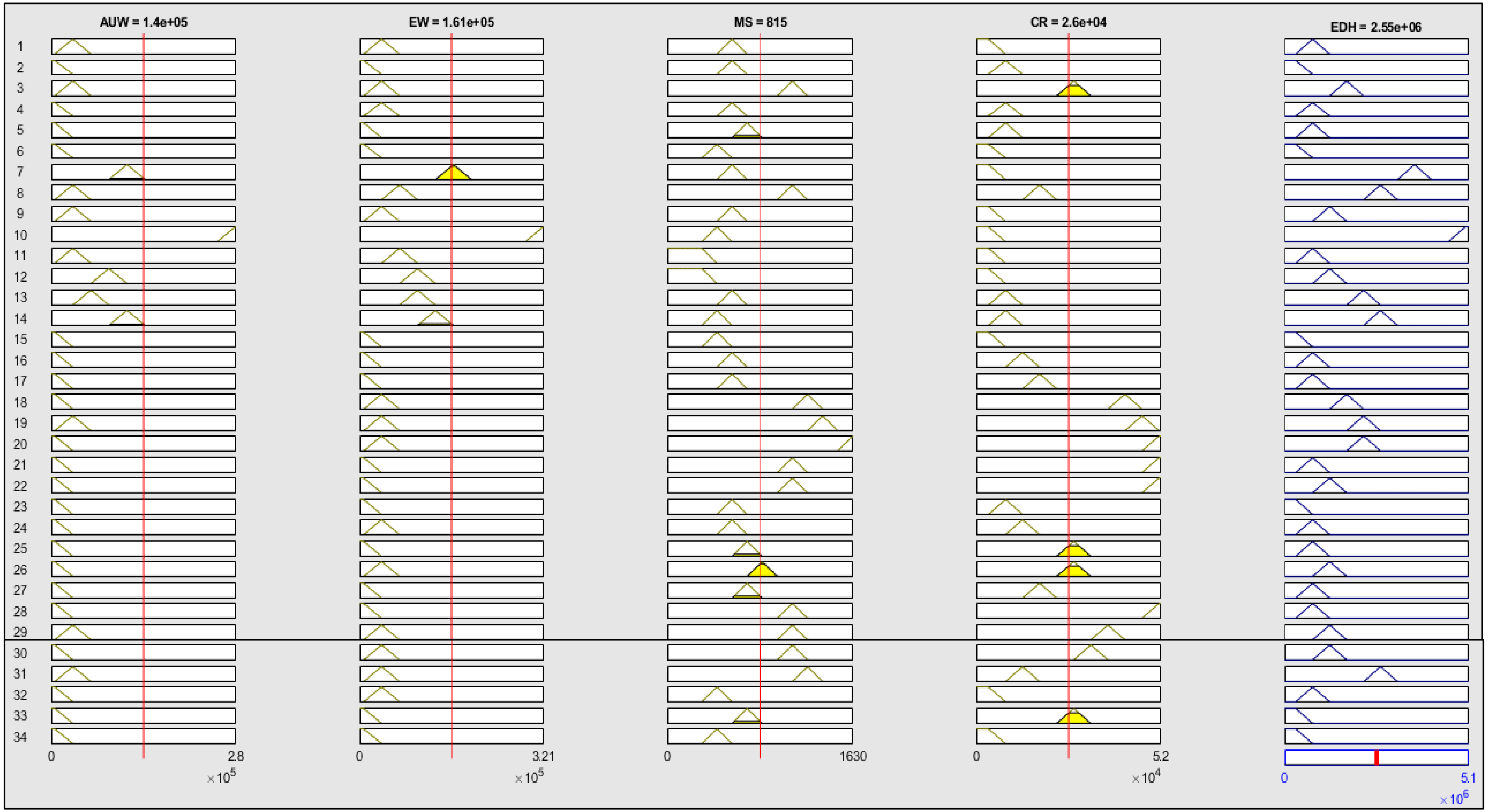


Figure 4.11 Fuzzy Rule Design

5. RESULTS

As stated in the earlier chapters, the purpose of this thesis is to examine the workload prediction of aircraft design process with the methodology of fuzzy logic. After getting the determined rules with fuzzy logic toolbox in previous section, the final stage of FIS is to take outputs. Model outputs are taken for every sample and both current values and model outputs are compared. The current design hours (current values) and fuzzy model outputs are shown in Table 5.1. and Figure 5.1.

Table 5.2. List of design hours (Current Values & Fuzzy Outputs)

Row	Current Values (hr)	Fuzzy Outputs (hr)	Row	Current Values (hr)	Fuzzy Outputs (hr)
1	1.000.288	983.000	18	1.668.815	1.670.000
2	355.668	316.000	19	2.274.788	2.090.000
3	1.803.163	1.660.000	20	2.112.966	2.190.000
4	779.127	590.000	21	934.204	1.020.000
5	644.754	762.000	22	1.146.608	1.020.000
6	465.280	508.000	23	397.490	430.000
7	3.488.623	3.600.000	24	726.907	652.000
8	2.721.242	2.660.000	25	785.891	709.000
9	1.142.757	1.020.000	26	1.135.161	1.250.000
10	5.005.016	4.890.000	27	754.682	785.000
11	915.080	785.000	28	805.956	1.020.000
12	1.458.067	1.250.000	29	1.400.996	1.330.000
13	2.093.929	2.190.000	30	1.386.136	1.250.000
14	2.568.323	2.890.000	31	2.566.799	2.660.000
15	439.897	559.000	32	637.010	596.000
16	746.726	783.000	33	365.299	527.000
17	605.156	785.000	34	315.935	416.000

According to the fuzzy outputs, variance table that is difference of fuzzy outputs with respect to current values is also demonstrated in Table 5.2.

Table 5.2. Variance of Current Values and Fuzzy Outputs

Row	Current Values (hr)	Fuzzy Outputs (hr)	Variance
1	1.000.288	983.000	17.288
2	355.668	316.000	39.668
3	1.803.163	1.660.000	143.163
4	779.127	590.000	189.127
5	644.754	762.000	-117.246
6	465.280	508.000	-42.720
7	3.488.623	3.600.000	-111.377
8	2.721.242	2.660.000	61.242
9	1.142.757	1.020.000	122.757
10	5.005.016	4.890.000	115.016
11	915.080	785.000	130.080
12	1.458.067	1.250.000	208.067
13	2.093.929	2.190.000	-96.071
14	2.568.323	2.890.000	-321.677
15	439.897	559.000	-119.103
16	746.726	783.000	-36.274
17	605.156	785.000	-179.844
18	1.668.815	1.670.000	-1.185
19	2.274.788	2.090.000	184.788
20	2.112.966	2.190.000	-77.034
21	934.204	1.020.000	-85.796
22	1.146.608	1.020.000	126.608
23	397.490	430.000	-32.510
24	726.907	652.000	74.907
25	785.891	709.000	76.891
26	1.135.161	1.250.000	-114.839
27	754.682	785.000	-30.318
28	805.956	1.020.000	-214.044
29	1.400.996	1.330.000	70.996
30	1.386.136	1.250.000	136.136
31	2.566.799	2.660.000	-93.201
32	637.010	596.000	41.010
33	365.299	527.000	-161.701
34	315.935	416.000	-100.065

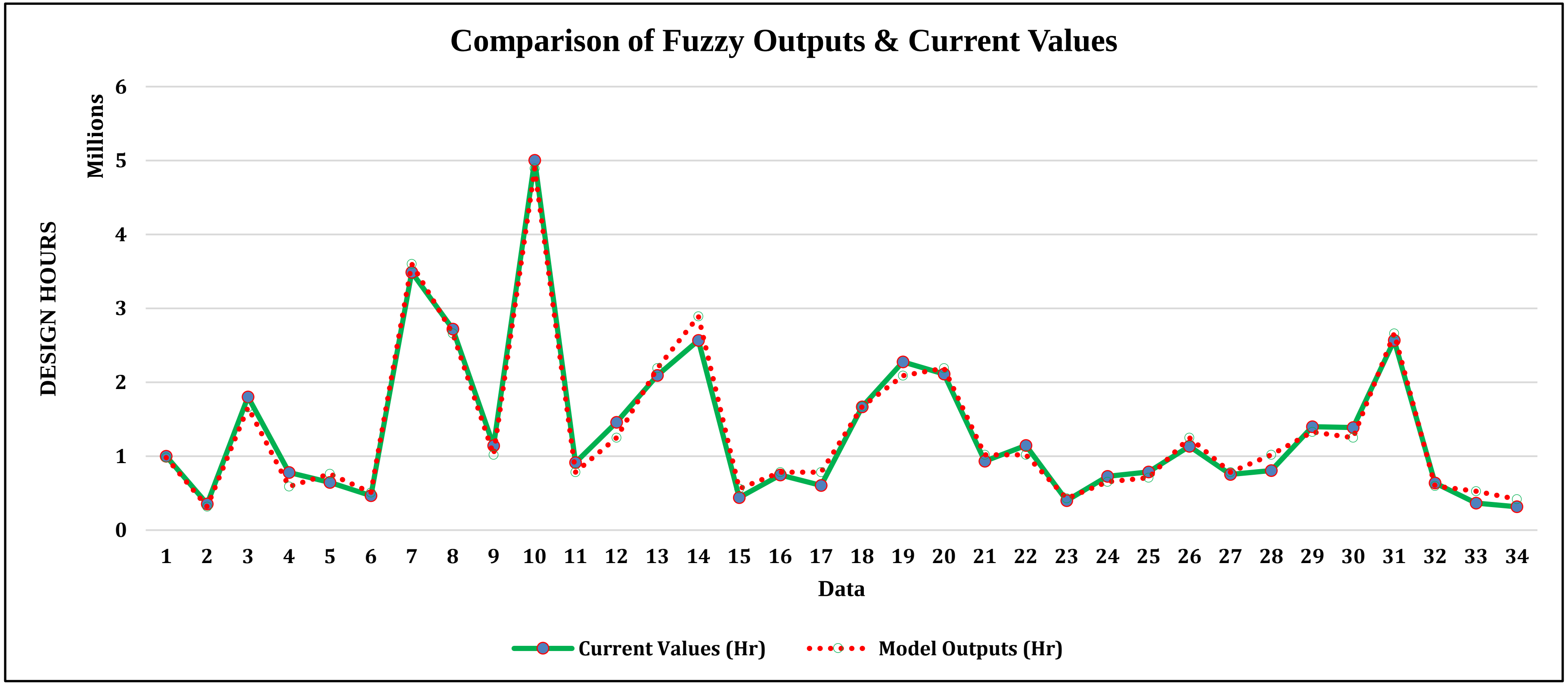


Figure 5.1. Comparison of Model Outputs and Current Values

6. CONCLUSION AND DISCUSSION

In aircraft manufacturing industry, big companies always struggle to get a slice off the cake in competitive environment. Cost is the primary aim for them and they always try to simplify both in manufacturing and design activities. Manufacturing side is more visible and controllable. However, design activities are invisible and imponderable. Also, throughout the design process there are many uncertain wish, demand, work, task, etc. That's why, cost estimation can make crucial affect especially for design projects in determining vagueness earlier to take action.

In this thesis, forecasting of design workload for aircraft projects is modeled with using methodology of fuzzy logic which is a qualitative cost estimation techniques. Thesis will also provide a practicle model for aircraft design projects to forecast design workload. The model has several advantages:

- It is really easy to perform fuzzy inference system and it does not have complex mathematics.
- Quick response to changes in both variables and samples,
- Better reaction to uncertainties,
- Can be taken close results.

This study has some constraints. First, the sample data is limited, since it does not contain various aircrafts and its information of design hours. It is probable that sharing any information about a product is a corporate confidentiality. Having the more sample about aircraft design hours the more precise results the model will give.

For future studies, adding new variables to the model can make more precious result. Aircrafts' weight can change in terms of material used in the structures. The samples used in the thesis have mostly metallic metarial in their structures. Today's aircraft manufacturers mainly use composite material and even lighter for decreasing cost. Therefore, for future aircraft cost estimation material will be a meaningful variable for model.

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APPENDIX

Appendix 1 – Oral and Poster Presentations

- Karakuz, V. C., Testik, Ö. M., “Hava aracı tasarımında iş yükünün bulanık mantık ile tahmin edilmesi”, 39. Yöneylem Araştırması ve Endüstri Mühendisliği Ulusal Kongresi, Ankara, 12-14 June 2019.

HACETTEPE UNIVERSITY
GRADUATE SCHOOL OF SCIENCE AND ENGINEERING
THESIS/DISSERTATION ORIGINALITY REPORT

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GRADUATE SCHOOL OF SCIENCE AND ENGINEERING
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Oral and Poster Presentations

- Karakuz, V. C., Testik, Ö. M., "Hava aracı tasarımında iş yükünün bulanık mantık ile tahmin edilmesi", 39. Yöneylem Araştırması ve Endüstri Mühendisliği Ulusal Kongresi, Ankara, 12-14 June 2019.