

Developing Model for Fuel Consumption Optimization in Aviation Industry

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Abstract

The contribution of aviation to society and economy is undisputedly significant. The aviation industry drives economic and social progress by contributing prominently to tourism, commerce and improved quality of life. Identifying the amount of fuel consumed by an aircraft while moving in both airspace and ground networks is critical to air transport economics. Aviation fuel is a major operating cost parameter of the aviation industry and at the same time it is prone to various constraints. This article aims to develop a model for fuel consumption of aviation product. The paper tailors the information for the fuel consumption optimization in terms of information development, information evaluation and information refinement. The information is evaluated and refined using statistical package R and Factor Analysis which is further validated with neural networking. The study explores three primary dimensions which are finally summarized into 23 influencing variables in contrast to 96 variables available in literature. The 23 variables explored in this study should be considered as highly influencing variables for fuel consumption which will contribute significantly towards fuel optimization.

Keywords: Fuel Consumption, Civil Aviation Industry, Neural Networking, Optimization

1. Introduction

During the one hundred years since the first flight of Orville and Wilbur Wright, the air transport industry has grown into a major sector of the global economy. Even more importantly, it has become essential for developing and maintaining cultural and economic links among countries and peoples. Air transport assists the people to connect within the countries and across the countries, facilitate cultural exchange and provide access to international markets. The aviation industry drives economic and social progress by contributing prominently to tourism, commerce and improves the quality of life. About 40% of the international travelers travel by air transport which is appreciably helping in the economic growth of the countries. Moreover, aviation has been considered as an indispensable element for driving the globalization of the production. About 35% of the total goods transportation is accounted by the air transport. According to the aviation industry "air transport provides 28 million direct, indirect and induced jobs worldwide" and carries "over 40% of the world trade of goods, by value"(Collaborative Forum 2003).

Literature explores that the foremost challenges that the civil aviation industry is facing currently are regional connectivity, high fuel consumption, aircraft noise emission, shortage of airport facilities, etc. Among these, fuel availability and fuel consumption originates as high impacting challenge in the present scenario. Decreasing reserves of the fuel resources and increasing demands has made this aspect more momentous. For instance, recently fuel crises were increased excessively as in 2008 when prices of crude oil per barrel increased from US $90 to $180. Therefore, literature on aviation industry considers fuel availability and consumption as a major challenge (Sgouris, 2010). Thus, in order to meet the demand for more air travel and to meet the economic and environmental restrictions, aircraft manufacturers are using innovative concepts for reducing oil consumption. Fuels are designed which are economic as well as environment friendly.

This article is organized as follows; Section 1 include introduction, need for optimization and research methodology followed. Section 2 tailors the information for fuel consumption optimization in terms of literature review, information evaluation and information refinement. The information is processed using statistical package R and refined using Factor Analysis. Section 3 develops the model for fuel consumption optimization of aviation product and validate with the help of neural networking. Section 4 concludes the article and discusses limitations and scope for future study.

1.1 Need for the fuel consumption optimization

In light of the aforementioned issues pertaining to the Fuel consumption in commercial aviation where we have observe the contrasting trends implies best possible use of Fuel, complying with availability and environmental concerns and at the same time sustaining the growth of the sector. The increasing passenger and freight traffic entail the proportional increase in fuel consumption. At the same time, constrained supply due to limited availability and environmental consideration calls for reduction in fuel consumption also. Literature advocates that the declining trend of fuel supply reflects the decreasing reserves of Fossil fuels, which if continued to be exploited at the current rate will deplete in next 50 years. According to D. Daggett (2006) "Jet fuel originates from crude oil and crude oil is limited natural resource subjected to depletion in near future". The increasing demand implies either the fuel resources should have to be increased or the fuel consumption should be decreased. Limited fuel resources augment for the optimized consumption of fuel.

1.2 Research methodology

For the exploration of parameters affecting fuel consumption, a literature survey was done by studying the various productive aspects of potential areas raised at different level by the researchers. The entire literature survey done from 1974 to till now converged upon few significant areas of aviation industry which are usefully identified as Technology & Design, Operation & Performance and Alternate Fuel & Fuel Properties. The information about these significant areas is put together in form of information framework that comprises of primary dimensions. The literature synthesis agreed upon three primary dimensions which includes a total of 96 decision variables. In order to identify whether information available in the information framework covers each aspect of fuel consumption in aviation industry, information needs to be evaluated scientifically. Therefore, to provide exploratory answer to research issue posed in this study, the aviation experts working in aviation sector of different organizations were asked to rate the decision variables on five point Likert scale. The entire questionnaire data was then processed with the statistical package R. Mean importance rating accredited by respondents lead to the development of ranking. The information refinement was then done by applying the Factor Analysis. It reduces 96 decision variables mentioned in the information framework in to 23 high impact decision variables. The variables having communality greater than 0.75 were regarded as high impact variables on which the fuel consumption of any aviation product depends. The seven variables identified for fuel optimization in the present study are the most influencing or high impact variables. To prove this claim, an optimization model was proposed. Now with the help of these extracted variables from our study, objective function, situation conditions (variables) and constraints were identified. To test the proposed fuel optimized based model, a specific aircraft was selected. It was tested with neural networking. It checked the authenticity of our research claim.

2. Literature review

To address the objective of this paper, a thorough literature review was made to explore the information for fuel consumption optimization. The most significant studies on fuel consumption optimization were begun after the Arab oil embargo in 1973 when scarcity of fuel was observed. The recent decade's research on optimization of fuel consumption has gained headway in converging upon a few important effective areas of aviation industry. The Literature (J.E. Green, 2003; D. Daggett, 2006; IEA Report, 2009; CCC Report, 2009) proposes the technological, operational and alternate fuels and fuel property as potential areas for fuel consumption optimization. The literature reveals specific areas which are taken into account for fuel optimization includes engine design, takeoff and landing fuel properties, flight route, technological trends, etc. The recent empirical studies assent that the optimization of fuel consumption needs to develop dimensions and inter-relationship among the various parameters. But how these parameters and their sub parameter coalesce with one another, is really challenging. Thus it becomes necessary to simplify the overall structure of the methodology of optimization of fuel to make it generic and applicable for aviation industry. We examined whether optimization of fuel consumption can however be radically redesigned to accommodate various research gaps that indicated in literature with the aim to make optimization of fuel consumption more logical and productive. The various challenges raised by the researchers are usefully grouped under three broad areas –

1. Technological & product design,

2. Operational and performances,

3. Alternate fuels and fuel properties.

Technological potential area literature contemplates the need of in-depth examination of technological parameters such as engine design, material composition, aircraft size, etc.(D L Green (1990), Nicholas E Antonie (2005)). Operational and performance potential area includes in depth examination of various operational parameters i.e. cruise speed, mach number, altitude, climb rate, flap setting, etc. to develop a sufficient knowledge base for developing enhanced models (David A Pilati (1974), Joosung Lee (2001), Antonio Filippone (2008)). Alternate fuels make the scope of use of the new fuels, fuels with better properties, their limiting cost, etc. (Robert O Price (1991), James I Hileman (2007)).

The findings of the literature survey act as initial information for our next step. It describes various productive aspects of the potential areas of aviation for the optimization of fuel consumption in aviation industry. The various variables which came to the surface after performing the exhaustive literature survey were classified as the primary dimensions. This identifies 96 distinct variables under primary dimensions. It included 34 variables under Technology and Product Design, 39 variables under Operational & Performance, 23 variables under Alternate Fuels & fuel Properties [Table 1].

In order to check that our study from the literature survey contains all inclusive solutions, the research gaps in the literature which includes aforementioned three areas of aviation industry were identified.. The initial information was clubbed together with the identified research gaps which lead to problem definition and set the objectives for our present work. It defined the problem as **"Developing model for fuel consumption optimization in Aviation Industry"**. The objectives of work as discussed above are outlined as under:

1. To explore the variables of fuel consumption optimization in aviation industry
2. To develop the model for fuel consumption optimization
3. To discuss the findings on fuel consumption optimization

2.1 Information evaluation

The next important issue is, whether the information mentioned in the framework covers each and every aspect of fuel consumption of aviation products. For that, information needs to be validated scientifically by the experts in Aviation Industries. In order to provide exploratory answers to the research issue posed in this study, the learned experts were asked to rate each of the decision variable of information framework in terms of "degree of importance they attach with the information". The options of evaluation were based upon Likert scale ranging from extremely important (1st level) to unimportant (5th level). A total of 140 responses were obtained. Entire questionnaire data is processed with statistical package R. The epitome of the means, standard deviations (SDs) and ranking of importance ratings accredited by respondents to the decision variables was obtained. For statistical analysis mean was calculated. The mean importance rating ranged from 1.16 (the highest importance rating for decision variable number 11) to 4.49 (the lowest importance rating for decision variable number 28) for Technology and Product Design decision variables. The mean importance rating ranged from 1.12 (the highest importance rating for decision variable number 28) to 4.52 (the lowest importance rating for decision variable number 34) for Operational decision variables. Also, the mean importance rating ranged from 1.21 (the highest importance rating for decision variable number 19) to 4.54 (the lowest importance rating for decision variable number 16) for Alternate Fuel decision variables.

This comprehensive study of information validation reveals three kinds of decision variables on the basis of their importance in fuel consumption optimization. The variables which have importance rating above or equal to 3 were rated as less important decision variables. The decision variables ranged from 1 to 2 on importance scale, were considered as important variables. The decision variables with importance rating ranged from 2 to 3, were acknowledged as moderately important decision variables. Therefore, it was expected that these distinguished sets of decision variables (important and moderately important) may help to make effectual and dynamic decisions for the fuel optimization [Table 2, 3, 4].

2.2 Information refinement

To refine the findings of information evaluation, the data of sample size 140 was subjected to Factor Analysis. After varimax rotation, the factors emerged with Eigen values greater than 1.0, accounting for the independent decision variables and explaining 66.8%0 of total variance. Seven variables are loaded on Factor Analysis 1 which account for 22.5% of the total variance. For Factor Analysis 2, nine variables are loaded which account for 25.5% of total variance. Eight variables are loaded for Factor Analysis 3, which account for 18.8% of the total variance [Table 5]. After applying the Factor Analysis, we obtained set of 23 variables having communality greater than 0.5. Therefore, this analysis explores 23 highly influencing decision variables for fuel optimization. It justifies the authenticity of previous finding related to importance of decision variables, mentioned in table 3,4 and 5. The decision variables highlighted as less important [table 2,3,4] for fuel consumption optimization are automatically excluded in Factor Analysis study [table 5].

The information refinement resulted in a set of 23 variables, which serve as parent set for developing fuel consumption optimization model. Seven variables having communality greater than 0.75 are considered most reliable and used for the development of present model. These seven variables are mentioned below

1. Aircraft Velocity
2. Altitude
3. Mach Number
4. Thrust
5. Wing Area
6. Maximum Takeoff Weight
7. Number of Engines

These 7 variables are further divided into two categories –

- Aircraft Velocity, Altitude, Mach number and Thrust have been considered as Situational Conditions (variables).
- Wing Area, Maximum Takeoff Weight and Number of Engines have been considered as Constraints.

3. Model development

The study of primary dimensions and highly influencing decision variable concludes a model for fuel consumption optimization. The existing fuel consumption model utilizes the energy balance relation to estimate the fuel consumption of an aircraft. This relation is based on aerodynamics and engine characteristics of an aircraft [Collins 1980]. The seven variables evolved in this study are claimed as the influencing variables which are sufficient to optimize the fuel consumption of aircraft. The model is customized with respect to the findings of information framework. These 7 high influencing variables have been used for model development.

3.1 Methodology

The general approach as well as the means and methods that were used to achieve the goals of this work are outlined through the following steps:

3.1.1 Selection of aircraft and data collection

For the purpose of this work, a medium sized jet aircraft is selected for testing. The aircraft manual consists of different charts related to fuel consumption. Along with these charts, aircraft characteristics are also given like engine weight, number of engines, maximum takeoff weight, maximum velocity of aircraft etc. The basic plane characteristics of this particular aircraft are:

Engine GEnx - 2B67

Maximum velocity	= 520 knots	Operating Empty Weight	= 470,100 lb
Maximum Takeoff Weight	= 973,000 lb	Number of Engines	= 4
Overall length	= 250 feet 2 inch	Height	= 63 feet 6 inch
Wing span	= 224 feet 7 inch	Maximum Fuel Capacity	= 242,470 liter
Wing Area	= 5200 ft^2	Seating capacity	= 581 persons

This aircraft is certified for the operations at altitudes up to 35,000 ft with takeoff weight up to 97,500 lb. Its minimum climb rate is 300 ft/sec and maximum operating speed of 550 knots.

3.1.2 Training neural network

To achieve the desired target, programs were developed in MATLAB to perform neural network computation which allowed performing the following task –

- Network training/learning,
- Testing and evaluation of trained network, and
- Implementation to calculate the fuel consumption of an aircraft

3.1.3 Implementation of Neural Network

Due to non linearity of the input data, non- linear transfer function are selected. The aim of model is to achieve accuracy between the inputs and outputs of a sum squared error of 0.05%, typically. A back propagation neural network with Levenberg Marquart approximation algorithm is employed that reduces the training time using Newton’s method (Simon Heykin, 2003). Input vectors and corresponding output vectors are used to train the network until it estimated the function. The transfer function used throughout the first layer is a hyperbolic tangent sigmoid function, called as **tansig** in MATLAB language. The second layer uses transfer function **purelin**. During the final feed forward process the nets compare the neurons outputs to associative target vectors.

3.2 Model envelop

For fuel optimization model, objective function, set of situation conditions (variables) and constraints were identified as mentioned below.

3.2.1 Objective function

The objective function formulated for the model development in present study has been used by the various researchers in past. The objective function for the present work has been identified as

To minimize the function

$$F = F_1 + F_2(\text{Thrust}) + F_3(\text{Thrust})^2$$

Where F is fuel flow and F_1 , F_2 and F_3 are aircraft fuel flow functions [Collins, 1984].

3.2.2 Situation conditions (variables)

The situation conditions for specific aircraft are

Aircraft Velocity = 175 Knots – 350 Knots   Altitude = 0 ft (sea level) – 45,000 ft

Mach number = 0.2 – 0.9   Thrust produced = $0 – 4 \times 10^5$ lobes

3.2.3 Constraints

The constraints which have been considered for model development in present study are;

Maximum Takeoff Weight = 973,000 lb   Number of engines = 4

Wing Area = 5,200 ft^2

4.Results & Discussion

4.1 Results

After training the neural networks with the help of the program written, optimized fuel consumption, altitude and velocity were obtained for the specific aircraft. Neural networking toolbox provided by MatLab software have been used to get the optimized values of variables for specific aircraft considered. 400 random data points are taken for the calculation of specific fuel consumption at 400 different velocities within the model envelope. The mathematical relations between different variables have been used to calculate the required specific fuel consumption of the aircraft. The standard value of the specific fuel consumption for the specific aircraft is between 0.8503×10^4 lb/hr and 13.76×10^4 lb/hr. Thus, if the proposed model gives the value of fuel consumption with in this specified range, it will prove the validity of the work. Various results obtained are elucidated below-

Figure1 represents the fuel consumption Vs velocity before and after using the neural networks. The black points show the fuel consumption at different velocities. The minimum value of fuel consumption after using the neural networks was found to be 0.8703×10^4 lb/hr which is in agreement with the standard value of fuel consumption specified in the aircraft manual. It clearly affirms that the velocity of the aircraft is significantly contributing towards the fuel consumption.

Figure 2 illustrates the fuel consumption of selected aircraft at different altitudes at which it flies. It is clear from the graph that at start i.e. from 0–10,000 feet of height, the fuel consumption of the aircraft is increasing but between 10,000–30,000 feet of height, the fuel consumption is less by the aircraft. After 30,000, consumption of the fuel increases at rapid rate.

Fuel consumption at different values of the Mach number has been shown in Figure 3 at 400 random data points. As clear from the graph, increasing Mach number has negative effect on fuel consumption of aircraft. Increasing value of the Mach number decreases the fuel consumption of the aircraft.

It is clear from Figure 4 that as the value of thrust goes on increasing; the consumption of the fuel for the aircraft also goes on increasing. The minimum consumption of fuel is at 0.4892×10^5 lb/ft^2 thrust and maximum amount of fuel is consumed for this aircraft is at 3.411×10^5 lb/ft^2 thrust.

4.2 Conclusions and Findings

In the present study, the model for the fuel consumption optimization is successfully developed. The energy balance concept in combination with neural network is successfully employed for modeling aircraft fuel consumption performance. Efforts are made to make the work exploratory and holistic in nature. Literature synthesis on aviation has identified 96 variables on which the fuel consumption depends. In order to optimize the fuel consumption of aviation product, we believe, 23 variables which come to surface during the information refinement stage, will be sufficient to achieve the objectives of this aimed research. The study also advocates that fuel consumption can be optimized with the help of seven variables identified for the model development, in contrast to 96 variables available in aviation industry.

The optimized values of the various parameters on the successful application of neural network are:

1. The optimized value of the aircraft velocity at which fuel consumption is minimized is obtained to be 319 knots with fuel consumption rate of 8703 lb/hr [Figure 5].

2. The optimized value of altitude is 24100 feet with optimum fuel consumption rate of 9313 lb/hr [Figure 6].

3. The optimized value of Mach number for the specific aircraft is found to be 0.74 with fuel consumption rate of 8072 lb/hr [Figure 7].

4. Also, the optimum thrust produced by the specific aircraft is found to be1.37×10^5 lobes with fuel consumption rate of 9303 lb/hr [Figure 8].

All these results obtained above lies in the range specified by aircraft manual. It strongly shows that the seven parameters are the most influencing parameters which affect the fuel consumption of any aircraft. Any studies regarding the optimization of fuel should consider these variables preferably. Also, results obtained from the neural network aided fuel consumption model show that a neural network with proper training is an efficient mean to calculate fuel consumption of an aircraft.

The research implications must be taken within the context of limitations. First, there is a scope of increase in sample size as small sample size limits the range of tests. Researchers should increase the sample size for better data interpretation. Second, because this study relied on the memory or recall of the respondents, some responses might have been inaccurate or biased. Moreover, in Aviation industry, it is difficult to obtain an accurate data due to classified information.

In the present model, only Technology & Product Design and Operational & Performance parameters have been considered in this study. So, in future one can also consider parameters of alternate fuel, Infrastructure and social political & economic growth. Also, only velocity, altitude, Mach number and thrust have been considered as input parameters in this study. Other parameters of Technology & Product Design and Operational & performance can also be used for the estimation of fuel consumption by aircrafts. Furthermore, instead of Artificial Neural Network, some other optimization techniques like genetic algorithm, simulated annealing etc. can also be used for the calculation of fuel consumption in aircraft and results can also be compared with each other.

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Table 1. List of Parameters

	Technological and Product Design	Operational & Performance	Alternate Fuel and Fuel Properties
1.	Engine Weight	Taxing	Aromatics
2.	By Pass Ratio	Fuel tanking	Fuel procurement
3.	Temperature ratio	Maintenance	Sulphur Mercapton Mass
4.	Pressure ratio	Operating cost	Fuel handling
5.	Nozzle Area	Operational weight	Contaminants
6.	Wing Area	Use of ground power	Additives
7.	Thrust	Number of engine	Water Vapors
8.	Engine Type	Airplane towing	Micro-Spectrometer Rating
9.	Alternative Engine Cycle	Aircraft replacement	Boiling Point
10.	Structural Weight	Refueling segment	Flash Point
11.	Lift/Drag	Cabin dead weight	Density
12.	Air Fuel ratio	Payload weight	Fluidity
13.	Wing Thickness over Chord	Aircraft extra weight	Lubricity
14.	Wing Aspect Ratio	Climb approach	Electrical Conductivity
15.	Aircraft centre of Gravity	Roll speed	Freezing Point
16.	Wing Taper Ratio	Roll Distance to Runway	Smoke Point
17.	Horizontal Tail Area	Climb Rate	Fuel prices
18.	Vertical Tail Area	Flap Setting	Acidity
19.	Aircraft Size	Max. takeoff weight	Energy per unit volume
20.	Wing Location over Fuselag	Engine Power Level	Energy Per Unit mass
21.	Lift Coefficient	Load Factor	Corrosivity
22.	Drag Coefficient	Altitude	Distillation Residue
23.	Wing Chord	Cruise Speed	Distillation Loss
24.	Angle Of Incidence	Mach No.	
25.	Induced Drag	Fuel Ferrying	
26.	Seating Capacity	Aircraft Range	
27.	Aircraft Design Range	Air-To-Air Refueling	
28.	Aircraft Maintenance	Crew Weight	
29.	Weight	Airborne Hour	
30.	Strength	Block Hour	
31.	Corrosion Resistance	Flight Hour	
32.	Fatigue Resistance	Fuel transportation	
33.	Air Cooling	Contingency Fuel	
34.	Electrical Systems	Cost Of Index For Flight Path	
35.		Pilot Techniques	
36.		Descent Approach	
37.		Descent Speed	
38.		Angle Of Descent	
39.		Reduced/Delayed Flap	

Table 2. Classification of Technology and Product Design Variables

Important Variables	Moderate Variables	Unimportant Variables
1,2,7,11,19,26,29	3,4,6,8,9,10,14,21,22,23,25,27	5,12,13,15,16,17,18,20,24,28,30,31,33,32,34

Table 3. Classification of Operational and Performance Variables

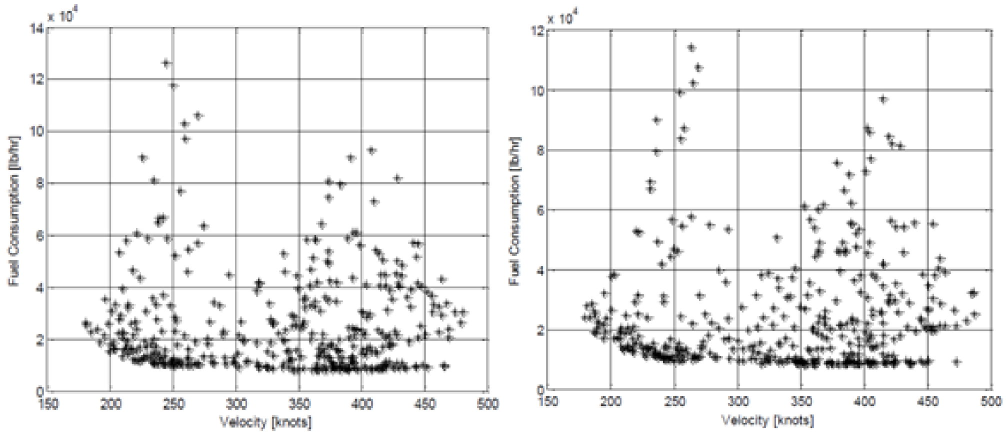
Important Variables	Moderate Variables	Unimportant Variables
2,4,18,24,25,26,27,28,35	3,5,6,7,8,10,11,12,19,20,21,22,23,29,30,31,32,33	1,9,13,14,15,16,17,34,36,37,38,39

Table 4. Classification of Alternate Fuel Variables

Important Variables	Moderate Variables	Unimportant Variables
8,11,12,15,19,20	1,2,3,4,10,13,17,18,21,22,23	5,6,7,8,14,16

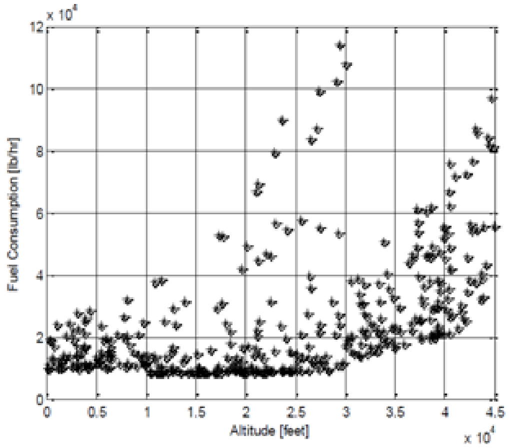
Table 5. Refined set of variable

Factors	Dimensions	Communality	Variance
Technological and product design	1. Engine Weight	0.74	22.5
	2. Thrust	0.77	
	3. Wing Area	0.87	
	4. Lift/Drag	0.62	
	5. Drag Coefficient	0.72	
	6. Lift Coefficient	0.57	
	7.Seating Capacity	0.73	
Operational and Performance	8.Payload Weight	0.74	25.5
	9.No. of engines	0.88	
	10.Altitude	0.80	
	11.Cruise Speed	0.83	
	12.Mach Number	0.82	
	13.Fuel tanking	0.66	
	14.Maximum Takeoff weight	0.78	
	15.Operating Cost	0.55	
	16.Fuel Transportation	0.61	
Alternate fuels And Fuel Properties	17.Density	0.58	18.8
	18.Flash Point	0.61	
	19.Freezing Point	0.57	
	20.Acidity	0.60	
	21.Fuel Prices	0.57	
	22.Fuel Handling	0.68	
	23.Fuel Procurement	0.71	



Before After

Figure 1. Comparison of fuel consumption Vs Velocity before and after using neural networking



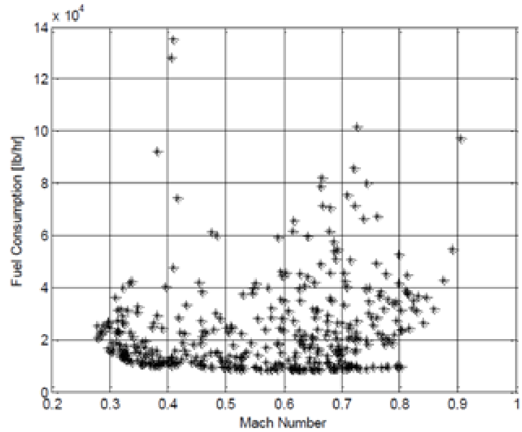
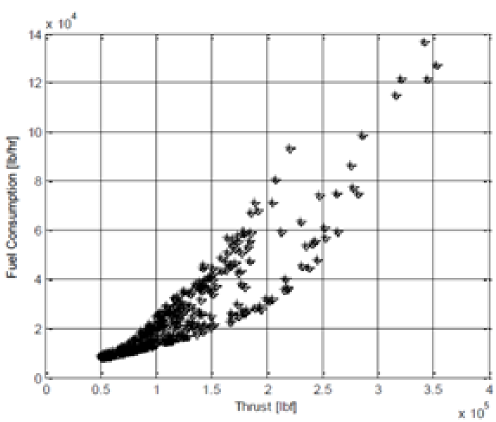


Figure 2. Fuel consumption Vs Altitude

Figure 3. Fuel consumption Vs Mach Number



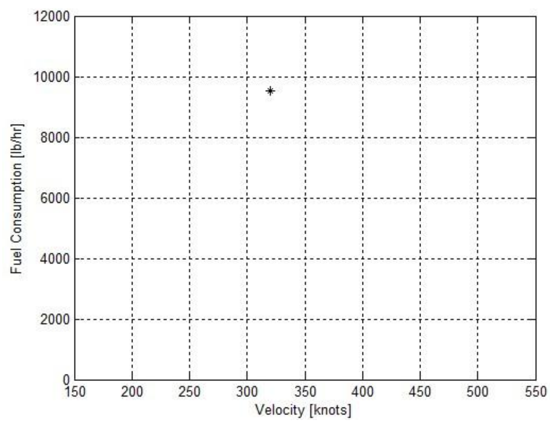


Figure 4. Fuel consumption Vs Thrust

Figure 5. Optimized velocity

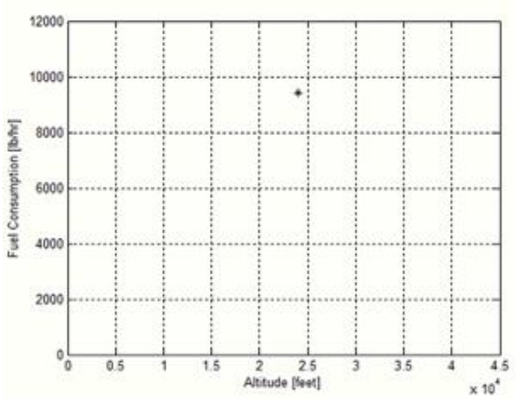


Figure 6. Optimized Altitude

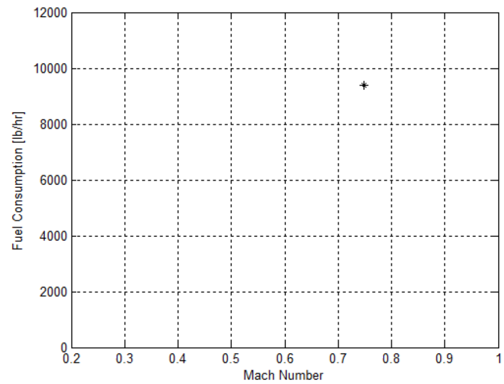


Figure 7. Optimized Mach number

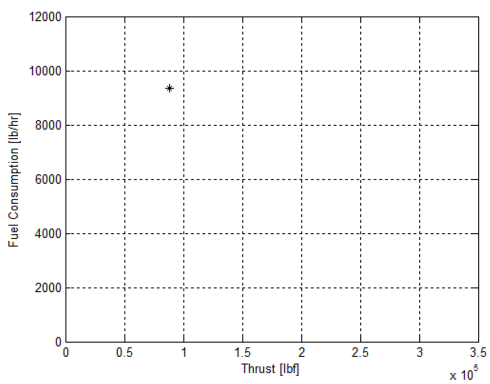


Figure 8. Optimized thrust