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ESTIMATION OF AIRCRAFT FUEL CONSUMPTION FOR A MISSION PROFILE USING NEURAL NETWORKS

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ABSTRACT: Today's air transportation industry is faced with the challenge of maintaining a viable economic position in the face of unparalleled increase in fuel costs in combination with the ever-present threat of fuel supply shortages. The rapid increase of air traffic makes the problem regarding aviation fuel challenging. The aviation fuel prices comprise an important expenditure for the airliners. Hence, aircraft fuel consumption becomes a relevant issue in the planning and analysis of aviation operations. The key elements that have major effect on fuel consumption are aircraft design and operating methods. Another element that makes a major impact on the aviation fuel consumption is the aircraft delay caused by air traffic congestion. It is necessary to minimize aircraft delays in air and on ground and thereby minimize aviation fuel consumption. This paper presents a method for the fuel consumption estimation, which has fuel efficient trajectory as one of the interesting by-products. The method presented in this paper, uses fuel consumption information directly from the flight manual provided by the aircraft manufacturer to predict fuel consumption accurately using neural network approach. Fuel consumption information is collected from the pilot's flight manual and segregated with respect to the different phases of flight like climb, cruise and descent. This segregated fuel consumption data is then presented to the neural network for the estimation of fuel consumption for different phases of flight. Fuel consumption is estimated using the neural networks and compared to the actual performance data given in the flight manual for validation. This neural network based information is then used for the estimation of fuel consumption for a chosen mission profile. The concept of fuel efficient trajectory will be used for the studies on optimized aviation fuel consumption which will lead to an improvement of air transport economics.

1. INTRODUCTION

Today's air transportation industry is faced with the challenge of maintaining a viable economic position facing unparalleled increase in fuel costs in combination with the ever-present threat of supply shortages. The rapid increase of air traffic makes the problem regarding aviation fuel challenging. The key elements that have major effect on fuel consumption are aircraft design, operating methods and the air traffic control environment [1].

It is aimed at using information given directly from the aircraft manufacturer to predict fuel consumption accurately and efficiently. Aircraft's information given in the pilot's flight manual is digitized and presented to the neural network for the modeling of different phases of flight. Results obtained are then compared to the actual performance in the flight manual for justification and used for the computation of fuel consumption for a chosen flight trajectory.

In this paper, the estimation of aircraft fuel consumption for a mission profile using neural network technology is discussed. The procedure to obtain neural network models for different phases of flight like climb, cruise and descent phases is explained along with the usage of these neural network models to estimate the aircraft fuel consumption for a chosen flight trajectory / mission profile. Fuel efficient trajectory is one of the interesting by-products of the fuel consumption estimation model that can be used for the studies on optimized aviation fuel consumption [1-2].

2. METHODOLOGY FOR FUEL ESTIMATION FOR A MISSION PROFILE

Fuel consumption of an aircraft depends on the aerodynamic characteristics, engine type and mission profile which defines speed and altitude schedule of a mission. For the purpose of this study, a medium sized jet aircraft (Fokker-F100) has been selected. The flight manual of this aircraft consists of different charts related to fuel consumption. From these fuel consumption charts, information is collected and segregated with respect to the different segments of flight. Fuel burn evaluation of a particular aircraft for each mission is divided in to six segments: Warm Up and Taxi, Takeoff and Climb-Out, Climb, Cruise, Descent, Approach and Landing. For warm up and taxi, the fuel flow rate is calculated using results from a linear fitting technique. The fuel burn for descent and landing is similar to the takeoff and climb-out phase.

The neural network models for aircraft fuel consumption are obtained for the following phases of flight:

- Take-off and climb out
- Climb
- Cruise
- Descent phase

Once the neural network models corresponding to different phases of flight are obtained, they are ready for use into the program that estimates aircraft fuel consumption for the chosen mission profile. The mission profile chosen for the estimation of fuel consumption is shown in Figure 1.

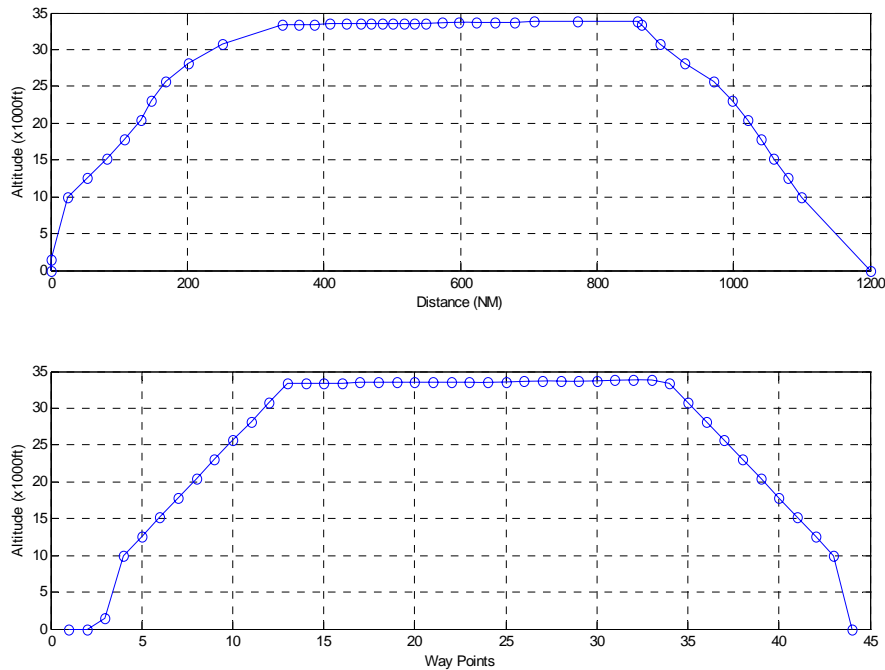


Figure 1: Mission profile along with the illustration of Way Points

This modeling of aircraft fuel consumption for different phases of flight is carried out in Matlab environment. The Neural Network aided Fuel consumption program consists of training programs for the Take-off and climb out, Climb, Cruise and Descent phases of flight.

Main program to calculate fuel consumption for the chosen flight trajectory consists of the following modules.

- Take-off and climb out subroutine
- Climb subroutine
- Cruise subroutine
- Descent subroutine

Once the training of the neural network is completed. The trained data of the four segments are saved as *.mat files (i.e., Climb. mat, Cruise3_8.mat, Descent. mat, Co. mat) separately. These *.mat files are imported into the main program. A sample flight trajectory data shown in Figure 1 becomes input to the main program.

From Figure 1, it can be seen that the number of waypoints is 44. First two way points correspond to the taxiing phase. Take-off and climb-out flight phase consists of only one way point. The number of waypoints included from the beginning of climb segment to cruise is 10. The number of waypoints included from the beginning of cruise segment to descent Segment is 20. The number of waypoints included from the beginning of descent to end of descent is 10. The last way point corresponds to approach and landing.

3 RESULTS

In the main program, number of waypoints for each of the segment, initial take off weight, altitude and taxi time have been initialized. Total fuel burn for taxi and take-off to a certain altitude is calculated. Weight change after taxi and take-off is updated. Climb phase sub-routine is called for each of the 10 waypoints of climb phase. Fuel burn for climb to cruise altitude is calculated and the corresponding weight changes are updated. Cruise phase sub-routine is called for each of the 20 waypoints of cruise phase. The fuel burn for cruise phase is calculated and the corresponding weight changes are updated. Similarly, Descent phase sub-routine is called for each of the 10 waypoints of descent phase. Fuel burn for descent phase is calculated and the corresponding weight changes are updated. Finally, fuel burn for approach and landing phase are calculated. Fuel consumption for all these phases and hence the variation in aircraft weight have been computed and plotted as a function distance and altitude.

Figures 2a and 2b show 3D flight profile (distance, mach and altitude). The input data for Figure 2a is taken from reference [2].

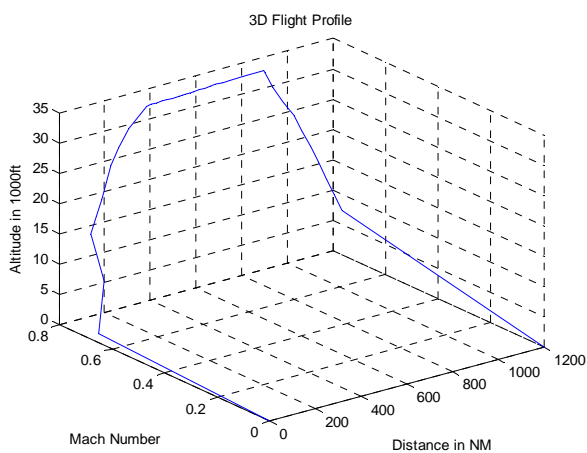


Figure 2a: Three Dimensional Flight Profile
(NAL Implemented)

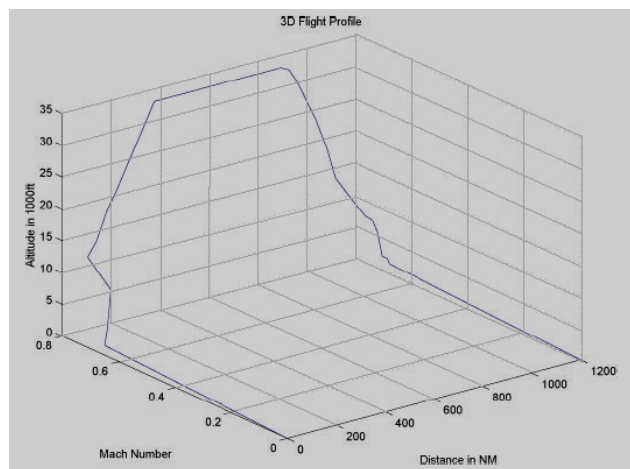


Figure 2b: Three Dimensional Flight Profile
(Reference [2])

Variation of the weight with respect to altitude is shown in Figures 3a and Figure 3b. The input data for Figure 3a is taken from reference [2]. This variation in weight is a result of the fuel consumption in different phases of a mission profile.

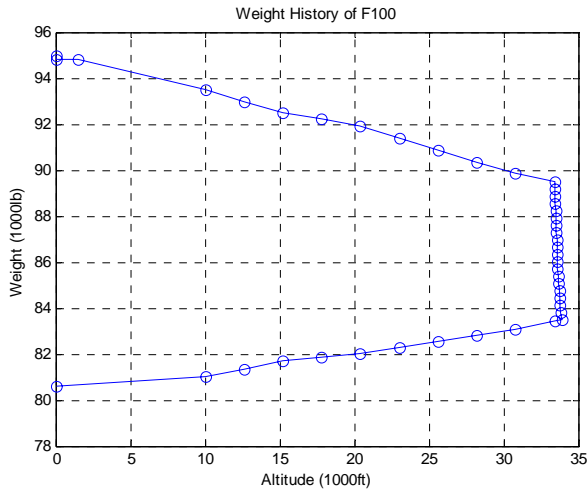


Figure 3a: Weight vs Altitude
(NAL Implemented)

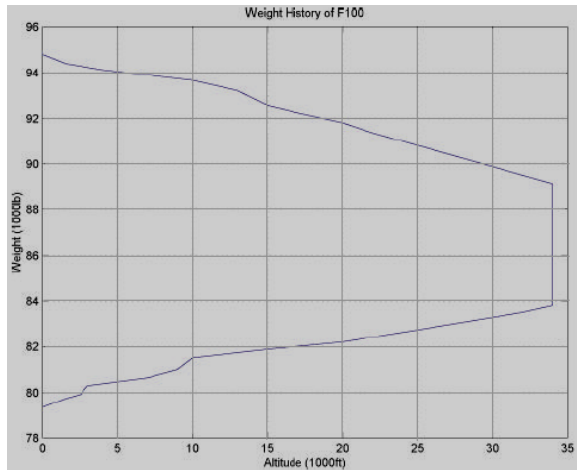


Figure 3b: Weight vs Altitude
(Reference [2])

From Figure 3a, total fuel consumed is found to be 14380 lb at the end of the mission. From Figure 3b, total fuel consumed is found to be around 15500 lb. Figure 3b is obtained based on the digitized data of fuel consumption charts taken from the flight manual. For NAL implementation purpose, input data is obtained by the visual inspection of fuel consumption charts, hence it is inaccurate. Hence, the mismatch of 1120 lb is attributed to the inaccurate input data used for NAL implementation.

A preliminary study has been carried out towards the fuel efficient trajectory [2-3] using the B747-100 data. Figure 4 shows the procedure to arrive at the fuel efficient flight trajectory. From the figure, it can be seen that d_1 and d_4 are Departure and Arrival points respectively. An iterative search is carried out from the arrival point to calculate minimum fuel burns. As a first step, a search is carried out to find out the velocity and altitude combination that gives minimum fuel from d_4 to d_3 . This point ($d_3_minfuel$) is marked with an arrow. The procedure is repeated from $d_3_minfuel$ to d_2 to obtain the minimum fuel point $d_2_minfuel$. The flight profile joining the points, d_4 , $d_3_minfuel$, $d_2_minfuel$ and d_1 will become the flight profile for minimum fuel consumption.

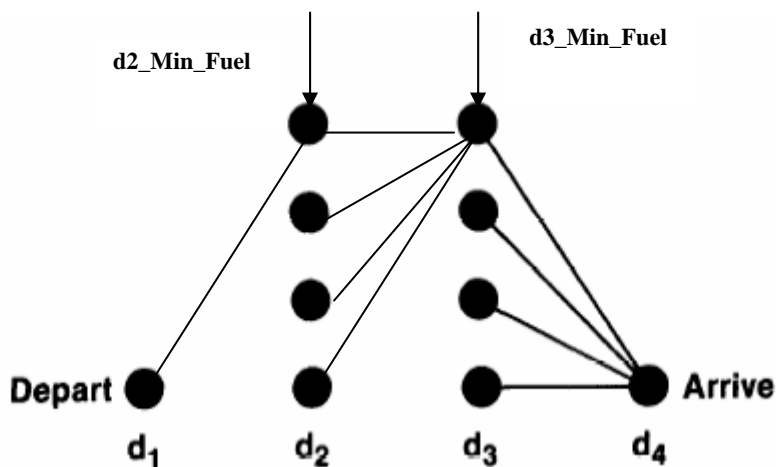


Figure 4 Procedure to obtain Fuel efficient flight trajectory

Based on the procedure given in Figure 4, a fuel efficient trajectory has been obtained for B747-100 aircraft. Results of the study are shown in Fig 5. Fuel efficient trajectory is marked with solid line.

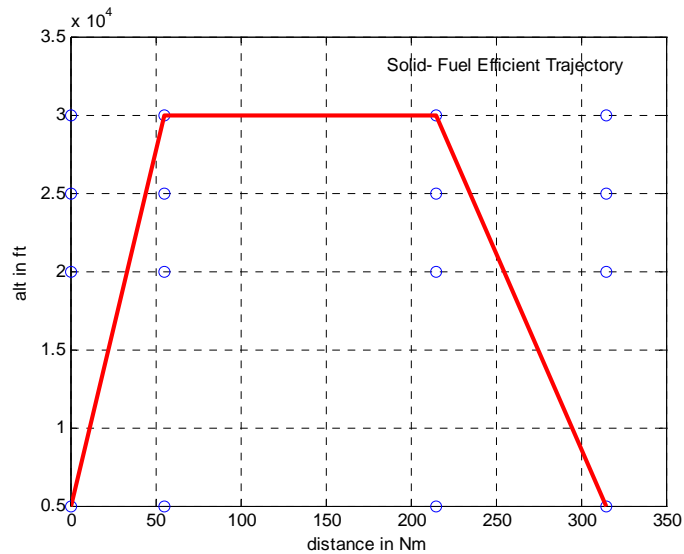


Figure 5 Fuel Efficient Trajectory

4 CONCLUSIONS

The modeling of the aircraft fuel consumption for different phases of flight has been carried out and validated. The match is found to be satisfactory. Fuel efficient flight trajectory is one of the interesting by-products of the fuel consumption estimation model that can be used for the studies on optimized aviation fuel consumption. Towards the optimal aviation fuel consumption, a preliminary study has been carried out to arrive at a fuel efficient flight trajectory from a set of altitude and velocity combination at defined distance way points.

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REFERENCES

1. Bela P. Collins, Estimation of Aircraft Fuel Consumption, The MITRE Corporation, McLean, Virginia, J. Aircraft, VOL.19.No.11, NOVEMBER 1982.
2. Wing Ho Cheung, Neural Network Aided Aviation fuel Consumption Modeling, M S Thesis submitted to Virginia Polytechnic Institute and State University in August 1997
3. B P Collins, A L Haines, A Concept for a Fuel Efficient Flight Planning aid for General Aviation, NASA Contractor Report 3533, March 1982