Water Consumption Using Artificial Neural Network Modelling in Commercial Aircraft

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Abstract

Amidst the current period of increased environmental consciousness and the aviation industry's dedication to sustainability, the delicate balance between water-carrying and fuel usage in commercial aircraft has become a crucial issue due to the rapid development of aviation technology. The primary purpose of this study is to evaluate the water usage of commercial aeroplanes and to optimise the aeroplanes' usage of water. Moreover, the study focuses on analysing the comparison between water consumption estimated using the Artificial Neural Networks (ANN) and historical data collected precisely. By referring to the actual operational data of water tank usage of the Boeing 787-9 fleet in a commercial airline, the flight hours, total passengers, and also actual portable water tank were obtained. The data were gathered over two years, starting from January 2022 until December 2023, for day and night flight time. After all the collected data were completed, the optimisation of the water consumption was conducted and analysed using ANN. The optimised results were then compared using two conventional methods, IATA and Boeing. In conclusion, the ANN method has the least errors compared to IATA and Boeing. The ANN method is suggested as a method to optimise the water tank volume for commercial aircraft.

1. Introduction

Amidst the current period of increased environmental consciousness and the aviation industry's dedication to sustainability, the delicate balance between water-carrying and fuel usage in commercial aircraft has become a crucial issue due to the rapid development of aviation technology. This research paper aims to optimise the water volume in commercial aircraft to minimise fuel consumption and enhance sustainability. The water and waste system in the aircraft industry plays a crucial role in providing water to galleys and lavatories, as well as efficiently handling wastewater. The system utilises meticulous engineering techniques to manage diverse forms of waste that may arise during flights. Water must be evenly distributed throughout the aircraft during the flight to ensure optimal comfort and convenience for passengers. This is accomplished by utilising a water tank located in the compartment situated behind the bulk cargo area. The passenger water system is a crucial part of the overall system. It is responsible for storing, delivering, monitoring, and controlling drinkable water for galley units and lavatory sink basins.

The aircraft model consists of several components, such as the fuselage, wings, tail planes, engines, flaps, and landing gear [1]. These components collaborate to guarantee the secure and effective functioning of the aircraft. An aircraft is described using parameters that encompass not only its physical components but also its geometry,

performance thresholds, engines, and operational circumstances [1]. The parameters encompass vital factors such as weight distribution, fuel capacity, range of operation, maximum Mach number, range of centre of gravity, and passenger seating. They furnish vital data for aircraft design, performance analysis, and operations planning.

The water and waste system in aircraft is essential for maintaining a safe and drinkable water supply and effectively managing waste on board [2]. The water tanks, usually situated beneath the cabin floor, hold potable water for passengers and crew members during the entire flight [3]. The system comprises multiple components, including pressurisation mechanisms, pipes that connect to galleys and restrooms, shut-off valves, waste storage tanks, and drain masts [4]. The force of gravity, along with the pressure difference, transports waste from the toilet bowl to the waste storage tank [4]. The system guarantees the provision of adequate water supply, efficient waste disposal, and effective sanitation measures on board the aircraft.

Optimising the water consumption volume in commercial aircraft water tanks can lead to several advantages. The main goal is to decrease fuel consumption, thereby contributing to sustainability initiatives. The optimisation process involved the duration of the flight and the number of passengers to calculate the precise amount of water required for each flight. The optimisation ensures that excessive water is not needlessly transported, thereby diminishing the overall burden of the aircraft. Therefore, by decreasing the burden and enhancing fuel efficiency, there will be cost savings and a diminished environmental footprint.

Diverse estimation techniques are utilised to enhance various facets of aircraft systems. The International Air Transport Association (IATA) proposes a mathematical equation (referred to as Equation 1) that the number of passengers and crew members, as well as the duration of the flight, to estimate the required amount of water [4]. Boeing employs a formula (refer to Equation 2) that includes passenger load and flight duration to calculate the amount of water needed on the aircraft [5]. These estimation techniques assist airlines in determining the optimal quantity of water to be carried on each flight, taking into account variables such as the number of passengers and the duration of the flight. In this research, the ANN is employed as a statistical and mathematical technique to model and analyse intricate aircraft systems. Its purpose is to optimise performance and enhance efficiency [6] [7].

$$WQ = 0.027 \times (PSG + FLC) \times FT \qquad \text{(Litre)} \qquad\qquad (1)$$

$$WQ = 0072(PSG + FLC) \times FT(0.98)^{FT} \quad \text{(US Gallon)} \qquad (2)$$

Where:
WQ   =   Water Quantity
PSG   =   Passenger
FLC   =   Flight crew
FT   =   Flight time

2. Methodology

The optimisation process utilises an Artificial Neural Network (ANN) for both data analysis and optimisation modelling. The ANN mathematical model produces data prediction and enables precise adjustment of water volumes by developing the actual value with the least error. The study evaluates the efficacy of ANN in established and employed by IATA and Boeing. Statistical comparisons, such as the calculation of percentage errors, are conducted to assess the efficacy of each approach.

The study employed actual operational data from a commercial airline's fleet of Boeing 787-9 and 787-10 aircraft. The data gathered by the company's aircraft maintenance personnel encompassed details such as the aircraft model, scheduled departure time (STD), flight duration, scheduled arrival time (STA), the total count of passengers and crew, and the quantity of potable water (POT) consumed and remaining in the water tank. Table 1 displays a representative sample of the data gathered for the research. The purpose of the data acquisition phase was to collect precise and dependable information for subsequent analysis. The data are divided into two distinct sets: the day flight data and the night flight data.

Table 1 *Real operational data of water tank usage of Boeing 787-9 fleet*

STA	AC Model	FLT Time (hrs)	Total Pax + crew	POT USED (LDG)	Comsumption (Lts per hr)
08-Mar-2023 22:20	787-9	15	197	367.92	24.53
04-Mar-2023 22:20	787-9	15	204	378.14	25.21
26-Dec-2022 22:20	787-9	15	193	398.58	26.57
08-Dec-2022 22:20	787-9	15	197	408.8	27.25
25-Jan-2023 22:20	787-9	15	181	408.8	27.25
28-Jan-2023 22:20	787-9	15	206	408.8	27.25
16-Jan-2023 22:20	787-9	15	224	419.02	27.93
04-Feb-2023 22:20	787-9	15	216	429.24	28.62
13-Feb-2023 22:20	787-9	15	208	429.24	28.62
28-Feb-2023 22:20	787-9	15	207	429.24	28.62
06-Jan-2023 22:20	787-9	15	214	439.46	29.30
11-Feb-2023 22:20	787-9	15	212	439.46	29.30
17-Mar-2023 22:20	787-9	15	204	439.46	29.30
30-Dec-2022 22:20	787-9	15	217	449.68	29.98
01-Feb-2023 22:20	787-9	15	210	449.68	29.98
08-Feb-2023 22:20	787-9	15	211	449.68	29.98

The objective of the study was to create architecture models and algorithms to maximise the efficiency of the water tank capacity in commercial aircraft. The study aims to improve the operational performance of aircraft by analysing the gathered data and implementing optimisation techniques to enhance water usage efficiency. The application of the ANN facilitated the development of complex neural networks and the determination of the ideal tank volume to achieve desired results.

The optimal volume of water required for each flight was calculated using equations derived from the IATA (Equation 1) and Boeing (Equation 2) methods. The calculations took into account the duration of the flight and the number of passengers on board to ensure that the water tank capacity was appropriate for the specific flight needs. The application of these established techniques offered a uniform method for assessing the volume of water in commercial aeroplanes.

The study employed the MATLAB toolbox net fitting, utilising the impact of the hidden layer size on the fitting of neural networks using the Levenberg-Marquardt training algorithm. By methodically modifying this parameter in MATLAB's Neural Network Toolbox, a careful equilibrium between model complexity and generalisation was discovered. The study highlighted the significance of meticulous selection to avoid overfitting. It recognised the computational requirements linked to more extensive hidden layers, demonstrating the intricate relationship between network architecture and performance. This resulted in increased efficiency and functionality of water tanks, thereby enhancing overall performance and operational effectiveness.

The study evaluates the accuracy of water quantity estimation by comparing the percentage error among the ANN, Boeing, and IATA methodologies. The discrepancies in error between the methods were analysed to determine the method that yielded more precise estimations of water quantity. This analysis facilitated the identification of the optimal approach or equation that minimised the error and yielded more accurate estimations of water quantity in commercial aircraft.

3. Result and Discussion

3.1 Mathematical Model

The study examines the optimisation results, compares them with the traditional IATA and Boeing methods, and analyses the statistical data in terms of percentage error. At the beginning of training, 279 and 566 sample data were decided to be trained and suitable hidden layer size as in Tables 2 and 3. The Levenberg-Marquart training algorithm was chosen because they both offer rapid convergence and maintain high accuracy in prediction or classification.

Table 2 *Table size of training, validation, and test samples for day and night flight time*

Approximator	Day	Night
Samples	250	556
Training	195	390
Validation	42	83
Testing	42	83

Table 3 *Approximator hidden layer for day and night flight time was attempted to be attained*

Network	Hidden layer size
1	2 -10 -1
2	2-20-1
3	2-30 -1

The final result of the training, following multiple attempts, reveals that the size of the hidden layer significantly exceeds initial expectations for both the day and night indices. The ANN is superior to historical methods in terms of minimising errors in both flight duration and timing. Out of the 20 hidden layers, the best model for the neural network was selected based on its ability to generate low Mean Squared Error (*MSE*) and Mean Absolute Error (*MAE*) values, as indicated in Table 4 and Table 5. Additionally, the scatter plot of the final regression and *MSE* can be observed in Figure 1 and Figure 2.
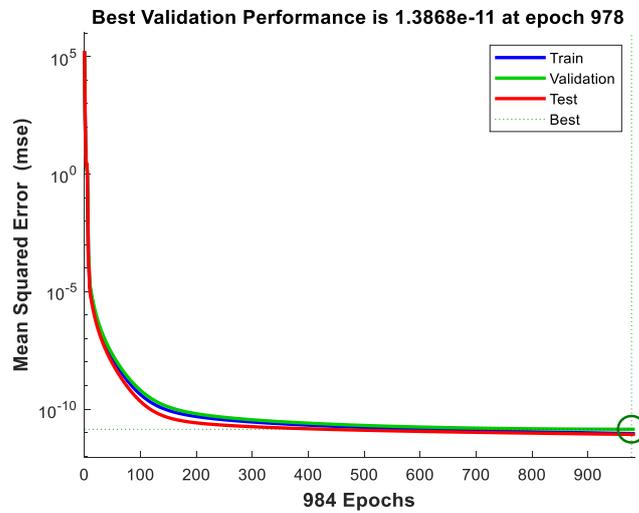

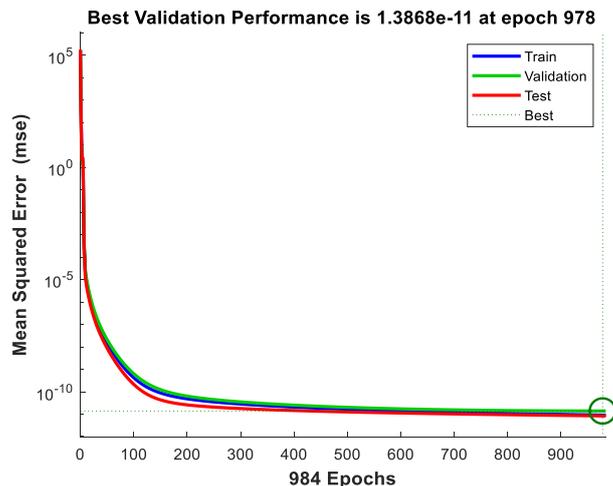**Fig. 1** *MSE for 20 hidden layers (day flight time)*

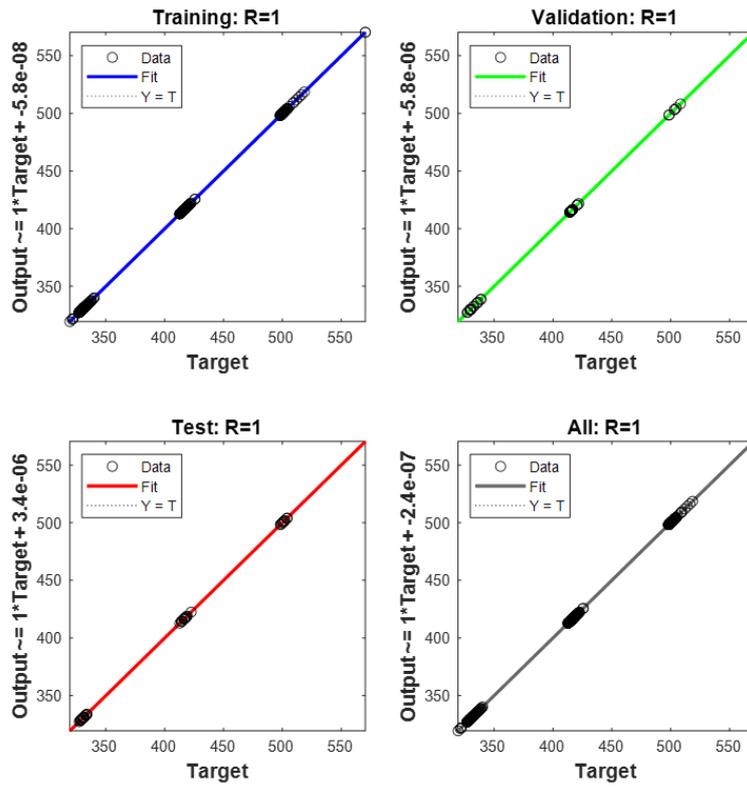**Fig. 2** *MSE for 20 hidden layers (night flight time)*

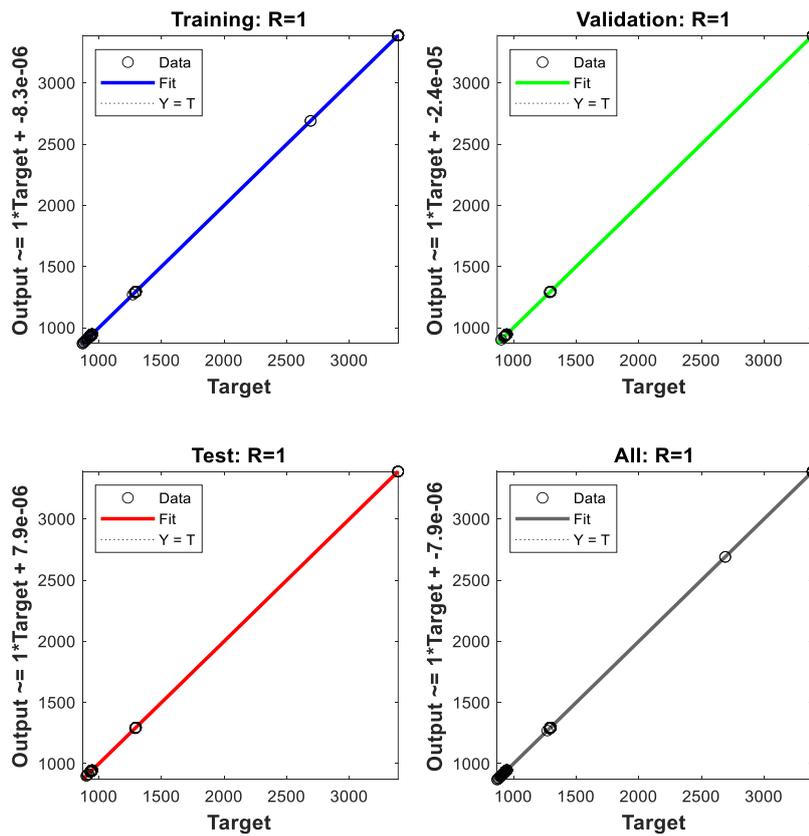**Fig. 3** *Final regression plot for 20 hidden layers (day flight time)*

Fig. 4 *Final regression plot for 20 hidden layers (night flight time)*

Table 4 *Approximator network/hidden layer size for day flight was attempted to be attained*

Attempt	Network size	MSE	Average Absolute Error(%)	Maximum Absolute Error	The number of numbers reaching EAbs 10%
1	2 -10 -1-1	$1.3413e^{-4}$	0.0321	0.0732	0
2	2 -20-1-1	$9.71e^{-12}$	$2.20e^{-04}$	$1.44e^{-05}$	0
3	2 -30 -1-1	$3.562e^{-10}$	0.000282	$8.489e^{-05}$	0

Table 5 *Approximator network/hidden layer size for night flight was attempted to be attained*

Attempt	Network size	MSE	Average Absolute Error(%)	Maximum Absolute Error	The number of numbers reaching EAbs 10%
1	2 -10 -1-1	$1.42e^{-6}$	0.082	0.01007	0
2	2 -20-1-1	$7.02e^{-8}$	0.017	0.0019	0
3	2 -30 -1-1	$7.9e^{-5}$	0.68	0.0223	0

At last, a careful and thorough method of developing models, combined with a strong emphasis on attaining a high level of accuracy during the validation process, has led to a demonstrated training effectiveness that surpasses over 95%. Table 4 and Table 5 highlight the dominance of the model with 20 hidden layers, confirming its ability to predict water consumption under different environmental circumstances accurately.
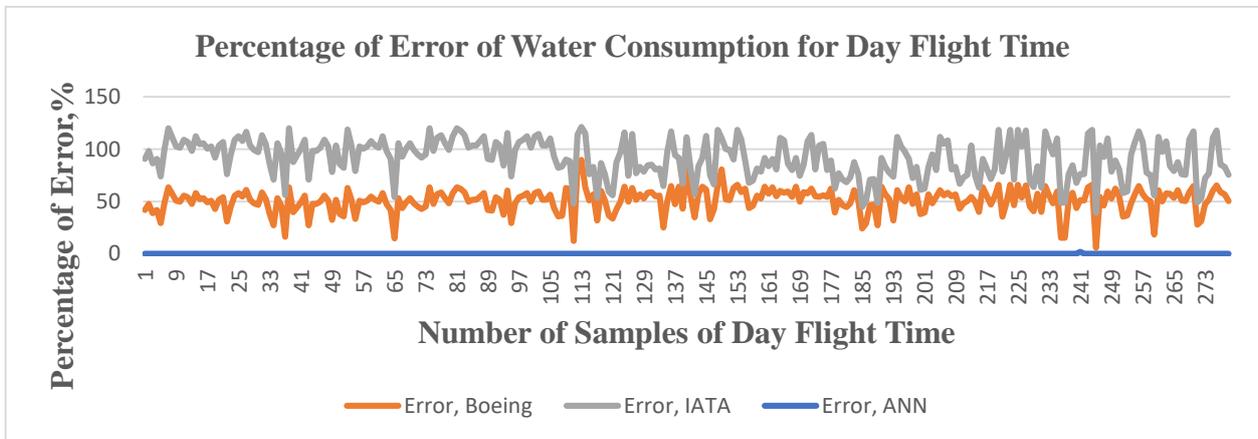
3.2 Comparison ANN, IATA, and Boeing

Fig. 5 *Percentage error graph of water consumption during day flight*
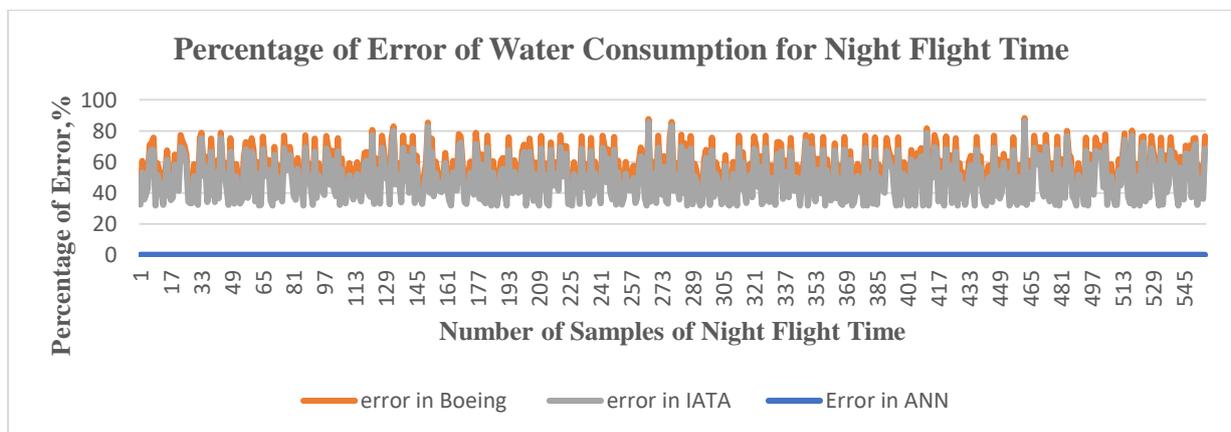

Fig. 6 *Percentage error graph of water consumption during day flight*

By comparing the ANN method with the IATA and Boeing methods, as shown in Figure 5 and Figure 6 for both day and night flights, it becomes apparent that the ANN approach consistently surpasses the other two methods in terms of accuracy and reliability. The percentage of percentage error consistently supports the ANN method, which demonstrates lower central tendency, reduced variability, and a more balanced error distribution.

4. Conclusion

The study aimed to enhance the capacity of water tanks in commercial aircraft during flight time to minimise the weight of the aircraft, attain fuel efficiency, and support environmental conservation. The efficiency of three methods, specifically ANN, IATA, and Boeing, was compared to ascertain their effectiveness in attaining the desired results. The findings conclusively demonstrate the superiority of the ANN method in optimising water volume. The ANN method demonstrated the least percentage error, suggesting a more precise determination of the optimal volume. The success of this can be ascribed to its capacity to integrate numerous variables, increasing the hidden layer size and accurately simulating the intricate connections among passenger and crew loads, flight duration, water consumption, and fuel effectiveness. The ANN method, which trained the high complexity as the human brain works, takes a comprehensive approach and surpasses the IATA and Boeing methods in accurately depicting complex relationships and achieving superior optimisation outcomes.

The effectiveness of the ANN method in optimising water volume has significant implications for the aviation industry. The implementation of the ANN method allows for significant fuel savings by optimising the water volume, thereby reducing the aircraft load [7]. The cost savings derived from these measures provide airlines with economic advantages while also promoting environmental sustainability through the reduction of greenhouse gas emissions. The ANN method's exceptional ability to optimise water volume highlights its effectiveness in achieving fuel efficiency and sustainability in commercial aviation. This paves the way for more efficient and environmentally conscious air travel, contributing to a greener and more sustainable future.

Acknowledgement

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Muhammad Aieman Muhamed Suhan, Mohammad Fahmi Abdul Ghafir; **data collection:** Muhammad Aieman Muhamed Suhan; **analysis and interpretation of results:** Muhammad Aieman Muhamed Suhan; **draft manuscript preparation:** Muhammad Aieman Muhamed Suhan, Mohammad Fahmi Abdul Ghafir. All authors reviewed the results and approved the final version of the manuscript.*

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