PROGRESS IN AEROSPACE AND AVIATION TECHNOLOGY
e-ISSN: 2821-2924

PAAT

Vol. 4 No. 1 (2024) 1-7
https://publisher.uthm.edu.my/ojs/index.php/paat

Optimisation of Water Volume Consumption in Commercial Aircraft

Muhammad Naqiuddin Bin Samsudin[1], Abdul Ghafir M.F.[1]*

[1] *Department of Aeronautical Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia*

*Corresponding Author: fahmi@uthm.edu.my
DOI: https://doi.org/10.30880/paat.2024.04.01.001

Article Info

Received: 3 August 2023
Accepted: 6 December 2023
Available online: 30 June 2024

Keywords

Water volume optimisation, fuel consumption, sustainability

Abstract

This research paper focuses on optimising water volumes consumed in commercial aircraft water tanks during flying to reduce fuel consumption and promote sustainability. The study employs a methodology that includes real data collection, statistical analysis, and optimisation using the Response Surface Methodology (RSM). The data obtained from Boeing 787-9 and 787-10 fleets used in this study spans from December 2022 to March 2023. The findings and analyses are based on various parameters such as water usage, flight duration, and passenger count. Statistical comparisons between the water usage optimised by RSM and the present estimation model developed by the International Air Transport Association (IATA) and Boeing methods are conducted, highlighting the superior performance of RSM in terms of lower percentage errors and better optimisation. The frequency distributions of percentage errors provide further support for the effectiveness of RSM. This research significantly contributes to our understanding of optimising aircraft water usage for improved fuel efficiency and sustainability. The findings have important implications for the aviation industry and environmental preservation. By reducing fuel consumption through optimised water volumes, airlines can enhance operational efficiency while minimising environmental impact.

1. Introduction

This research paper focuses on optimising the water volume in commercial aircraft to reduce fuel consumption and promote sustainability. The water and waste system within the aircraft industry is critical in supplying water to galleys and lavatories while effectively managing wastewater. The system employs thoughtful engineering methods to handle various types of waste that may occur during flights. Water must be distributed throughout the aircraft during the flight to ensure passengers' comfort and convenience. This is achieved through a water tank in the compartment aft of the bulk cargo area. The passenger water system, responsible for storing, delivering, monitoring, and controlling drinkable water for galley units and lavatory sink basins, is an integral component of the overall system.

The aircraft model comprises various components, including the fuselage, wings, tail planes, engines, flaps, and landing gear [1]. These components work together to ensure the safe and efficient operation of the aircraft. In addition to the physical components, parameters related to geometry, performance thresholds, engines, and operational circumstances are used to describe an aircraft [1]. These parameters include crucial weights, fuel capacity, design range, maximum operating Mach number, the center of gravity range, and passenger seating. They provide essential information for aircraft design, performance analysis, and operational planning.

The water and waste system in aircraft plays a crucial role in maintaining a potable water supply and managing waste on board [2]. Water tanks, typically located beneath the cabin floor, store drinkable water for passengers and crew members throughout the flight [3]. The system includes various components such as pressurisation mechanisms, pipes connecting to galleys and restrooms, shut-off valves, waste storage tanks, and drain masts [4]. Gravity and differential pressure move waste from the toilet bowl to the waste storage tank [4]. The system ensures proper water supply, waste disposal, and sanitation on board the aircraft [5].

By optimising the volume of water consumed within the commercial aircraft water tank, several benefits can be achieved. The primary objective is reducing fuel consumption, which contributes to sustainability efforts [6]. The optimisation process considers flight duration and passenger count to determine the appropriate water volume needed for each flight. This ensures that excess water is not carried unnecessarily, reducing the overall load of the aircraft. Hence reducing the load and improving fuel efficiency will result in cost savings and reduced environmental impact.

Various estimation methods are employed to optimise different aspects of aircraft systems. The International Air Transport Association (IATA) suggests a formula (see Equation 1) based on the passenger and crew numbers and flight duration to estimate the water quantity needed [4]. Boeing utilises a formula (see Equation 2) based on passenger load and flight time to estimate the quantity of potable water required on board [5]. These estimation methods help airlines determine the appropriate amount of water to carry on each flight, considering factors such as passenger count and flight duration. Additionally, the Response Surface Method (RSM) is used in this research as a statistical and mathematical technique to model and analyse complex aircraft systems, allowing for performance optimisation and efficiency improvements [7, 8].

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

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

where:

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

2. Methodology

To carry out the optimisation, Response Surface Methodology (RSM) is employed for data analysis and optimisation modelling. The RSM mathematical model generates data and allows for fine-tuning water volumes. The research compares the performance of RSM with existing methods used by the IATA and Boeing. Statistical comparisons, including percentage errors, are made to evaluate the effectiveness of each method.

The study utilised actual operational data from a commercial airline's Boeing 787-9 and 787-10 fleet. The data collected by the company's aircraft maintenance personnel included information such as aircraft model, standard time of departure (STD), flight duration, standard time of arrival (STA), the total number of passengers and crew, and the amount of portable water (POT) used and remaining in the water tank. Table 1 shows a sample of the data collected for the research. The data acquisition phase aimed to gather accurate and reliable information for further analysis. These data are clustered into two sets: the day flight data and the night flight data.

Progress in Aerospace and Aviation Technology Vol. 4 No. 1 (2024) p. 1-7

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

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

The study aimed to develop new models and algorithms to optimise the aircraft's water volume. By analysing the collected data and applying optimisation techniques, the study aimed to enhance the efficiency of water usage in aircraft, leading to improved operational performance. The utilisation of the RSM provided a framework for designing experiments, building mathematical models, and identifying the optimal tank volume for desired outcomes.

Equations derived from the IATA (see Equation 1) and Boeing (see Equation 2) methods were used to calculate the optimal volume of water needed for each flight. These calculations considered flight duration and the number of passengers on board, ensuring that the water tank capacity matched the specific flight requirements. The utilisation of these established methods provided a standardised approach to estimating water quantity in commercial aircraft.

The Design Expert software used in this study by utilising the RSM was then used to develop two new equations for optimising the volume of water tanks for day and night flights. The software facilitated experiment design, mathematical modelling, and identification of the optimal tank volume to achieve desired outcomes. Using RSM enhanced the efficiency and functionality of water tanks, contributing to improved performance and operational effectiveness.

The study compares the percentage error between the RSM, Boeing and IATA methodologies to assess the accuracy of water quantity estimation. The differences in error between the methods were analysed to identify the method that provided more accurate estimations of water quantity using Equation 3. This analysis helped determine the approach or equation that minimised the error and provided more precise estimates of water quantity in commercial aircraft.

$$\mathrm{ERR\%} = \frac{|\mathrm{OPTVal} - \mathrm{ACTVal}|}{\mathrm{ACTVal}} \times 100 \tag{3}$$

where:

ERR = Percentage error

OPTVal = Optimised water tank consumption using RSM, IATA or Boeing

ACTVal = Actual water tank consumption obtained from the operational data

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 and frequency distributions. Fig.1 depicts the 3D surface graph generated by the RSM for the day flight. The figure illustrates the intricate relationship between flight parameters and the Portable Water Tank (POT) volume. The graph allows for identifying areas with larger water volume values, helping to optimise design variable configurations. Contour lines on the graph reveal trends and patterns in the optimisation landscape. In addition, Equation 4 and 5 provides the new equations generated by the Design Expert for day and night flights, respectively.

$$\mathrm{WQ} = -1876.747 + 428.62\ \mathrm{FT} - 0.2117\ \mathrm{PSG} - 18.167\ FT^2 \quad (4)$$

$$\mathrm{WQ} = -1877.457 + 363.86\ \mathrm{FT} + 1.0274\ \mathrm{PSG} - 14.946\ FT^2 - 0.00199\mathrm{PSG}^2) \quad (5)$$

3.2 Comparison RSM, IATA and Boeing

The statistical analysis, including mean, median, mode, standard deviation, and sample variance, consistently favours the RSM method, which exhibits lower central tendency, less variability, and more balanced error distribution. The frequency distributions of percentage errors also reveal that the RSM method yields a lower frequency of more significant errors than the IATA and Boeing methods. These findings support the conclusion that the RSM method provides more accurate and trustworthy optimisation results for water volume in commercial aircraft design.

By analysing the frequency distributions of percentage errors, as shown in Fig. 2 to Fig. 4, it becomes apparent that the RSM method yields lower errors and a more balanced distribution than the IATA and Boeing methods. These findings underscore the accuracy and reliability of the RSM model in optimising water volume onboard. The figures show that the new equations generated by RSM produce relatively better predictions than IATA and Being, with approximately 90% of the calculated data from the two equations having a prediction error of 15%. Overall, the RSM mathematical model proves to be a valuable tool for optimising the water volume in commercial aircraft design. Its ability to consider multiple variables simultaneously and provide accurate estimations makes it superior to the traditional IATA and Boeing methods. The insights gained from the analysis of the RSM model, including the optimisation outcomes, frequency distributions, and comparison statistics, highlight the benefits of using this approach in the aviation industry. By implementing the RSM method, airlines and maintenance engineers can make informed decisions regarding water tank capacity, leading to more efficient and reliable operations.

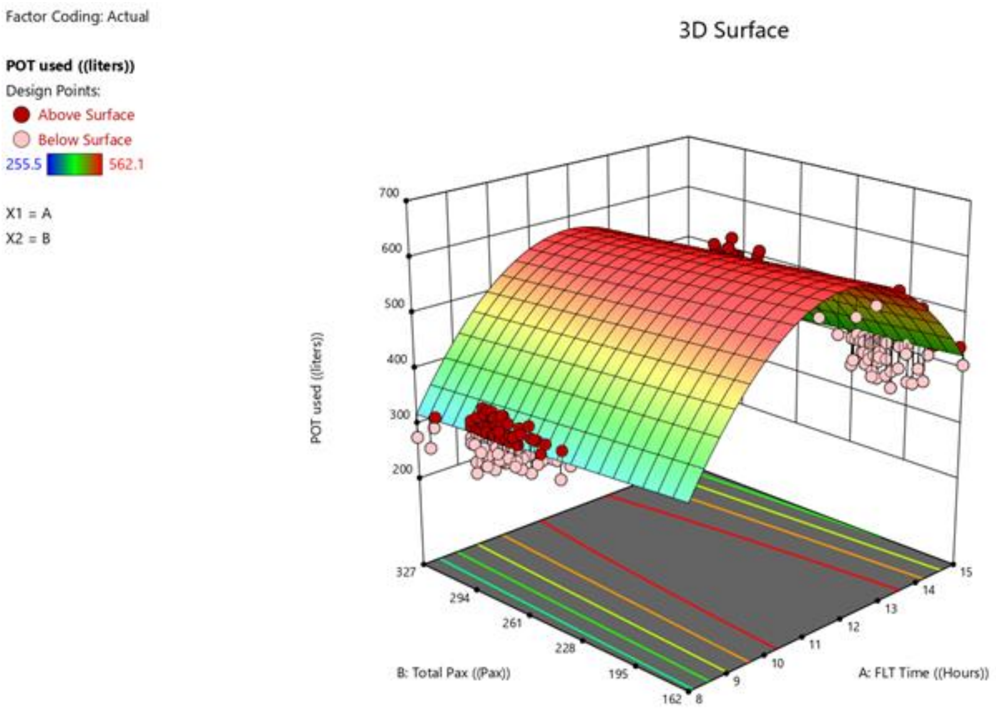

Fig.1 *3D surface graph by Design Expert (day)*

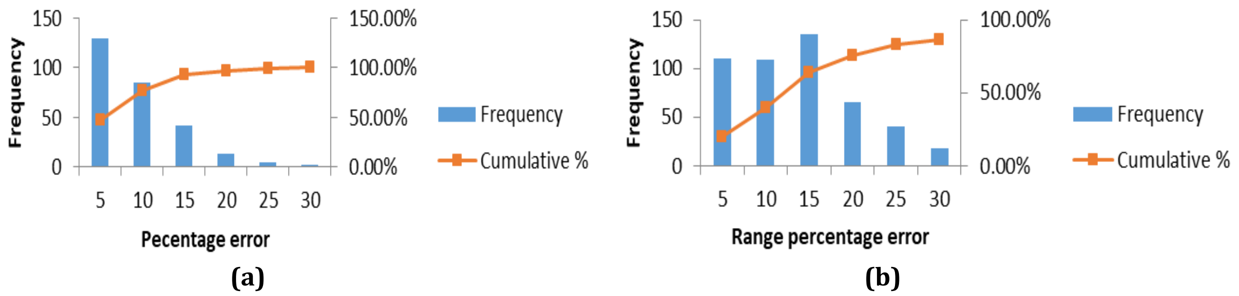

Fig. 2 *The frequency distributions of percentage errors produced by RSM (a) Day flight; (b) Night flight*

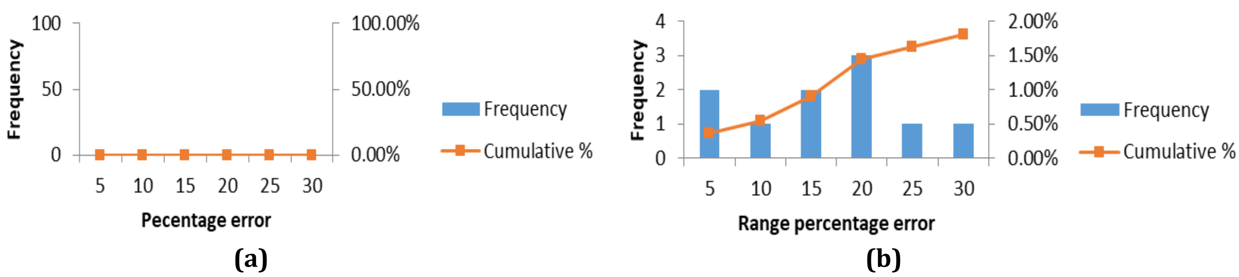

Fig. 3 *The frequency distributions of percentage errors produced by IATA (a) Day flight; (b) Night flight*

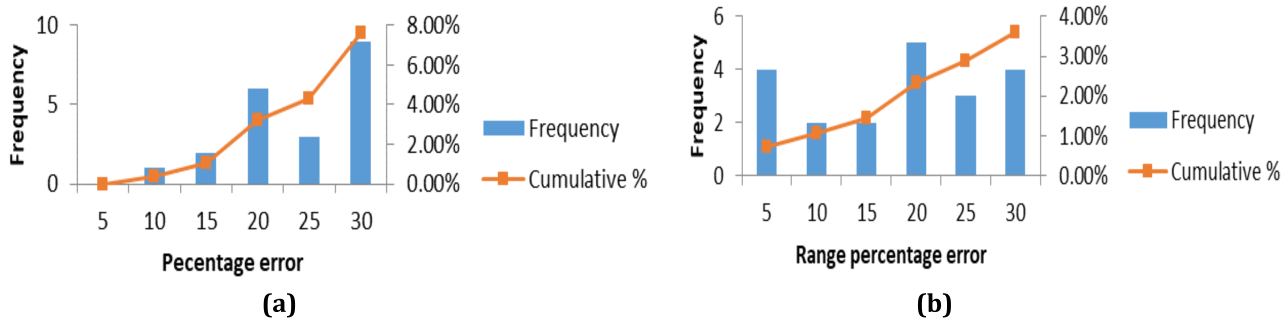

Fig. 4 *The frequency distributions of percentage errors produced by Boeing (a) Day flight; (b) Night flight*

4. Conclusion

In conclusion, the study focused on optimising the volume of water tanks in commercial aircraft during flight duration to reduce aircraft load, achieve fuel savings, and promote sustainability. Three methods, namely RSM, IATA, and Boeing, were compared to determine their efficiency in achieving the desired outcomes. The findings unequivocally establish the superiority of the RSM method in optimising water volume. The RSM method exhibited a lower percentage error, indicating a more accurate determination of the optimal volume. This success can be attributed to its ability to incorporate multiple variables and effectively model the complex relationships among passenger and crew loads, flight time, water usage, and fuel efficiency. Adopting a holistic approach, the RSM method outperforms the IATA and Boeing methods in accurately representing these intricate relationships and delivering superior optimisation results.

The implications of the RSM method's effectiveness in optimising water volume are significant for the aviation industry. Implementation of the RSM method enables substantial fuel savings by reducing aircraft load through optimal water volume. These savings have economic benefits for airlines and contribute to environmental sustainability by reducing greenhouse gas emissions. The study highlights the importance of advanced optimisation techniques, such as RSM, in the aviation industry to enhance fuel efficiency, minimise operational costs, and reduce environmental impact. However, further research and validation are warranted to strengthen these findings and explore potential refinements of the RSM method for even more excellent optimisation benefits. In conclusion, the RSM method's superior performance in optimising water volume underscores its efficacy in achieving fuel savings and sustainability in commercial aviation, paving the way for more efficient and environmentally conscious air travel, and creating a greener, more sustainable future.

Acknowledgement

The authors would like to express their gratitude for the support provided by Universiti Tun Hussein Onn Malaysia (UTHM). The authors also extend sincere appreciation to the Faculty of Mechanical and Manufacturing Engineering, UTHM, for their invaluable assistance and resources. The authors would like to appreciate Associate Professor Ts. Dr. Nur Kamilah Yusuf for valuable advice and guidance.

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 Naqiuddin Samsudin, Mohammad Fahmi Abdul Ghafir; data collection: Muhammad Naqiuddin Samsudin; analysis and interpretation of results: Muhammad Naqiuddin Samsudin; draft manuscript preparation: Muhammad Naqiuddin Samsudin, Mohammad Fahmi Abdul Ghafir. All authors reviewed the results and approved the final version of the manuscript.

References

[1] Filippone, A., (2008) Comprehensive analysis of transport aircraft flight performance, *Prog. Aerosp. Sci.*, vol. 44, no. 3, pp. 192–236. doi: 10.1016/j.paerosci.2007.10.005.

[2] Maaz, M.A., (2022) How Does an Aircraft's Water and Waste System, Available: https://www.hydro.aero/en/newsletter-details/what-you-should-know-about-aircraft-water-tanks.html#:~:text=A water heater is installed, amount of water is collected.

[3] Koocheki, A., Nassiri Mahallati, M., Moradi, R., and Mansoori, H., (2014) Optimizing water, nitrogen and crop density in canola cultivation using response surface methodology and central composite design, *Soil Sci. Plant Nutr*., vol. 60, no. 2, pp. 286–298. doi: 10.1080/00380768.2014.893535.
[4] Sultana, S., (2020) Economic growth of airlines industry: An overview of domestic airlines in Bangladesh," *J. Manag. Res. Anal*., vol. 5, no. 1, pp. 61–68. doi: 10.18231/2394-2770.2018.0012.
[5] G. N. and M. Wagner, (2009) Boeing 787 Dreamliner, no. Mi. 2009.
[6] IATA, (2021) IATA Reference Manual for Audit Programs Edition 11, no. March. 2021.
[7] Douglas C. Montgomery, (2017) Design and Analysis of Experiment, 9th ed. Arizona State University, 2017.
[8] I. Sopyan et al., (2022) Overview of pectin as an excipient and its use in the pharmaceutical preparation formulation, doi: 10.22159/ijap.2022v14i4.45091.