Technologia i Automatyzacja Montażu

Volume 122, Issue 4/2023, Pages 28-37
https://doi.org/10.7862/tiam.2023.4.4

Original Research

A SIMULATION MODEL FOR SMALL AIRCRAFT FUEL SYSTEM DESIGN

MODEL SYMULACYJNY PROJEKTOWANIA UKŁADU PALIWOWEGO MAŁYCH SAMOLOTÓW

Leonardo MAZZITELLI[1], Paulo WATANABE[2], José C. TEIXEIRA[1] José MACHADO[1]

[1] MEtRICs Research Center, University of Minho, 4800-058, Guimarães, Portugal
[2] Propulsion Systems Department, CEiiA, 7005-841, Évora, Portugal

* Corresponding author: a87049@alunos.uminho.pt, tel. +351 930580341

Abstract

An aircraft fuel system is responsible for storing, managing and properly delivering fuel to the engines. Fuel systems models are used to simulate various configurations and analyse how the system responds to different flight conditions and failure scenarios. In this paper, a generic aircraft fuel system model architecture is proposed and modelled using MATLAB and Simulink's Simscape add-on to analyse the pressure and flow rate variations in different locations of the system. The model capabilities are explored with meaningful simulations and analyses focused on the feed and transfer functions, such as the sensitivity analysis of the scavenge jet pump, showing that the position where the jet pump is assembled in the wing can highly impact its performance. Additionally, the wing dihedral is modelled and simulated to prove that a positive dihedral angle benefits the fuel transfer and helps minimize unusable fuel quantities. The results also demonstrate how computational tools such as Simscape Fluids can be integrated with MATLAB and used on the system's modelling, providing a reference for small aircraft fuel system design and an approach for analysing complicated non-linear systems.

Keywords: Aircraft Fuel System, System modelling, Simscape

Streszczenie

Układ paliwowy samolotu odpowiada za przechowywanie, zarządzanie i prawidłowe dostarczanie paliwa do silników. Modele układów paliwowych służą do symulacji różnych konfiguracji i analizy reakcji systemu na różne warunki lotu i scenariusze awarii. W tym artykule zaproponowano ogólną architekturę modelu układu paliwowego samolotu, którą zamodelowano przy użyciu programu MATLAB i dodatku Simulink Simscape w celu analizy zmian ciśnienia i natężenia przepływu w różnych lokalizacjach układu. Możliwości modelu bada się za pomocą znaczących symulacji i analiz skupiających się na funkcjach zasilania i przenoszenia, takich jak analiza czułości przepłukiwania pompy strumieniowej, pokazująca, że położenie pompy strumieniowej zamontowanej w skrzydle może mieć duży wpływ na jej działanie. Dodatkowo modeluje się i symuluje dwuścienny skrzydło, aby wykazać, że dodatni kąt dwuścienny korzystnie wpływa na transfer paliwa i pomaga zminimalizować nieużyteczne ilości paliwa. Wyniki pokazują również, w jaki sposób narzędzia obliczeniowe, takie jak Simscape Fluids, można zintegrować z MATLAB-em i wykorzystać w modelowaniu systemu, zapewniając odniesienie do projektowania układów paliwowych małych samolotów i podejście do analizy skomplikowanych układów nieliniowych

Słowa kluczowe: Układ paliwowy statku powietrznego, modelowanie systemu, Simscape

1. Introduction

An aircraft fuel system is a critical and complex system which is responsible for several functions that ensure the aircraft's reliability, safety, and high performance. Although the fuel system might seem simple, it is a complex connection of fluid mechanical components which interact with each other, making it difficult for one to study it relying on fundamental laws of physics. Moreover, physical prototypes are not the best solution to analyse these systems since they are expensive to build and test. Therefore, for clever engineering design, manufacturing and assembly processes, these systems must be modelled and simulated to support the development process, especially in the early design phase.

While the aircraft fuel system encompasses various functions, including storage, engine feed, transfer, refuelling/defueling, and jettison, this paper concentrates on the storage and transfer functions. The transfer function is of great importance for modern fuel systems since it provides a means of actively controlling the centre of gravity (CG) position, reducing the amount of bending moment felt by the wings and ensuring that the main tanks never run out of fuel. One important aspect of many fuel transfer systems is that the collector tank is kept full during all flight phases, so the feed pumps never run out of fuel, even in negative g conditions. The transfer function also allows fuel to be transferred by gravity to inner tanks by the flapper valves, also called baffle check valves, and they are responsible for letting the fuel flow in between tanks when the fuel is being consumed or replenished in the aircraft tanks.

Fuel system models have been extensively studied and applied to various problems. Many fuel system models are developed to be used as an auxiliary tool for aircraft systems design. (do Nascimento Pinheiro & Góes, 2017) describe a study that develops a simulation model to study the system's performance during pressure refuelling and single-engine operation, emphasising the importance of the system's sub-functions integration. (Li et al., 2023) studied the inerting system performance, the variation of the oxygen concentration and airflow into the tank during a complete flight envelope, proposing a method for fire prevention and explosion suppression. (Jimenez et al., 2007) developed a simulation environment in MATLAB-Simulink to study the logic of fuel management under different failure circumstances. The simulation environment provides a platform for developing an onboard fuel system management program with predefined actions for each studied failure mode. (Ellström & Gavel, 2013; Hutchison et al., 2014; Tu et al., 2022) developed methods to predict and assess pressure surges in aircraft fuel systems, discussing critical design and safety considerations. (Yue et al., 2010) analysed the heat management in a fighter aircraft fuel system through 1D thermal fluid simulations. (Feng et al., 2022) study the system's failure modes from a component-level perspective and correlate with fluid mechanical behaviour, bringing insights into the system's health management and maintenance strategies. (Liu et al., 2022) studies the ventilation system performance during the pressure refuelling process, suggesting design solutions. (Tiwari & Harrison, 2019) proposes a method for solving flow equations for complex 3D tank geometry using a 1D flow solution.

Most of the studies assume a predefined parametrisation of the model components, so the geometrical and spatial configuration of the system components is considered fixed and, therefore, is not analysed. The aircraft fuel system is highly influenced by the wing geometry and the location of its components, and after a careful analysis of the works published in this domain, it is possible to identify some gaps, namely the absence of the wing dihedral effect on fuel transfer and the jet pump's optimisation, considering its position within the system.

This paper is intended to propose a simulation model of a fuel system that is used to assess aircraft design parameters such as the wing dihedral angle and the jet pump's location and geometry and how these variables affect the fuel system functions, namely the fuel transfer and storage. This research aims to prove the influence of the assessed parameters and expose a process of modelling a non-linear system which can later be adapted to various engineering systems. In order to achieve these goals, this document is organised as follows: Chapter 2 proposes a model for the studied system and describes the implementation of the jet pump and wing dihedral angle in the model. Chapter 3 presents some of the simulation results generated post-simulations for a typical flight envelope, highlighting the benefits of each parameter in the overall system's performance by analysing the flow rate and pressure and fuel tank level variation over time. Chapter 4 draws conclusions on the modelling approach taken, the results obtained and how this can benefit the fuel system design process.

2. System Modeling

System modelling is often required when dealing with complex systems with high non-linearity. Examples of non-linear systems that are studied through modelling and simulation are road traffic management systems (Valente et al., 2022), manufacturing processes and assembly stations (Brzozowska et al., 2023), air traffic control systems (Glover & Lygeros, 2004), wireless networks for automated factories (Ming et al., 2021), and many other engineering systems. All of these systems can be classified as non-linear, as even small changes in the input parameters can result in significant changes in the output. The fuel system on an aircraft includes a complex network of pipes, valves, elbows, joints, pumps, and other flow devices. All of these components work together in a highly interdependent manner, resulting in intricate interactions that make the system complex and non-linear.

The model for this study was built based on the architecture presented in Fig. 1. The Simscape tool available in the Simulink environment was used to build the model which appears in Figure 2. Simscape provides a library of pre-modelled fluid system components, such as pumps, valves, lines, etc. The approach for the model development initially considered a basic feed system and gradually added more complexity while continuously checking if the simulation produced the expected values of flow rate and pressure at the engine inlet, according to the engine chosen for the aircraft. Regarding the system's parametrisation, most of the values were left at their default value, not affecting much of the final result. Components like the centrifugal and pipe pumps had their parametrisation based on datasheets from aeroplane fuel system's components suppliers.

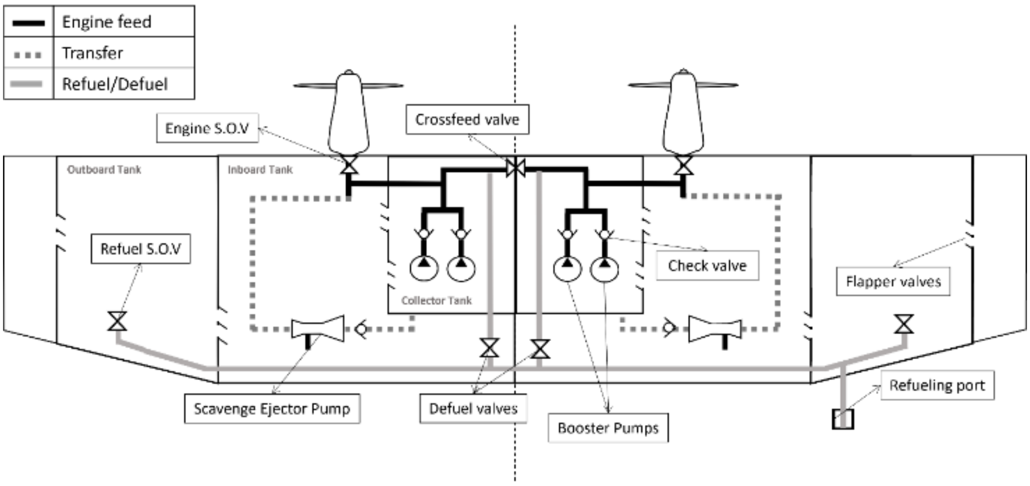

Fig. 1. Fuel system reference architecture.

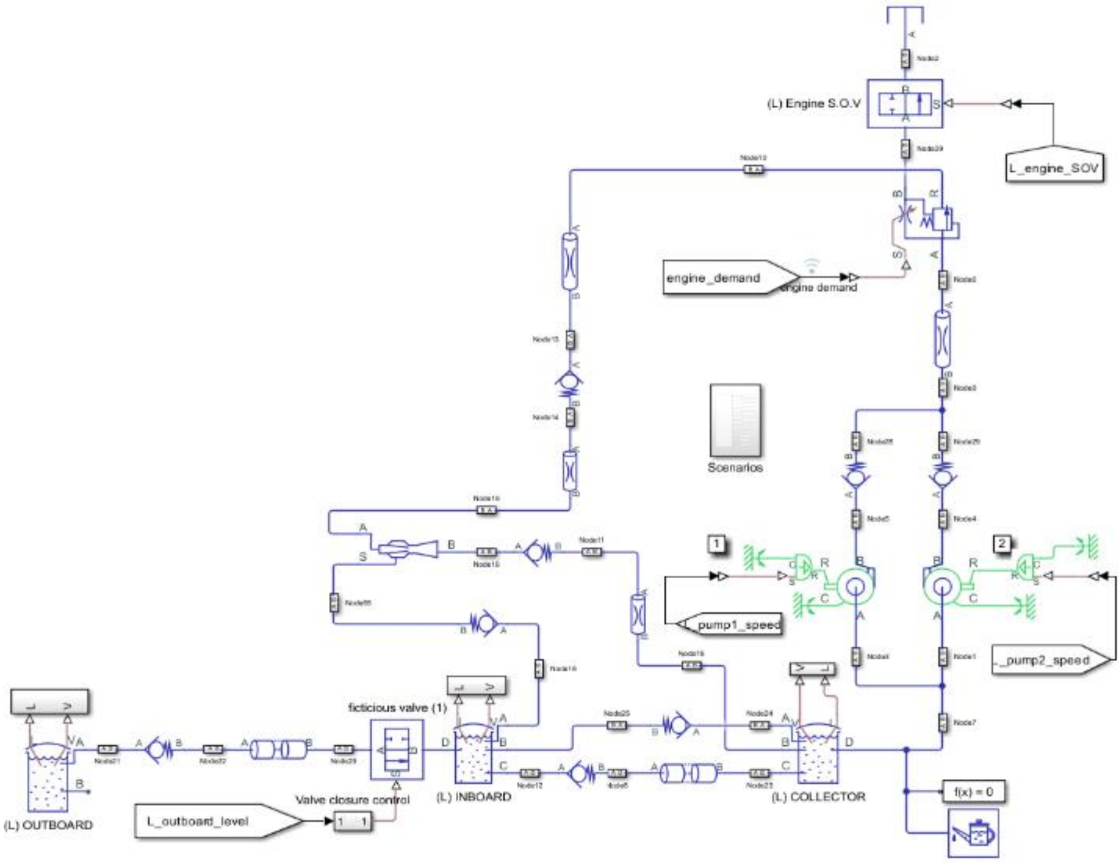

Fig. 2. Fuel system model in Simulink Simscape environment

The proposed architecture also aimed to eliminate some of the complexities of unnecessary functions for this study, such as jettison, refuel/defuel and venting. Given the simplified system functionality, this initial architecture considered some premises based on small civil aircraft types, such as the absence of centre tanks, Auxiliary power unit (APU) and centrifugal transfer pumps. In contrast, the system should include an outboard, inboard, and collector tank in each wing, having a scavenge jet pump at the inboard tank powered by the additional flow coming from the feed lines, transferring fuel from the inboard tank to the collector tank. The presented studies analyse mainly the fuel flow rate and pressure variations, so the components for the modelling were extracted from the Isothermal Liquid library from Simscape, neglecting the temperature variations. Since both sides of the system include the same components, the system can be considered symmetrical for normal engine feed operation, so only the left side was used to perform the simulations, as illustrated in the model from Fig. 2., resulting in reduced computational effort.

The figure shows the model of the previously presented architecture; however, the crossfeed valve component is not modelled since the system is only simulated during normal twin-engine operation. The storage part of the system consists of an outboard, inboard, and collector tanks, each one with the same height and flapper valve location. The feed function consists of a feed pipe, two booster pumps positioned in parallel for redundancy purposes, check valves, a pressure-compensated flow control valve, and an engine shutoff valve. The transfer function is also included by adding the check valves and pipe components between tanks, allowing for gravity transfer and a jet pump drawing fuel from the inboard tank and transferring it to the collector tank in every phase of the flight.

2.1. Dihedral angle

The dihedral angle is the upward angle of the wing measured from the lateral axis, shown in Fig.. It is an important parameter for the aircraft's stability since it helps bring it to its original position after rolling moment perturbations. stability since it helps bring the aircraft to its Also, in some cases, it helps give the engines a better ground clearance. In the context of a fuel system, the dihedral angle can increase the pressure difference between tanks, increasing the flow rate towards the wing root and minimising unusable fuel quantities for the same flapper valve heights.

In Simscape Fluids, the modelling of the dihedral angle Γ is not straightforward since there is no way to introduce an angle of inclination for the defined tank geometry. In this case, the modelling approach considered the neighbouring tanks' centre distance L_{tank} and height difference e, as shown in Fig. 4.

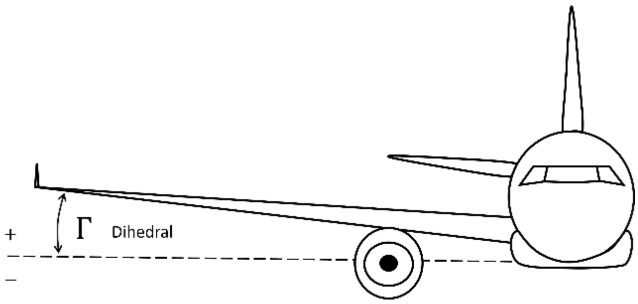

Fig. 3. Dihedral angle schematic

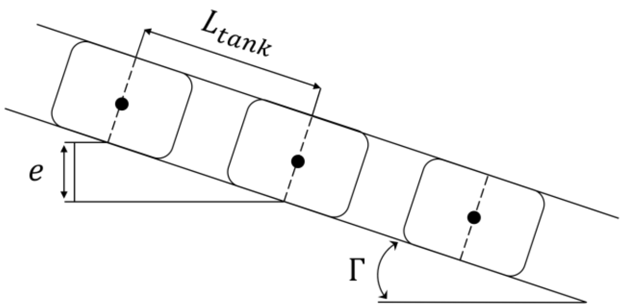

Fig. 4. Pipe elevation proposed model

To model this effect in Simscape, an elevated pipe connection was used, as demonstrated in the schematic from Fig. 5.

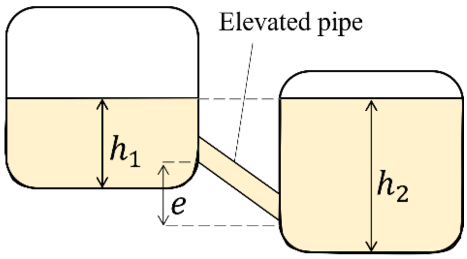

Fig. 5. Elevated pipe model approach

From Fig. 4., the equation for the pipe elevation can be expressed as:

$$e = -\sin(\Gamma) \times L_{tank} \tag{1}$$

The minus sign appears because the elevation is negative from port A to B, assumed to be the normal direction of the flow. Equation 1 was included in a MATLAB script used for the system's initialisation function, so the pipes' elevation is computed at the beginning of each simulation.

The transfer system also accounts for gravity transfer, which is done through the flapper valves. These valves represent connections between the tanks that allow flow only in the wing root direction to avoid excessive centre of gravity (CG) variation. The flapper valves are modelled as check valves with a very low cracking pressure differential, thus allowing fuel to flow only inboards with low fuel level differences between the tanks.

2.2. Jet Pump Considerations

A jet pump, often called an ejector or eductor pump, is an extremely reliable device because it has no moving parts. This pump operates according to the venturi's effect, where the momentum of a motive fluid will be transferred to a secondary fluid, often called the induced flow, thus generating an additional flow rate at the discharge port. The jet pump's motive flow can come from several sources; in this case, the booster pumps provide more fuel than what the engines need, so part of it is bypassed and reused as the motive source. The inclusion of the jet pump in the model was mainly to ensure that while fuel is being drawn from the collector tank, it can be replenished by the inboard tank during engine feed, ensuring a constant volume during all flight phases, as required for negative g operation and to avoid booster pump's fuel starvation.

In the model, the feed line has a 3-way pressure-compensated flow control valve, which controls the flow directed to the engine and bypasses the additional flow to the motive line of the jet pump, still keeping the pressure at the required range for optimal engine operation. The motive flow will go through the nozzle area of the jet pump and create a vacuum pressure that induces fuel from the inboard tank to mix with the motive fuel flow. An important parameter that characterises the performance of the jet pump is the flow ratio, represented by:

$$M = \frac{Q_i}{Q_m} \tag{2}$$

Where Q_i and Q_m are the induced and motive flow rates, respectively. The sum of the motive and induced flow will result in the discharge flow rate Q_d, shown in Fig. 6. The presented system has the necessary components to simulate the engine feed process, which triggers the fuel transfer process. The booster pump angular velocity is assumed to be constant during the engine feed process, while the engine feed flow rate can be controlled by the flow control valve's spool position upstream of the engine interface.

3. Model Simulation and Analyses

3.1. Jet pump performance evaluation

The scavenge jet pump keeps the collector tank always full by replacing the fuel taken to feed its respective engines. This is extremely important to minimise the unusable fuel quantities and prevent pumps from running out of fuel when in negative g conditions (when the fuel tends to move up in the tank). By isolating the collector tank, the flow requirement for keeping it always full can be expressed as follows:

$$\mathrm{Q_{in}} \geq \mathrm{Q_{out}} \tag{3}$$

Where Q_{in} and Q_{out} are the flow in and out of the collector cell, illustrated in Fig. 6. Considering that part of the fuel sent to the feed lines is bypassed to serve as the motive flow of the scavenge jet pump, equation 3 can be re-written as a function of the induced and feed flow rates:

$$\mathrm{Q_{i}} \geq \mathrm{Q_{feed}} \tag{4}$$

Where Q_{feed} is the fuel used to power the engines. This means that the induced flow rate from the inboard tank must be at least equal to the current engine flow rate demand. When transferring more fuel than needed, the excess flow can return to the inboard tank by a return line at the top of the collector tank.

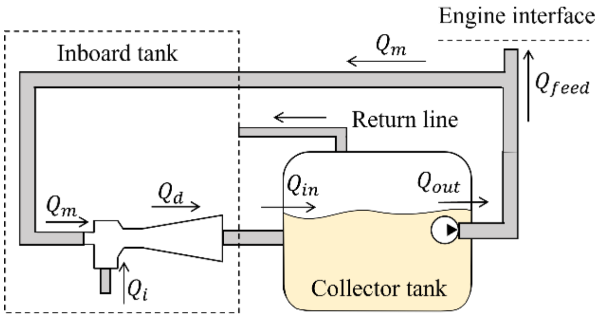

Fig. 6. Jet pump and collector tank flow balance

As mentioned before, the flow ratio is an important quantity to evaluate the jet pump's performance, as it is proportional to the jet pump's efficiency:

$$\eta = \mathrm{N} \times \mathrm{M} \tag{5}$$

Where N is the jet pump's pressure ratio, not discussed in the present analysis. On the other hand, the flow ratio M will be critical to ensure that the motive flow rate coming from the feed lines will produce enough induced flow to maintain the collector tank full. A sensitivity analysis was conducted to understand how the flow ratio is impacted by system variables and some of its geometric parameters. In Fig. 7., the length of the motive, suction, and discharge pipes, represented respectively by L_1, L_2, and L_3 were chosen as potentially correlated variables since they affect the pressure drop due to friction, and consequently, the pressure values at the jet pump's ports.

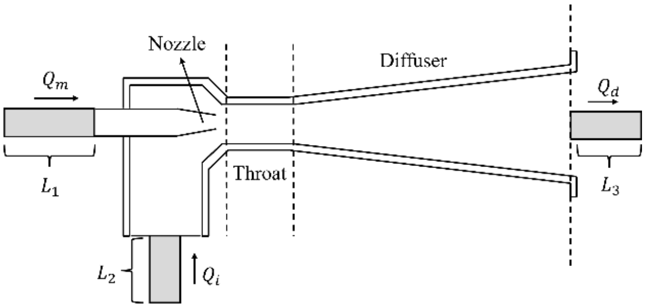

Fig. 7. Jet pump study variables

The sensitivity study considered the seven variables previously mentioned. The approach taken was to generate 50 sets of random values for each variable, uniformly distributed within a specified range. The selected variables and their respective ranges are shown in Table 1, where the variables $ratio_1$ and $ratio_2$ are the nozzle-to-throat and diffuser inlet-to-outlet area ratios, respectively.

Table 1. Parameter range specification for random value generation

Parameter	Min	Max	Type of Distribution
Nozzle area (m^2)	1e-5	1e-4	Uniform
$ratio_1$	0.1	0.4	
$ratio_2$	0.1	0.4	
L_1 (m)	0.01	2	
L_2 (m)			
L_3 (m)			
Eng. demand (L/min)	0.8	5.3	

The first study considered 50 simulations with randomised values for each variable. Then, the flow ratio was calculated in each simulation and plotted against each variable. A line obtained from the data linear regression was overlayed to visualise the correlation between variables. The plots in Fig. 8. show that the flow ratio ranges from almost zero to around 0.8, indicating a high variability.

From the plots, the only correlation evidence was found in the nozzle area plot, where the linear fit indicates a strong negative correlation between the flow ratio and the jet pump's nozzle area. In fact, a smaller nozzle area can be beneficial to increasing the flow ratio, though it is expected to increase the pressure at the nozzle entry, thus reducing the amount of flow coming from the feed line.

Although the remaining six parameters did not show any clear correlation with the flow ratio, it probably happened because the flow ratio's strong impact has hidden the influence of other parameters, so a second study was performed. The second case excluded the nozzle area from the analysis by fixing its value at the best option from the previously specified range, 10^{-5} m^2. For the second study, 50 new sets of values were generated for each variable, and after the simulations, the nozzle-to-throat ratio has shown itself to be more relevant than in the previous simulation. Fig. 9. shows the plots from the second sensitivity study, and the flow ratio fluctuated between approximately 0.9 and 2.4, still showing a high variability.

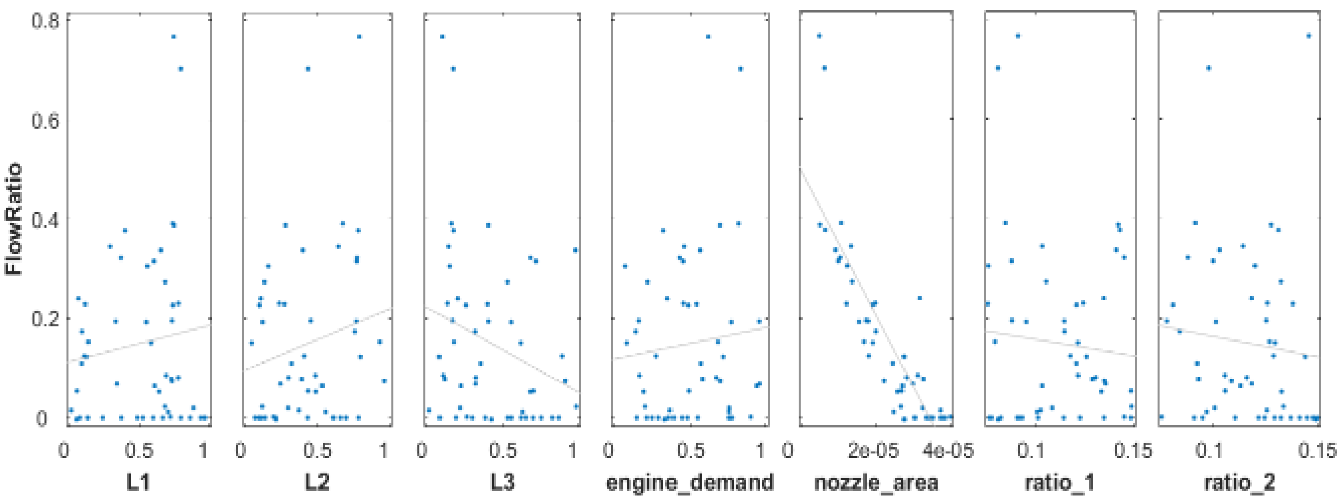

Fig. 8. Sensitivity analysis of the flow ratio considering all 7 study variables

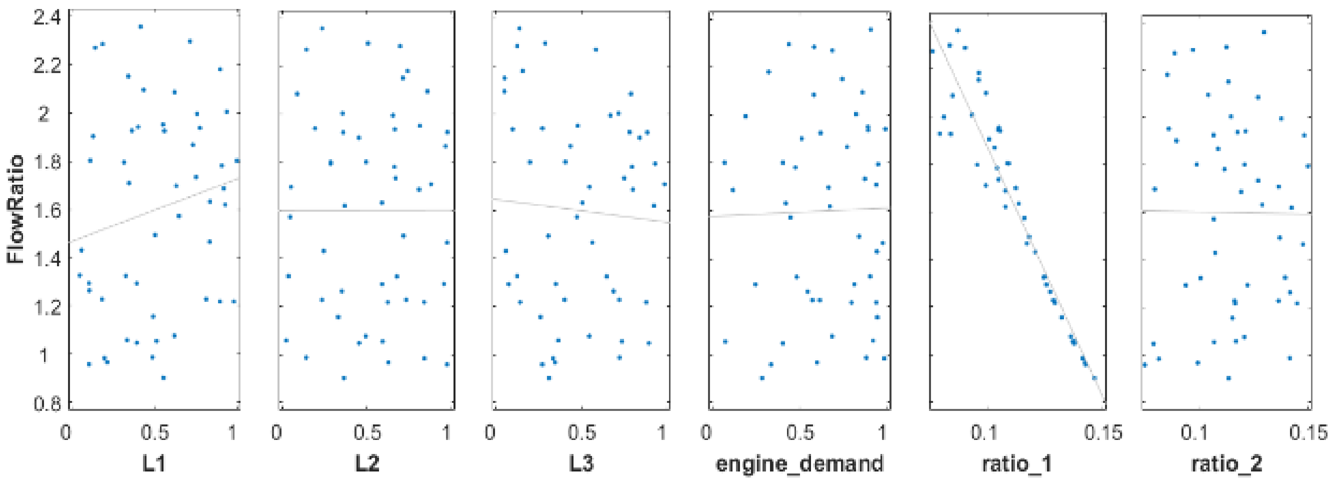

Fig. 9. Sensitivity analysis with 6 variables, neglecting the nozzle area influence

So far, the most influential parameters were the geometric variables of the jet pump's component. Although the other variables do not show any evident correlation with the system's output, the high variability of the flow ratio motivated a third study, excluding the variability of $ratio_1$. The nozzle-to-throat ratio was set to its best value from the specified range, 0.1 for the next study, and the results appear in Fig. 10. The plots show that the flow ratio ranges approximately from 1.9 to 3.1, but most of the values appear between 1.9 and 2.5. The higher values of the flow ratio resulted from the lowest values of L_1, L_2, and L_3, which agrees with the hypothesis that the pressure drop in the lines affects the amount of flow drawn from the inboard tank. Although this hypothesis may sound obvious, the lengths of the lines have different impacts on the system's output. Unlike in the previous studies, this analysis shows evidence of two correlated variables: the discharge line length L_3 and suction line length L_2. The motive line length L_1 did not show any influence over the flow ratio results, demonstrating that the pressure drop at each section of the system will have different impacts, and in this case, placing the jet pump closer to the collector tank's inlet is the best option.

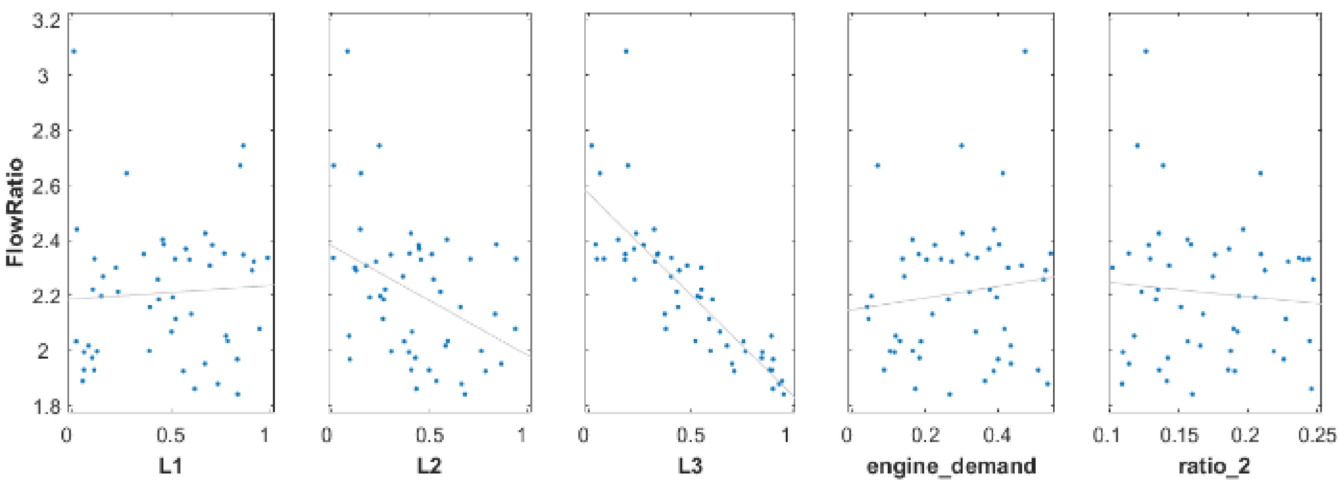

Fig. 10. Sensibility analysis with the 5 remaining variables

As per the previous analyses, it became evident that a careful study of the placement of the jet pump can greatly benefit in achieving an optimised jet pump performance, namely a higher flow ratio. In this scenario, where the flow ratio must be high enough to maintain the collector tank at its maximum capacity, the strategy for optimising its performance should involve placing it as close as possible to the collector tank, minimising the pressure drop in the lines and keeping the nozzle area at a lower value. The study also indicates that the engine demand does not significantly influence the flow ratio. Therefore, the flow ratio during flight is expected to remain constant regardless of the fuel consumption rate.

3.2. Dihedral angle effect on fuel transfer

The fuel transfer function is highly integrated into the storage and feed function and is an essential part of the fuel management task. Besides the scavenge jet pump, gravity can also transfer fuel through the flapper valves, used during engine feed and refuelling/defueling operations. In this study, the effect of the dihedral angle is analysed during the engine feed process.

During engine feed, the fuel is drawn from the collector tank and pressurised to the feed lines, while the excess fuel is redirected to the motive port of the jet pump, thus allowing the fuel to be replenished in the collector tank. Over time, the inboard tank level will decrease, creating a height difference between the outboard and inboard tanks. In this situation, the flapper valves allow fuel to be transferred from the outboard tank to the inboard tank when there is enough head difference to overcome the valve's cracking pressure. In the proposed configuration, the objective is to empty the outboard tank first, considering the absence of a scavenge jet pump within the outboard tank. To understand the impact of the dihedral angle on the fuel transfer, the engine feed process was simulated by inputting a simplified engine consumption signal based on a typical mission profile, as shown in Fig. 11. The first analysis considered zero dihedral, so the fuel transfer happened only because of the head difference created by the fuel consumption itself. Fig. 12. shows that the collector tank is kept full during all phases of the flight, as expected. In addition, as the inboard tank fuel level decreases, the head difference between the outboard and inboard tanks increases until the flapper valve opens, allowing fuel at the outboard tank to migrate toward the wing root.

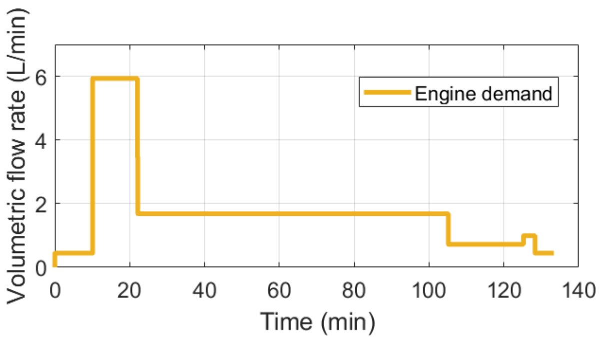

Fig. 11. Engine demand for a simplified typical flight envelope

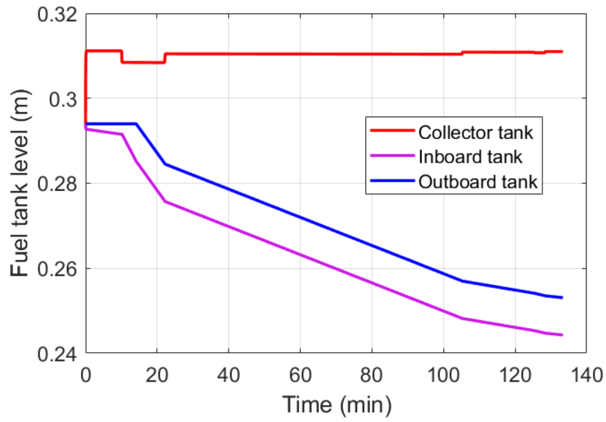

Fig. 12. Fuel tank levels for zero dihedral configuration

However, the inboard tank level is always below the outboard tank, suggesting that in the long run, the inboard tank will empty first, leading to a high amount of unusable fuel at the outboard tank, which will no longer be transferable to the collector tank.

A second simulation was performed, with the same configuration but adding 2 degrees of dihedral to the wings. Fig. 13. demonstrates that adding a dihedral increases the head difference between outboard and inboard tanks, thus making the outboard empty first. From the plot, it can be seen that, initially, the tanks have the same level as in the previous simulation, but in a short time interval, the levels reach another equilibrium position, and this is because now there is a pipe elevation between the tanks. In addition, the collector tank level has a higher value because the dihedral also influences the available fuel pressure at the jet pump's suction inlet, resulting in an increased transfer flow into the collector tank.

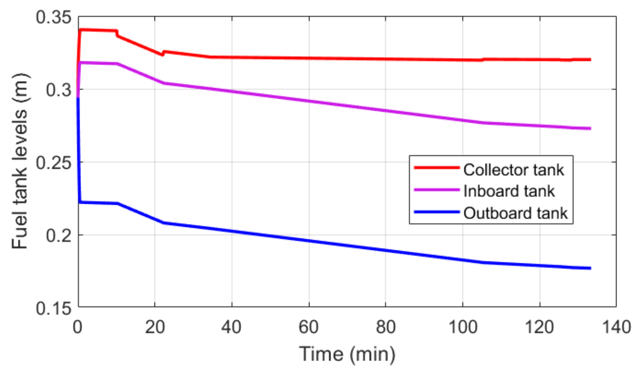

Fig. 13. Fuel tank level for 2 degrees of wing dihedral

The previous simulations show that, although the dihedral angle is often mentioned in the aerodynamics and stability context, this variable can influence the amount of unusable fuel in the outboard tank, especially in architectures where not all tanks have a scavenge ejector pump. For the zero dihedral configuration, an additional jet pump may be needed.

4. Conclusions and future works

This paper proposed a reference architecture and simulation model of a typical small aeroplane fuel system to aid the fuel system design during the product development process, especially during the preliminary design phase. With the proposed architecture, a modelling approach for fuel system was adopted and the dihedral angle effect on the model was discussed. Within Simulink, simulations related to the fuel transfer function were performed, where the jet pump performance and dihedral angle effects on the system were analysed. The obtained results from the simulations have shown that the nozzle area, suction and discharge line lengths are strongly correlated with the resulting jet pump's flow ratio. These results demonstrate that the jet pump is influenced by the distance it is placed from the discharge and suction ports. With this, it can be concluded that the jet pump should be placed as close as possible to the collector tank for optimising its efficiency. Additionally, a second study was conducted, where the dihedral angle proved to be significant for fuel transfer, directly affecting the order in which the fuel tanks empty, thus the number of jet pumps required in the fuel system architecture.

The fuel system model presented in this paper was explored in terms of simulation to highlight its capabilities inside the Simulink environment and show how complex and non-linear systems can be modelled using the physical library from Simscape. The obtained results are consistent with the ones available in the literature, and, therefore, the presented methods and simulation results can provide a reference for smaller aircraft fuel system design. Moreover, the sensitivity analysis of the jet pump demonstrated a statistical method for studying complex systems and/or components, and it must serve as a reference for other works which deal with engineering systems.

This work demonstrated one of the possible approaches when modelling and simulating an aircraft fuel system. It would be interesting, for future works, to improve the accuracy of the developed model, since the present version has been developed purely based on previous works which used the physical modelling software. Additionally, the model considered some simplifications, such as neglecting temperature variations, heat transfer effects, and the gas phase inside the fuel tanks, creating some constraints regarding the range of possible analysis. Future work can also be dedicated to integrating the existing system model with the control and automation system, where the valves and pumps can be controlled automatically to respond to new scenarios conditions.

References

1. Brzozowska, J., Gola, A., & Kulisz, M. (2023). Problems of forecasting the length of the assembly cycle of complex products realized in the MTO (make-to-order) model. *Technologia i Automatyzacja Montażu*, *121*(3), 13–20. https://doi.org/10.7862/tiam.2023.3.2
2. do Nascimento Pinheiro, N. R., & Góes, L. C. S. (2017). Modeling and simulation of a single engine aircraft fuel system. *Proceedings of 15: Th Scandinavian International Conference on Fluid Power, June 7-9, 2017, Link{\"o}ping, Sweden*, 45–50.
3. Ellström, H., & Gavel, H. (2013). Simulation of Cavitation and Pressure Surge: An Engineering Approach. *Journal of Aircraft*, *50*(4), 1038–1045. https://doi.org/10.2514/1.C031886
4. Feng, D., Jiang, C., Lu, M., Li, S., & Ye, C. (2022). Simulation of One Aircraft Fuel Supply System Based on AMESim. *2022 14th International Conference on Measuring Technology and Mechatronics Automation (ICMTMA)*, 812–818. https://doi.org/10.1109/ICMTMA54903.2022.00166
5. Glover, W., & Lygeros, J. (2004). A Stochastic Hybrid Model for Air Traffic Control Simulation. *International Workshop on Hybrid Systems: Computation and Control*, 372–386. https://doi.org/10.1007/978-3-540-24743-2_25
6. Hutchison, M., Lenoble, G., Badiali, U., Sommerer, Y., Verseux, O., & Desmet, E. (2014). Jet Engine Fuel System Integration in Aircraft Environment - Methodology for Pressure Surge Simulation through Model-Based System Engineering. *SAE International Journal of Aerospace*, *7*(1), 2014-01–2135. https://doi.org/10.4271/2014-01-2135
7. Jimenez, J.F., Giron-Sierra, J.M., Insaurralde, C., & Seminario, M. (2007). A simulation of aircraft fuel management system. *Simulation Modelling Practice and Theory*, *15*(5), 544–564. https://doi.org/10.1016/j.simpat.2007.01.007
8. Li, C., Yang, H., Liu, S., Feng, S., Xu, L., & Wang, Z. (2023). Performance Analysis and Optimization of Fuel Tank Ground-Based Washing Inerting on Unmanned Aerial Vehicles. *Aerospace*, *10*(3), 244. https://doi.org/10.3390/aerospace10030244
9. Liu, M., Wang, Z., & Ren, J. (2022). Study on impact pressure and ventilation capability of aircraft pressure refueling system. *CSAA/IET International Conference on Aircraft Utility Systems (AUS 2022)*, 745–750. https://doi.org/10.1049/icp.2022.1653
10. Ming, W. H., Hawari, M. Z. K., & Apandi, N. I. (2021). Mathematical modeling on application of wireless networks for industrial automation-factory automation. *Journal of Physics: Conference Series*, *1988*(1), 012024. https://doi.org/10.1088/1742-6596/1988/1/012024
11. Tiwari, A., & Harrison, J. (2019). Simulation of Aircraft Fuel System with Complex 3D Tank Geometry Using a 1D Flow Solution. *AIAA Propulsion and Energy 2019 Forum*. https://doi.org/10.2514/6.2019-4360
12. Tu, Y., Chen, X., Yin, L., Zheng, Q., & Zeng, Y. (2022). Numerical Study on Pipeline Pressure Surge of the Large Aircraft Fuel System. *Shock and Vibration*, *2022*, 1–13. https://doi.org/10.1155/2022/7529857

13. Valente, E., Avram, C., Astilean, A., & Machado, J. (2022). A systematic approach for microscopic models based on cellular automata for road traffic. *Technologia i Automatyzacja Montażu*, 14–27. https://doi.org/10.7862/tiam.2022.1.2

14. Yue, Z., Guiping, L., Yi, T., & Mao, X. (2010). Conceptual Design and Dynamic Simulation of Thermal Management for Fighter Aircraft Fuel System. *AIAA Modeling and Simulation Technologies Conference*. https://doi.org/10.2514/6.2010-8087