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Optimization of Aircraft Fuel Systems Considering Fluid Dynamics Principles

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Abstract - The fuel system is the lifeline of any aircraft, pivotal for its operation and future advancements. This study delves into aircraft fuel system design methodologies, aiming to streamline development processes. Through optimization and matrix methods like the morphological matrix, Saab Aerospace pioneer's conceptual designs. These methods automate development and deepen our understanding of how top-level requirements impact engineering details. Quantifying matrices opens doors to design optimization and probabilistic design. Furthermore, a systematic approach to simulation modeling minimizes development time, leveraging parallel development and collaborative engineering. With stakeholder expectations in mind, experience gleaned from projects like the Gripen fuel system shapes an overarching process for future endeavors. This journey promises to reshape aircraft fuel system design, ensuring each drop of fuel propels us towards boundless horizons.

***Key Words*:** Aerospace engineering, Fuel system, Optimization techniques, Matrix methods, Simulation models, Conceptual design, System integration, Aircraft performance, Fuel tank configurations, Operational flexibility, Gripen Fuel, DSM- Design Structure Matrix

1.INTRODUCTION

- In the realm of aerospace engineering, the design and optimization of fluid systems are critical components that significantly impact the performance, efficiency, and safety of aircraft. Among these systems, the fuel system stands out as the largest and most vital, serving as the lifeblood that powers the aircraft through its journey. As advancements in aviation continue to push the boundaries of technology and innovation, the importance of efficient fuel system design becomes increasingly apparent. Future aircraft projects necessitate not only the development of advanced propulsion systems but also the meticulous design and integration of fuel systems to meet the demands of modern aviation.

This study delves into the intricate world of aircraft fuel system design methodologies, aiming to expedite the system development process while enhancing overall performance and reliability. With the overarching goal of shortening

development time, various optimization techniques and matrix methods have been explored and implemented. Examples from Saab Aerospace provide insight into how these methodologies, such as the morphological matrix, house of quality, and design structure matrix, are applied in the conceptual design phase, introducing automation and improving understanding of engineering parameters.

Furthermore, this research discusses the systematic approach employed in building large-scale simulation models of fluid systems. By minimizing development time and ensuring the correct level of detail, these simulation models become invaluable tools for predicting system behavior and optimizing design parameters. Drawing from experiences gained at Saab, particularly from projects like the Gripen fuel system, this study seeks to distill wisdom and best practices into an overarching process that can be applied to future endeavors in aircraft fuel system design and development. Through collaborative efforts and innovative methodologies, this research aims to propel the field of aerospace engineering towards new heights of efficiency and excellence.

A Focus on Fuel System Optimization –

The conceptual design phase is pivotal in engineering, defining the principal solution following the clarification phase. It encompasses concept generation and selection, where novel combinations or modifications of existing products are explored. Methods like the morphological chart aid in identifying innovative solutions. Concept selection involves iterative screening and scoring to refine concepts. Matrix methods, such as the Design Structure Matrix (DSM), facilitate mapping dependencies within complex systems, like fuel systems. DSM application ensures critical subsystem interactions are accounted for, crucial for evaluating complex systems. Notable methods like Kesselring's and Pugh's are omitted from this study. The DSM, an information exchange model, originated from Steward and finds utility across engineering domains, including conceptual design. Illustrative examples compare fuel system proposals, highlighting subsystem dependencies and interactions. Maintaining the DSM in a lower triangular form improves robustness and simplifies modification, aligning with principles of axiomatic design. The DSM's uncoupled or lower triangular configuration ensures compliance with the first axiom of axiomatic design, enhancing design efficiency and clarity.

The significance of aircraft conceptual design extends far beyond mere sizing considerations, encompassing the intricate integration of subsystems and components. the inclusion of aircraft systems at the conceptual level is paramount, given their substantial contribution to both aircraft mass and development costs. This chapter illuminates the early integration of system design through a case study involving a conceptual examination of a long-range variant of the JAS 39 Gripen aircraft. This study not only forms a cornerstone for subsequent research but also provides empirical insights into conceptual design methodologies.

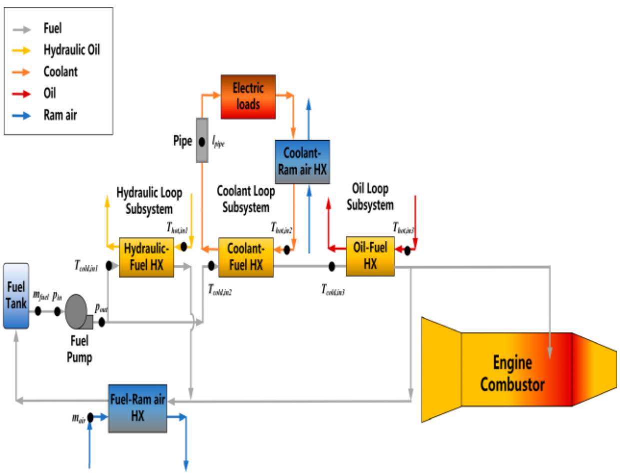

Fig- Fuel TMS

The investigation aimed to enhance the Gripen's competitiveness and versatility in the long-range fighter market. Various concepts were explored, including modifications to fuel tanks, engines, and airframe configurations. Among these, proposals involving the integration of new conformal fuel tanks and internal tank configurations showed considerable promise. However, each concept presented unique challenges, such as aerodynamic impacts and structural modifications.

For instance, the introduction of ventral conformal fuel tanks, while economically appealing, posed challenges related to aerodynamic stability and increased drag. Similarly, the exploration of dorsal conformal tanks highlighted concerns regarding directional stability and transonic behavior. Additionally, proposals involving internal tank configurations necessitated structural modifications to accommodate additional fuel volume, raising issues such as CG management and aerodynamic interference.

One particularly promising solution involved the relocation of main gear cavities for housing fuel tanks. This approach not only capitalized on existing fuselage space but also minimized aerodynamic disruptions. Various configurations were evaluated, including integrating the main gear into blended wing structures or adapting them to the existing wing geometry. Ultimately, the concept featuring externally mounted gear attached to the wing box emerged as the most viable option, offering improved weapon carriage capability and operational flexibility.

In conclusion, this study exemplifies the multifaceted nature of aircraft conceptual design, emphasizing the critical role of early system integration. By balancing innovative design modifications with the integrity of the existing aircraft concept, researchers can unlock new avenues for enhancing aircraft performance and mission capabilities. This investigation sets the stage for further research and development efforts aimed at advancing the state-of-the-art in aircraft system design and integration.

Matrix Methods in Engineering Design A number of matrix based methods have been developed to support engineers in different stages of design. In this section, a small selection of these are described in more detail. Two notable matrix methods that are omitted are Kesselring’s criteria-weight method described in Pugh’s datum method, intended for concept On Aircraft Fuel Systems comparison and selection. These two methods are left out since they are not exploited in the research described in this thesis. The Design Structure Matrix the Design Structure Matrix is an information exchange model, originally developed by Steward. Complex systems and processes include several components/subsystems or activity steps which interact in a sometimes complex network of dependencies. The DSM is useful as a tool for mapping dependencies. The DSM may be applied in several engineering domains such as engineering management, design optimization, and conceptual design, to give just a few examples. In the illustrative example shown here, the purpose is to map subsystem dependencies so as not to overlook any combinatory effects. This is vital when evaluating complex systems. The example used is the comparison of the two fuel system proposals in Figure 6, one with pump transfer and one with fuel transfer by siphoning. The pump transfer concept includes a transfer pump that pumps fuel from the transfer tank and an engine feed pump that pumps fuel to the engine. Both tanks are pressurized in order to avoid pump cavitation. In the siphon concept, only the transfer tank is pressurized and the fuel is siphoned by differential pressure to the engine feed tank from where the fuel is pumped to the engine

Conclusion: Exploring conceptual design proposals for the JAS 39 Gripen aircraft highlights the crucial role of early system integration in aircraft design. Despite challenges, each concept aimed to enhance competitiveness and versatility. Relocating main gear cavities for fuel tanks emerged as promising, balancing capacity and aerodynamics. This study underscores the importance of holistic design approaches, integrating subsystems from the outset. These insights inform future aircraft advancements, driving performance and capability in next-generation designs.

Subsystem dependencies of the pump and the siphon concepts are shown in Figure 7. For instance, it is possible to see how the engine feed in the pump concept relies on the pressurization system (to minimize cavitation). Another example is the interaction between the refueling and vent systems. Note that it is preferable to partition the matrix so that it becomes as lower triangular as possible in order to obtain as good a view of the information flow as possible.

It might also be argued that if the matrix is kept diagonal or lower triangular this will yield some advantages: the system becomes more robust, it simplifies modification since changes only will affect subsystems that are 'downstream', which otherwise may lead to an endless loop of redesign without any clear optimum. This is in many ways similar to axiomatic design, which is discussed in a later section. If the DSM is uncoupled or lower triangular, the design will most likely satisfy the first axiom of axiomatic design.

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