Hydrogen Storage in a Commuter Aircraft: Combining Classical Engineering Design Process with Model Based System Engineering for CFRP Pressure Vessel Integration

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Abstract:

For the integration of hydrogen storage in the center wing of a commuter aircraft, the requirements for the storage system are specified and the boundary conditions are analyzed. High-pressure storage tanks with increased gravimetric storage density are designed for the resulting installation space. In a first step, an analytical dimensioning of the tank is carried out. In the next step, numerical manufacturing and structural simulations are done and an exemplary manufacturing technology is implemented. The pre-designed tank is integrated into a Model-Based Design model, from which the flight range and any necessary system adjustments to increase the range are derived.

Keywords: hydrogen, MBSE, high pressure tank, virtual-physical engineering

Nomenclature

CFRP	:	Carbon Fiber Reinforced Polymer
MBD	:	Model-Based Design
MBSE	:	Model Based System Engineering

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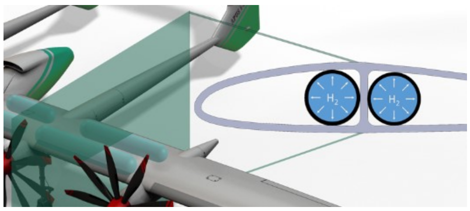
1. Introduction

Due to its low volumetric energy density, hydrogen must be stored under high pressure or cryogenic conditions. The integration of hydrogen tanks into aircraft therefore raises new challenges compared to conventional tanks for fossil fuels. At the same time, designing an aircraft with an alternative propulsion system brings with it a the lack of empirical data on the new propulsion system. This makes it difficult to answer the question of whether the aircraft design under development will meet the performance requirements. Model-Based Design (MBD) can be used to reduce errors in the early stages of design and to minimize costs and time. This approach places models at the center of the design process from the outset. MBD is particularly useful when dealing with dynamic systems such as aircraft. An additional advantage is that the models developed can be used in other projects, thus speeding up the design phase (Kelemenová et al., 2013; Peciak and Skarka, 2022). For such a model-based approach, knowledge of the subsystems is crucial. In this case, the hydrogen storage subsystem is considered as a white box and the necessary information is generated through the classical Engineering Design Process. It is expected that commuter up to short range aircraft will be the first aircraft categories in which hydrogen-powered aircraft will enter service (Gao et al, 2022). Therefore, a commuter aircraft is considered as the baseline.

2. Integration of Hydrogen Tank in the Aircraft Wing

The integration of hydrogen tanks into the wing seems (cf. fig.1) an attractive solution to avoid aerodynamical disadvantages compared to underwing pods.

Fig.1. Concept of high-pressure hydrogen tanks integrated in the cross section of an aircraft wing



However, as aircraft wings are significantly deformed during flight, design of integrated tanks must account for both the internal pressure loading as well as the bending of the wing. The latter results in either assuming the aerodynamic wing loads partially bore by the tank as external loads, or by defining a suitable design space in the deformed wing that allows a tank bearing without external loads.

2.1. Pressure Vessel Design

Based on current technologies with a sufficient technology readiness level, non-load-bearing tank are chosen as a starting point. To determine the allowed design space, the wing bending is calculated first (cf. fig.2).

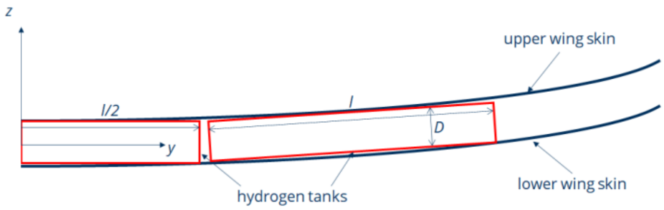


Fig.2. Schematic illustration of non-load-bearing tanks in aircraft wing bent due to aerodynamic loads

The tanks are sized according to Barlow's formula and the optimal length *l* and outer diameter *D* of the spanwise-segmented tank are determined. For the chosen reference aircraft and a working pressure *p* = 700 bar, an optimum of two spanwise-segmented tanks per half wing with *l* = 2,53 m and *D* = 202 mm results.

2.2. Virtual and physical demonstration of the manufacturability

Next, the tank is modeled using CADWIND (cf. fig.3 (left)) in order to develop a suitable fiber deposition process used for manufacturing a demonstrator (cf. fig.3 (right)).

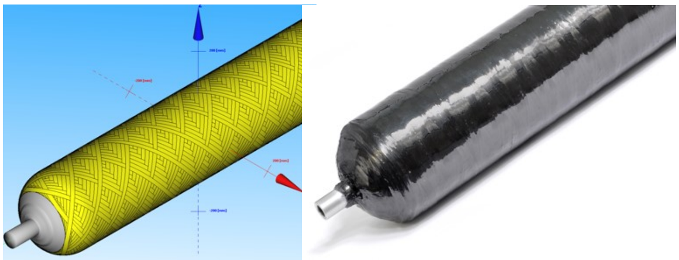


Fig.3. Winding core covered with fibres (yellow) in the software CADWIND (left) and manufactured CFRP vessel (right)

3. Development of a simulation model for aircraft performance evaluation

Using the MBD approach, a system-level simulation model of the aircraft has been developed to assess the energy and power requirements during flight.

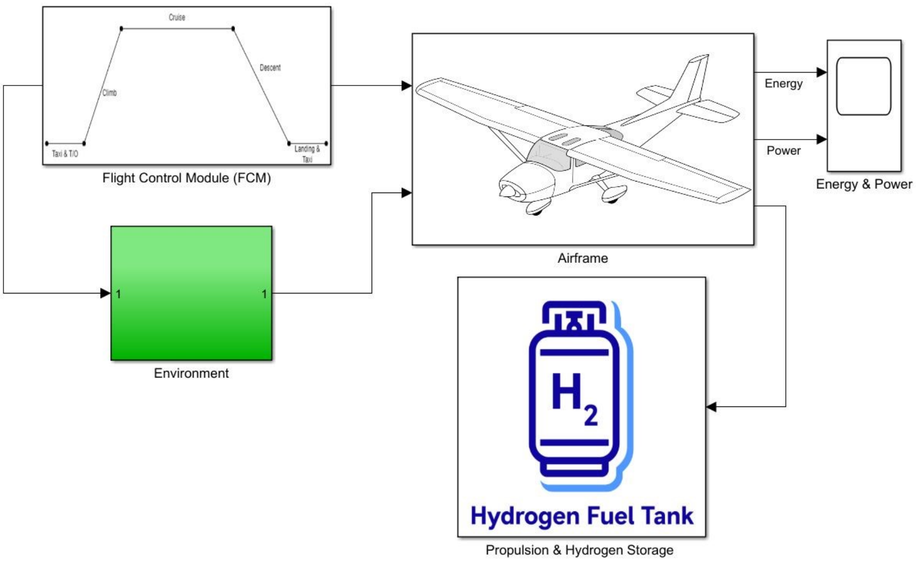


Fig.4. Simulation model developed with MATLAB /Simulink software to assess the energy and power demand of the analyzed aircraft

It possible to size the propulsion components accordingly, check the amount of hydrogen required stored in the tanks, and thus verify and optimize the flight parameters. The model is based on the forces acting on the aircraft and consists of four main subsystems (cf. fig.4): Flight Control Module, Environment, Airframe (in fig.4) and Propulsion with Hydrogen Storage. Currently, the model is still developed to simulate the aircraft's behaviour due to the placement of drive components, including hydrogen tanks, and to analyse the propulsion parameters. This will provide a more holistic view of the propulsion system and the aircraft as a whole.

4. Conclusion

Model Based Design allows the description of complex overall systems and can be used to model new aircraft with alternative fuel systems. Due to the low volumetric storage density of hydrogen, the integration of a sufficient amount of the energy carrier into the aircraft structure is a major challenge. There is limited empirical information available, so the subsystems of a MBSE model must be converted from a subsystem described by its boundaries (black box) to a subsystem where the inside is explored and described (white box). The necessary information can be generated by applying classical and established interactive engineering design processes. The disciplines of design, layout and manufacturing are applied to the development of CFRP high pressure tanks. In a combined virtual-physical approach, tanks have been developed that can be integrated into the center wing of a commuter aircraft. In the next step, the tanks developed in this way will have to be integrated into the center wing by means of CAD modelling and the corresponding mountings will have to be worked out. This will allow the input data for the model-based design to be derived in a well-founded manner, enabling the aircraft to be designed and its range to be estimated.

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