Hydrogen Aircraft Design Optimisation for Minimal Global Warming Impact

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Abstract:

With an eye on a more sustainable future, recent aircraft design research has focused on reducing the climate impact of aviation. For conventional aircraft, with kerosene-powered turbofan engines, this objective has been shown to conflict with the traditional fuel and cost objectives [1]. Although non-CO2 effects perform a prominent role in this analysis, the long-term effects of CO2 emissions cannot be neglected. A promising technology targeting this specific aspect is the use of liquid hydrogen [2].

To gain insight into the potential of liquid hydrogen and the associated trade-offs, it is recommended to compare the performance of kerosene- and hydrogen-powered aircraft, both optimised for their climate impact. Hence, the research question of interest is: What is the potential climate impact reduction of an optimised liquid hydrogen aircraft compared to an optimised kerosene-powered aircraft, both employing turbofan technology? The current study focuses on a medium-range, narrow-body aircraft, similar to the Airbus A320 or Boeing 737, operating in a continental fleet.

To perform the analysis and optimisation, an existing multidisciplinary design framework, presented in Figure 1, is extended to capture to particularities of liquid hydrogen propulsion in the conceptual design stage. Changes to the framework include a hydrogen tank mass estimation method, adapted turbofan gas modelling and an updated emission and climate module. A hybrid optimisation strategy is employed to first explore the design space and subsequently refine the result.

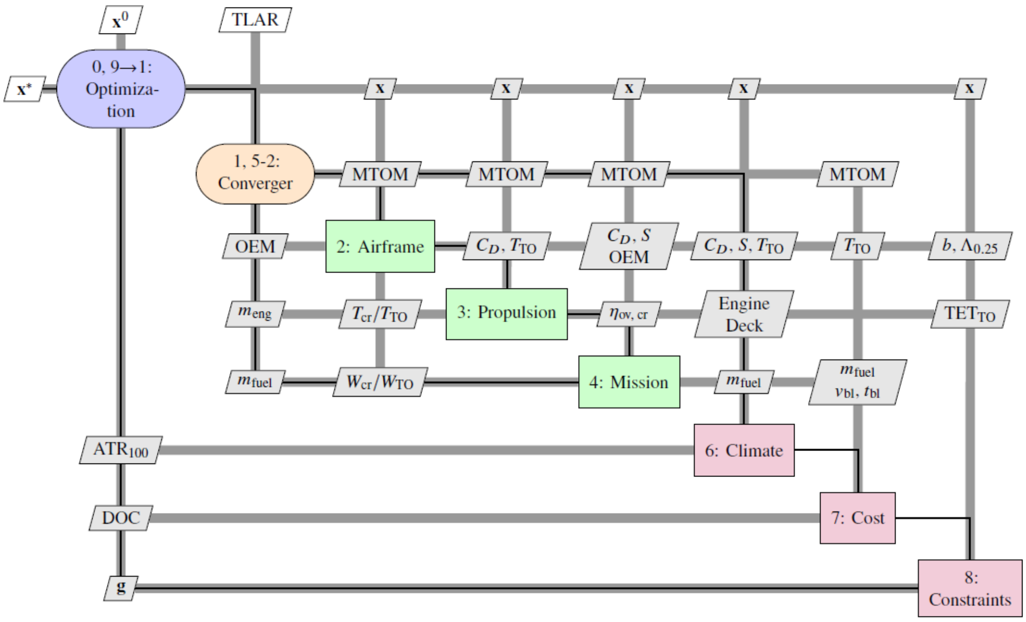

Figure 1 - Multidisciplinary aircraft design and optimisation framework. A hydrogen tank mass estimation method is added to module 2, while modules 3 and 6 are updated to capture the chemistry of hydrogen.

Firstly, the hydrogen aircraft is optimised for three objectives: its climate impact, measured by the average temperature response over a period of 100 years, the operating costs and the fuel mass burned. A direct comparison between the three resulting designs provides a clear insight into the trade-off decisions and design rationale, tailored to the hydrogen aircraft concept. Additionally, the sensitivities of design variables are studied.

Secondly, the potential climate impact reduction is compared to the kerosene-powered counterpart. Based on the findings, conclusions can be drawn regarding the most suitable fuel type in terms of climate impact reduction, while also evaluating the total energy consumption and other design quantities of interest. Furthermore, also the impact of the climate-optimal design on fleet productivity and the number of aircraft required is discussed.

Overall, the aim of the research in this paper is to create a holistic comparison of optimised hydrogen- and kerosene-powered aircraft, both employing state-of-the-art turbofan technology. By closely inspecting both fuel options, insightful conclusions can be formulated towards future technology selection and the influence on fleet operations.

References:

[1] K. Dahlmann, A. Koch, F. Linke, B. Lührs, G. Volker, T. Otten, D. Seider, V. Gollnick and U. Schumann, “Climate-Compatible Air Transport System—Climate Impact Mitigation Potential for Actual and Future Aircraft,” *Aerospace,* vol. 3, p. 38, 2016.

[2] McKinsey & Company for the Clean Sky 2 JU and Fuel Cells and Hydrogen 2 JU, “Hydrogen-powered aviation - A fact-based study of hydrogen technology, economics and climate impact by 2050,” Publications Office of the European Union, 2020.