Comparative Life Cycle Assessment and Operating Cost Analysis of Long-Range Hydrogen and Biofuel Transport Aircraft

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1. INTRODUCTION

The growing awareness of emissions footprint and the dwindling fossil oil resources [1] have led the aviation industry to contemplate new propellants and advanced low-carbon propulsion technologies. Among others, hydrogen and sustainable aviation fuels (SAF) such as biofuel are seen as promising candidates to attain the specified emission goals.
Numerous previous studies attest the technical feasibility of liquid hydrogen as propellant and present conceptual aircraft designs exploiting different applications (e.g. subsonic, supersonic, short-range, long-range etc.). SAF have the advantage of being drop-in fuels that do not require changes in aircraft and fuel infrastructure and are already in use since 2016 [2].
However, current studies do not provide complete and transparent environmental and economical reviews of respective configurations (see e.g. [1], [3], [4], [5], [6]). Nevertheless, to provide a meaningful evaluation in terms of the environmental impact a full life cycle assessment (LCA) is necessary. In order to assess the aircraft from an economic perspective, a direct operating cost (DOC) model enables to examine the financial impact for airlines considering the prospects of new aviation fuels.
The objective of this work is to perform a comparative LCA and DOC analysis of long-range liquid hydrogen and biofuel to conventional transport aircraft that considers the aforementioned shortcomings of previous studies. The goal of the study is then to determine if, and under which circumstances, hydrogen and biofuel aircraft are valuable solutions from both an environmental and economic perspective to reduce the aviation industry's climate impact.

2. METHODOLOGY

The proposed methodology is outlined in FIGURE 1. As a top-level requirement (TLAR) a representative long design range is chosen as the large fuel loads represent an upper limit to performance improvements for the adoption of hydrogen. Therefore, using the in-house aircraft design environment ADEBO [6], a long-range conventional transport aircraft is designed based on the Airbus A330-200. For the drop-in biofuel, the aircraft design remains the same. The liquid hydrogen aircraft requires a new design due to additional and reinforced components for e.g. hydrogen storage tanks.
In a next step, the LCA methodology according to Johanning [7] is applied on all three configurations to examine the propulsion technologies in contrast. Parallelly, a DOC model is applied.
Trade-offs are then identified using parameter variations regarding the design variables (e.g. hydrogen tank material) and future scenarios (e.g. electricity mix and fuel costs).

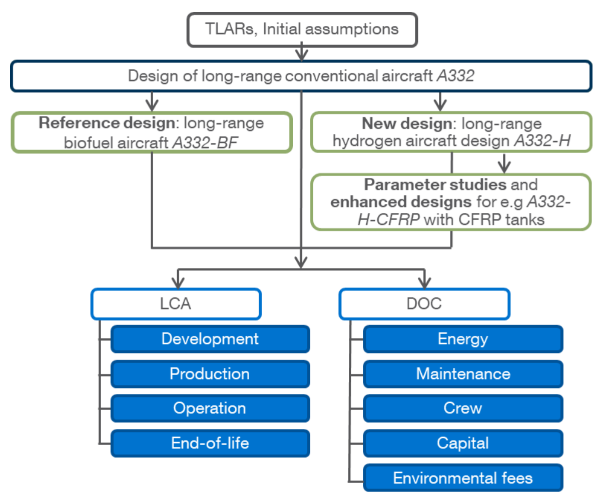

FIGURE 1. Proposed methodology

3. CURRENT WORK

In the past months, the in-house aircraft design environment ADEBO has been expanded with models for conventional and hydrogen based long-range aircraft including methods for e.g. tank models for hydrogen storage. Further improvements for e.g. of the hydrogen aircraft in terms of the tank positioning are in progress. Additionally, the LCA model has been implemented for the conventional, liquid hydrogen and biofuel aircraft. A research was conducted on existing DOC models for conventional aircraft such as in [8], [9] and [10]. These models have also been used in previous studies on hydrogen aircraft. ADEBO is currently being expanded with these DOC models.

4. PRELIMINARY RESULTS

The utilization of liquid hydrogen instead of kerosene has a distinct effect on the design and performance of the aircraft. Hydrogen offers a great opportunity due to its high specific energy but poses a technical challenge due to its cryogenic property, its low density and the resulting necessary tank volume. Therefore, the storage tank design must be considered with special attention.

FIGURE 2 depicts the preliminary aircraft design result of the long-range hydrogen aircraft A332-H. The hydrogen tanks (in orange) are located in front and behind the cabin (in blue). To ensure a low surface-to-volume ratio of the tanks and hence minimize heat leakage and structural weight, the fuselage diameter of the A332-H was increased by 1 m compared to the conventional configuration A332. The usage of hydrogen as aviation fuel results in a reduction of 57.6 % in fuel mass. Due to the heavy tank structure and other component reinforcement the operating empty mass increases by 7.8 %, however the maximum take-off mass is decreased by 11.1 %.

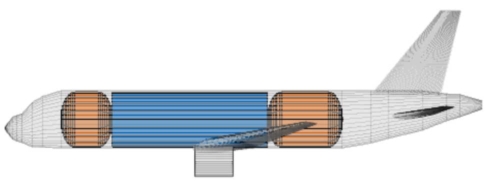

FIGURE 2. Long-range hydrogen aircraft with cabin (blue) and tanks (orange)

To be able to interpret the result of the LCA, the so-called Single Score (SS) is used which expresses the entire environmental impact in a single metric. The lower the SS will be, the lower the environmental impact of the aircraft and vice versa. TABLE 1 summarizes the preliminary results for the A332-H, an enhanced aircraft configuration with CFRP tanks A332-H-CFRP and A332-BF relatively to the kerosene fueled aircraft for two scenarios. In the baseline scenario, the fuel production bases on the current electricity mix. Electricity produced from renewable sources is considered for the future scenario. The results show, that under today's fuel production conditions, neither hydrogen nor biofuels are yet environmentally competitive. The highest priority is to cover the energy demand with renewable energies. Enhancing the tank design and reducing the weight of the heavy tank structure can further improve the environmental impact.

TABLE 1. Relative comparison of Single Score of hydrogen versus conventional aircraft

	Single Score A332-H	**Single Score A332-H-CFRP**	**Single Score A332-BF**
Baseline scenario	+ 57.4 %	+ 52.1 %	+ 526 %
Future scenario	- 27.1 %	- 29.5 %	-25.9 %

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