REFUELING OF LH2 AIRCRAFT – PART 2: ASSESSMENT OF TURNAROUND PROCEDURES AND AIRCRAFT DESIGN IMPLICATIONS

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Abstract

As highlighted in Part 1, green liquid hydrogen (LH2) could play an important role as a zero-carbon aircraft fuel to achieve long-term sustainable aviation. Besides the already touched challenges in setting up hydrogen (H2) fuel infrastructure at airports, this part investigates the interconnection between the refueling system and the aircraft and the impacts on aircraft operation. Furthermore, it provides answers to key technology design decisions for LH2 refueling procedures and its effects on the turnaround times as well as aircraft design. Thus, operational economics behind these procedures are reflected.

Based on a comparison to JetA1 refueling, new LH2 refueling procedures are described and evaluated. Process steps that are considered are connecting/ disconnecting, purging, cooldown and refueling.

Two methods for connecting and purging the refueling system are developed, and their technical feasibility is investigated to enable coupling by an adapter to the aircraft. Therefore, the avoidance of expensive helium for the purging process is targeted. In the next step, a lumped capacitance method is used to calculate the cooling process of warm pipelines in order to investigate the temporal influence under a reduced mass flow for low thermal stress. The heat transfer is estimated using the Nukiyama curve to account for the effects of different boiling regimes. Then, new limitations for LH2 refueling are derived by applying dimensionless numbers of the Space Shuttle Loading and determining the dimensions of the pipeline and the mass flow (Fig 1).

For the assessment of impacts on LH2 aircraft operation, changes on the level of ground handling vehicles are compared to current procedures with JetA1 refueling of short-, medium- and long-range aircraft. In addition, the technical challenges at the airport for refueling trucks as well as pipeline systems and dispensers are presented. Moreover, an easy-to-implement pressurization system and a design with pumps are considered to deliver the required mass flow. The necessary quantities of the pressurizing gas and its cost will be evaluated. Solutions are shown on how to handle vaporized H2 to generate minimal losses.

In addition to the technology solutions, explosion protection and applicable safety regulations are analyzed and the overall refueling process is validated. Even more, influences on the turn-around process and cash operating costs are evaluated. The comparison in terms of time needed is shown with the help of a Gantt chart and potentials for optimization are described. It is shown that achievable turn-around times are mainly driven by the refueling rates and procedures, which constitutes an important factor influencing the economic competitiveness of the energy carrier LH2. However, if spark free areas around the refueling point would be required, the turn-around process might be significantly extended. Other options for the safe handling of vaporizing H2 are shown.

The thermodynamic properties of LH2 as a real, compressible fluid are considered to derive implications for airport-side infrastructure, see Fig 2. The advantages and disadvantages of a subcooled liquid are evaluated and cost impacts are transferred. Cost increases due to airport-side supply by the different vehicle concepts and the losses of the purging process and cooling process are considered. Problems such as cavitation, two-phase flows because of too low tank pressure or too high temperatures of the LH2 are addressed.

Finally, implications on LH2 aircraft design are tested. By understanding the thermodynamic properties, three calculation methods for the tank volume in the aircraft are shown. These methods are related to maximum and minimum tank pressure under saturated conditions and to realistic tank conditions. With this, the losses of LH2 for a constant tank pressure in flight are derived, and thus an optimal insulation quality for the respective flight phase is calculated, see Fig 3. For longer ground or standstill times at the airport, the losses and the necessary procedure for a return flight without refueling are presented.

Keywords
Liquid Hydrogen; Refueling; Hydrogen Aviation; Hydrogen Fuel Supply

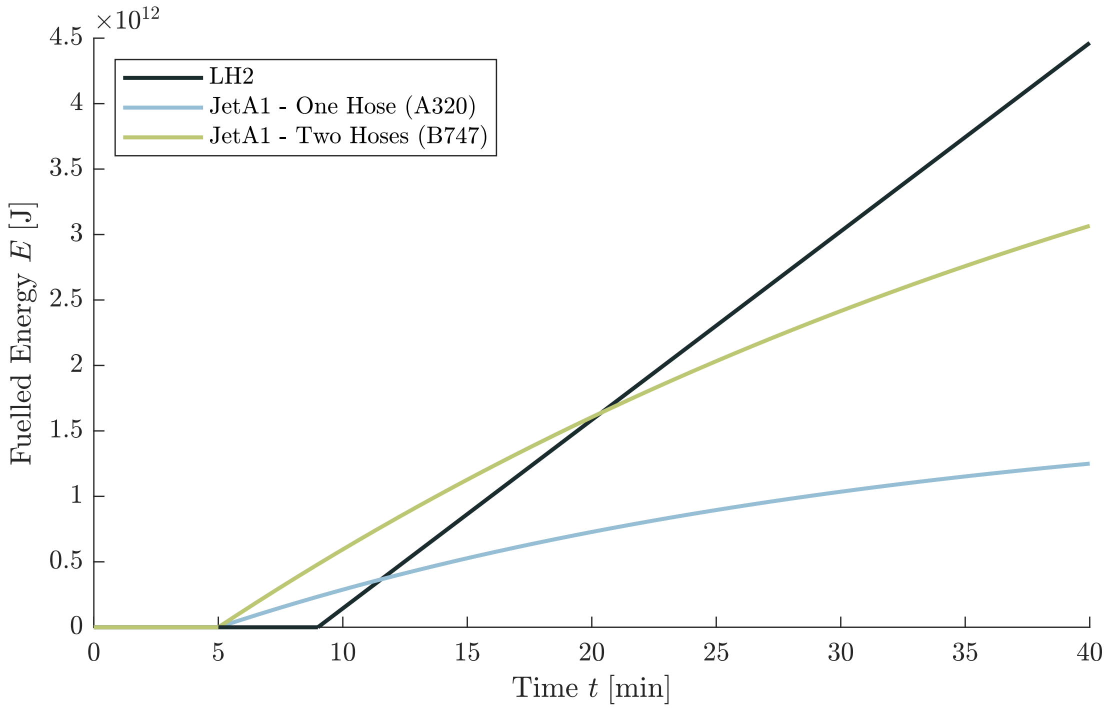

FIG 1. Fueling Comparison between JetA1 and Liquid Hydrogen; considering time influences before and after the refueling process

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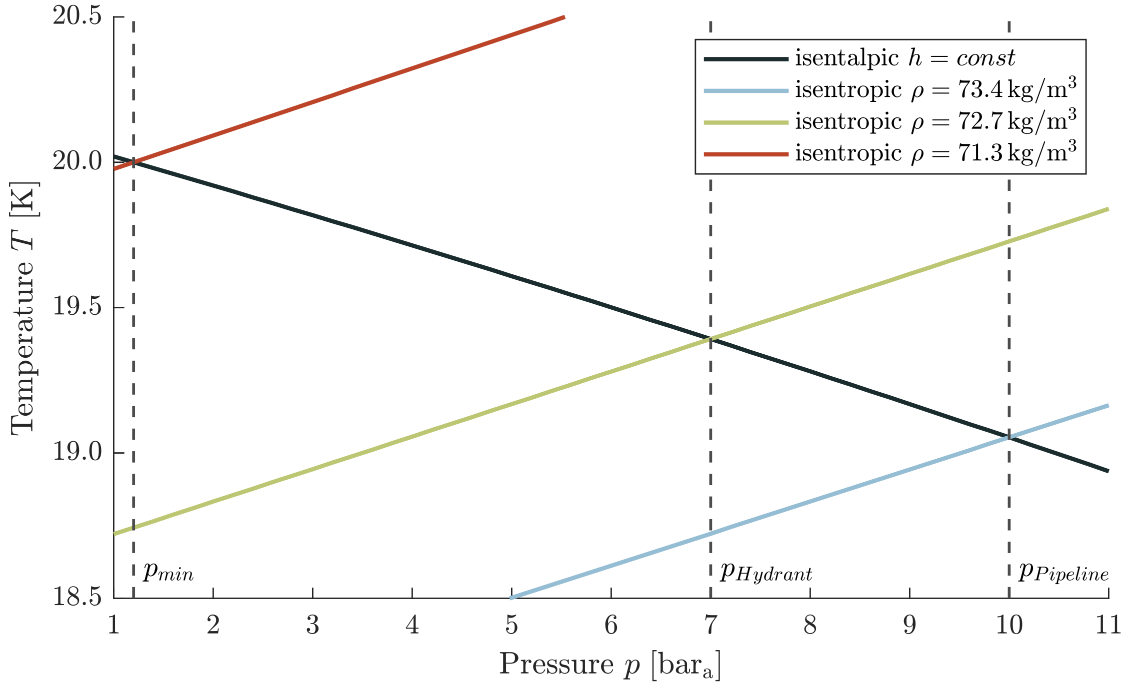

FIG 2. Effects of temperature and density of a real compressible fluid on pressure losses due to friction; Showing an isenthalpic change of state from the storage tank to the aircraft tank.

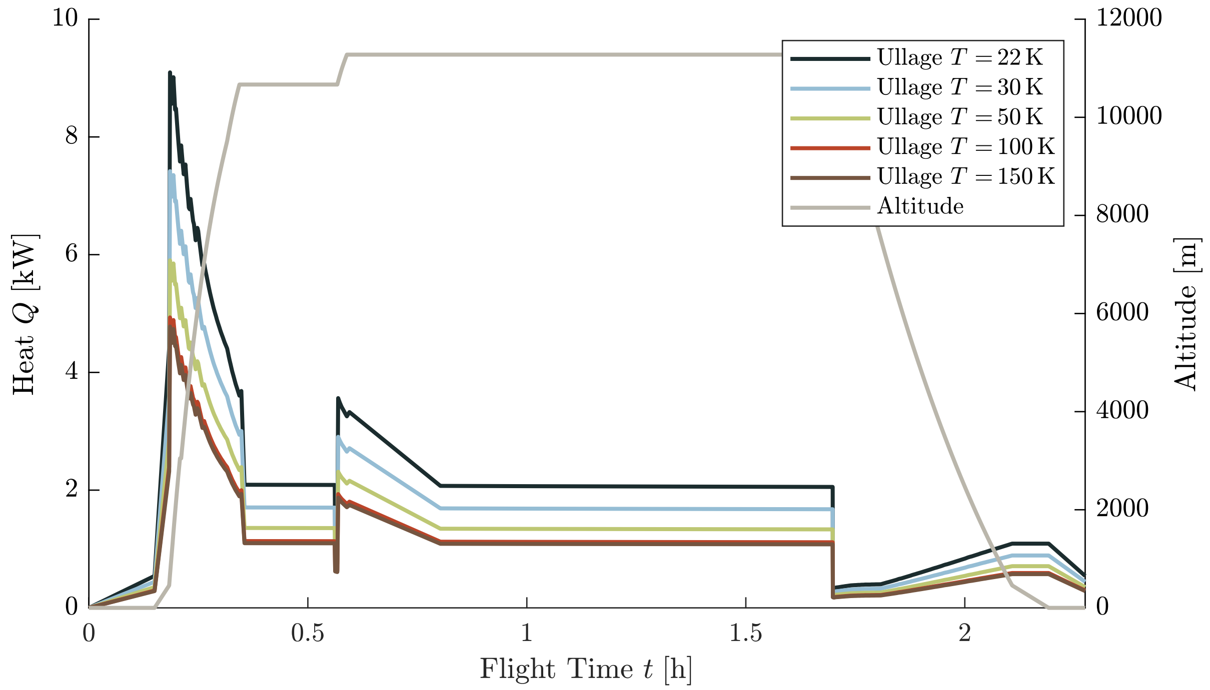

FIG 3. Required heat input to aircraft tank for constant tank pressure with variation of ullage gas temperature; Flight envelope for a 180-passenger aircraft over an 800 nautical mile mission