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Corresponding author: LAMPEAS George
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Title

Analysis and simulation of a cryogenic hydrogen aircraft fuel tank

Authors

George Lampeas [1] , George Tzoumakis [2]*

** Corresponding author*

[1] *Mechanical Engineering and Aeronautics Department, University of Patras, 26500 Rion Greece, labeas@upatras.gr*

[2] *Mechanical Engineering and Aeronautics Department, University of Patras, 26500 Rion Greece, georget1012.gt@gmail.com*

Hydrogen is a promising alternative fuel for greenhouse gas reduction achievement. Specifically for the aviation sector, hydrogen when produced carbon-free, presents several advantages, as it allows for the elimination of CO_2 emissions in flight, [1]. Its usage in fuel cells allows for zero-emission propulsion, including NO_x and particles. When burnt in a turbine engine, exceptionally low particle emissions can be expected, as well as reduced NO_x emissions, provided that the combustion system is optimized.

The key elements of the liquid hydrogen commercial aircraft technology are still at very low Technology Readiness Level and for this reason, advanced parametric modelling is required to support an optimized tank design. In this direction, the present work refers to the development of a thermo-mechanical simulation model of a small-scale liquid hydrogen fuel tank for aviation applications. A cylindrical tank with hemispherical heads is considered with capacity of 1000 liters of liquid hydrogen, at 4 bars design pressure, 10 bars design overpressure and 20K design temperature.

The liquid hydrogen tank insulation must meet conflicting requirements, as it has to demonstrate very low heat losses in order to meet the boil off requirements, while at the same time to be a light-weight system, fulfilling the tank mass requirements. A dewar tank design with composite materials used for the outer and inner tank are considered in the tank construction to achieve a high gravimetric index.

The developed thermo-mechanical simulation methodology accounts for all the distinctive and critical parameters regarding the simulation of cryogenic metallic hydrogen tanks. The model comprises a thermo-mechanical module to account for temperature history effects on the mechanical response and a structural module to account for thermo-mechanical stress analysis.
Environmental conditions inside the fuselage part where the tank is to be placed are not always defined, yet some accurate assumptions can be used for the heat transfer analysis. The process for heat transfer analysis, material selection, and boil-off rate calculation have been described in detail. The heat transfer within the tank and its surrounding structure depends on thermal conduction, thermal convection and thermal radiation. Each type of heat transfer results in a specific coefficient, thus a methodology to define their corresponding coefficients is considered.
Numerical modelling approaches combining beam with thin-shell element approaches are applied and parametric studies for different tank variations having variable wall thickness of the double-walled vessel are performed. The FE heat transfer model comprised the tank, the supporting structure and the necessary associated fuselage structure. Suitable element types having temperature degrees of freedom, capable to account for thermal conduction and convection behavior are selected. For the inner and outer tank walls, 4-node shell elements are used, while the supporting beams are meshed using 2-node

elements, modeling the supporting structural elements. For the structural analysis, 4-node shell elements have been used to model the inner and outer tank walls and 2-node beam elements for the beam-like structural parts.
The developed model predicts temperature distributions, as well as displacement and stress distribution within the tank and can be used to draw conclusions about the structural performance of the tank and its mass efficiency, as function of its sizing parameters.

References

[1] https://www.clean-aviation.eu/sites/default/files/2022-01/CAJU-GB-2021-12-16-SRIA_en.pdf (Accessed June 22, 2022)