Doctoral Dissertation
Doctoral Program in Mechanical Engineering (38^{th}cycle)

MBSE and design of hydrogen storage and distribution system for UAVs

By

Filippo Mazzoni

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Supervisor(s):
Prof. E.Brusa, Supervisor
Prof. C.Gastaldi, Co-Supervisor
Dr. Eng. G.Accardo, Company Supervisor

Doctoral Examination Committee:
Prof. A.B. , Referee, University of...
Prof. I.J, University of...

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Abstract

The current work is the result of a doctoral activity conducted at the Leonardo Innovation Hub & Intellectual Property, specifically at the Advanced Power & Energy Systems R&D unit, during which Model-Based Systems Engineering (MBSE) has been applied to the design of a hydrogen storage and distribution system (H_2SDSys) for airborne applications. The purpose of the analysis was derived from Leonardo's need to investigate hydrogen-powered aircraft, while the MBSE is a must for the aerospace sector and for the company.
Thus, a conceptual design path for applying the MBSE has been described and initially applied to unmanned aerial vehicles (UAVs) through requirements and functional analyses. Then, a hydrogen tank parametric sizing model has been described and applied to two use cases to assess the feasibility of retrofitting two UAVs. Then, the MBSE design path has been newly applied at a deeper level of detail to design the H_2SDSys. Specifically, a set of requirements has been written for this system, the functional analysis has been applied, and a functional architecture has been created. Finally, the dynamic analysis has been conducted on the complete hydrogen storage and distribution system.
The contributions of the work conducted are both methodological, referring to the application of the MBSE, and technical, concerning the design of the H_2SDSys. Indeed, the implementation of the MBSE to an industrial product, such as the UAV, allowed the identification of both the obstacles and the advantages of such methodology, while in the design of the hydrogen storage and distribution system, the MBSE approach allowed for drawing both qualitative and quantitative conclusions for a straight finalisation of the H_2SDSys architecture. Conversely, the static analysis revealed that, for the same amount of energy stored onboard, the retrofitting of the two UAVs analysed could not be performed due to volume constraints. However, the high gravimetric and volumetric indexes of the liquid hydrogen tank obtained through the parametric design model, which, depending on the insulating material used, range

between 40% and 60% and between 60% and 70%, respectively, encouraged further investigation. Thus, the dynamic analysis has been conducted, leading to the final configuration of the H_2SDSys. The system demonstrated satisfactory performance, covering the entire flight mission without the need to evacuate hydrogen due to boil-off, consuming a relatively low amount of electric power during operation, efficiently conditioning hydrogen, and maintaining dormancy for more than 7 hours. Viewed holistically, the main contributions of this thesis include the application of the MBSE and the analyses conducted for the H_2SDSys design. Furthermore, as the thesis unfolds, the practical correlations between these two aspects gradually become appreciable.