Doctoral Dissertation
Doctoral Program in Mechanical Engineering (33° cycle)

Design of Additive Manufactured Structural Shells for Harsh Environment Probes

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Summary

Design methodologies for complex systems, where multiple components are interacting together, or multi-physical phenomena are involved, are currently one of the most interesting field of study of Machine Design. Indeed, the development of new technologies and materials, together with improved predictive models and simulations tools, are bringing the industry to develop new, high performance products, designed to fulfill multiple functions, acting as systems rather than single components.
In this context, Additive Manufacturing represents one of the most disruptive technologies, not only because of the great design freedom offered by the novel fabrication processes, but also because of the new digital approach, involving the entire design and manufacturing process, starting from the digital Computer-Aided Design model and ending with the physical product. The novelty of the technology requires to re-think the design process, that has to evolve as an iterative process through the design, optimization, verification and validation steps, involving experimental testing at specimen, component, and system level.

Thermo-structural systems for special applications, such as the exploration of harsh environments, represent well suited candidates for investigating both the potential benefits of new technologies, and new design methodologies, starting from practical applications. The object of the study has been provided in a collaboration framework between the Department of Mechanical and Aerospace Engineering (DIMEAS) of Polytechnic of Torino (Italy), and the NASA Jet Propulsion Laboratory / California Institute of Technology, under the JPL Visiting Student Research Program and it is represented by a concept of a Venus surface lander.

The harsh environmental conditions of the surface of the planet pose unique challenges for both the structural and the thermal control systems, which need to withstand very high external pressures, up to 93 bar, and extreme temperatures, up to 462°C. Past landing missions used metallic spherical shells produced by conventional manufacturing techniques, such as spin forming, protected by insulating or phase change materials, to mitigate the effects of the extreme temperatures, for the duration of the mission. At that time, the fabrication techniques limited

the design freedom to simple geometries, such as plain shells, without internal ribbing systems. Since Additive Manufacturing has come to the fore, new design opportunities have become available. Novel concepts and architectures for Venus landing probes have recently been proposed by Jet Propulsion Laboratory, including integrated thermo-structural systems, in which thermal control devices, such as evaporators, are embedded within the primary structure, potentially resulting in a increased lifetime of the probe.

The present work has the objective to propose an Additive Manufactured lightweight layout for the primary structure of a concept of a Venus lander, in which a periodic pattern of stiffening ribs is used to improve the mechanical performance of the system. Moreover, a prototype for laboratory testing of the evaporator, to be embedded within the primary structure, has been structurally optimized, by recurring to lattice structure infill.
The complexity of the geometry of the primary structure under study, together with the extreme loading conditions and the uncertainties of the novel manufacturing processes, requires a modeling that starts with simple analytical and numerical tools, evolves through an optimization phase, and it involves experimental testing, aimed at the validation of the models. In this context, a novel analytical optimization method for isogrid-stiffened spherical shells has been developed and validated through an experimental campaign.
A preliminary activity on the evaporator, to be embedded within the structural shell, has been performed, working on a proof case for laboratory testing. A design methodology for optimizing the structure, based on structural and thermal requirements has been proposed, including experimental activities at specimen level, aimed to assess manufacturing limitations in fabricating small struts. Unfortunately, the research activities have been affected by Covid-19 events, and the planned experimental testing on the evaporator level has been delayed.

The challenging application provided the opportunity to study the potential benefits of Additive Manufacturing, and also to investigate design methodologies to fully exploit these benefits. The space field, together with the collaboration with the Jet Propulsion Laboratory, has proved to be an excellent testing ground, benefiting from a consolidated experience in system engineering and verification and validation processes.

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