Doctoral Dissertation
Doctoral Program in Aerospace Engineering (33rd Cycle)

THERMAL ANALYSIS AND CONTROL OF SMALL SPACE PLATFORMS

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I hereby declare that, the contents and organisation of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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Summary

Thanks to its low costs and technical developments, small satellite are becoming one of the key players for scientific and technological missions in Low Earth Orbit. In addition, new interesting concepts for interplanetary nanosatellites missions are also appearing. The future for small satellites depends on the increments of performance and reliability of enabling and critical technologies such as navigation, propulsion, communications and thermal management. The last one is a challenging area of research, especially for missions with stringent thermal requirements such as astrobiology experiments, or observation in particular spectral bands (e.g. IR imaging payloads). To meet these requirements, the thermal engineer has to design the Thermal Control System (TCS), which has the purpose to keep the temperature of the equipment of the spacecraft inside the temperature limits for each mission phase.

The research presented in this thesis can be framed in the field of thermal analysis and thermal design for space application, and it is targeted to miniaturised spacecraft, such as CubeSats and nanosatellites in general. In particular, the purposes of this research are 1) to develop a thermal analysis tool tailored to small space platforms, for the early design phases 2) to develop solutions for the thermal management system of small platforms. Therefore, to achieve these objectives effectively, a tool, named Small Satellite Thermal tool (S2T2), that supports both thermal analysis and thermal design, is developed in MATLAB® environment. Through the application, mission (e.g. orbit) and platform (e.g. configuration) data are provided to perform the first iteration of the thermal analysis, then, if the temperatures of the equipment result to be out of the operative range, the tool starts searching the optimal solution of the Thermal Management System according to an iterative process until convergence is achieved. At the end of the optimisation process, the solution is proposed to the analyst for final assessment and acceptance. An important driver for the tool development is that it must be user-friendly to make

it possible for many parametric analyses, useful during the first design phases, to be carried out also by non-domain experts. For this reason, the GUI of this tool has been developed to guide the user during the thermal analysis process. The capabilities and the functions available of the tool has been simplified with respect to commercial thermal analysis software, bearing in mind the context in which this tool come forward.

An algorithm is integrated into S2T2 to speed up the thermal design task, using the thermal analysis with the support of the Multi-Objective optimisation exploiting the Multi-Design analysis. The purpose of this algorithm is to find the right combination of active and passive TMS solutions to meet the thermal requirements (e.g. components temperature ranges), considering different surface finishes, thermal straps and heaters.

The thermal analysis algorithm has been compared with a commercial thermal analysis tool, highlighting the strengths and weaknesses of the software developed by the author. In particular, the results in terms of heat fluxes obtained from the environmental analysis and temperatures trends of the components are compared, reporting acceptable errors taking into account the margins suggested in the ECSS.

In addition, S2T2 is applied and validated considering three study cases. The first project considered is Space Rider Observe Cube (SROC), an innovative small satellite mission that would fly around and in formation with ESA's Space Rider (SR) re-entry vehicle. Several solutions for the thermal design of SROC, which constitute the design points that meet the thermal requirements, have been found, representing a good first iteration to improve during the next design phases.

The validation of S2T2 is performed considering two projects. The first one is μProp that consists of setting up a system to support testing of miniaturised propulsion systems integrated into a test platform, with the final goal of assessing the effects of operations and the interactions between the propulsion system and the platform. The second one is a flight mission to demonstrate Search & Rescue capabilities. For both projects, the thermal behaviours are analysed and compared with the telemetry data, reporting a good correlation with the results obtained with S2T2.

The author does not want to develop a code in order to compete with more sophisticated commercial thermal analysis software. This research aims to create an effective, reliable, and user-friendly tool optimised for carrying out feasibility analyses, typical of the early design stage. The commercial solutions are all more targeted to detailed thermal analysis, thus requiring information that is not available at the very beginning of a mission study. Indeed, these solutions can be used in conceptual design, but the analysis would require a level of complexity, and an amount of time and resources that are unacceptable for most projects. Having a simpler tool, dedicated to first-order analysis, it is possible to make many iterations of the thermal design in a reasonable time, and with the appropriate level of details. The analyses conducted with this tool will be then refined and validated in the next project phases with the support of dedicated software and more accurate thermal models.