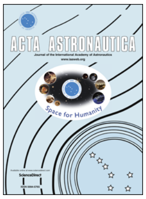
Acta Astronautica 115 (2015) 247–261

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro



Thermal design and analysis of a nanosatellite in low earth orbit

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ARTICLE INFO

Article history:
Received 8 January 2015
Accepted 7 May 2015
Available online 16 May 2015

Keywords:
Nanosatellite
Design methods
Spacecraft thermal control system
Thermal analysis
Numerical simulation
Thermal models

ABSTRACT

In this paper, we present the process and the results of the thermal analysis applied to a nanosatellite developed at Politecnico di Torino. First, main mission parameters and the spacecraft design are presented, in order to fix the boundary conditions and the thermal environment used for the analysis. Then, the thermal model built to solve the thermal balance problem is described into details, and the numerical simulation code is presented. Finally, results are given and discussed in depth. The tool developed provides excellent modelling capabilities and temperature distributions have been validated through commercial software.

The analysis has been used to refine the spacecraft configuration and to set the requirements applicable to the thermal control system of the satellite. The results showed that a basically passive control is sufficient to maintain most spacecraft's components within their temperature range when appropriate thermal coatings and/or tapes are provided. However, heaters to warm up batteries are recommended to survive coldest conditions.

1. Introduction

In the last few years, small satellites have changed the landscape of space missions. The small satellites category includes space platforms that weigh less than 1000 kg, and within this category further subdivisions do exist, as reported in [1]. In the present paper we refer specifically to nanosatellites, i.e. satellites whose mass does not exceed 10 kg. These space platforms have two main inherent advantages: 1) the cost, which is low if compared to that of traditional satellites; 2) the time for development, which is generally one order of magnitude lower than that of bigger systems and more complex missions. However, these space platforms do also have criticalities mainly related to their performance and reliability [2]. To accomplish ambitious mission goals, a set of technological challenges need to be addressed. Design processes, and verification and operation activities will also require specific advancement.

In the framework of small satellites, nanosatellites developed in universities for educational, scientific and technological purposes are worth mentioning [3]. Main aims of these initiatives are

- to engage students in a challenging team work, which is aimed at the design, development and manufacturing of a complex product; thus training the students' capability of solving real problems;

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http://dx.doi.org/10.1016/j.actaastro.2015.05.012
0094-5765/

Symbols

Latin letters

a	thermal diffusivity, m^2/s
A	area, m^2
B	radiative absorption factor
c	heat capacity at constant pressure, J/kgK
d	distance between two nodes of the grid, m
e	orbit eccentricity
F	view factor
Fo	Fourier number
h	thermal conductance, W/m^2K
IR	infrared Earth radiation (239 W/m^2)
i	orbital inclination angle
k	thermal conductivity, W/mK
m	mass, kg
$\dot{q}_v$	volumetric heat flux, W/m^3
$\dot{q}_s$	heat flux, W/m^2
$\dot{Q}$	heat rate, W
r	radiative reflectivity
R	distance between the satellite and the Earth's centre
R_E	Earth radius
s	material thickness, m
S	Solar radiation, W/m^2
T	temperature, K
x, y, z	spatial coordinates

Greek letters

α	albedo (0.29)
β	orbital angle between the orbit and the Sun–Earth vector
γ	angle between the Earth–satellite vector and the perpendicular to the satellite external face
δ	Kronecker delta
$\Delta\tau$	time step, s
ε	emissivity
θ	solar zenith angle, the angle between the Earth–satellite and the Earth–Sun directions
ι	angle between the Earth–satellite vector and the tangent to the Earth viewed from the satellite
ρ	density, kg/m^3
σ	Stefan-Boltzmann constant ($5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$)
ζ	angle between a surface and the vector opposite to solar radiation
τ	time, s

Subscripts

α	albedo
cav	cavity
i, j	ith, jth element
int	inside the satellite
IR	Infrared Earth radiation
g	gap between two nodes
sun	solar
S1	electronic board nr.1

- to test in orbit components and materials designed for terrestrial use, in order to pursue cost reduction of future space missions;
- to demonstrate the feasibility of innovative missions and systems concepts.

The process of development of University satellites follows that of traditional space products but it applies alternative methods and resources, in order to keep costs and development times down and to make the process suitable to personnel with developing skills, i.e. students. To this purpose, the CubeSat standard was created in 1999 at California Polytechnic State University and Stanford University [4]. The basic CubeSat unit (1U) is a 10 cm-side cube-shaped platform whose mass is less than 1.33 kg, complying with the CubeSat Design Specification [5]. One of the most crucial issues for nanosatellite missions is the effect of the thermal environment on the satellite. University satellites, because of their own nature (costs, size, developers), have generally a full (or almost full) passive Thermal Control System (TCS). Moreover, taking into account the limited budget, simple technical solutions and Commercial-Off-The-Shelf (COTS) components, i.e. components available on the market, are usually adopted in design and manufacturing. Without vehicles dedicated to launching CubeSats as primary payloads, launch opportunities only exist in the form of secondary payload missions. This implies that the orbit is not chosen by the CubeSat developer and that the mission's starting date is not known well in advance. Eventually, as far as thermal issues are concerned, there is always the need to optimize the costly test campaign, in order to reduce its impact on the development time and costs of the satellite. The capability of performing effective and reliable thermal analyses represents therefore a fundamental role in the design of the TCS and of the whole satellite.

The paper describes the results of a theoretical and numerical study, aimed at assessing the thermal conditions and the range of operative temperatures encountered by a nanosatellite in orbit.

Thermal analyses are usually conducted by means of commercial energy-balance software, e.g. multi-physics tools that couple computational fluid dynamics (CFD) and finite elements method (FEM) analyses. Even though a powerful set of referenced tools available on the market provide detailed results and a variety of post-processing options, the creation and implementation of in-house software has the advantage to give the analyst the ability to tailor and optimise the model to the actual case study. CFD models are limited for space application since the